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essentials

interactive eBook inside

PEARSON BACCALAUREATE

Biology

ALAN DAMON • RANDY McGONEGAL • WILLIAM WARD
SERIES EDITOR: CHRISTIAN BRYAN

Supporting every learner across the IB continuum

ALWAYS LEARNING

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Dedications
Alan Damon:
To Angèle, Lucas, Anna and Lysa for their support.

Randy McGonegal:
For my father, who taught me why the word 'gentle' is found within the word, 'gentleman'.

William Ward:
I dedicate this book to all my students in 41 years of teaching. Each one has helped make my career enjoyable and fulfilling.

Contents

Introduction

Welcome to your Essentials guide to Biology. This book has been designed to solve the key problems of many IB Diploma students:

- relating material you have been taught to the syllabus goals and outcomes
- remembering it from one lesson to the next
- recalling it months later in an exam situation
- demonstrating your understanding of it in an exam situation within a strict time limit.

Who should use Essentials guides?

Essentials guides serve as highly effective summaries and have been carefully designed with all IB students in mind.

However, the guides also deal with the particular interests of IB students whose first language is not English, and who would like further support. As a result, the content in all Essentials guides has been edited by an EAL (English as an additional language) expert to make sure that:

- the language used is clear and accessible
- key terms are explained
- essential vocabulary is defined and reinforced.

Key features of an Essentials guide

Reduced content: Essentials guides are not intended to be comprehensive textbooks – they contain the essential information you need to understand and respond to the Understandings in the IB Biology Guide. This allows you to understand material quickly and still be confident you are meeting the essential aims of the syllabus. We have reduced the number of words as much as possible to ensure everything you read has clear meaning, is clearly related to the IB Biology Guide, and will help you in an exam.

Format and approach: The content of the book is organized according to the Understandings in the IB Biology Guide. Each Understanding is looked at separately so that you can study each one without having read or understood previous sections. This allows you to use the book as a first text, or a revision guide, or as a way to help you understand material you have been given from other sources.

Main ideas: Most sub-topics start with a main idea, which gives a simple introduction to the topic and an idea of the main learning point.

> ### Main idea
> Chromosomes carry genes in a **linear** sequence that is shared by members of a species.

Model sentences: These summarize key concepts so that you gain a clearer understanding of them. They are examples of the sort of sentences you could use in an exam. For example:

> Model sentence: **It is possible to find out the gender of an unborn child or determine if there are any chromosomal anomalies by preparing a karyogram.**

Applications and skills: These relate to the applications and skills in the IB Biology Guide, and show how you can apply the Understandings in a more practical way; they illustrate how theory can be used in practice in real situations.

Skill: Use of a database to determine differences in the base sequence of a gene in two species

Application: Use of karyograms to deduce sex and diagnose Down syndrome in humans

Vocabulary and synonym boxes: Useful words and phrases are colour coded in the text and given matching colour-coded explanations in the margins. There are three different sets: **vocabulary related to the topic**, **synonyms**, and **general vocabulary**. These are included to help identify and support your understanding of academic and difficult words. In order to make the text more accessible to students whose first language is not English, we have avoided using a highly academic tone. However, at the same time we have ensured that the complexity of the content is at the level required by successful IB Diploma students.

Subject vocabulary

hypothesis possible explanation for a set of observations or possible answer to a scientific question

ratio a relationship between two numbers

nutrient chemical material a cell or organism needs

excretion process in which a cell rids itself of waste products

Synonyms

rid................ remove

General vocabulary

squaring process of multiplying a number by itself

cubing process of taking a number times itself twice

Internal Assessment and Extended Essay sections: These are intended to help you design, research, and write your own investigations and essays. They provide useful guidance on how to complete your investigation or essay, and explain what is required to achieve the top marks.

eText and audio: In the accompanying eText you will find a complete digital version of the book. There are also links to spoken audio files of the vocabulary terms and definitions to help with comprehension and pronunciation. In addition, all the vocabulary lists are located together as downloadable files.

Above all, we hope this book helps you to understand and consolidate your Biology course more easily than ever, helping you to achieve the highest possible result in your exams.

How to use your enhanced eBook

Jump to any page

Switch from single- to double-page view

Highlight parts of the text

Search the whole book

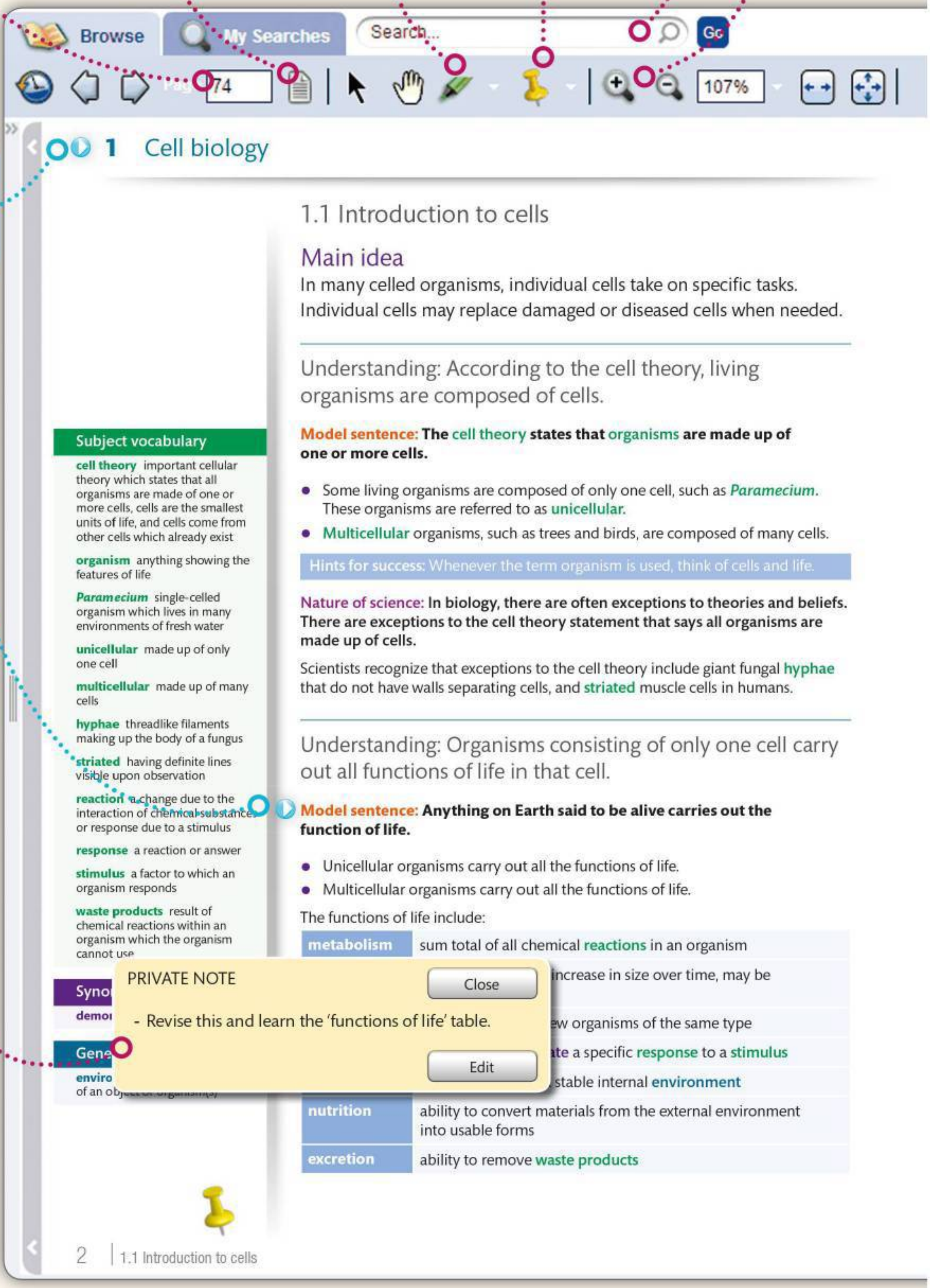
Create notes

Zoom

Audio

Select the icons to hear audio of the headers and model sentences.

Note



See the definitions of key terms in the glossary

Switch to whiteboard view

Create a bookmark

Hints for success: When asked how one would know if something was alive, state that anything alive would have to demonstrate all the functions of life listed in the table.

Any living organism may be observed over a period of time to recognize the functions of life mentioned in the table. *Paramecium* and *Chlorella* are unicellular organisms which when grown in a lab culture will allow the observation of most of the functions of life mentioned in the table.

Nature of science: A hypothesis is often produced by scientists before any observations or experiments are carried out.

Understanding: Surface area to volume ratio is important in the limitation of cell size.

Model sentence: When a cell becomes too large there is not enough surface area to rid the cell of all the waste produced by metabolism.

- Large cells also have problems bringing in enough materials for cell metabolism to occur.
- The surface area of a cell is that area of the cell which makes contact with its external environment.
- The surface area controls the movement of materials in and out of the cell.
- When the cell grows, the thin surface layer increases by a factor involving squaring the cell radius.
- The volume of a cell includes everything inside the thin surface layer.
- It is in the interior of the cell, the volume area, where most of the chemical reactions of the cell occur.

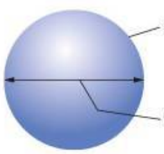


Figure 1.1 *General cell diagram*

- When the cell grows, the volume of the cell increases by a factor involving cubing the cell radius.
- If the ratio between the surface area and the volume is low, not enough nutrients can enter the cell to keep the necessary chemical reactions of life occurring.
- If the surface area to volume ratio is high, such as 11:1, the cell will be healthy and may continue to grow.
- If the surface area to volume ratio is low, such as 2:1, the cell will not grow. It may even die because not enough nutrients may enter the cell and excretion of waste is slowed.

Hints for success: Remember that a large cell has less surface area compared to its volume than a small cell. The larger a cell is, the less it will continue to grow. Larger organisms are composed of many small cells, not larger cells.

Subject vocabulary

hypothesis possible explanation for a set of observations or possible answer to a scientific question

ratio a relationship between two numbers

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Synonyms

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General vocabulary

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cubing process of taking a number times itself twice

1 Cell biology | 3

Definitions with audio

Click on highlighted terms to see the definition and hear the audio.

Vocabulary lists

Select the icons at the back of the book to see complete vocabulary lists.

1.1 Introduction to cells

Main idea

In many celled organisms, individual cells take on specific tasks. Individual cells may replace damaged or diseased cells when needed.

Understanding: According to the cell theory, living organisms are composed of cells.

Model sentence: The cell theory states that organisms are made up of one or more cells.

- Some living organisms are composed of only one cell, such as *Paramecium*. These organisms are referred to as unicellular.
- Multicellular organisms, such as trees and birds, are composed of many cells.

Hints for success: Whenever the term organism is used, think of cells and life.

Nature of science: In biology, there are often exceptions to theories and beliefs. There are exceptions to the cell theory statement that says all organisms are made up of cells.

Scientists recognize that exceptions to the cell theory include giant fungal hyphae that do not have walls separating cells, and striated muscle cells in humans.

Understanding: Organisms consisting of only one cell carry out all functions of life in that cell.

Model sentence: Anything on Earth said to be alive carries out the function of life.

- Unicellular organisms carry out all the functions of life.
- Multicellular organisms carry out all the functions of life.

The functions of life include:

metabolism	sum total of all chemical reactions in an organism
growth	ability to change or increase in size over time, may be limited in amount
reproduction	ability to produce new organisms of the same type
response	ability to demonstrate a specific response to a stimulus
homeostasis	ability to maintain a stable internal environment
nutrition	ability to convert materials from the external environment into usable forms
excretion	ability to remove waste products

Subject vocabulary

cell theory important cellular theory which states that all organisms are made of one or more cells, cells are the smallest units of life, and cells come from other cells which already exist

organism anything showing the features of life

Paramecium single-celled organism which lives in many environments of fresh water

unicellular made up of only one cell

multicellular made up of many cells

hyphae threadlike filaments making up the body of a fungus

striated having definite lines visible upon observation

reaction a change due to the interaction of chemical substances or response due to a stimulus

response a reaction or answer

stimulus a factor to which an organism responds

waste products result of chemical reactions within an organism which the organism cannot use

Synonyms

demonstrate... show

General vocabulary

environment the surroundings of an object or organism(s)

Hints for success: When asked how one would know if something was alive, state that anything alive would have to demonstrate all the functions of life listed in the table.

Any living organism may be observed over a period of time to recognize the functions of life mentioned in the table. *Paramecium* and *Chlorella* are unicellular organisms which when grown in a lab culture will allow the observation of most of the functions of life mentioned in the table.

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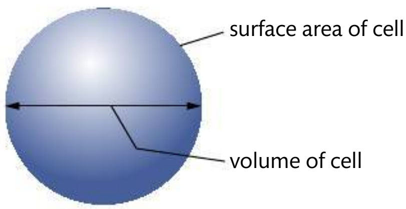

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Skill: Use of a light microscope to investigate the structure of cells and tissues, with drawing of cells

You are expected to be able to:

- Name the parts of a typical light microscope.
- State the major function of each part of the light microscope.
- Determine the total **magnification** when making observations with the light microscope.
- Calculate the diameter of the **field of view** when looking through the eyepiece/ocular of the light microscope.
- Use the diameter of the field of view to determine the approximate size of cells.
- Use **scale bars** on a **micrograph** to determine the actual size of cells or cell parts.
- Make proper drawings of cells when observing with the light microscope that include correct labelling.

Understanding: Multicellular organisms have properties that emerge from the interaction of their cellular components.

Model sentence: Cells working together can accomplish more than cells working individually.

- Multicellular organisms have specific cells carrying out unique **functions**.
- Usually, no single cell in a multicellular organism carries out all the functions to keep the organism alive.
- Multicellular organisms are able to carry out more functions than the sum of the functions of the individual cells they contain.
- These increased properties of the multicellular organism over the sum of its individual cells are called **emergent** properties.

Hints for success: Remember that the whole is greater than the sum of the parts. This relates to the organism compared to the cells it is composed of. The greater properties of the organism **emerge** from the **interaction** of the organism's cells.

Understanding: Specialized tissues can develop by cell differentiation in multicellular organisms.

Model sentence: Groups of cells in a multicellular organism may go through similar changes over time to produce a mass of similar cells called a tissue.

- A group of cells with similar structure and function within a multicellular organism is called a tissue.
- **Differentiation** is a process cells may go through over time to bring about change in their structure and/or function.
- Differentiated cells are specialized to carry out functions more efficiently than undifferentiated or **unspecialized** cells.
- Differentiation of cells to perform specific functions is important to the overall success of the multicellular organism.
- Differentiation of cells allows emergent properties to develop within the multicellular organism.

Subject vocabulary

magnification the ratio of the image size to the actual object size

field of view what is visible when looking through the ocular/eyepiece of a microscope

scale bar line added to a micrograph or drawing to show the actual size of an object or structure

micrograph visual representation of a microscopic image

functions specific actions or jobs

emergent coming into existence, arising through an evolving process

specialized having a specific function or action

differentiation series of changes which transforms unspecialized cells into specialized cells and tissues in multicellular organisms

unspecialized without specific function, general in function

Synonyms

accomplish..... achieve

General vocabulary

emerge to come from, as a result of

interaction the process of having an effect on other objects or organisms or being affected by other objects or organisms

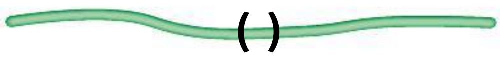
Hints for success: Think of differentiation of cells as being important in bringing about greater **efficiency** in multicellular organisms. Greater efficiency results in a greater chance of survival.

Understanding: Differentiation involves the expression of some genes and not others in a cell's **genome.**

Model sentence: When not all the genes of a cell's DNA become active, the genes which do become active cause the cell to differentiate.

- DNA is the **hereditary** material of the cell and is present on structures called **chromosomes**.

The complete line represents a chromosome



The small area in parentheses would be a gene.
Many, many genes exist on a single chromosome.

Figure 1.2 *Representation of a gene on a chromosome*

- All of the DNA within a cell is called the cell's genome.
- Cells of different **species** of organisms will have different numbers of chromosomes in their genome.
- A **gene** is a **segment** of DNA on a chromosome which controls a particular structure or function in the cell.
- Not all genes of a cell are active at the same time. When certain genes become active, the function, and even structure, of cells may change.
- Cells become specialized according to which DNA segments become active.

Hints for success: Think of DNA as the controlling material within the cell. Also, keep in mind not all the DNA of a cell is active at any one time. The activities and properties of a cell will change depending on which genes are active at a particular time.

Example: flowering plants

The form and structures of a flowering plant go through great changes over the life of the plant. The DNA of all the cells stays the same during the plant's life. However, at different times in the life cycle of the plant, sections of the DNA in specific cells become active and non-active. Different areas of DNA activity cause the changes in form and structures of the plant.

General vocabulary

efficiency level of production

Subject vocabulary

genome the complete DNA sequence of an organism

hereditary passed from generation to generation by genes

chromosomes structures on which DNA occurs within a cell

species a group of organisms which are structurally similar and able to pass their genetic traits on to their offspring

gene section of DNA molecule which codes for a particular trait/protein in an organism

Synonyms

segment......... part

Synonyms

capacity......... ability
retain............ keep
significant...... large
derived.......... taken
controversy.... disagreement/debate

Subject vocabulary

therapeutic relating to the treatment of disease

bone marrow soft tissue which fills the inner, hollow spaces of certain types of bones

disease change or condition, other than injury, that affects the normal functioning of the organism

umbilical cord structure which attaches the embryo to the mother in mammals

eukaryote organism composed of a cell or cells which are complex in structure and always include organelles

prokaryote organism composed of a cell which does not contain most of the known cell organelles

Understanding: The capacity of stem cells to divide and differentiate along different pathways is necessary for embryonic development and also makes stem cells suitable for therapeutic uses.

Model sentence: Stem cells are non-specialized cells which may go through the process of differentiation to become cells needed in the multicellular organism's future.

Stem cells have a function in the development of the embryo of an organism. A multicellular organism is an embryo during the stages it goes through before it is able to live on its own.

The undifferentiated stem cells may also be used therapeutically. Stem cells are cells within an organism which **retain** their ability to divide and differentiate into various cell types. These stem cells are relatively large in number in an organism's embryo stages. As the embryo develops, the undifferentiated stem cells specialize to become certain types of tissue necessary for the function of the adult organism. Most tissues in adult multicellular organisms retain a **significant** number of stem cells. The large stem cell number allows possible repair of damaged or diseased cells in that tissue.

The use of stem cells in therapeutic situations is largely in the experimental stage at present. Their use in the treatment of disease and trauma seems very promising. **Bone marrow** stem cells have been successfully used in human therapeutic instances.

Application: Use of stem cells

The use of stem cells is very promising for the possible treatment of Stargardt's **disease** and diabetes. Stargardt's disease is due to a genetic condition which eventually results in blindness. Diabetes results in a problem metabolizing sugars within the organism's cells.

The use of stem cells **derived** from specially created embryos has created ethical concerns amongst some groups of people. There are also questions of right or wrong in using stem cells obtained from an organism's tissues or from **umbilical cord** blood in humans.

Nature of science: Research involving stem cells has not been without controversy. Many religions and cultures have questions about the ethics of stem cell research.

1.2 Ultrastructure of cells

Main idea

Cells of organisms known as **eukaryotes** have a more complex structure than cells of organisms known as **prokaryotes**.

Understanding: Electron microscopes have a much higher resolution than light microscopes.

Model sentence: Electron microscopes allow a clearer image of cells and their structures.

- Electron microscopes provide greater magnification than light microscopes. Electron microscopes may enlarge objects over 500 000 times. Light microscopes can enlarge objects only 2000 times.

- Electron microscopes use electrons to produce high-resolution images. Resolution refers to the clarity of an image. Light microscopes use light to produce images. Resolution is not nearly as high in light microscopes as in electron microscopes.
- One advantage light microscopes have over electron microscopes is that light microscopes can allow observation of living cells or specimens. Electron microscopes are only able to provide images of non-living cells or specimens.

Scale bars are often used with micrographs or drawings so that the actual size may be determined. One may calculate magnification or enlargement of an object by using the following formula:

Magnification = size of image ÷ actual size of specimen

Understanding: Prokaryotes have a simple cell structure without compartmentalization.

Model sentence: The lack of compartments within the prokaryotic cell leads to their simple structure.

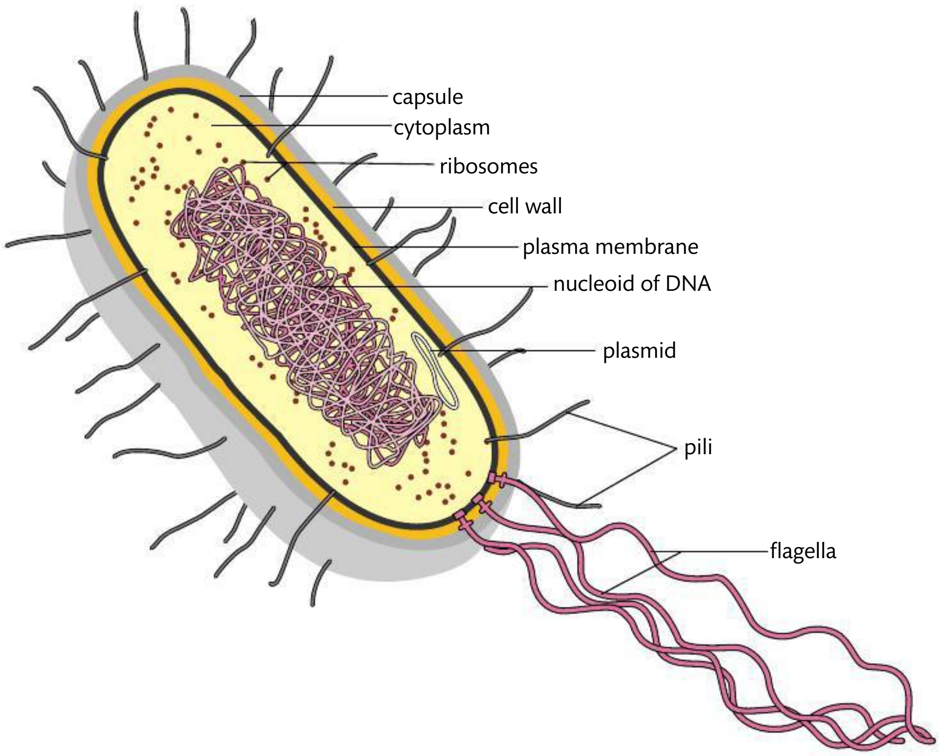


Figure 1.3 *Drawing of the ultrastructure of a prokaryotic cell*

- As you examine the drawing of the ultrastructure of a prokaryotic cell, notice there are no internal compartments. All the structures within the **plasma membrane** are mixed together.
- Bacteria are examples of prokaryotic cells. The drawing is of a type of **bacterium**.
- Note the **nucleoid** region containing DNA. The nucleoid region contains the DNA which is the material that controls the cell.
- The prokaryotic DNA also allows characteristics to be passed to offspring of prokaryotic cells.

General vocabulary

compartment area separated from other areas

Subject vocabulary

plasma membrane membrane which surrounds the cell

bacterium (bacteria) organism which is an example of a prokaryotic cell

nucleoid region of a prokaryotic cell where the DNA exists

Subject vocabulary

binary fission simplified form of cell division in bacteria

ultrastructure detailed structure of a cell not visible with light microscope

cell wall outermost layer of bacterial and plant cells

pili hairlike growths on bacterial cells which function in attachment and DNA exchange between bacteria

flagella (singular: flagellum) whip-like structure which allows movement of cells

cytoplasm region of the cell within the plasma membrane in which the cell organelles exist

ribosome organelle within cells where polypeptides are formed

General vocabulary

compartmentalization division into separate areas or groups

complexity the state of being complicated

- Prokaryotic cells divide by **binary fission**. Binary fission is a simple form of cell division which produces two cells or organisms from one.
- Many prokaryotes reproduce by carrying out binary fission. Binary fission is why many types of bacteria can increase in numbers very rapidly.
- Prokaryotic cells contain ribosomes, just as more complex cell types do. However, the ribosomes of prokaryotes are simpler in structure than those of more complex cells.

Skill: Drawing the ultrastructure of a prokaryotic cell

When asked to draw the **ultrastructure** of a prokaryotic cell in an exam, be certain to include the following structures and their labels: **cell wall**, **pili**, **flagella**, plasma membrane, **cytoplasm**, and **ribosomes.** These structures must be clearly drawn and their relative size and position must be correct. The drawing provided should be studied carefully and used as a model when making drawings.

Application: The division of prokaryotic cells by binary fission is a simple process

The simplicity of binary fission is partly due to the DNA of the nucleoid region of the prokaryotic cell being pure. The DNA is not attached to any other compounds or proteins as it is in more complex cells.

Understanding: Eukaryotes have a compartmentalized cell structure.

Model sentence: Eukaryotic cells have compartments within an outside membrane to produce greater interior complexity than prokaryotic cells.

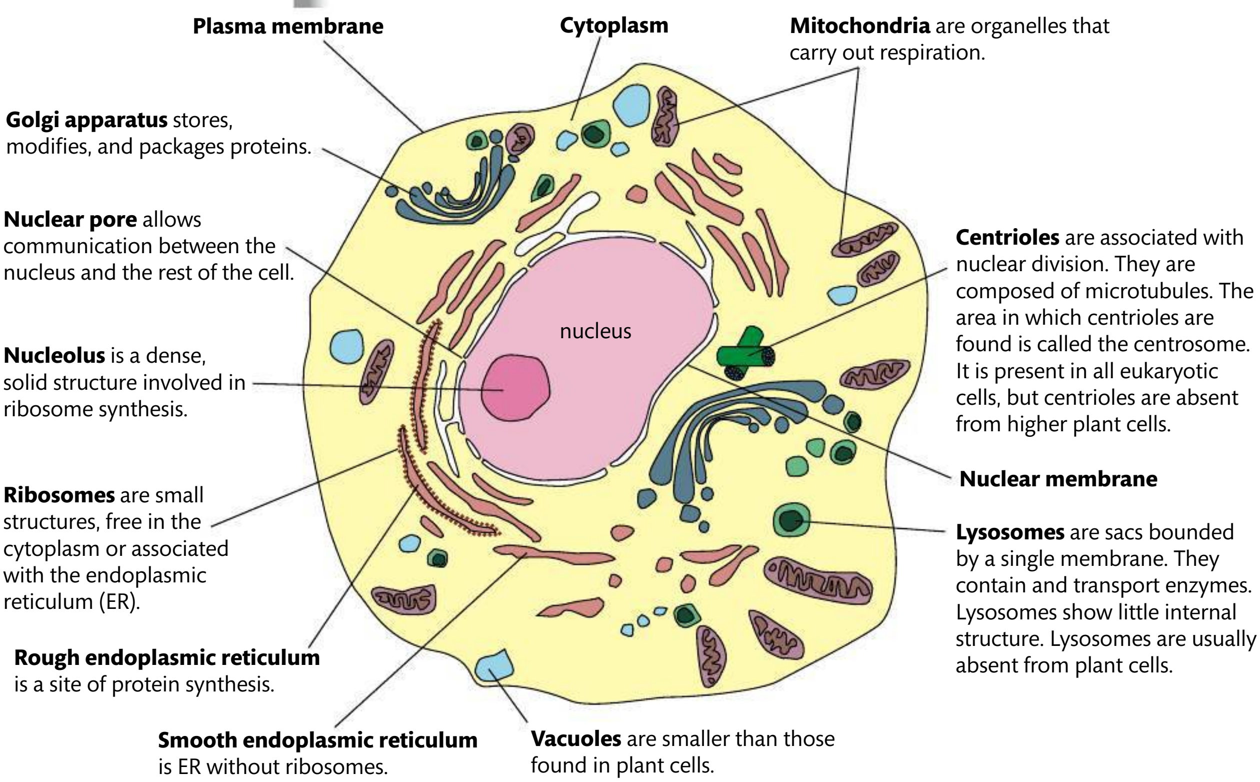


Figure 1.4 *Generalized animal eukaryotic cell*

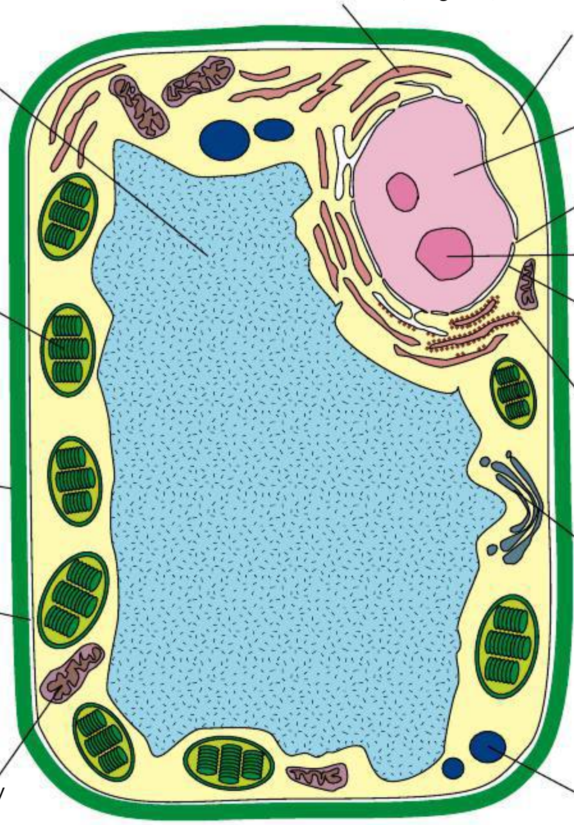


Figure 1.5 *Generalized plant eukaryotic cell*

- The compartments formed in eukaryotic cells are separated from the cell cytoplasm and other structures of the cell by at least one plasma membrane.
- The structures formed by these compartments are called **organelles**.
- The plasma membranes which form compartments are very similar to the plasma membrane which occurs on the outside of the eukaryotic cell. Plant cells are eukaryotic. Most plant cells have a cell wall outside their plasma membrane. Animal cells are also eukaryotic cells. They do not have a cell wall.
- Compartmentalization allows greater efficiency for chemical reactions which occur in specific regions of the eukaryotic cell.
- Ribosomes are unique structures which occur in both prokaryotic and eukaryotic cells. The ribosomes of eukaryotic cells are greater in mass than the ribosomes of prokaryotic cells. Ribosomes of prokaryotic cells are 70S. Ribosomes of eukaryotic cells are 80S.
- The figures above represent the ultrastructure of animal and plant eukaryotic cells. Most of the ultrastructure of a eukaryotic cell is visible only with an electron microscope.
- The DNA of the eukaryotic cell's nucleus is combined with protein. The DNA of prokaryotic cells is not combined with any other compound.

Skill: Drawing the ultrastructure of eukaryotic cells

Study both the plant and animal cell figures so you can draw each with all structures properly labelled. The structures and organelles in these drawings must be of correct relative size. They must also be in the correct cell position.

Subject vocabulary

organelles non-cellular structures within a cell which carry out organ-like processes

Skill: Interpretation of electron micrographs to identify organelles and deduce the function of specialized cells

Study electron micrographs of both plant and animal cells. Practise correctly labelling the structures and organelles shown in these micrographs.

Nature of science: It took the development of the electron microscope to form an understanding of the ultrastructure of the cell.

Application: The pancreas is able to act as an exocrine gland due to the structure and function of certain cell parts

The pancreas has cells which produce and send chemicals called **enzymes** into specialized tubes called **ducts**. These enzymes help in the digestion of food in the **intestine**. Pancreas exocrine cells have the following **modifications** to accomplish this task: increased number and activity of ribosomes, increased development and activity of the **Golgi apparatus**, more extensive **endoplasmic reticulum** within the cytoplasm, and a larger number of **mitochondria**. The mitochondria provide the energy necessary for the increased production of enzymes which occurs in the ribosomes. The Golgi apparatus is very active in the final preparation and packaging of the enzymes for release from the cell into ducts. The endoplasmic reticulum is important in the transportation of necessary raw materials within the cell.

Application: Specialized cells within the leaf called palisade mesophyll cells are able to carry out high amounts of sugar production which is necessary for plant growth and maintenance

These palisade mesophyll cells contain large numbers of **chloroplasts** which carry out **photosynthesis**. Photosynthesis is the plant process which uses light energy to produce the carbohydrate commonly known as sugar. These plant cells will also have few, but large, **vacuoles** for storing these sugars as **starch**. In these plant cells, the nucleus is pushed away from the centre of the cell by the large vacuole(s).

Hints for success: Use a pencil to practise drawing plant and animal cells. Your drawing must include the following structures and organelles in their proper cell position and their proper relative size: 80S ribosomes, nucleus, mitochondria, plasma membrane, cell wall (if a plant cell), chloroplast (if a plant cell), endoplasmic reticulum, Golgi apparatus, lysosomes (if an animal cell), and centrioles (if an animal cell). It is very important to know the internal parts and function of all the structures and organelles of the cell. Use the following summary table to study the parts and functions of eukaryotic cells.

Organelle or location name	Major function	Organism type
cytoplasm	contains the organelles	plant and animal
endoplasmic reticulum (ER)	transportation	plant and animal
rough ER	protein transportation, processing, and packaging, along with cell support	plant and animal
smooth ER	lipid synthesis, transportation, and packaging, along with cell support	plant and animal
ribosomes	protein synthesis	plant and animal
lysosomes	intracellular digestion	animal and some plants

Subject vocabulary

exocrine gland a gland that secretes a substance into a duct for transport

enzyme a protein that acts as a catalyst

duct a small tube

intestine digestive system part involved in breakdown of food

Golgi apparatus cell organelle involved in the storage, modification, and packaging of proteins

endoplasmic reticulum organelle involved in transport within the cell

mitochondrion (plural: mitochondria) cell organelle(s) involved in cell respiration

palisade mesophyll cells cells in the middle section of leaves specialized for carrying out photosynthesis

chloroplasts organelles involved in carrying out photosynthesis

photosynthesis process which converts light energy into chemical energy

vacuoles cell storage structures especially visible in plants

starch large molecule made up of many sugars chemically bonded to one another

Synonyms

modifications changes/alterations

Organelle or location name	Major function	Organism type
Golgi apparatus	storage, packaging, and transport	plant and animal
mitochondria	ATP generation	plant and animal
nucleus	control centre containing chromosomes	plant and animal
chloroplasts	photosynthesis	plant
centrosome	region that aids in cell division	plant and animal (but no centrioles in plants)
vacuole	storage	most obvious in plants similar smaller structures in animal cells are called vesicles and tend to be temporary

1.3 Membrane structure

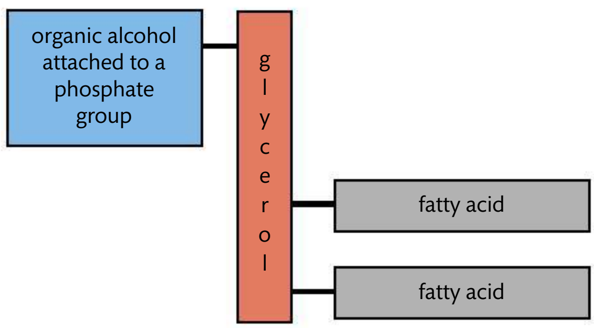
Main idea

All cellular membranes have a structure that allows them to be flexible and active in cellular activities.

Understanding: **Phospholipids** form **bilayers** in water due to the **amphipathic** properties of phospholipid molecules.

Model sentence: Phospholipids form the foundation of cellular membranes and have regions of different solubility properties with water.

- Phospholipids are made up of three parts: a phosphate group, a glycerol molecule, and two fatty acids.
- The phosphate region of the phospholipid is **polar**, while the fatty acid region is **non-polar**.
- In the figure notice the polar region is said to be **hydrophilic**. The hydrophilic region associates freely with water.
- The fatty acid region of the molecule shown in the figure is **hydrophobic**. This region does not associate freely with water.
- Two layers of phospholipids form the foundation of cellular membranes. The hydrophobic regions of each phospholipid bilayer attract one another when placed in water.



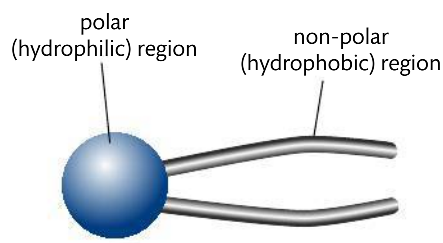


Figure 1.6 *This is a model of a phospholipid*

Subject vocabulary

ATP a molecule used for a source of chemical energy

phospholids lipids formed from two fatty acids, a phosphate group, and glycerol; important component of cell membranes

amphipathic molecule with both hydrophobic and hydrophilic regions

polar having a region of electrical charge

non-polar region of no electrical charge

hydrophilic 'water loving', substances that dissolve in water

hydrophobic 'water fearing', substances that do not dissolve in water

General vocabulary

bilayer structure composed of two layers

solubility ability of a substance to dissolve

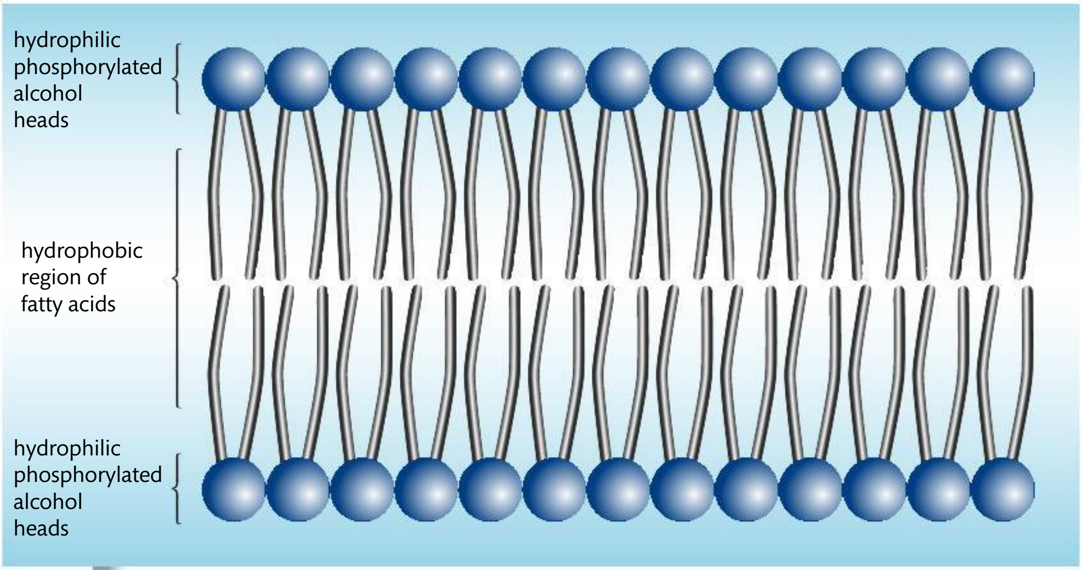


Figure 1.7 *A model of the phospholipid bilayer in cellular membranes*

- The hydrophilic parts of the two layers face outward where there is water present.
- Since the phospholipid molecule has both hydrophobic and hydrophilic regions, it is said to be amphipathic.

Hints for success: Remember when it comes to solubility, hydrophilic compounds and regions associate freely with other hydrophilic compounds and regions. The same is true for hydrophobic compounds and regions. Hydrophobic and hydrophilic compounds and regions do not associate freely with one another. Because most cellular membranes are surrounded by water, the hydrophilic portions of the amphipathic phospholipids are positioned toward water, while the hydrophobic portions are positioned toward each other and away from water.

Understanding: Membrane **proteins** are diverse in terms of structure, position in the membrane, and function.

Model sentence: Various kinds of proteins occur at different positions within the cell membrane and carry out many different functions.

There are two major types of proteins seen when observing their position in membranes. **Peripheral** proteins occur on the external or internal surfaces of the phospholipid bilayer and are hydrophilic. **Integral** proteins occur completely through the phospholipid bilayer and have amphipathic properties. Observe these two types of proteins in the following diagram.

Each of the different proteins in the membrane has a specific function. Some of the functions of these proteins are cell **adhesion**, enzyme action, **active transport**, **passive transport**, communication between cells, and **hormone** interaction. Some of these proteins have carbohydrate chains attached to them. When proteins are attached to carbohydrates the combined structure is called a **glycoprotein**.

Subject vocabulary

proteins biochemical compounds composed of large numbers of amino acids connected by peptide bonds

active transport cellular transport requiring energy from the cell

passive transport cellular transport not requiring cellular energy to occur, occurs along a concentration gradient

hormone chemical messenger produced in very small amounts in one area, used to send messages to other areas

glycoprotein combination of a carbohydrate and a protein

General vocabulary

peripheral at the edge

integral membrane protein present in both layers of the membrane

adhesion process where two different substances stick together or attach to one another

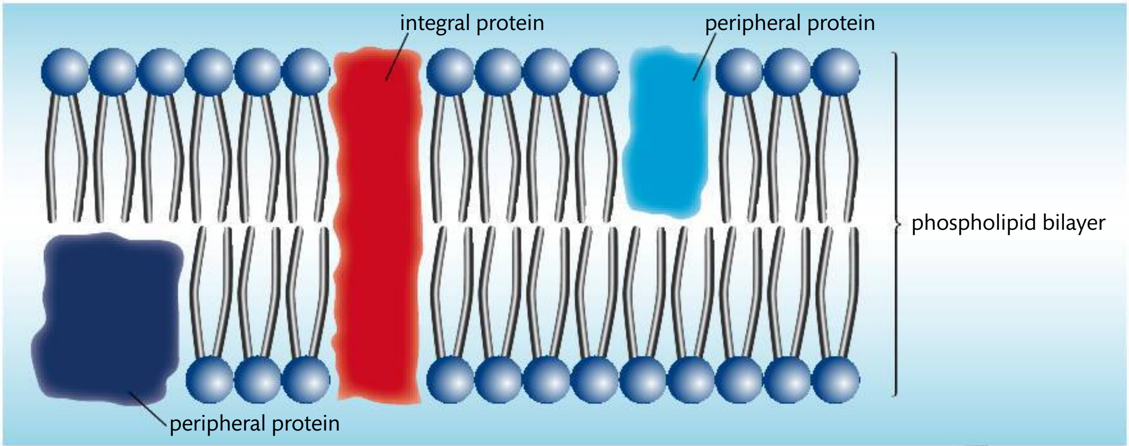


Figure 1.8 *Positions of proteins in the cell membrane*

Skill: Analysis of evidence from electron microscopy led to the proposal of the Davson–Danielli model

Early studies of the cell membrane indicated they were largely made up of proteins and phospholipids. Using this information, Davson and Danielli produced the first model of the cell membrane, the Davson–Danielli model. These scientists used relative amounts and solubility properties of proteins and phospholipids to form a model with a phospholipid bilayer on the inside surrounded by a thin protein layer on both surfaces. It was simply a protein–phospholipid–protein sandwich.

Singer and Nicolson modified the Davson–Danielli model of the cell membrane. They based their modified model on:

- Electron microscope observations of the cell membrane.
- Cell membranes differ in their composition.
- Cell membranes are asymmetrical.
- Membranes with different functions have different structure and composition.
- Proteins do not form a layer. They are only found at certain locations within the phospholipid bilayer.
- Evidence from freeze fracture studies shows proteins often occur inside the membrane.

Singer and Nicolson used the modifications of the Davson–Danielli model to produce the Singer–Nicolson model. This model has been slightly changed over recent years to produce the present cell membrane model, which is known as the fluid **mosaic** model.

Understanding: **Cholesterol** is a component of animal cell membranes.

Model sentence: Animal cell membranes contain cholesterol in their structure. Plant cell membranes do not contain cholesterol in their structure.

The cholesterol component of animal cell membranes allows these membranes to work effectively over a wide range of temperatures. The cholesterol contributes to the fluid or flexible characteristic of the membrane. The cholesterol acts as a fluidity **buffer** in which it keeps the fluidity of the cell membrane within proper limits for *optimum* function. The cholesterol molecules occur at various locations within the hydrophobic region of the animal cell membrane.

General vocabulary

mosaic structure made up of visible smaller pieces

buffer something that prevents or slows change

Subject vocabulary

cholesterol a lipid steroid found in animal membranes

Examine the following figure and note the positions of the cholesterol, phospholipids, and proteins within the fluid mosaic model of the cell membrane.

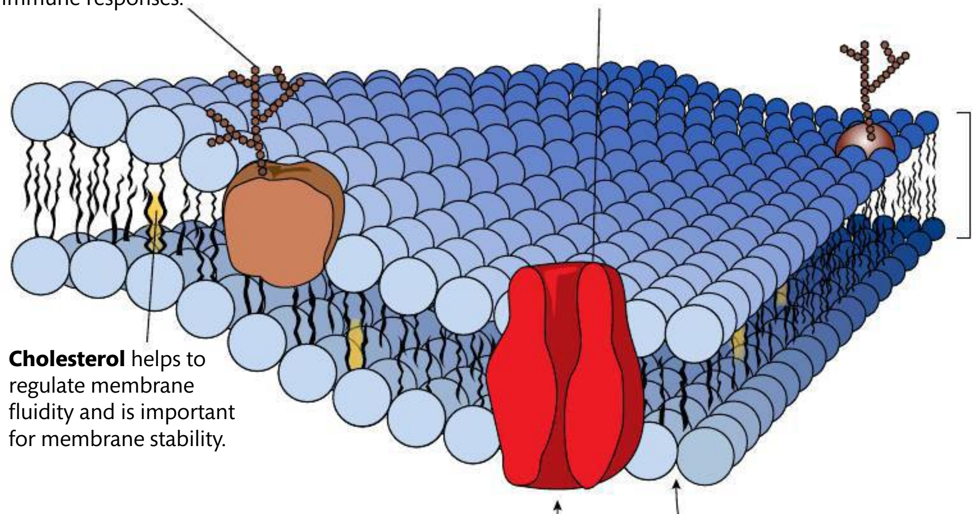


Figure 1.9 *In the fluid mosaic model of the cell membrane there is a double layer of lipids (fats) arranged with their tails facing inwards. Proteins are thought to 'float' in the lipid bilayer*

Plant cells do not have membranes containing cholesterol. The membranes of plant cells depend on modifications of their phospholipid fatty acid tails to maintain a fluid or flexible characteristic.

Hints for success: Recognize that it is because of detailed analysis that we now recognize the best representation of cell membranes is the fluid mosaic model. This model is named fluid mosaic because:

Fluid – this term is used because phospholipid molecules allow a flexible or fluid basic structure. Animal membranes have cholesterol which helps in maintaining their optimum flexibility. Plant membranes do not.

Mosaic – proteins occur in patches or as single proteins 'floating' in the phospholipid bilayer producing a mosaic appearance.

Remember that carbohydrates can be attached to both proteins and lipids. Carbohydrates are sometimes found attached to membrane lipids and proteins as short, branched chains. When carbohydrates are attached to lipids, **glycolipids** are formed. When carbohydrates are attached to proteins, glycoproteins are formed.

Subject vocabulary

glycolipid combination of a carbohydrate and a protein

Skill: Drawing of the fluid mosaic model

Study the diagram of the fluid mosaic model. Practise drawing it with the following structures correctly labelled: phospholipids, integral proteins, peripheral proteins, glycolipids, glycoproteins, and cholesterol. All structures must be properly positioned within the drawing to earn marks in the exam. Always show the structure of a phospholipid as a circle with two parallel tails attached.

1.4 Membrane transport

Main idea

Membranes control homeostasis and functions within the cell.

Understanding: Particles move across membranes by simple diffusion, facilitated diffusion, osmosis, and active transport.

Diffusion and osmosis are types of passive transport. Passive transport does not require energy from the cell when it occurs. Passive transport is movement of particles from an area of high concentration to an area of low concentration of the same type of particles. These two areas of different concentrations of the same particles produce a concentration gradient. Study this table.

Type of passive transport	Description of movement at the membrane	Example
simple diffusion	Particles of substances other than water move between membrane phospholipid molecules or through integral proteins which possess channels.	oxygen moving through plasma membrane along a concentration gradient
facilitated diffusion	Proteins of the membrane form an attachment to the particles and move them through the membrane. The proteins which attach to the particles are called carriers. Facilitated diffusion does not describe water movement.	glucose moving into cells involving a carrier potassium channels allowing potassium to move along a concentration gradient in nerve cells
osmosis	Osmosis allows movement of water molecules through membranes. Water may move through aquaporins which are proteins with specialized channels. Water may also move directly through the membrane.	water moving in and out of the cell to keep the proper water concentration in the cell

The sodium–potassium pump, endocytosis, and exocytosis are types of active transport. For active transport to occur, the cell must provide energy in the form of ATP. Active transport does not require a concentration gradient to occur. Study this table.

Type of active transport	Description of movement at the membrane	Example
sodium-potassium pump	A protein binds with sodium and potassium to move them through a membrane against a concentration gradient. Sodium is transported out of the cell and potassium is transported into the cell.	functions in nerve cells and allows their continual action

Subject vocabulary

homeostasis steady or controlled state

diffusion movement along a concentration gradient not requiring cell energy

osmosis movement of water through a membrane along a concentration gradient

concentration gradient(s) change(s) in a chemical concentration between two areas of chemical concentrations

carrier substance which helps in the movement of another material, usually involving proteins in the plasma membrane

potassium channels transmembrane proteins that allow potassium ions to move in or out of a cell

nerve cells neurones

sodium–potassium pump process carried out by membrane proteins which keep sodium and potassium at proper levels

endocytosis active transport in which substances are brought into the cell

exocytosis active transport in which substances are lost from the cell

General vocabulary

channels openings in a larger object

Type of active transport	Description of movement at the membrane	Example
exocytosis	A membrane from a vesicle fuses with a plasma membrane to allow release of the vesicle's contents to the cell exterior.	release of insulin from pancreas cells into the bloodstream
endocytosis	The plasma membrane forms around a substance forming a vesicle or vacuole and allowing the substance to enter the cell interior.	fluids and small particles brought into the cell by pinocytosis; larger particles and substances are brought into the cell by phagocytosis

A change in membrane shape is visible in both pinocytosis and phagocytosis. Pinocytosis involves a small deformation of the membrane called invagination in which a small channel forms and material from the cell exterior flows into the channel. Pinocytosis results in the temporary formation of smaller storage structures. Phagocytosis involves a much more obvious change in membrane shape. The membrane will actually flow around a substance on the cell exterior to form a larger temporary storage structure.

Understanding: The fluidity of membranes allows materials to be taken into cells by endocytosis or released by exocytosis. Vesicles move materials within cells.

Model sentence: Endocytosis and exocytosis require membrane fluidity to occur.

Membranes may change shape. The fluidity, which gives them the ability to change shape, allows them to form vesicles transporting substances from outside the cell into the cell interior. The property of fluidity also allows the fusing of vesicles with the plasma membrane. The fusing of vesicles with the plasma membrane allows materials produced inside the cell to be released to the cell exterior.

Application: Irrigating the eye

A sterile solution of 0.9% sodium chloride in water is best to use when irrigating the eye. This concentration is very similar to the concentration of water and chemicals inside the cells of the eye exterior. Because the concentrations are very similar there will be no significant fluid loss or gain in the cells of the eye during the irrigation. This allows the eye cells to maintain homeostasis. A similar solution may be used to irrigate skin wounds so that little damage will be done to exposed cells due to fluid gain or loss. The gain or loss of water in cells when not using the proper concentration of irrigating solution would be due to osmosis.

Skill: Investigating differing concentrations of solute

A required lab for this section involves the effect of differing concentrations of solute in water on living cells. Potato cells are often used for this lab. In the lab, several key observations are required:

- In isotonic solutions (solution has same concentration of solutes as are in the potato cells), potato cell mass remains the same. This indicates homeostasis between the cell and the surrounding solution with no net gain or loss of water.

Subject vocabulary

vesicle smaller storage structure surrounded by a membrane in cells

insulin hormone produced and released by exocytosis from the pancreas which controls glucose absorption by cells

pancreas an organ within the body that has many functions including production of three important digestive enzymes

pinocytosis active transport in which fluids and small particles are brought into the cell

phagocytosis active transport in which larger particles and substances are brought into the cell

sterile free of disease-causing organisms and viruses

isotonic solutions solutions with equal concentrations of solutes and solvents

solute(s) molecules dissolved in a solvent (water)

General vocabulary

deformation a change in shape

irrigating applying water

Synonyms

fusing............ merging

- In **hypotonic solutions** (solution has a lower concentration of solutes in water than that inside the potato cells), potato cell mass will increase. This increase in mass is because water moves from outside to inside the potato cells.
- In **hypertonic solutions** (solution has a higher concentration of solutes in water than the solute concentration inside the potato cells), the mass of the potato cells will decrease. This decrease in mass is because water moves from inside the cell to outside the cell.

Knowing these principles, one can estimate the **osmolarity** (solute concentration) in cells using solutions of known osmolarity. The solution concentration with the least gain or loss of mass in the cells used is the most accurate osmolarity of the cells.

Application: Structure and function of sodium–potassium pumps for active transport and potassium channels for facilitated diffusion in axons

The sodium–potassium pump has several features which maintain proper sodium and potassium ion concentrations within nerve cells at rest.

These are that:

- An integral protein exists in the nerve cell membrane which is involved in the sodium–potassium pump.
- Three sodium ions attach to the open protein on the interior surface of the membrane.
- When ATP attaches to the protein, the protein changes shape and opens to the exterior of the cell membrane.
- When this happens, the three sodium ions are released to the exterior of the cell. Then two potassium ions attach to the open end of the protein.
- Next, the phosphate from ATP is released from the interior of the protein. The result of this is the protein now opens on the inside of the cell membrane. The potassium ions are then released to the interior of the cell.

Hints for success: The sodium–potassium pump transports three positively charged sodium ions to the outside of the cell. Immediately after, it transports two positively charged potassium ions to the inside of the cell. The result of this is a slightly negative charge inside the cell.

Subject vocabulary

hypotonic solution a solution with a lower concentration of solute and a higher concentration of solvent

hypertonic solution a solution with a higher concentration of solute and a lower concentration of solvent

osmolarity solute concentration

1.5 The origin of cells

Main idea

The cells we see in organisms today have arisen from the first cells which appeared on Earth.

Understanding: Cells can only be formed by division of pre-existing cells.

Model sentence: The cell theory states that new cells only come from already existing cells by a process of division.

One reason for saying all cells are related by a common ancestor is the similarity of the genetic code in cells. There are 64 code terms (codons) observed in all studied cells today. Each of these codes in all cells observed has the same meaning. There are only minor changes in this code in some cells. These minor changes indicate a common beginning for all cells.

The slight changes in the DNA code are explained by mutations. Mutations are structural changes which occur to DNA.

Hints for study: The hereditary material of life is DNA. It is a molecule which does not often change. When it does change, a mutation is said to occur. These changes occur at a relatively constant rate. The longer the time between the first cells on Earth and the present cells, the more changes will be in the DNA. Very closely related cells or organisms will show very little difference in their DNA.

Understanding: The first cells must have arisen from non-living material.

Model sentence: A major part of the cell theory is to explain how the very first cells formed on Earth.

- We have not observed non-living materials giving rise to living cells. The production of living cells from non-living sources is called **spontaneous generation**.
- The first cells on Earth were most likely very simple. However, these simple cells had to have demonstrated the functions of life.

Application: Evidence from Pasteur's experiments that spontaneous generation of cells and organisms does not now occur on Earth

Louis Pasteur used nutrient broth in different types of flasks to show spontaneous generation of cells and organisms does not occur today.

Understanding: The origin of eukaryotic cells can be explained by the **endosymbiotic theory**.

Model sentence: The endosymbiotic theory is an explanation of how a compartmentalized, complex cell may result from a non-compartmentalized simple cell.

Major points of the endosymbiotic theory:

- Very simple, non-compartmentalized cells existed 2 billion years ago.
- A smaller prokaryote cell was **engulfed** by a larger existing cell and survived.
- The two cells formed a symbiotic relationship in which both were helped. **Symbiosis** refers to a close relationship between two unrelated organisms.
- As time proceeded, the cells changed resulting in an even stronger positive relationship between them. The beneficial symbiotic relationship between two organisms is referred to as **mutualism**.

Evidence for the endosymbiotic theory:

- Organelles such as mitochondria and chloroplasts are about the same size as bacterial cells.
- Mitochondria and chloroplasts divide by fission as do bacterial cells.
- Mitochondria and chloroplasts divide independently of the overall cell.
- Mitochondria and chloroplasts have their own DNA which is very similar in code to bacterial DNA.
- Mitochondria and chloroplasts have two membranes on their exterior.

Subject vocabulary

spontaneous generation the disproven idea that living organisms can arise from non-living sources

endosymbiotic theory a theory which attempts to explain the formation of a complex cell from simple cells

symbiosis condition in which two or more species have a close relationship

mutualism a type of symbiotic relationship where two different species benefit from a relationship they have with each other

Synonyms

engulfed .... surrounded

Nature of science: There is a need to replicate how the first cells formed on Earth. This will most likely be done when scientists can assemble all the non-living components of life in the laboratory and produce a living cell. It is possible that some other explanation than spontaneous generation for the first cells on Earth will be found. This explanation would have to be based on proper scientific observation and experimentation.

1.6 Cell division

Main idea

Cell division is an essential process. However, it must be controlled or a condition called cancer may occur.

Understanding: Cell division involves both mitosis and cytokinesis.

Model sentence: For controlled cell division to occur, mitosis and cytokinesis are both necessary.

- Mitosis refers to division of the nucleus.
- Cytokinesis involves division of the cytoplasm.

Hints for success: If a cell is to successfully divide, it must include division of the nucleus and the cytoplasm. Controlled and proper division of both cell parts is essential for the continuation of the cell and the well-being of the organism. If cell division becomes uncontrolled, large numbers of abnormal cells may be produced. This condition is called cancer.

Understanding: Mitosis is division of the nucleus into two genetically identical daughter nuclei.

Model sentence: The DNA of the two nuclei produced by mitosis is an exact copy of the original nucleus.

DNA replication in the process of mitosis is very accurate. Rarely, changes occur in the process of copying DNA in mitosis. These changes are called mutations. Most of the time mutations are bad for the cell and organisms. Mutations are often lethal.

Hints for success: It is important to remember that mitosis only occurs in eukaryotic cells. Since prokaryotic cells do not have a nucleus, they cannot go through mitosis.

Synonyms

replicate .... copy/repeat

Subject vocabulary

cancer disease involving uncontrolled abnormal cell growth

mitosis cell division where one diploid cell becomes two diploid cells

cytokinesis division of the cytoplasm in cell division

General vocabulary

lethal causing the end of life functions, death

Subject vocabulary

condense process of shortening and thickening

chromatid the identical parts of a doubled chromosomes held together by a centromere

centromere region where sister chromatids attach

sister chromatids the two identical structures of a doubled chromosome

mitotic spindle microtubules which form in the cell division process

General vocabulary

equator middle region of an object

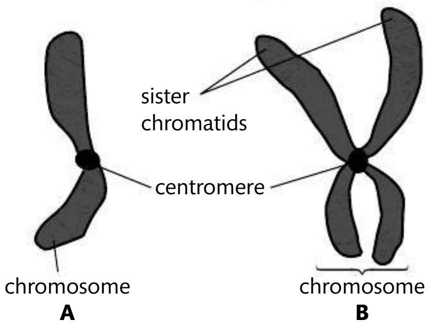


Figure 1.10 *Comparison of a non-doubled and doubled chromosome*

Understanding: Chromosomes condense by supercoiling during mitosis.

Model sentence: Chromosome condensation by supercoiling is necessary for mitosis to occur efficiently.

- Supercoiling is the wrapping process DNA goes through to become condensed enough for mitosis to proceed. DNA is first coiled around spherical proteins called histones. Then it continues to be folded, coiled, and condensed enough to form a chromosome. It is the movement of chromosomes that is described in mitosis.
- DNA that is not supercoiled into chromosomes represents active DNA. Active DNA is DNA carrying out the life activities of the cell. If chromosomes are not present in the nucleus of a cell, that cell is not going through mitosis.
- Before mitosis may occur, two things must happen to the DNA:
  - DNA must be replicated or doubled.
  - DNA must supercoil to form chromosomes.
- In the diagram both **A** and **B** represent chromosomes. Example **A** is a chromosome in which the DNA has not been replicated. Example **B** is a chromosome in which the DNA has been replicated. Example **B** is often referred to as a doubled chromosome. Each identical part of a doubled chromosome is called a **chromatid**. The chromatids are attached to one another by the **centromere**. These attached chromatids are often called **sister chromatids**. Example **B** is the doubled chromosome which enters the process of mitosis. Example **A** represents a chromosome at the conclusion of mitosis.
- The stages of mitosis with their major events are:

Stage of mitosis	Major events
prophase	Chromosomes condense and become visible with the microscope, nuclear membrane disappears, **mitotic spindle** forms.
metaphase	Mitotic spindle fibres line the centromere of the chromosomes along the **equator** of the cell.
anaphase	Doubled chromosomes which are composed of two sister chromatids split at the centromere, the separated chromatids are now called chromosomes, these separated chromatids move toward opposite poles of the cell.
telophase	Mitotic spindle disappears, nuclear membrane reforms, chromosomes go through a process of uncoiling to produce the active form of DNA called chromatin, and two identical nuclei are produced.

Hints for success: Condensed DNA in the form of chromosomes can be efficiently managed during mitosis to produce two daughter nuclei which are genetically identical. Mitosis involves four stages. These stages represent the major changes chromosomes go through in nuclear division.

Skill: Identification of phases of mitosis in cells viewed with a microscope or in a micrograph

Identify the stages of mitosis while viewing squashes made of living plant root cells. These stages can be viewed by using a light microscope. Roots of plants grow relatively rapidly. Squashes of plant root cells may be performed to view the location of chromosomes in the various stages of mitosis.

You may also use micrographs to practise identifying the various stages.

Understanding: Cytokinesis occurs after mitosis and is different in plant and animal cells.

Model sentence: In cell division, mitosis occurs first and is followed by cytokinesis.

Cytokinesis involves division of the cytoplasm in the cell division process. Cytokinesis occurs immediately after mitosis. Cytokinesis occurs differently in plant and animal cells.

- In plant cells, the cell wall is involved in the process of cytokinesis. A **cell plate** forms about **midway** between the two groups of chromosomes. These two identical groups of chromosomes are the result of mitosis. The cell plate begins to form in the central area of the cell. It then continues to form towards both sides of the cell. This proceeds until the cell with two nuclei is separated into two halves. Each half is now a cell with one nucleus and is called a **daughter cell**.
- In animal cells, there is no cell wall and a cell plate is not involved in cytokinesis. Cytokinesis in animal cells occurs when the plasma membrane pinches inward from the outside. The pinching inward continues until the cytoplasm of the one cell with two nuclei is separated into two halves. Each half is now a cell with one nucleus and is called a daughter cell.

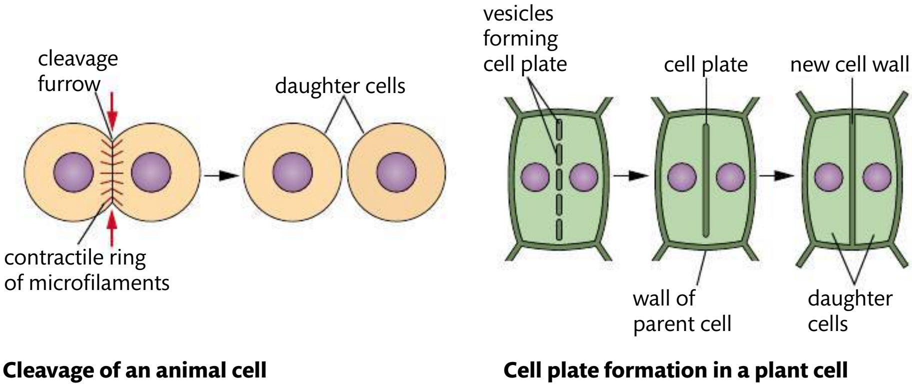


Figure 1.11 *Cytokinesis in animal and plant cells*

Hints for success: The process of cytokinesis in cell division is different in plant and animal cells because plant cells have a cell wall and animal cells do not. The formation of the cell wall must be explained in questions involving plant cell cytokinesis. Animal cell cytokinesis is explained by only describing the action of the plasma membrane.

Subject vocabulary

cell plate structure which forms in plant cells to allow cytokinesis to occur

daughter cells cells produced as a result of cell division

General vocabulary

midway halfway through

Subject vocabulary

interphase stage in the life of a cell in which it is carrying out activities other than cell division

cell cycle the stages in the life of a cell

parent cell cell which gives rise to daughter cells in cell division

cyclin group of proteins which control the cell's progression through the cell cycle

kinase enzymes which may activate or deactivate other proteins by catalyzing a chemical reaction in which phosphate is added to these proteins

G_0 cell cycle stage, some cells are said to be in when they do not progress beyond the G_1 phase

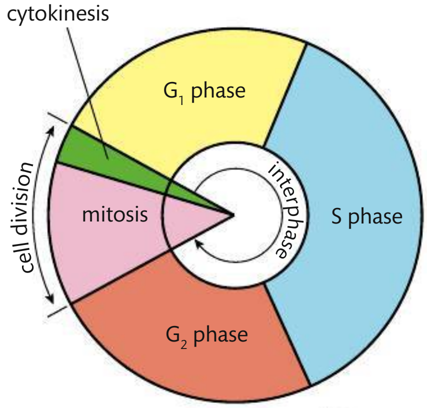


Figure 1.12 *The eukaryotic cell cycle*

Understanding: Interphase is a very active phase of the cell cycle with many processes occurring in the nucleus and cytoplasm.

Model sentence: The cell goes through a series of phases called the cell cycle in its life with the most active phase called interphase.

- The cell cycle includes three major parts. They are:
  - interphase
  - mitosis
  - cytokinesis.
- Mitosis and cytokinesis together are referred to as cell division. They involve the production of two daughter cells by division of the nucleus and the cytoplasm of a parent cell.
- Interphase is usually the longest lasting phase of the cell cycle. Interphase is the phase when the cell carries out all the cell functions other than cell division. Interphase is a very active phase in which the following occurs:
  - Organelles increase in number.
  - The cell increases in overall size.
  - In multicellular organisms, the cell carries out functions necessary for the well-being of the organism.
- Study the figure closely noting that interphase makes up most of the cell's life.
- Interphase of the cell cycle is divided into three shorter phases as shown in the figure. Each phase has specific actions occurring. The following table relates interphase phases to main actions.

Phase of interphase	Major action of phase
G_1	Overall growth of cell occurs in this phase.
S	DNA of the cell is replicated.
G_2	Cell continues to grow with organelles increasing in number. Preparations are occurring for mitosis to begin. DNA begins to condense into chromosomes.

Hints for success: Study the cell cycle diagram and the table of the phases of the cell cycle. Be aware of the major occurrences within each phase. Note that during interphase the cell carries out its specialized functions which are necessary for the well-being of the organism.

Understanding: Cyclins are involved in the control of the cell cycle.

Model sentence: Cyclins are proteins which control the progress of the cell through the cell cycle.

- Cyclins bind to other proteins called kinases at specific points of the cell cycle.
- When the binding of a cyclin with kinase occurs, the cell moves into the next phase of the cell cycle.
- Some cells never progress past G_1 of interphase. Human nerve and muscle cells remain in G_1 throughout their life. These cells grow very little in their lifetime. These cells are said to be in a phase referred to as G_0.

Understanding: Mutagens, oncogenes, and metastasis are involved in the development of primary and secondary tumours.

Model sentence: Many factors may be involved in causing a cell to begin going through uncontrolled cell division; this may result in a cancerous tumour.

- A **tumour** is a mass of abnormal cells in an organism. The cells in a tumour do not carry out tasks necessary for the well-being of the organism.
- A **primary tumour** occurs at the original site of the cancer. A **secondary tumour** is produced when cells from a primary tumour move to a different site resulting in an additional tumour or tumours.
- The spreading of cancer cells is called **metastasis**.
- **Oncogenes** are sections of DNA in a normal cell which may become active and contribute to the development of a cancer cell. These oncogenes may become active through a change or mutation caused by an outside agent. The outside agent which **activates** the oncogene is called a **mutagen**.
- Cigarette smoke shows a **positive correlation** with the occurrence of certain types of cancers.
- Components of cigarette smoke appear to have a high positive correlation in the occurrence of cancers of the **trachea**, **bronchi**, and **lungs**. These components of cigarette smoke are considered mutagens.

Skill: Determination of a mitotic index from a micrograph

The **mitotic index** is an important tool in predicting the success of **chemotherapy** in the treatment of a cancer. The mitotic index is determined as follows:

- Obtain a micrograph or microscope slide of a tumour section.
- Count the number of cells showing chromosomes in the four stages of mitosis.
- Count the number of cells in which chromosomes are not visible. These cells are not going through mitosis.
- Determine the ratio of the number of cells undergoing mitosis compared to the number of cells not going through mitosis. This is the mitotic index.
- A high mitotic index (ratio) indicates a low success in the chemotherapy treatment of the cancer.

Hints for success: Uncontrolled cell division is not good for the well-being of the organism. It may result in the development of cancers. Oncogenes present in the nucleus of a cell may be acted upon by mutagens to bring about uncontrolled cell division and primary tumours. Primary tumours may go through metastasis to produce secondary tumours.

Subject vocabulary

tumour mass of cancerous cells

primary tumour first site of a cancer

secondary tumour sites of cancer in an organism which originated at a primary site

metastasis spreading process of the cells of a tumour

oncogenes segments of DNA which when active may contribute to the development of a cancer

mutagens chemicals capable of causing changes in DNA

positive correlation two factors that both increase together or decrease together

trachea section of the respiratory system which carries air to the bronchi

bronchi respiratory structure which carries air from the trachea into the lungs

lungs major respiratory organs in many organisms

mitotic index ratio of the number of cells undergoing mitosis to cells not undergoing mitosis in a tumour section

chemotherapy treatment of cancer involving chemicals

General vocabulary

activates makes active

2.1 Molecules to metabolism

Understanding: The chemistry of living organisms is called molecular biology.

Model sentence: Molecular biology can be thought of as all of the chemical reactions within a living cell.

Living organisms must do many activities to stay alive. Cells of living organisms must do the following chemical processes:

- Replicate their DNA.
- Use sugars and other substances as fuels for energy (cell respiration).
- Synthesize their own proteins.
- Produce sugars using the energy of sunlight (photosynthesis).

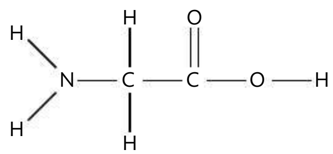
All of the molecules and reactions involved in the above processes are part of the metabolism of the organism. Think of metabolism as being the sum total of all chemical reactions in an organism.

Understanding: Carbon atoms form four covalent bonds leading to organic compounds of great diversity.

Model sentence: Many different types of organic compounds can form because the element carbon forms four covalent bonds.

The element carbon exists in all organic substances. Each time an atom of carbon bonds with another atom, the two atoms share electrons. This type of bond is known as a covalent bond:

- Carbon always forms four covalent bonds.
- Carbon frequently forms covalent bonds with other carbon atoms, oxygen atoms, nitrogen atoms, and hydrogen atoms.



- C = carbon
- H = hydrogen
- O = oxygen
- N = nitrogen

Figure 2.1 *A diagram of a relatively small molecule important to cells. Notice that the two carbon atoms are surrounded by four covalent bonds each. Notice also that carbon is bonded to another carbon. In addition, carbon is bonded to nitrogen, oxygen, and hydrogen*

Synonyms

replicate .... copy/repeat

Subject vocabulary

DNA the molecule that determines which polypeptides are produced within cells

cell respiration chemical process used by cells to gain energy from sugars and other substances

photosynthesis process which converts light energy into chemical energy

covalent bond chemical bond in which electrons are shared

compound a molecule that contains at least two different kinds of elements

element a substance that is impossible to break down further by chemical means

organic substances a collection of carbon-based compounds found in living organisms

General vocabulary

synthesize produce from smaller building block units

diversity existing in many different types or forms

Understanding: Living things are made up of carbon compounds, including carbohydrates, lipids, proteins, and nucleic acids.

Model sentence: Carbohydrates, lipids, proteins, and nucleic acids are the four organic compound types found within living things.

Carbon compound	In brief	Common example
carbohydrates	molecules often referred to as sugars	glucose
lipids	fat when a solid, oil when a liquid	triglyceride
proteins	diverse functions	proteins making up muscles
nucleic acids	molecules most often used in genetics	DNA

Skill: Identification and drawings of common biochemically important molecules

Practise drawing and recognizing the following molecules. You will learn more about their functions and terminology in later units of study:

- alpha-D-glucose
- beta-D-glucose
- D-ribose
- a saturated fatty acid
- a generalized amino acid.

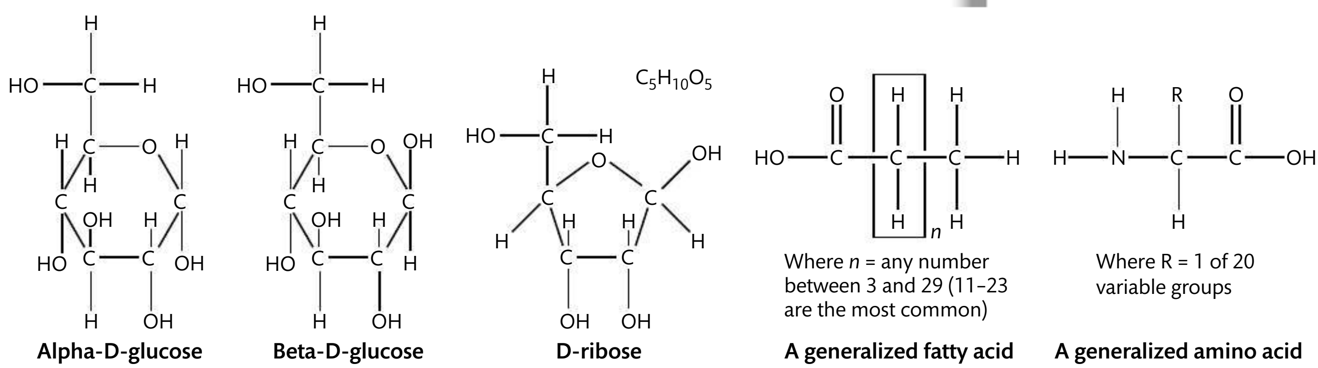


Figure 2.2 *Common molecular structures to practice*

Understanding: Metabolism is the term used for all of the enzyme-catalysed reactions in a cell or entire organism.

Model sentence: A cell's metabolism is very complex, as metabolism includes all of the reactions in the cell, with each reaction catalysed by an enzyme.

A catalyst is a substance that increases the rate of a reaction, but the catalyst is not considered a reactant or a product. A catalyst was there before the reaction began and it will still be there after the reaction is over. Thus, catalysts are reusable for many reactions.

When a catalyst is a protein molecule, the catalyst is called an enzyme. Each enzyme only catalyses one reaction. Many times the product of one reaction is catalysed

Subject vocabulary

glucose a simple sugar produced by photosynthesis and used for cell respiration

triglycerides fats or oils formed from three fatty acids and a glycerol molecule

genetics transfer of traits from parents to children

fatty acid one of the components of a lipid molecule

metabolism sum total of all reactions in a cell or organism

enzyme a protein that acts as a catalyst

catalyst molecule that increases the rate of a reaction without being consumed by the reaction

reactant one or more molecules that are used in a reaction to create one or more products

product those molecules that are formed as a result of a reaction

General vocabulary

terminology related technical words

reusable can be used many times for the same purpose by another enzyme to create a second product. The second product may then be catalysed by a third enzyme and so on. This is called a 'chain of reactions'.

There can be many chains of reactions going on within a cell all at the same time. The sum total of all of these reactions is that cell's metabolism. The sum total of the metabolism of all of the cells is the metabolism of the organism.

Subject vocabulary

anabolism type of metabolism in which smaller compounds are used to build larger compounds in organisms

synthesis constructing complex molecules from smaller, simpler ones

macromolecules large, complex organic molecules

monomer a 'building block' unit of a macromolecule

condensation reaction a chemical reaction in which two monomers are bonded together to form a larger molecule

synthesized chemically created

catabolism type of metabolism in which larger compounds are broken down with the release of energy

hydrolysis a chemical reaction in which a larger molecule is split into two smaller molecules

Understanding: **Anabolism** is the **synthesis** of complex molecules from simpler molecules, including the formation of **macromolecules** from **monomers** by **condensation reactions**.

Model sentence: Anabolism is the part of metabolism where larger molecules (macromolecules) are formed from smaller molecules (monomers) by reactions called condensation.

Living organisms must be able to form their own large complex organic molecules known as macromolecules. They often form these from smaller, simpler molecules known as monomers. The reaction that bonds one monomer to another monomer is known as a condensation reaction. The part of an organism's metabolism where monomers are bonded together to create macromolecules is known as anabolism.

Hints for success: In examinations, be sure to include the water molecule that is always one of the products of a condensation reaction.

Application: Organic molecules are frequently formed within living organisms, but many can be produced artificially as well

The first organic molecule to be produced in a laboratory setting was urea. Urea is produced in the liver tissue of many animals and becomes a component of urine. In 1828, a German physician by the name of Friedrich Wohler **synthesized** urea from inorganic compounds in his laboratory. This showed that organic substances can be artificially synthesized.

Understanding: **Catabolism** is the breakdown of complex molecules into simpler molecules including the **hydrolysis** of macromolecules into monomers.

Model sentence: Catabolism is the part of metabolism where smaller molecules (monomers) are formed from larger molecules (macromolecules). These reactions are called hydrolysis.

Organisms often ingest foods that contain macromolecules. As part of digestion, the organism must be able to breakdown the large molecules into smaller molecules. This chemical reaction is an example of catabolism. Notice that catabolism is the opposite of anabolism. In catabolism, macromolecules are turned back into monomers by a reaction type known as hydrolysis.

Hints for success: During examinations, be sure to include a water molecule as a reactant during a hydrolysis reaction. Notice that this is the opposite of condensation where a water molecule was formed as a product.

2.2 Water is the medium of life

Understanding: Water molecules are polar and hydrogen bonds form between them.

Model sentence: Each water molecule has a positive and a negative end permitting hydrogen bonding between water molecules.

Covalent bonds are bonds between atoms formed by the sharing of electrons between those two atoms. Sometimes that sharing is equal and sometimes it is not equal. Here are two examples:

Figure 2.3A *Notice that when two hydrogen atoms share a pair of electrons between them, neither takes on a charge. This is because the sharing is equal. This is called a non-polar covalent bond*

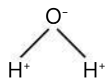


Figure 2.3B *Notice that when hydrogen atoms share electrons with an oxygen atom, the oxygen atom takes on a negative charge and each hydrogen atom takes on a positive charge. This is because the sharing of the negative electron is not equal. This is called a polar covalent bond*

Notice that:

- Both hydrogen and oxygen take on a slight and opposite charge because they are not sharing their pair of electrons equally.
- Molecules that contain these types of covalent bonds where the electrons are not shared equally are called polar molecules.

A single drop of water contains millions of moving polar water molecules. As each water molecule comes near another water molecule, the positive end of any one is attracted to the negative end of another. This attraction is called a hydrogen bond. Each hydrogen bond is very weak and short-lived. The many millions of hydrogen bonds that occur within water at the same time lead to many of the important properties of water. Some of those properties will be discussed in the upcoming section.

Remember that oxygen atoms do not share electrons equally when they form a covalent bond with some other atoms. One of those atoms is hydrogen. Because electrons are negatively charged, an oxygen atom will take on a slight negative charge and the hydrogen will take on a positive charge when the two atoms are bonded together.

Understanding: Hydrogen bonds and dipolarity explain the cohesive, adhesive, thermal, and solvent properties of water.

Model sentence: Each water molecule has both a positive and negative end (dipolarity) giving rise to many of the important properties of water.

Hydrogen bonding between nearby water molecules explains the following properties:

- Cohesion – term used when water molecules attract other water molecules.
- Adhesion – term used when water molecules attract another polar substance besides water.

Subject vocabulary

hydrogen bond a weak bond that forms between positive and negatively charged areas of two molecules

covalent bond chemical bond in which electrons are shared

polar molecules molecules that contain one or more unequally shared electrons

dipolarity having two oppositely charged ends

solvent the liquid portion of a solution (solution = solvent + solute(s))

cohesion attraction of one water molecule for another

General vocabulary

adhesion process where two different substances stick together or attach to one another

General vocabulary

thermal related to/caused by heat

Subject vocabulary

hydrophilic 'water loving', substances that dissolve in water

hydrophobic 'water fearing', substances that do not dissolve in water

soluble a substance that will dissolve

non-polar region of no electrical charge

insoluble a substance that will not dissolve

immiscible two substances that when mixed together will tend to separate from each other in layers

cytoplasm region of the cell within the plasma membrane in which the cell organelles exist

haemoglobin a protein found in red blood cells used to carry oxygen in the blood

Synonyms

transport .... movement

- **Thermal** properties:
  - High specific heat – water can absorb and give off a great deal of heat without changing its temperature much.
  - High heat of vaporization – water requires a great deal of heat in order to convert it from the liquid phase to the gas phase.

Hints for success: Have you ever thought about why sweating cools your body? The cooling is due to the body heat that is absorbed by the (sweat) water. The heat that is taken from your body is used to evaporate the water from your skin. For an examination, this would be a good example to remember for the importance of high heat of vaporization.

Water is an excellent solvent for other polar (charged) substances. The following are a few examples of substances that are polar and thus dissolve well in water:

- ions
- glucose
- amino acids.

Understanding: Substances can be hydrophilic or hydrophobic.

Model sentence: The polarity of a substance determines whether that substance is hydrophilic 'water loving' or hydrophobic 'water fearing'.

Polar substances like glucose are 'water loving'. This is because of their numerous alcohol (-OH groups). They easily dissolve in a water solution. We say that these molecules are water soluble.

Non-polar substances, like lipids, are 'water fearing'. This is because of their lack of polar covalent bonds. They do not mix with water very well. We say that these molecules are water insoluble or the two substances are immiscible.

The following tables show common molecules and their solubility in water solutions. These solutions could represent the cytoplasm of a cell or perhaps blood.

Polar molecules (hydrophilic)	Mode of transport in blood
glucose	easily dissolves in plasma
amino acids	easily dissolve in plasma
sodium chloride (salt)	easily dissolves in plasma

Non-polar molecules (hydrophobic)	Mode of transport in blood
cholesterol	attaches to polar proteins
lipids	attaches to polar proteins
oxygen	carried by haemoglobin

Understanding: Monosaccharide monomers are linked together by condensation reactions to form larger carbohydrate molecules.

Model sentence: Single carbohydrate units are covalently bonded together to make disaccharides and polysaccharides.

Fundamentals of carbohydrates:

- The smallest carbohydrates are monosaccharides.
- Two monosaccharides bonded together form a disaccharide.
- Many monosaccharides bonded together form a polysaccharide.

Examples of carbohydrates:

- monosaccharides – glucose and fructose
- disaccharides – sucrose and maltose and lactose
- polysaccharides – starch and cellulose.

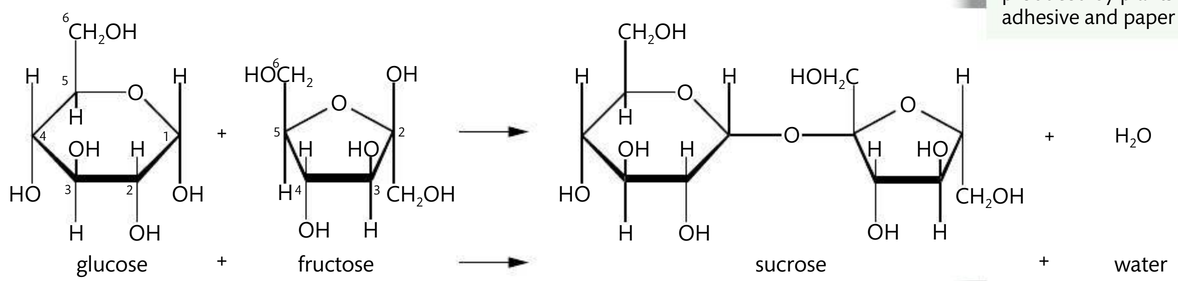


Figure 2.4 *The condensation reaction between glucose and fructose to form the disaccharide sucrose and a water molecule. Each corner of the sugar rings has an 'unshown' carbon atom. Each carbon atom is numbered in the reactants. Glucose and fructose are isomers of each other because they have the same chemical formula,* $C_6H_{12}O_6$

Application: Common uses and structure of polysaccharides

Name of polysaccharide	Structural form (shape)	Common use
cellulose	linear	used by plant cells within plant cell walls
starch	highly branched	used by plants to store glucose for later use
glycogen	highly branched	used by humans to store glucose for later use

Note: starch is composed of two types of polysaccharide, amylose and amylopectin.

Subject vocabulary

monosaccharide smallest (monomer) unit of carbohydrates

carbohydrates any of a group of molecules often referred to as 'sugars'

disaccharide two monosaccharides bonded together by a condensation reaction

polysaccharide many monosaccharides bonded together by many condensation reactions organized into a linear or branched shape

amylose type of starch that is the most common storage form of carbohydrates in plants

amylopectin type of starch produced by plants that has adhesive and paper uses

Understanding: Fatty acids can be saturated, monounsaturated, or polyunsaturated.

Model sentence: Fatty acids are classified into one of three categories depending on the presence of double bonds within the molecule.

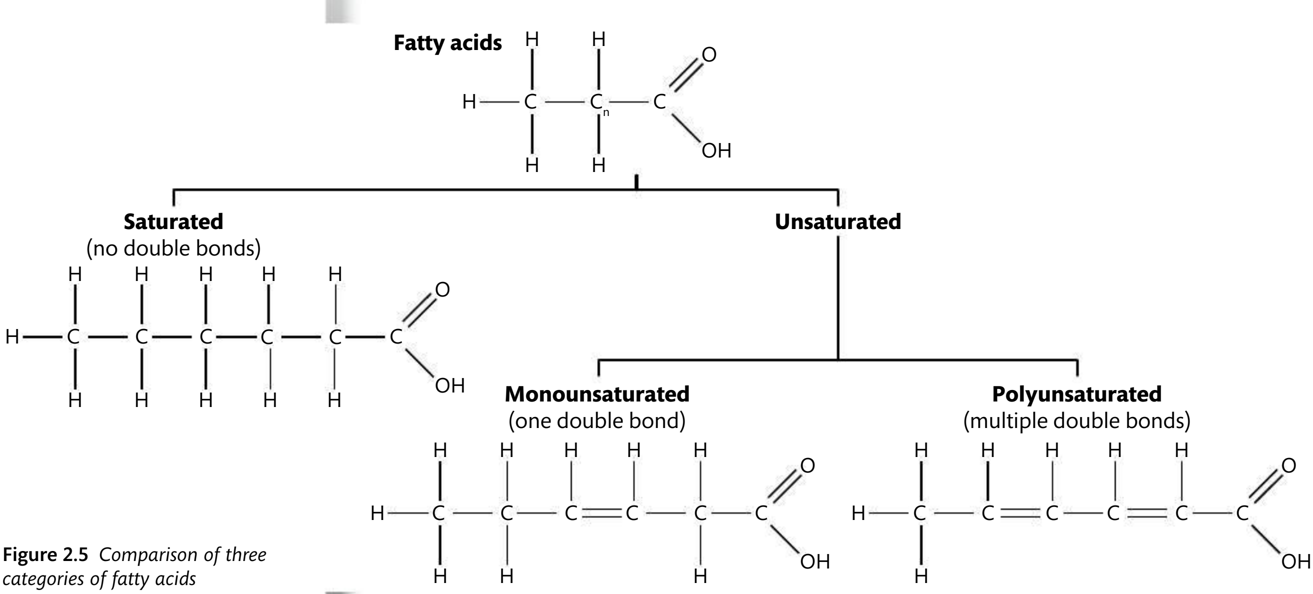


Figure 2.5 *Comparison of three categories of fatty acids*

Subject vocabulary

cis term used to describe a natural form of an unsaturated fatty acid

trans a chemically modified fatty acid sometimes used by food-processing companies

isomers two molecules that have the same chemical formula but differ in structure

Understanding: Unsaturated fatty acids can be **cis** or **trans** **isomers**.

Model sentence: Food-processing companies often modify unsaturated fatty acids converting them from a cis form to a trans form.

When polyunsaturated (generally healthy) fatty acids are used in packaged foods, the food product has a relatively short **shelf life**. Many food-producing companies modify the fatty acids they use to a form with fewer double bonds. This extends the shelf life of the product.

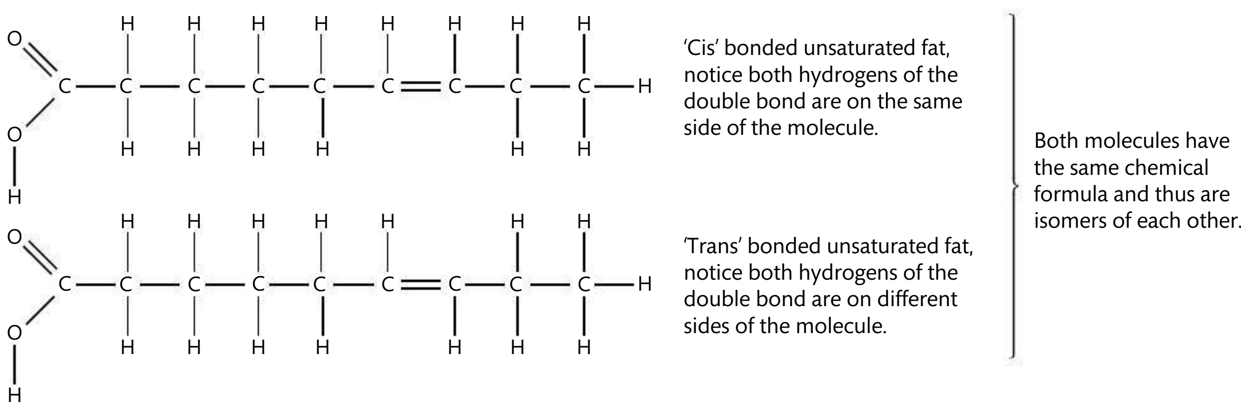


Figure 2.6 *When food companies attempt to modify unsaturated fatty acids the remaining double bonds are often converted from a cis form to a trans form. The cis form is considered relatively healthy and the trans form is unhealthy as part of your diet*

General vocabulary

shelf life how long a food product can remain without becoming spoiled

- The relatively healthy, original form of the fatty acid is called the cis form.
- The unhealthy, modified form of the fatty acid is called the trans form.
- Foods that are made with the modified trans fatty acids are said to contain trans fats.
- Most polyunsaturated fatty acids found in nature are in the cis form.

Understanding: Triglycerides are formed from one **glycerol** and three fatty acids by condensation reactions.

Model sentence: The 'building block' molecules of triglycerides are one glycerol molecule and three fatty acid molecules.

- Several types of molecules can be classified as lipids.
- Triglycerides are one type.
- Triglycerides are most often used for energy storage within cells.
- The subcomponent (building block) units are bonded together by condensation reactions.

Application: Lipids are better for long-term energy storage in humans as compared to carbohydrates

Imagine a kilogram of lipid in one container and a kilogram of carbohydrate in another container. Next imagine that each is burned and the energy release from each was measured. There would be approximately twice as much energy released from the container with lipid as compared to the container with carbohydrate.

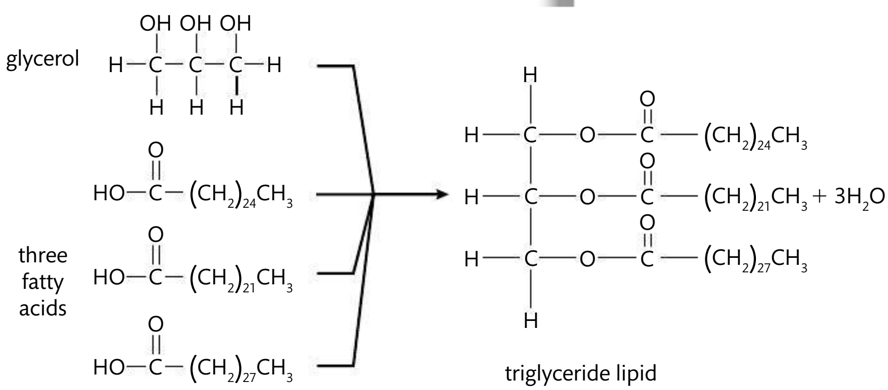


Figure 2.7 *Condensation reaction showing the four reactants necessary to form a triglyceride lipid. Notice that there are four products: the three water molecules as well as the triglyceride*

- This shows that lipids are much more efficient at storing energy as compared to carbohydrates.
- This also demonstrates why long-term energy storage is done by way of lipids.

Skill: Determination of body mass index by calculation or use of a nomogram

A determination of one's weight compared to one's height can be done by calculation of a value known as the Body Mass Index (BMI).

A BMI can be determined by a formula with one's known mass and height. The BMI can also be determined by consulting a graph or using an **online calculator**. The BMI value is then compared to a published chart to show relative health.

BMI	Description category
below 18.5	underweight
18.5–24.9	normal weight
25.0–29.9	overweight
30.0 and above	obese

Subject vocabulary

glycerol a three-carbon molecule found within lipids

General vocabulary

online calculator a website designed to do mathematics

Understanding: Amino acids are bonded together by condensation reactions to form **polypeptides**.

Model sentence: A polypeptide forms when amino acids become linked together by condensation reactions.

Building block molecules often bond together to form the larger molecules important to living organisms. This is true for molecules called polypeptides. A polypeptide is formed when many amino acids bond together in a chain. A condensation reaction has occurred each time one amino acid bonds to another in the chain. Each new covalent bond that forms is called a peptide bond.

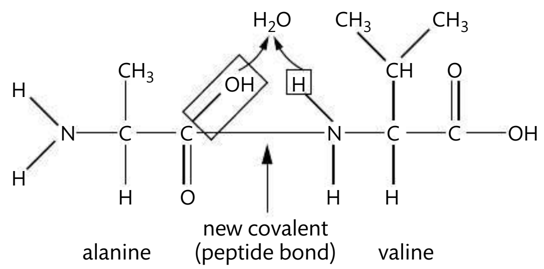


Figure 2.8 *Condensation reaction between the amino acids alanine and valine. Note that for simplicity the amine and carboxyl groups are being shown in a non-ionized form. This reaction looks the same for any two amino acids, as the only change would be to the R (variable) groups*

Hints for success: Practise drawing two or more amino acids undergoing a condensation reaction. You will need to be able to do this in an examination.

Understanding: There are 20 different amino acids in polypeptides synthesized on **ribosomes**.

Model sentence: When a polypeptide is created, as many as 20 different types of amino acids may be used at the ribosome where this occurs.

Each of the 20 amino acids is very similar in overall structure. The exception is the one part of each amino acid that is called its **R-group**. The chart on the following page shows the structure of all 20 amino acids with a box around the R-group of each. You do not need to memorize all of these structures.

Subject vocabulary

polypeptide polymer of many amino acids joined by peptide bonds

ribosome organelle within cells where polypeptides are formed

R-group the portion of each of the 20 amino acids that is different from one another

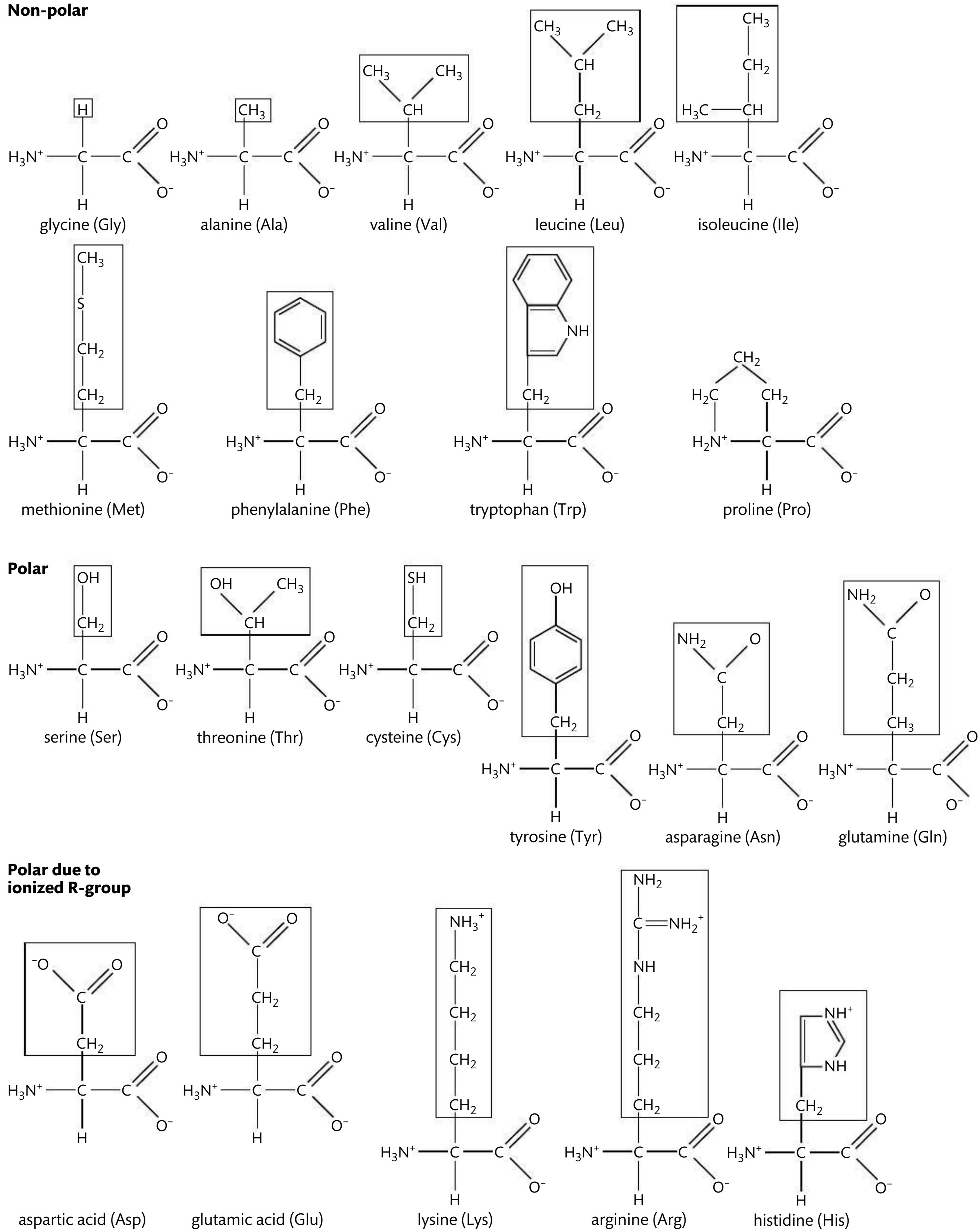


Figure 2.9 *A chart showing the structures of the 20 amino acids. The boxed areas shown are the R-groups of the amino acids. Note how each amino acid is identical except for the variable R-group*

Understanding: Amino acids can be linked together in any sequence, giving a huge range of possible polypeptides.

Model sentence: The many kinds of polypeptides are explained by the 20 types of amino acids being bonded together in any possible order and number.

Consider a very short polypeptide that has only four amino acids of four different types. Imagine those four types of amino acids to be glycine, alanine, serine, and threonine. Here are eight possible sequences in which they could be arranged:

1. glycine – alanine – serine – threonine
2. alanine – glycine – serine – threonine
3. serine – alanine – glycine – threonine
4. alanine – glycine – threonine – serine
5. serine – alanine – threonine – glycine
6. glycine – serine – alanine – threonine
7. glycine – threonine – serine – alanine
8. alanine – serine – glycine – threonine

Now imagine a polypeptide that has 50 or more total amino acids. Some of the 20 types of amino acids would have to be used more than once. The number of possible sequences is incredibly large.

Understanding: The amino acid sequence of polypeptides is coded for within our genes.

Model sentence: The DNA of living organisms contains sections called genes each coding for a different polypeptide.

- Each DNA is a very long molecule containing a great deal of genetic information.
- A single DNA molecule may contain a thousand or more sections called genes.
- Each gene is enough genetic information to code for a polypeptide.
- The coding information is for the sequence of amino acids that make up the polypeptide.

Subject vocabulary

gene section of DNA molecule that codes for a particular trait/protein in an organism

protein one or more polypeptides that has a defined function

Understanding: A protein may consist of a single polypeptide or two or more polypeptides linked together.

Model sentence: Some proteins are made up of a single polypeptide, whereas other proteins are made up of two or more polypeptides bonded together.

A protein is a molecule that has a function within a living organism. A single polypeptide that begins its function soon after being synthesized can also be called a protein. In some instances, a single polypeptide is not functional until it combines with one or more other polypeptides. Only then is the molecule called a protein. In short, a single polypeptide is a protein only when it does not require one or more other polypeptides to begin its function.

Examples of proteins are:

- **Myoglobin** is a single polypeptide that is found within muscle cells. Myoglobin's single polypeptide is capable of binding to an oxygen molecule that is only released when you exercise very hard. It functions as a single polypeptide and is a protein.
- Haemoglobin is composed of four polypeptides and is found within red blood cells. Haemoglobin can bind to and release as many as four oxygen molecules. Its function does not begin until all four polypeptides are bonded to each other. Haemoglobin is a protein only when all four polypeptides are present and working together.

Understanding: The amino acid sequence determines the three-dimensional shape of a protein.

Model sentence: Each type of protein has a unique three-dimensional shape that is a result of its amino acid sequence.

When a polypeptide is first formed, the amino acids that it is made up from begin to interact with each other. Through a series of positive and negative charges, amino acids either attract or repel one another. The polypeptide settles into an overall three-dimensional shape that is repeated every time that same polypeptide is synthesized. Remember that some proteins do not function until two or more polypeptides join together. The joining that they do is also due to forces between charges they contain. Every time a protein forms it will automatically take on the exact same shape.

Understanding: Living organisms synthesize many different proteins with a wide range of functions.

Model sentence: The proteins found within any one living organism are numerous and serve a number of different functions.

Application: This table shows just a few examples of the incredible variety of proteins in nature:

Protein	Function
rubisco	enzyme used in photosynthesis
insulin	**hormone** involved in **regulating** blood sugar
immunoglobins	helps fight viruses and bacteria
collagen	component of skin and **tendons**
spider silk	used for making webs
rhodopsin	pigment found in retina cells of the eye

Subject vocabulary

myoglobin a protein found within muscles that bonds to an oxygen molecule

hormone a chemical messenger produced by an endocrine gland

tendons tissue used to connect muscles to bones

Synonyms

regulating ...... controlling

Subject vocabulary

proteome the unique collection of proteins within a cell, tissue type, organ, or organism

genetic determined by DNA and passed on from parents to offspring

active site the area of an enzyme to which the substrate(s) attach(es)

substrate substance which begins a chemical reaction or process

reaction a change due to the interaction of chemical substances or response due to a stimulus

catalysed the action of a catalyst, such as an enzyme, whereby the enzyme increases the rate of reaction

catalysis the action of a catalyst such as an enzyme

General vocabulary

collision two things moving toward and eventually impacting each other

Understanding: Every individual has a unique proteome.

Model sentence: The genetic makeup of each individual is slightly different and thus the collection of proteins in every individual is also slightly different.

Researchers have known for years that each individual organism has unique DNA. This explains why humans are all a little different from each other. The same is true for all other species as well. Each member of a species is genetically different from all other members of that species.

DNA is the genetic code for proteins. It makes sense that if every organism has unique DNA, then every organism also has a unique set of proteins as well. The unique collection of proteins within any one organism is called the proteome of that organism.

2.5 Enzymes

Understanding: Enzymes have an active site to which specific substrates bind.

Model sentence: Each enzyme molecule has a specific area called its active site where the substrate(s) of that enzyme attach.

- Each enzyme is a protein with a very specific three-dimensional shape.
- Part of that three-dimensional shape is an area called an active site.
- The molecule or molecules that enter the active site are called the substrate(s) of that enzyme.
- When the substrate(s) are within the active site a reaction is catalysed.

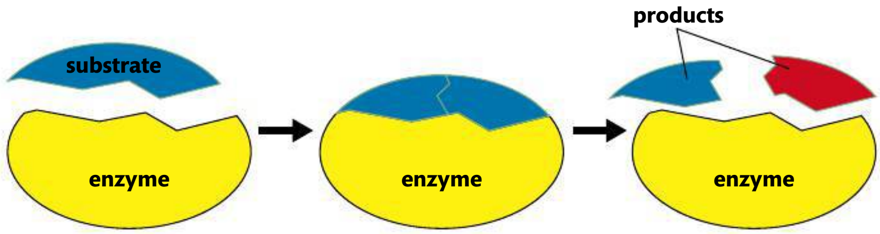


Figure 2.10 *An enzyme and substrate are specific for each other*

Understanding: Enzyme catalysis involves molecular motion and the collision of substrates with the active site.

Model sentence: The ability of an enzyme to act as a catalyst depends on the substrate(s) colliding with the active site.

Reactions require energy. This energy is called the activation energy of a reaction. Activation energy is most often in the form of heat. An increase in heat results in molecules moving faster. When molecules move faster they collide with other molecules with greater energy. The function of an enzyme is to provide an active site where the collision that occurs has a better chance of the reaction being successful.

Understanding: Enzymes can be denatured.

Model sentence: The three-dimensional shape of an enzyme can be altered in a process called denaturing.

Each specific enzyme has its own ideal conditions in which it best catalyses reactions. Altering those ideal conditions leads to a change in the shape of the enzyme. This is called denaturing the enzyme. The same denaturing happens to all proteins. The most important part of an enzyme that must be perfectly shaped is the active site of the enzyme.

Understanding: Temperature, pH, and substrate concentration affect the rate of activity of enzymes

Model sentence: Each enzyme has an optimum temperature, pH, and concentration of substrate that ensures the maximum reaction rate.

Factors affecting an enzyme reaction that are not optimum will lower the rate of reaction as compared to the ideal.

Factor	What does condition do?	Why?
temperature below ideal	molecules in a reaction move relatively slowly	Even when an active site helps, a minimum activation energy is required.
temperature above ideal	molecules in a reaction move relatively fast	Enzyme begins moving fast as well. Enzyme becomes denatured.
pH below ideal	reaction becomes more acidic than ideal	Acidic environment modifies the structure of the enzyme leading to denaturing.
pH above ideal	reaction becomes more basic than ideal	Basic environment modifies the structure of the enzyme leading to denaturing.
substrate concentration below ideal	reaction does not have enough reactant(s)	Enzyme can provide more available active sites but there is not enough substrate to fill those 'openings'.
	Note: if substrate concentration is above ideal, the reaction rate is not increased nor is it decreased.	Each active site of each enzyme is saturated and is thus working as fast as is possible.

Subject vocabulary

denature to cause a molecule to lose its natural three-dimensional shape

pH a measure of the acidity or alkalinity of a solution

concentration a measurement of the density of a substance in a solution

reaction rate number of successful reactions per unit of time

acidic a fluid that has a pH measured at less than 7.0

basic a fluid that has a pH measured at more than 7.0

saturated all four iron atoms within a single haemoglobin are bonded to an oxygen molecule

Synonyms

optimum .... best/ideal

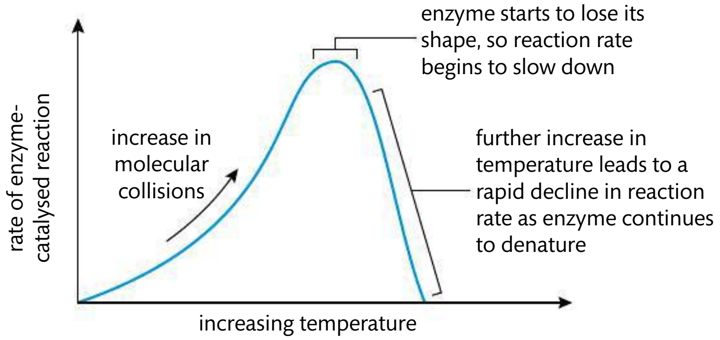


Figure 2.11 *The effect of increasing temperature on the rate of an enzyme-catalysed reaction*

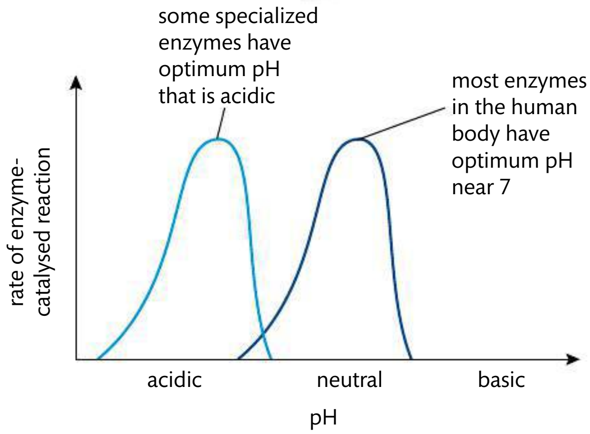


Figure 2.12 *The effect of pH on the rate of an enzyme-catalysed reaction. This illustrates that there is no single pH that is best for all enzymes*

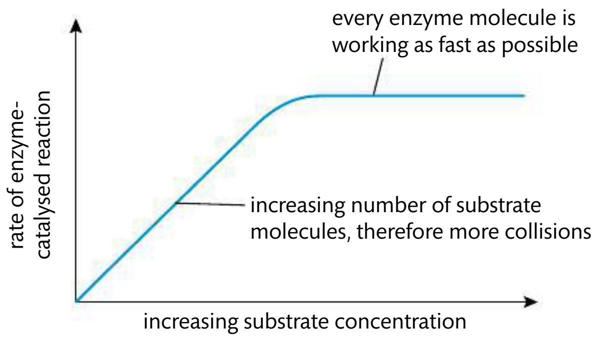


Figure 2.13 *The effect of increasing the substrate concentration on the rate of an enzyme-catalysed reaction*

Understanding: Immobilized enzymes are widely used in industry.

Model sentence: Commercially used enzymes are often embedded into a permanent substance in order to avoid losing the enzymes.

Using enzymes in industry is an expensive process. One of the most expensive parts is acquiring and **purifying** the enzyme needed. The solution is to make sure that the enzyme used does not get wasted and is recycled. One way this is done is to trap the enzyme molecules in small beads called **alginates**. The enzyme molecules are said to be immobilized in the small beads. When the factory uses the enzyme the small beads are recovered from any product formed and can be reused many times.

Application: Methods of production of lactose-free milk and its advantages

Lactose-free milk can be produced by adding the enzyme lactase to milk. The lactase is trapped within small alginate beads that are then mixed with milk. The lactase converts the lactose to two monosaccharide sugars. Those people that cannot digest their own lactose (lactose intolerance) have milk products 'pre-digested' by this method.

Subject vocabulary

immobilized to contain something so that it remains trapped

alginates chemicals derived from a seaweed (algae)

lactose a disaccharide sugar composed of glucose and galactose

General vocabulary

embedded positioned firmly and deeply

Synonyms

purifying .... cleansing/cleaning

2.6 Structure of DNA and RNA

Main idea

DNA has a structure which allows genetic information to be stored efficiently.

Understanding: The nucleic acids DNA and RNA are polymers of nucleotides.

Model sentence: DNA and RNA are nucleic acids made up of large numbers of nucleotides.

- **Nucleic acids** are one of the major organic groups. DNA and RNA are classified as nucleic acids.
- DNA and RNA are made of **polymers** or large chains of **nucleotides**. These nucleotides are connected by chemical bonds. A **generalized** nucleotide is shown to the right.
- Parts of a DNA nucleotide:
  - one **phosphate group**.
  - one deoxyribose – a 5-carbon sugar.
  - one nitrogenous base – adenine (A), thymine (T), cytosine (C), or guanine (G).
- Parts of a RNA nucleotide
  - one phosphate group
  - one ribose – a 5-carbon sugar
  - one nitrogenous base – adenine (A), uracil (U), cytosine (C), or guanine (G).
- **Covalent bonds** attach the parts within a nucleotide. Covalent bonds also attach individual nucleotides together to form a polymer (chain).
- It is the sequence of bases in a DNA or RNA molecule which provides the genetic code.

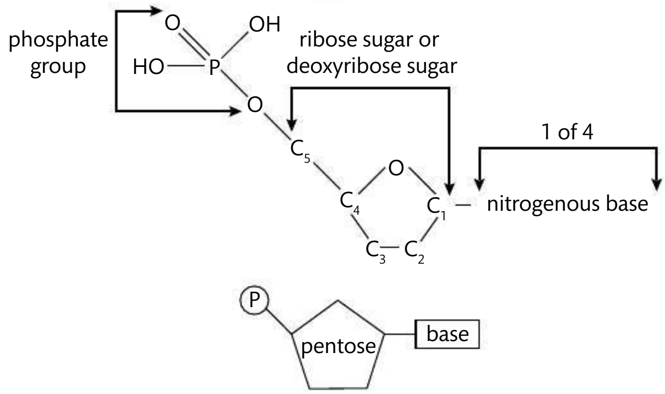


Figure 2.14 *The first diagram represents the structure of a nucleotide showing bond locations. The second diagram represents the structure of a general nucleotide using the symbols suggested by the IB*

Hints for success: Organisms are quite complex. The base sequence in nucleic acids must be quite long to code for this complexity. When asked to draw a nucleotide for IB, always show the phosphate group as a circle. Always show the pentose (5-carbon sugar) as a pentagon. Always show the nitrogenous base as a rectangle.

Skill: Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons and rectangles to represent phosphates, pentoses, and bases

Subject vocabulary

nucleic acids one of the major organic groups which includes DNA and RNA

polymer large molecules composed of smaller units (monomers) connected by covalent bonds

nucleotides smaller units chemically bound to form nucleic acids

phosphate group chemical group composed of phosphorus and oxygen

covalent bond chemical bond in which electrons are shared

General vocabulary

generalized not specific, relates to a group

Understanding: DNA differs from RNA in the number of strands present, the base composition, and the type of pentose.

Model sentence: DNA is double-stranded while RNA is single-stranded. DNA has a difference from RNA in bases present. DNA has a different 5-carbon sugar than RNA.

The sugar of DNA is deoxyribose. The sugar of RNA is ribose. Both these sugars are made up of five carbons. DNA is composed of two strands of nucleotides. These two strands are connected to one another by **hydrogen bonds** between the bases. RNA is composed of only one strand of nucleotides.

RNA contains the nitrogenous bases A, U, C, and G. DNA contains the nitrogenous bases A, T, C, and G.

Hints for success: Use a table or t-chart to represent the main characteristics of DNA and RNA. In your table or t-chart include similarities and differences.

Subject vocabulary

hydrogen bond a weak bond that forms between positively and negatively charged areas of two molecules or within a single molecule to help shape the molecule

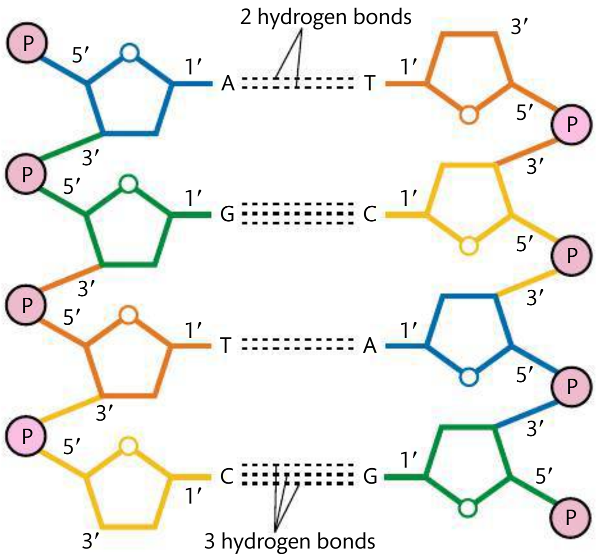
complementary base pairs nitrogenous bases which pair together in nucleic acids, A–T, A–U, C–G

double helix three-dimensional shape of DNA involving a double spiral

Understanding: DNA is a double helix made of two antiparallel strands of nucleotides linked by hydrogen bonding between complementary base pairs.

Model sentence: The structure of DNA is a double helix made up of two strands connected by hydrogen bonds.

- DNA has a double helix shape. This is because there are two strands and each is in a spiral form.
- Relatively weak hydrogen bonds connect the two DNA strands. These hydrogen bonds occur between complementary bases. A and T are complementary bases and are connected by two hydrogen bonds. C and G are complementary bases and are connected by three hydrogen bonds
- The two strands of DNA are antiparallel because they occur in opposite directions. On one strand the number 5 carbon is on top. On the other strand the number 3 carbon is on top.



Nature of science: Watson and Crick worked with models to discover the actual structure of DNA. They used information from many sources to construct their final actual model.

Hints for success: When drawing the structure of DNA a ladder structure shown to the left is required. It is not necessary to show the actual number of hydrogen bonds between complementary bases.

Figure 2.15 *The ladder structure of DNA is represented in this figure. Note the two strands have carbons numbered in the opposite direction. Also note the hydrogen bonds between complementary bases. All other bonds in this molecule are covalent bonds*

2.7 DNA replication, transcription, and translation

Main idea

DNA **transcription** and **translation** allow the production of the proteins necessary to the cell.

Understanding: The replication of DNA is semi-conservative and depends on complementary base pairing.

Model sentence: DNA replicates based on complementary base pairing. The replication process is said to be semi-conservative.

- DNA in the nucleus of the cell must replicate before cell division occurs.
- DNA replication is referred to as semi-conservative.
- Semi-conservative means that each of the two molecules of DNA formed in replication has one strand of the original DNA molecule. The other strand of the new DNA molecule is new. This new strand is formed from free nucleotides in the nucleus.
- The two strands of DNA are chemically bound by hydrogen bonds between adenine (A) and thymine (T), and between cytosine (C) and guanine (G).

Hints for success: Because of complementary base pairing, two identical copies of DNA are produced from one. Each molecule of DNA produced in replication has one strand from the original DNA molecule.

Subject vocabulary

transcription the process of creating RNA from DNA

translation process of protein production which occurs at the ribosome in cells, DNA language is changed into the language of proteins

semi-conservative type of replication in DNA in which each new DNA molecule has one original strand of the parent molecule

helicase enzyme which opens the DNA double helix in the replication process

General vocabulary

unwind to loosen from the original shape

unzipping to open a zipper-like structure, to open a closed structure

Synonyms

replicate .... copy

Understanding: Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.

Model sentence: Helicase is an enzyme which causes the DNA double helix to unwind and breaks the hydrogen bonds between complementary base pairs.

Initial steps in the replication of DNA:

- First, the double helix of the DNA molecule must unwind.
- Next, the hydrogen bonds which connect the two strands of the DNA must be broken. This is often referred to as an **unzipping** process.
- Helicase, an enzyme, allows these two steps to occur very rapidly.

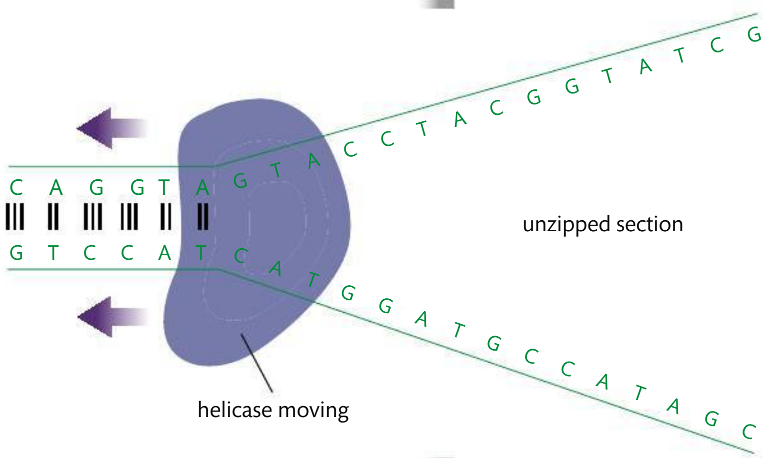


Figure 2.16 *The first steps of DNA replication is helicase catalysing the unwinding and unzipping of the double-stranded DNA molecule, forming a section with two single strands*

Hints for success: Remember the enzyme helicase allows the unwinding and unzipping of DNA to occur very rapidly so that replication can efficiently occur.

Understanding: DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.

Model sentence: DNA polymerase is an enzyme which catalyses the linking of nucleotides in the new DNA strand.

- When DNA unzips, free nucleotides in the nucleus pair with the exposed bases of the existing strands.
- Each strand of the unzipped DNA acts as a template for the formation of a new complementary strand.
- Nucleotides with the nitrogenous base A always pair with nucleotides with the nitrogenous base T. The same is true for C and G.
- A type of DNA polymerase catalyses the formation of a covalent bond between adjacent nucleotides as complementary bases line up.
- The result of this is two molecules of DNA which are exact copies of one another. Study the figure below:

Subject vocabulary

DNA polymerase group of enzymes which are involved in DNA replication

Taq DNA polymerase enzyme stable at high temperatures which is used to produce large numbers of copies of DNA in the laboratory

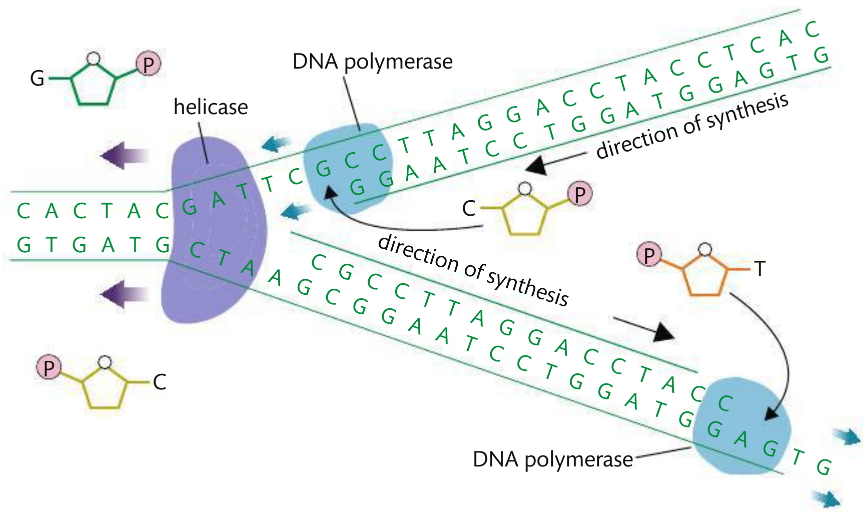


Figure 2.17 *DNA replication*

Hints for success: Study the figure carefully. Note the two molecules of DNA being formed from the original one molecule. Notice the locations where both helicase and DNA polymerase carry out their functions. A is always paired with T, and C is always paired with G in both new molecules.

Skill: Analysis of Meselson and Stahl's results to obtain support for the theory of semi-conservative replication of DNA

Meselson and Stahl carried out a beautifully designed experiment to provide evidence for the semi-conservative method of DNA replication. They used bacterial cultures of *Escherichia coli* and an isotope of heavy nitrogen to tag DNA. Percentages of DNA strands composed of heavy nitrogen to DNA strands composed of 'lighter' nitrogen were then analysed. Their findings provided support for semi-conservative replication.

Application: There is a special type of DNA polymerase called Taq DNA polymerase. Taq DNA polymerase is relatively stable at high temperatures. It can be used in laboratory settings to artificially create large numbers of small segments of DNA by the DNA replication process. These replicated copies of DNA are exact copies and may be used for analysis and study. This technique is often used to increase small amounts of DNA found at some crime scenes so that a potential source may be found. Taq DNA polymerase has also allowed great advances in the field of gene technology.

Understanding: Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.

Model sentence: RNA polymerase is an enzyme which catalyses the copying of the DNA base sequence onto mRNA by the process called transcription.

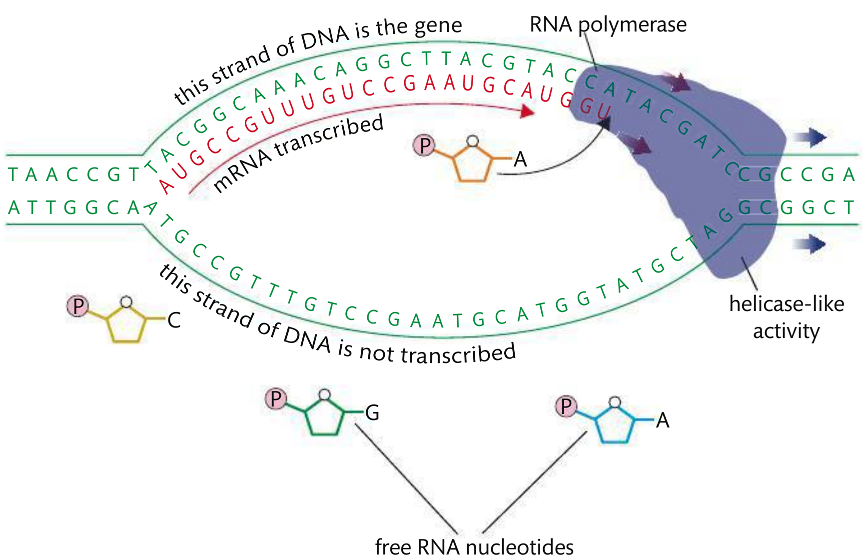
DNA controls almost all the cellular activities through the process of protein synthesis. Many of the proteins produced in the cell are enzymes. It is the sequences of bases on the DNA molecule which determine the specific proteins to be made. Specific regions of the DNA molecule code for specific proteins. Each of these regions is called a **gene**. The first steps in the formation of proteins in the cell are:

- A region of the DNA molecule, the gene, becomes unzipped. The unzipping process is similar to that which occurred in DNA replication.
- Only one strand of the unzipped DNA molecule is used as a template to form mRNA. mRNA is single stranded.
- RNA polymerase is the enzyme involved in unzipping of the DNA region. RNA polymerase is also needed to bring about the complementary base pairing of RNA nucleotides with the exposed DNA bases in the unzipped region of the DNA molecule.

This table summarizes the differences between DNA and RNA.

DNA	RNA
composed of two strands of covalently bonded nucleotides in a double helix	composed of one strand of covalently bonded nucleotides
each nucleotide contains the 5-carbon sugar called deoxyribose	each nucleotide contains the 5-carbon sugar called ribose
each nucleotide may contains one of four nitrogenous bases: adenine (A), thymine (T), cytosine (C), and guanine (G)	each nucleotide may contain one of four nitrogenous bases: adenine (A), uracil (U), cytosine (C), and guanine (G)

Hints for success: Study the figure below to be able to explain the process of transcription.



Subject vocabulary

RNA polymerase enzyme involved in the transcription process

gene section of DNA molecule that codes for a particular trait/protein in an organism

Figure 2.18 *Transcription (synthesis of an RNA molecule). RNA polymerase has helicase-like activity as it plays a role in opening the DNA double helix. It also catalyses the addition of free RNA nucleotides to the growing mRNA strand*

Understanding: Translation is the synthesis of polypeptides on ribosomes.

Subject vocabulary

polypeptide polymer of many amino acids combined by peptide bonds

mRNA–ribosomal complex structure formed when a mRNA is combined with a ribosome in the cytoplasm

peptide bonds covalent bond which occurs between the amino group of one amino acid and the carboxyl group of another

Model sentence: The production of the polypeptides necessary for cell activities occurs at the ribosomes and is called translation.

A polypeptide is a polymer of many amino acids. A protein may include more than one polypeptide and has a complex three-dimensional shape. Polypeptides are produced at the ribosomes which then form proteins needed for the cell's activities. Translation requires an mRNA, a ribosome, many tRNAs, amino acids and enzymes. There are three types of RNA and all play a role in translation. Study this table comparing the three RNA types.

RNA type	Function
mRNA or messenger RNA	carries the DNA code from the nucleus to the ribosomes in the cytoplasm
rRNA or ribosomal RNA	provides a large percentage of the ribosome composition
tRNA or transfer RNA	carries one of 20 possible amino acids to the mRNA-ribosomal complex

The sequence of actions in translation are:

1. mRNA moves out of the cell nucleus and forms a complex with a ribosome. This complex is called the **mRNA–ribosomal complex**.
2. tRNAs bring specific amino acids to the mRNA-ribosomal complex. The amino acids brought to the complex are coded for by mRNA.
3. The amino acids are lined up in a sequence indicated by the mRNA.
4. Bonds called **peptide bonds** occur between adjacent amino acids. These bonds result in the formation of the specific polypeptide molecule.

Hints for success: The DNA in the cell nucleus carries the code for almost all the activities of the cell. This code is transcribed onto mRNA. mRNA carries the code for the specific polypeptide needed for a ribosome in the cytoplasm. Translation then occurs at the ribosome to produce the needed polypeptide. Once the polypeptide is produced the mRNA–ribosomal complex breaks apart. The ribosome is then able to combine with a different mRNA to produce a totally different polypeptide. The tRNA moves to a different cytoplasm location to pick up the same type of free amino acid. It then can become active in the translation process of another polypeptide.

Understanding: The amino acid sequence of amino acids of polypeptides is determined by mRNA according to the genetic code.

Model sentence: It is the sequence of bases on the DNA molecule which is the genetic code. This code is transcribed onto an mRNA so that translation of the proper polypeptide may occur at the ribosome.

Hints for success: It is the sequence of the bases, A, T, C, and G, in a cell's DNA which determines what polypeptides will be produced at the ribosomes of that specific cell. This genetic code is passed through cell division from one generation to the next after DNA replication, **mitosis**, and **cytokinesis** occur.

Understanding: Codons of three bases on mRNA correspond to one amino acid in a polypeptide.

Model sentence: Each three-base sequence of nucleotides along an mRNA molecule is called a codon and codes for a specific amino acid.

The mRNA molecule produced by transcription represents a complementary copy of one gene of DNA. The genetic code is written in **triplets**. The region of DNA called a gene is made up of many, many bases. These bases of the DNA are organized into 'genetic words' called **DNA triplets**. Transcription allows the formation of the mRNA codons from DNA triplets. Each mRNA codon corresponds to one amino acid in a polypeptide. Some mRNA codons act as 'punctuation marks' starting or stopping the production of a polypeptide.

DNA triplet → transcription → mRNA codon

gene (many DNA triplets) → transcription → mRNA molecule (many mRNA codons)

The mRNA molecule formed by transcription is quite large. The fact that mRNA is single-stranded allows it to carry the DNA code from the nucleus to the ribosomes in the cytoplasm. Translation then occurs at the ribosome to produce the needed polypeptide.

Skill: Use a table of mRNA codons and their corresponding amino acids to deduce the sequence of amino acids coded by a short mRNA strand of known base sequence

Use these bases in mRNA to determine the sequence of amino acids which would be produced by translation at the ribosome.

A-U-G-A-A-A-G-C-U-C-C-U-U-A-U-U-A-G

Skill: Use a table of the genetic code to deduce which codon(s) corresponds to which amino acid

Use the table on the next page to determine the codons corresponding to the following amino acids:

methionine (start) – asparagine – alanine – proline – tyrosine – stop

Subject vocabulary

transcribed the production of an mRNA molecule from a DNA template

mitosis cell division where one diploid cell becomes two diploid cells

cytokinesis division of the cytoplasm in cell division

codon a group of three bases that together code for a single amino acid

DNA triplets three bases of DNA making up a 'word' in the genetic code

General vocabulary

triplets groups of three

The genetic code. The first, second, and third positions represent the base location in the codon. Twenty amino acids are coded for. Note AUG is the start codon. Also, note the three stop or termination codons. These start and stop codons are the punctuation marks referred to above

	Second position				
First position	U	C	A	G	Third position
U	phenylalanine	serine	tyrosine	cysteine	U
					C
	leucine		stop	stop	A
			stop	tryptophan	G
C	leucine	proline	histidine	arginine	U
					C
			glutamine		A
					G
A	isoleucine	threonine	asparagine	serine	U
					C
			lysine	arginine	A
	*methionine				G
G	valine	alanine	aspartic acid	glycine	U
					C
			glutamic acid		A
					G

*and start

Understanding: Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA.

Model sentence: Codons of mRNA go through complementary base pairing with anticodons of tRNA in the process of translation.

The genetic code of DNA is carried by the codons of mRNA to the ribosomes of the cell cytoplasm. tRNA molecules are present within the cell cytoplasm. Each tRNA has a region called the **anti-codon** which pairs with the complementary mRNA codon. There are 20 different amino acids which make up polypeptides and 61 different tRNA molecules. The difference in tRNA molecules is based on the anticodon present. Each of the different tRNA molecules attaches to a specific amino acid. Both the codon and the anticodon have three bases. These three bases of codons and anticodons complementary base pair, A with U, and C with G. By the complementary pairing of bases between codons and anticodons, amino acids are lined up in the exact sequence called for in the genetic code. This allows the proper polypeptide to be produced.

Application: Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species

The process of producing polypeptides/proteins uses a DNA code that is **universal** in most organisms on Earth. This universal nature of the genetic code has allowed scientists to insert the gene from humans that produces **insulin** into bacteria. This gene transfer between species allows the bacteria to actually produce human insulin. This insulin may then be successfully used to treat many humans who have **diabetes**.

Subject vocabulary

anti-codon group of three nucleotides on tRNA which base-pair with the complementary codon of mRNA

insulin hormone produced and released by exocytosis from the pancreas which controls glucose absorption by cells

diabetes disease which creates problems in the metabolism of sugars

General vocabulary

universal common, the same

2.8 Cell respiration

Main idea

The energy necessary to maintain the functions of life is provided by cell respiration.

Understanding: Cell respiration is the controlled release of energy from organic compounds to produce ATP.

Model sentence: ATP is produced from the breakdown of organic compounds by cell respiration.

- **Cell respiration** is a cellular process which occurs in a controlled series of **oxidation reactions**. Each step in the oxidation reaction of cell respiration is controlled by enzymes.
- It is the breakdown or oxidation of **covalent bonds** in organic compounds which provides the energy to produce **ATP**.
- The breakdown of covalent bonds occurs one bond at a time so small amounts of energy are released. The small amounts of energy released are used to produce the ATP molecules.
- The small amounts of energy released at a time allow the efficient production of ATP. Large amounts of energy release would result in increased heat within the cell. The increased heat is because not all the energy released would be converted to ATP. The increased heat produced could very well damage the cell.
- ATP is the molecule which provides the energy for all the life processes of the cell to occur.

Hints for success: **Glucose** is the organic molecule cells most prefer for cell respiration. If no glucose is present, other organic molecules may be used. The release of energy in cell respiration is due to a specific sequence of enzymes. This sequence of enzymes results in a very controlled release of energy. The sequence of enzymes and intermediate compounds bringing about the breakdown of a particular organic compound makes up a **metabolic pathway**.

Subject vocabulary

cell respiration chemical process used by cells to gain energy from sugars and other substances

oxidation reaction a chemical reaction in which electrons are lost

covalent bond chemical bond in which electrons are shared

ATP a molecule used for a source of chemical energy

glucose a simple sugar produced by photosynthesis and used for cell respiration

metabolic pathway a chemical pathway in which a series of enzymes produces intermediate compounds on the way to producing a final product needed by the organism

phosphate group chemical group composed of phosphorus and oxygen

high energy bonds the chemical bonds which allow bonding of the last two phosphate molecules in ATP

ADP cellular energy compound which contains two phosphate molecules and one high energy bond

Understanding: ATP from cell respiration is immediately available as a source of energy in the cell.

Model sentence: The ATP produced in cell respiration is the form of energy used by the cell to carry out the life functions.

ATP contains three **phosphate** molecules. The last two phosphates are bonded to the ATP molecule by **high energy bonds**. These high energy bonds are easily broken by the cell. The released energy is then used by the cell to carry out the necessary functions of the cell.

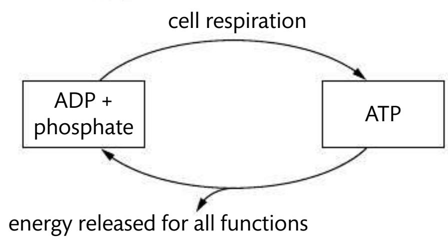


Figure 2.19 *The diagram shows* ***ADP*** *has a phosphate added to it by the process of cell respiration to produce ATP. The energy contained in the high energy bonds of ATP may then be used by the cell to carry out the cell functions*

Hints for success: ATP is the essential source of energy for the cell to carry out all of its functions. Cell life ends when ATP is no longer available.

Understanding: Anaerobic cell respiration gives a small yield of ATP from glucose.

Subject vocabulary

anaerobic cell respiration cellular breakdown process of organic molecules which does not require oxygen, produces a net gain of two ATP molecules

pyruvate 3-carbon compound formed by the breakdown of glucose in glycolysis, the first stage of cell respiration

glycolysis first stage of cell respiration in which oxygen is not required and glucose is broken down into 2 pyruvate molecules

fermentation process where sugar is changed to alcohol

General vocabulary

partial part of, not the whole

net gain increase after consideration of the amount used to obtain increase

Model sentence: Anaerobic cell respiration brings about partial breakdown of glucose. Anaerobic cell respiration results in a small number of ATP molecules.

- Anaerobic cell respiration does not require oxygen to occur.
- Anaerobic cell respiration occurs in the cell cytoplasm.
- Anaerobic cell respiration is the first stage in the breakdown of glucose. If glucose is not present, another organic molecule will be substituted for it.
- Anaerobic respiration breaks glucose down into two 3-carbon compounds called pyruvate.
- When the covalent bonds of glucose are broken in anaerobic respiration, energy is released. The released energy is used to produce a small number of ATP molecules.
- Two ATP molecules are needed to begin the process of anaerobic cell respiration.
- A total of four ATP molecules are produced from glucose anaerobic cell respiration.
- The results of the first portion of anaerobic cell respiration from the breakdown of glucose are:
  - two molecules of 3-carbon pyruvate
  - a net gain of two ATP molecules.
- This first part of anaerobic cell respiration is also called glycolysis.

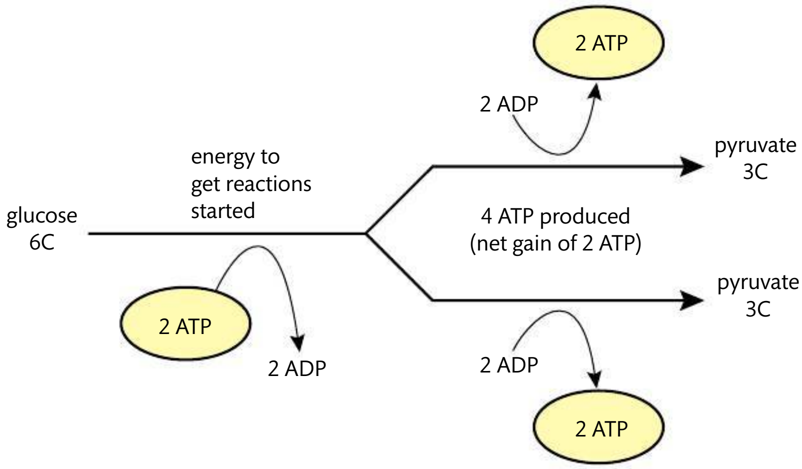


Figure 2.20 *A simplified version of the events of glycolysis*

If no oxygen is present after the first part of anaerobic cell respiration called glycolysis, a process called fermentation will occur. Fermentation is often described using yeast cells and human cells.

Yeast cells	Human cells
occurs in the cell cytoplasm	occurs in the cell cytoplasm
occurs in the absence of oxygen	occurs in the absence of oxygen
begins with pyruvate	begins with pyruvate
end products are ethanol and carbon dioxide	end products are lactic acid (lactate)
no gain in ATP number after glycolysis	no gain in ATP number after glycolysis

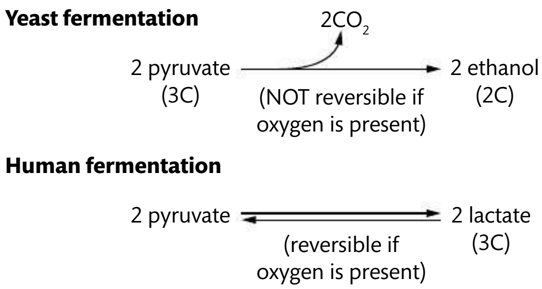


Figure 2.21 *A comparison of fermentation in yeast and human cells*

Hints for success: Study the table and diagrams carefully to understand the similarities and differences between yeast and human cell fermentation. Note that if oxygen becomes available in human cells, the lactic acid (lactate) produced may be changed back to pyruvate. This is referred to as a **reversible reaction**. If oxygen becomes available in yeast cell fermentation, a reversible reaction to reform pyruvate will not occur.

Subject vocabulary

reversible reaction reaction which produces products from raw materials and also raw materials from products

Application: Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking

The carbon dioxide produced by yeast in the fermentation process is valuable in baking. This gas causes bread to rise.

Application: Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions

Lactate production in humans occurs during intense muscle activity. Due to the intensity of the activity not enough oxygen can be delivered to the muscles. The result of this lack of oxygen delivery is maximum muscle contraction. However, the lactate produced will seriously limit the number of maximum muscle contractions.

Understanding: Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.

Model sentence: Aerobic respiration produces a much larger number of ATP molecules than anaerobic respiration when glucose is broken down.

- When oxygen is present, the two pyruvate molecules produced by glycolysis from one glucose molecule move into the mitochondrion.
- Once inside the mitochondrion, the two pyruvates enter the Krebs cycle one at a time and are completely broken down.

Aerobic respiration:

Pyruvate → enters the mitochondrion → becomes part of the Krebs cycle → completely oxidized → final products are water, carbon dioxide, and a large number of ATP molecules

Hints for success: Notice the final products of aerobic respiration include the production of a large number of ATP molecules. Organisms with cells containing mitochondria are capable of aerobic cell respiration.

Skill: Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer

It is possible to use devices called **respirometers** to measure cell respiration rates. The respirometer measures the oxygen rate of exchange. By analysing the oxygen usage when seeds germinate or as **invertebrates** carry out the life functions, one can determine the rate of cell respiration. Analysis of oxygen usage data will show changes in cell respiration rate when factors such as temperature and pH are changed.

2.9 Photosynthesis

Main idea

Photosynthesis is a cell process which converts the energy in sunlight to chemical energy.

Understanding: Photosynthesis is the production of carbon compounds in cells using light energy.

Model sentence: Photosynthesis allows the production of carbon compounds using the energy present in light.

- Photosynthesis uses the energy of light to produce carbohydrates.
- The most common carbohydrate produced by photosynthesis is glucose.
- Glucose is then broken down by cell respiration to produce ATP.

Understanding: Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.

Model sentence: Photosynthesis uses energy from the visible light spectrum which has increasing wavelengths from violet to red.

- Sunlight includes all the colours of the visible light spectrum. Sunlight is said to be white light.

  violet (400 nm) → blue → green → yellow → orange → red (700 nm)

  The wavelength of each colour increases from violet to red (400 nm to 700 nm). The energy of each colour decreases from violet to red.

- Violet of the visible light spectrum has the shortest wavelength (400 nanometres). Red of the visible light spectrum has the longest wavelength (700 nanometres).
- The colours with the shortest wavelengths possess the highest energy.

Subject vocabulary

respirometers devices used to measure the rate of cellular respiration by analysing oxygen usage

invertebrate living creature with no backbone

photosynthesis process which converts light energy into chemical energy

visible light spectrum that portion of the light spectrum which is visible to the human eye, includes wavelengths of 400 nm to 700 nm

Understanding: Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colours.

Model sentence: Chlorophyll is the main pigment of photosynthesis and it absorbs red and blue light most efficiently.

Photosynthesis depends largely on the pigment called chlorophyll to absorb light energy. This absorbed light energy in then used to convert carbon dioxide and water into carbohydrates such as glucose.

Red and blue are the colours of the visible light spectrum that are most efficiently absorbed by chlorophyll. The energy of the red and blue colours is then used in the production of glucose.

Green light from the visible spectrum is not absorbed by chlorophyll. It is reflected and is the reason plant parts with chlorophyll appear green in colour.

Hints for success: Remember that red and blue colours play a large role in the process of photosynthesis. Wavelengths producing green colours are reflected by chlorophyll and not used in photosynthesis. This is why plants with chlorophyll appear green.

Skill: Separation of photosynthetic pigments by chromatograph

Chlorophyll is not the only pigment active in photosynthesis in most plants. Pigments in different types of plants may be isolated and studied by using a chromatograph. Key concepts of this required practical include:

- Producing a chromatograph so that paper chromatography or thin layer chromatography may be carried out.
- Different pigments have different solubilities in the solvent used.
- Different pigments have different molecular masses.
- Different solubilities and different pigments will cause the pigments to separate on the chromatogram.
- Varying colours in different areas of the chromatogram with different R_f values indicate separate pigments.

The more pigments a plant has, the more light wavelengths may be absorbed. More light wavelengths absorbed may increase the rate of photosynthesis.

Understanding: Oxygen is produced in photosynthesis from the photolysis of water.

Model sentence: An early stage of photosynthesis is the splitting of water to produce oxygen.

- Photolysis is the process in which energy from light is used to split water.
- When photolysis occurs oxygen gas is produced. Most of the oxygen is released into the atmosphere. Hydrogen is also produced. The hydrogen is used in later stages of photosynthesis.

Application: Changes to the Earth's atmosphere, oceans, and rock deposition due to photosynthesis

Much of the oxygen produced when photolysis occurs is released into the atmosphere. This allows a continual supply of oxygen for those organisms dependent on aerobic cell respiration for their ATP.

Subject vocabulary

chlorophyll main pigment involved in the process of photosynthesis, absorbs light energy

pigment a substance with colour, able to absorb light energy in the process of photosynthesis

chromatograph instrument used to carry out chromatography

chromatography process used to separate the components of a chemical mixture

chromatogram pattern, usually of colours, formed as a result of chromatography

R_f distance moved of separate pigments compared to distance moved of the solvent, expressed as a decimal

photolysis process in photosynthesis where water molecules are split using the energy from light

Understanding: Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.

Model sentence: The energy from the absorbed colours of the visible light spectrum is used to build carbon compounds which include carbohydrates.

- In photosynthesis plants combine carbon dioxide from the atmosphere with water to produce carbon compounds such as carbohydrates.
- Glucose is commonly referred to as the carbohydrate produced by photosynthesis.
- When red and blue wavelengths are **abundant**, photosynthetic activity is at its highest.

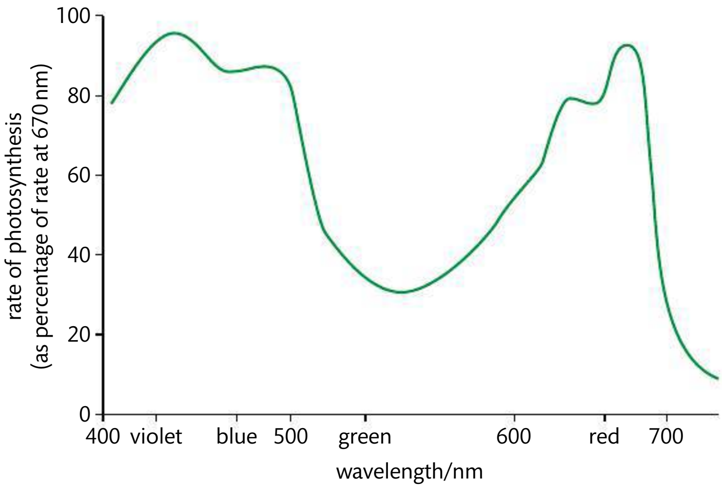


Figure 2.22 *This action spectrum of photosynthesis indicates that most photosynthesis occurs in the blue and the red wavelength areas. Note the lower rate of photosynthesis with the green wavelength*

- The above figure represents an **action spectrum** for photosynthesis. Chlorophyll is the key pigment in photosynthesis. Where photosynthetic activity is highest on the graph is also the areas where the most visible light wavelengths are absorbed.

General vocabulary

abundant existing in large numbers

Subject vocabulary

action spectrum a graph showing photosynthetic rate in relation to light wavelength

absorption spectrum a graph showing absorption of light at various wavelengths in the process of photosynthesis

Skill: Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis

A visible light **absorption spectrum** drawn for chlorophyll would have similar peaks and valleys as the action spectrum for photosynthesis. An absorption spectrum for chlorophyll would show very little light absorbed at the green wavelength. Action spectrums show lesser rates of photosynthesis at the green wavelength.

Application: Changes to the Earth's atmosphere, oceans, and rock deposition due to photosynthesis

Carbon dioxide is removed from the atmosphere by photosynthesis. This causes a decrease in the overall carbon dioxide levels of the atmosphere. Also, when photosynthesis occurs there are increased carbon compounds produced from plants. The increase in plant matter may result in rock-like deposits of coal over long periods of time. When photosynthesis rates are relatively low, carbon dioxide levels rise. High levels of carbon dioxide in our atmosphere may add to an increase in overall temperatures of our planet. High carbon dioxide levels may also increase the acidity of our rain and our oceans. Higher rain and ocean acidity levels may harm existing organisms.

Hints for success: Practise drawing absorption and action spectrums for photosynthesis. Both graphs should show highest light wavelength absorption and highest rates of photosynthesis at the same blue and red wavelengths. Both graphs should show little absorption and low photosynthetic rates at the green wavelengths.

Understanding: Temperature, light intensity, and carbon dioxide concentration are possible limiting factors on the rate of photosynthesis.

Model sentence: Varying the temperature, light intensity, and carbon dioxide concentration all affects the rate of photosynthesis.

- A **limiting factor** is a factor that most directly affects the rate of a process such as photosynthesis.
- A limiting factor is often the factor which is in shortest supply. When low light intensity is present, the rate of photosynthesis is decreased even if all other factors are present in **adequate** supply. If light intensity is adequate, low levels of carbon dioxide will decrease the rate of photosynthesis.
- A limiting factor may also be an environmental factor such as temperature. If temperatures are lower than normal, photosynthetic rates will be decreased. Lower rates of photosynthesis due to low temperatures are due to decreased enzyme activity.

Skill: Design of experiments to investigate the effect of limiting factors on photosynthesis

Be certain to vary only one potential limiting factor at a time. All other photosynthetic factors should be in adequate amounts. The rate of photosynthesis may then be determined by measuring oxygen production, carbon dioxide absorption or usage, or plant biomass increase. This method allows you to say for certain whether a factor is a limiting factor or not.

Subject vocabulary

limiting factors environmental factors that determine the maximum rate of a process

General vocabulary

adequate satisfactory or sufficient for a particular requirement

3.1 Genes

Main idea

Every living thing inherits genetic material from its parents.

Subject vocabulary

genetic determined by DNA and passed on from parents to offspring

heritable a genetic trait which can be passed on to offspring

trait a characteristic that distinguishes one individual from another, such as blood type

locus (plural: loci) the specific place where a gene is found on a chromosome

base the basic unit of the DNA code, represented by A, T, C, or G

sequence a series of bases in the genetic code in a particular order

Understanding: A gene is a heritable factor that consists of a length of DNA and influences a specific characteristic.

Model sentence: A gene is a sequence of DNA that controls a genetic trait such as blood type.

The genes which you possess are organized into chromosomes.

Examples of genetic traits include: eye colour, the ability to digest lactose, wet or dry earwax, and blood type.

Hints for success: Whenever a definition is given for a major concept in biology – in this instance, the term 'gene' is defined in the heading – be sure to memorize its definition word for word. Such definitions have been phrased carefully in such a way that all important details are included.

Understanding: A gene occupies a specific position on a chromosome.

A gene for a specific trait occupies a corresponding place, called a locus (plural, loci), on a chromosome.

For example, the gene controlling a protein called transducin that allows for colour vision is found on chromosome 1. A difference of one base (T instead of C at position 235) in the gene's sequence causes an error in the production of the transducin protein and the person cannot perceive any colours.

Application: Comparison of the number of genes in humans with other species

Organism	Scientific name	Number of bases	Genes
virus	T2 bacteriophage	160 000	269
bacterium	*Escherichia coli* (type K-12)	4 639 000	4 377
human	*Homo sapiens*	3 000 000 000	21 000
fruit fly	*Drosophila melanogaster*	122 654 000	13 918
Japanese canopy plant	*Paris japonica*	150 000 000 000	unknown

Understanding: The various specific forms of a gene are **alleles**.

Model sentence: Variations or versions of a gene are called alleles.

In the example of transducin above, a single base pair difference between the most common allele and the rare mutated allele affects the ability to distinguish colours.

Example: cystic fibrosis

A gene called *CFTR*, found on chromosome 7, plays a key role in the production of **mucus**.

The standard allele allows a person's mucus-producing cells to function properly, but there is an allele generated by a **mutation** of the *CFTR* gene that causes **cystic fibrosis**.

People with this genetic condition produce abnormally thick and sticky mucus in various organs. They have difficulties with their respiratory and digestive systems, among other complications.

Understanding: Alleles differ from each other by one or only a few bases and new alleles are formed by mutation.

Model sentence: A mutation is a random, rare change in genetic material.

Mutations can be **beneficial**, **detrimental**, or **neutral**. A beneficial mutation is one that improves chances for survival.

Beneficial mutations contribute to an organism's success. For example, LRP5 is a rare mutation that can block infection by certain types of **HIV**. People with this mutation are more resistant to **AIDS**.

Detrimental (or harmful) mutations make survival more difficult. For example, the inability to distinguish colours could make it more challenging for an animal to find food or to see **predators** in time to escape.

Neutral mutations do not have an effect on survival. A mutation from GAG to GAA would not make any difference in the production of the protein concerned because both codons code for the same amino acid: glutamic acid.

The type of mutation which results in a single letter being changed is called a **base substitution mutation**; for example, sickle cell disease.

Application: The causes of sickle cell disease

Sickle cell disease gives a different shape to the haemoglobin molecule responsible for giving red blood cells their shape. The mutation GAG to GTG causes the haemoglobin to clump together to make the cells **elongated** and curved instead of disc shaped. This is due to the fact that valine replaces glutamic acid at a key point in the sequence.

The disease causes weakness, **fatigue**, and shortness of breath. Oxygen cannot be carried as efficiently by the irregularly shaped red blood cells. In addition, the haemoglobin tends to **crystallize** within the red blood cells, causing them to be less flexible. The affected red blood cells can get stuck in capillaries so blood flow can be slowed or blocked, a condition that is painful for the person. When the malformed cells are removed from the blood, the person's red blood cell count gets low and causes **anaemia**.

However, having the disease can be beneficial in regions where malaria is a problem because the mutation gives a person resistance to *Plasmodium*, the **parasite** in the blood that causes malaria.

Subject vocabulary

allele version of a gene, differing by one or more bases

mucus a slimy, protective secretion

mutation an accidental change in a genetic sequence

cystic fibrosis a genetic disease causing the overproduction of mucus in the body

HIV human immunodeficiency virus, the virus that causes AIDS

AIDS a viral infection caused by HIV and resulting in weakening of the immune system

predator an organism that hunts and eats other organisms

base substitution mutation an accidental change in one base of a genetic sequence

anaemia a low number of red blood cells in the blood

parasite a plant/animal that lives on/in another plant/animal and feeds from it

Synonyms

beneficial....... helpful

detrimental.... harmful

neutral .... neither good nor bad

fatigue........... tiredness

General vocabulary

elongated longer than normal

crystallize form a hard solid

Understanding: The genome is the whole of the genetic information of an organism.

To **sequence** a genome (meaning to locate each A, T, C, and G in all the genes of the organism), researchers use highly specialized laboratory equipment including **sequencers** to locate and identify the sequence of bases.

Here is an example of a fragment of a genome sequence: GTGGACCTGACTCCTGAGGAG. This short fragment contains 7 **codons** with a total of 21 bases represented by letters. The human genome possesses 3 billion **base pairs**.

Only a very limited number of organisms have had their genomes fully sequenced: baker's yeast, the fruit fly, and humans are among them.

Subject vocabulary

sequence the order of bases in a fragment of DNA

sequencer machine that determines the order of bases in a fragment of DNA

codon a group of three bases that together code for a single amino acid

base pair a matching pair of nucleotides (A-T or C-G)

General vocabulary

linear organized along the shape of a line

Understanding: The entire base sequence of human genes was sequenced in the Human Genome Project.

Started in 1990, an international cooperative venture called the **Human Genome Project** set out to sequence the complete human genome. In 2003, the Project announced that it had succeeded in achieving its goal. Now, scientists are working on which sequences represent genes and which genes do what.

Skill: Use of a database to determine differences in the base sequence of a gene in two species

You are expected to be able to analyse a sequence and compare the same sequence between species in order to be able to recognize mutations and changes that have lead to evolution.

Retrieve the PDF file from the following web link: www.indiana.edu/~ensiweb/lessons/molb.ws.pdf

Or do a search for 'Cytochrome c Comparison Lab on www.indiana.edu' and you should find it. Follow the instructions to compare the genetic sequences for various organisms for the gene that makes cytochrome *c*, a protein all living things need.

The uses of genetic comparisons

The number of mutations a species has in that gene compared to another species gives insight into how closely they are related to each other.

Example: biologist Carl Woese proposed the domain Archaea to distinguish certain single-celled organisms from bacteria (prokaryotes) and eukaryotes

It took decades for Woese's proposal to be accepted but the overwhelming evidence in Archaea's favour made it very difficult for opponents of the idea to resist it.

3.2 Chromosomes

Main idea

Chromosomes carry genes in a **linear** sequence that is shared by members of a species.

Understanding: Prokaryotes have one chromosome consisting of a circular DNA molecule.

Instead of a membrane-bound nucleus, **prokaryotes** have a **nucleoid** region containing one molecule of DNA in a loop.

These single-celled organisms (bacteria and archaeans) reproduce **asexually** by **binary fission** – the chromosomes are not in pairs the way **eukaryote** chromosomes are.

Application: Cairns' technique for measuring the length of DNA molecules by autoradiography

How do we measure the length of a DNA molecule? In 1962, John Cairns used a technique called **autoradiography** to capture an image of a DNA molecule in order to measure its length. Autoradiography consists of first getting a bacterium to absorb a **radioactive marker** called ^{3}H-thymidine so that it can build its DNA with it. When placed on a photographic film in a dark room, the radioactive marker exposes the film, tracing an outline of the DNA. The outline of the DNA on the film can be used to measure the length of the loop, making it possible to know how long the DNA molecule is.

Understanding: Some prokaryotes also have plasmids but eukaryotes do not.

Plasmids are small circles of DNA consisting of segments of a prokaryote's genome.

Plasmids are not found in eukaryotes so plants, animals, fungi, and protists do not have them in their cells.

Plasmids can be used by prokaryotes to transfer some of their genetic information from one individual to another. Plasmids can also be used in laboratories to genetically modify a prokaryote. More about this in section 3.5.

Understanding: Eukaryote chromosomes are linear DNA molecules associated with histone proteins.

Model sentence: Bacteria and Archaea have a single circular chromosome in their cells, whereas eukaryotes have multiple linear chromosomes.

Eukaryotes have a membrane-bound nucleus containing chromosomes made of DNA that is not in the form of loops. Instead of circular DNA, eukaryotes have linear DNA.

The DNA is wrapped around protein molecules called **histones**. Histones stacked together form structures called **nucleosomes** that act as a packaging system to keep the DNA organized. As in eukaryotes, archaeans also have histones associated with their DNA.

The process of wrapping DNA around these proteins again and again is called **supercoiling**. Supercoiled DNA cannot be **transcribed** or worked on by enzymes – it must be **unwound** before such things can happen.

Subject vocabulary

prokaryote single-celled organism whose organelles are not bound by membranes

nucleoid region of a prokaryotic cell where the DNA exists

binary fission a method of reproduction whereby a single-celled organism makes a copy of itself and splits in two

eukaryote single-celled organism that contain organelles bound by membranes

autoradiography technique of capturing images of radioactive substances on photographic film

radioactive marker a radioactive isotope of an element introduced into an organism and used to follow how the organism uses that element

plasmid small ring of DNA separate from the bacterial chromosome often used in genetic modification

histones proteins associated with DNA in eukaryotic chromosomes

nucleosome structure found in eukaryotic chromosomes consisting of a strand of DNA wrapped around eight histone molecules

supercoiling a process in which intense folding and coiling of a structure occurs

transcribed the production of an mRNA molecule from a DNA template

General vocabulary

asexually without sexual association

unwound loosened from the original shape

Understanding: In a eukaryote species there are different chromosomes that carry different genes.

Typically, eukaryotes have many different chromosomes (see the table opposite) and each chromosome will have different genetic information controlling the various traits of the organism.

Example: wild wheat plants

A wild wheat plant (*Triticum baeoticum*) that can be used to produce flour for bread has 14 chromosomes arranged in 7 pairs. In each pair, one chromosome is from the plant's father and the other from the plant's mother. Some chromosomes will carry information about the plant's height or its colour, other chromosomes will have DNA that codes for its root system or for producing sex cells.

Skill: Use of databases to identify the locus of a human gene and its polypeptide product

Students are expected to be able to use a database to identify the locus of a human gene and its **polypeptide** product. One example of such a database is the National Center for Biotechnology Information (NCBI). Search for it online and see if you can find the gene sequence that codes for human insulin; the gene is found on chromosome 11, its name is *INS* and its ID number is 3630.

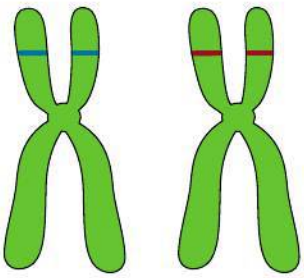


Figure 3.1 *Homologous chromosomes. Although these are the same size and shape, and carry the same genes, the different coloured bands on the short arms of each chromosome reveal that they do not carry the same allele of the gene at the locus shown*

Understanding: Homologous chromosomes carry the same sequence of genes but not necessarily the same alleles of those genes.

When referring to similar chromosomes, the term **homologous** means having similar size and shape and it means that the two chromosomes carry the same genes. For a chromosome, shape usually refers to the position of the **centromere**.

Since genes can come in different forms (alleles), the information on two homologous chromosomes will not necessarily be identical.

Example: homologous chromosomes and alleles

For a given gene with the alleles ***B*** or ***b***, a child could receive the allele ***B*** from her mother and the allele ***b*** from her father, the maternal chromosome in the child's homologous pair will have a ***B*** and the paternal chromosome will have a ***b***.

Understanding: Diploid nuclei have pairs of homologous chromosomes. Haploid nuclei have one chromosome of each pair.

The term **diploid** is used to describe a nucleus in which the chromosomes are organized into pairs.

Most cells in the human body, for example, are diploid with 46 chromosomes organized into 23 pairs. Some cells have no nucleus, such as red blood cells.

The letter n indicates the number of sets of chromosomes a nucleus can have. In humans, $n = 23$ because humans have 23 different chromosomes. Diploid human cells are $2n = 46$.

Haploid cells contain only one of each chromosome, instead of containing pairs of chromosomes.

Subject vocabulary

polypeptide polymer of many amino acids combined by peptide bonds

homologous chromosome pairs that occur at fertilization, one from the female parent and one from the male parent

centromere region where sister chromatids attach

diploid a cell which has chromosomes in homologous pairs

haploid a cell that has only one chromosome of each homologous pair

Sex cells (sperm cells and egg cells) are haploid. For example, in humans, sex cells contain $n = 23$ chromosomes. When a sperm cell encounters an egg, the newly formed cell becomes diploid.

It is rare for adult eukaryotes to contain only haploid cells, but adult male bees, wasps, and ants are haploid.

Understanding: The number of chromosomes is a characteristic feature of members of a species.

One aspect that makes a species different from others is the number of chromosomes it possesses.

Example: number of chromosomes in different species

The fruit fly (*Drosophila melanogaster*) used in genetics experiments has four pairs of chromosomes ($n = 4$) and the first organism whose genome was sequenced, *Caenorhabditis elegans*, has six pairs of chromosomes ($n = 6$).

The table below shows more examples.

	Types of cells and chromosome numbers	
Species	**Haploid (*n*)**	**Diploid (2*n*)**
human, *Homo sapiens*	23	46
chimpanzee, *Pan troglodytes*	24	48
domestic dog, *Canis familiaris*	39	78
rice, *Oryza sativa*	12	24
roundworm, *Parascaris equorum*	2	4

Skill: Comparison of diploid chromosome numbers

Compare the chromosome numbers of the organisms in the table above. Also, have a look at the table in Section 3.1 comparing the number of bases and genes in various organisms.

Understanding: A karyogram shows the chromosomes of an organism in homologous pairs of decreasing length.

Model sentence: It is possible to find out the gender of an unborn child or determine if there are any chromosomal anomalies by preparing a karyogram.

A **karyogram** is a diagram used to arrange the chromosomes of a cell into pairs in order of their size, shape (position of their centromere), and banding patterns (lines across the **chromatids**).

It is usually made from the cells of an unborn baby and uses images of the chromosomes taken during **mitotic metaphase**.

A karyogram is used to determine a person's **karyotype**, which can reveal various kinds of genetic information such as the number of chromosomes they have and the kinds of sex chromosomes they have.

Synonyms

anomalies ...... differences

Subject vocabulary

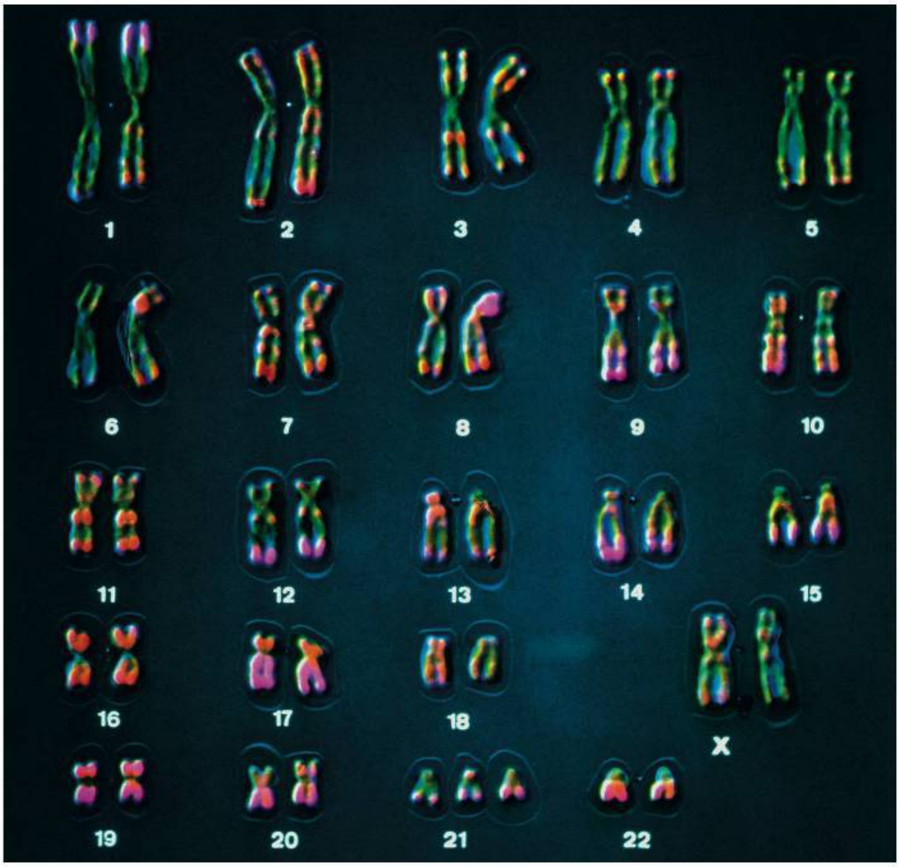
karyogram a diagram showing the chromosomes of an organism

chromatid the identical parts of a doubled chromosomes held together by a centromere

mitotic metaphase a stage of meiosis during which homologous chromosomes line up and the nuclear membrane disintegrates

karyotype the number and appearance of chromosomes within the cell of an organism

When interpreted correctly, a karyogram can indicate whether or not the unborn baby is a boy or a girl and whether or not the child has any chromosomal disorders such as extra or missing chromosomes.



Source: Science Photo Library / CNRI

Figure 3.2 *This is a karyogram showing all 23 pairs of chromosomes. What can we learn about the individual's karyotype from this figure? This karyogram was prepared using false colour imagery*

Application: Use of karyograms to deduce sex and diagnose Down syndrome in humans

By looking at the 23rd set of chromosomes in the karyogram above, doctors are able to determine the sex of this child: XX means it is a girl (see next section). Also, by looking at the 21st pair, a specialist is able to see if the child has **Down syndrome**. The image above shows that this girl has three chromosomes in the 21st pair (**trisomy**) and therefore has Down syndrome.

Understanding: Sex is determined by sex chromosomes and **autosomes** are chromosomes that do not determine sex.

The gender of humans is determined by the last set of chromosomes, the 23rd pair.

There are two types of sex chromosomes: X and Y.

X chromosomes are big, with long chromatids, whereas Y chromosomes are easy to recognize by their very small size and short chromatids.

Typically, one of two configurations can happen: XX for a girl and XY for a boy. Mothers donate one of their two X chromosomes and fathers can donate either an X (found in half the sperm cells he produces) or a Y chromosome (found in the other half of the sperm cells he produces).

The other chromosomes, numbers 1 to 22, are called autosomes. Any traits whose genes are found on these 22 chromosomes are called autosomal traits.

Subject vocabulary

Down syndrome a chromosomal anomaly characterized by 3 chromosomes in the 21st pair

trisomy presence of three copies of a chromosome in a cell rather than the usual pair

autosomes chromosomes that do not determine sex

3.3 Meiosis

Main idea

Alleles segregate during meiosis allowing new combinations to be formed by the fusion of gametes.

Understanding: One diploid nucleus divides by meiosis to produce four haploid nuclei.

Gametes, otherwise known as sex cells, are haploid. In humans, this means there are 23 chromosomes present in sperm cells or in egg cells.

A special type of cell division called meiosis is needed for the production of gametes. Whereas most cells in the body divide using mitosis, sex cells are the only ones to use meiosis.

Meiosis is known as a reduction division because the number of chromosomes in the cell is reduced from $2n$ to n. The number of nuclei that can be produced by meiosis is four.

For example, inside the testes, a cell that uses meiosis to divide will produce four sperm cells, each containing half the information from the parent cell.

Understanding: The halving of the chromosome number allows a sexual life cycle with fusion of gametes.

Model sentence: In order to ensure that the chromosome number is maintained from generation to generation, meiosis produces sex cells with half the total number of chromosomes per cell that the individual possesses.

Genetic information is precious to a species so it might seem contradictory to eliminate half of it when producing gametes.

The reason for putting only half of the genetic information into a sperm cell or egg cell is to maintain the same chromosome number generation after generation.

If a woman donated all of her 46 chromosomes and a man donated all of his 46 chromosomes to their future baby, the child would receive a total of 92 chromosomes. This would generate too much conflicting genetic information and the baby's cells would not form correctly.

Instead, the mother donates 23 chromosomes and the father donates 23, producing a baby with a number of chromosomes that is characteristic to humans: 46.

The fertilized egg, called a zygote, is now diploid. The sexual life cycle is complete.

Understanding: DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids.

As with mitosis, meiosis requires two copies of all the DNA in a cell before it can begin. This copying happens during the S phase of a cell's life cycle.

Synonyms

segregate .... separate

contradictory . inconsistent

replicate .... copy/repeat

Subject vocabulary

meiosis cell division where one diploid cell becomes four haploid cells

fusion two cells that join together as one

gamete a sex cell, either a sperm cell or an egg cell

reduction division meiosis, so called because the number of chromosomes in the daughter cells is half the original number in the parent cell

zygote diploid fertilized egg

S phase the stage in the cell cycle when DNA is replicated before division begins

life cycle the repeating pattern of cell growth, reproduction, and death that allows a species' DNA to be passed on generation after generation

Subject vocabulary

sister chromatids the two identical structures of a doubled chromosome

condensation in DNA, the coiling of chromatin to form chromosomes; in chemical reactions, the joining of two organic molecules during which a water molecule is produced

meiosis I first part of meiosis during which homologous chromosomes separate to produce two diploid cells

meiosis II second part of meiosis during which sister chromatids separate to produce four haploid cells (gametes)

prophase I a stage of meiosis during which homologous chromosomes line up and can perform crossing over

crossing over a process during meiosis I involving the exchange of genetic material between non-sister chromatids

Synonyms

offspring........ young/children

When DNA replication is complete, each chromosome has two identical **sister chromatids**. They are joined together at the centromere, giving the chromosome the 'X' shape we are familiar with.

Later, these two sister chromatids will separate so that each one will become a distinct chromosome. For now, however, they must be considered sister chromatids of the same chromosome.

Understanding: The early stages of meiosis involve pairing of homologous chromosomes and crossing over followed by **condensation**.

Meiosis consists of two parts: **meiosis I** and **meiosis II**. There are four stages in each part: prophase, metaphase, anaphase, and telophase.

Prophase I: homologous chromosomes pair up and **crossing over** happens

Crossing over involves sections of two non-sister homologous chromatids breaking at the same point, twisting around each other, and then connecting to the other's initial position.

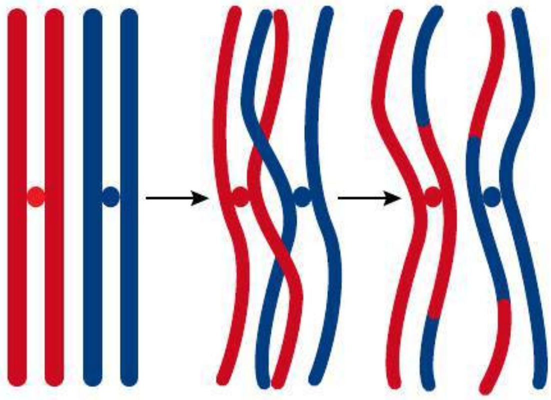


Figure 3.3 *Crossing over occurring in a pair of homologous chromosomes*

Crossing over is one way to increase genetic variety in the gametes by creating some chromosomes that are a mix of the person's maternal and paternal chromosomes. We will see later why variety in **offspring** is so important to evolution.

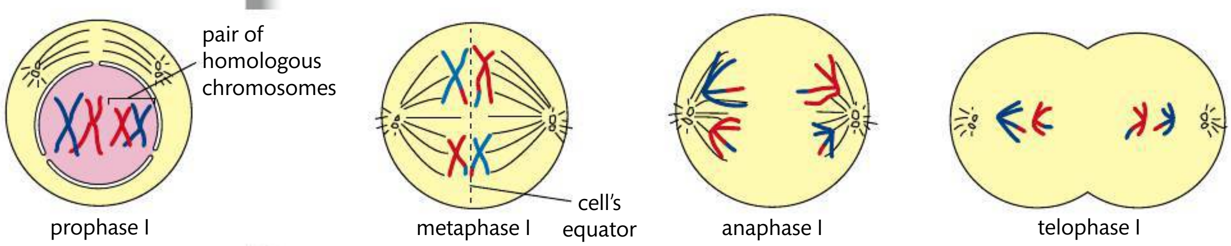


Figure 3.4 *The stages of meiosis I*

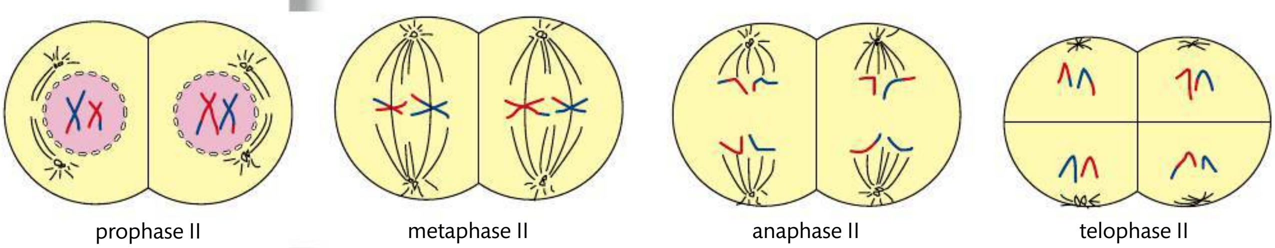


Figure 3.5 *The stages of meiosis II*

Skill: Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells

You are expected to be able to draw the eight stages of meiosis shown in the diagram above starting with a parent diploid cell and resulting in four haploid daughter cells.

Hints for success: To be sure you are ready for an exam question asking you to draw a diagram, take out a blank sheet of paper and try to draw what is asked for without looking at your notes or at the original diagrams. Remember: for drawings, always use pencil and always label or annotate using arrows that touch the details concerned.

Understanding: **Orientation** of pairs of homologous chromosomes prior to separation is random. Crossing over and random orientation promotes genetic variation.

Model sentence: Two effective ways of increasing variety in offspring are random orientation and crossing over.

Metaphase I: the way in which the homologous pairs line up along the cell's equator is random.

In humans, there are 2^{23} ways in which chromosomes can be randomly aligned. That's over 8 million different possible orientations.

Like crossing over, **random orientation** also helps to increase the genetic variety in the gametes, making it very unlikely for any two of a woman's eggs to be identical or any two of a man's sperm cells to carry the same combination of alleles.

Understanding: Separation of pairs of homologous chromosomes in the first division of meiosis halves the chromosome number.

Anaphase I: one of each of the homologous chromosomes in a pair is pulled to one side of the cell and the other is pulled to the other side. At this point, the chromosomes still are composed of two chromatids connected at the centromere.

Telophase I: usually, the chromosomes **uncoil** and a new nuclear membrane forms around each of the two nuclei.

By the end of meiosis I, the chromosome number has been halved. It has gone from $2n$ to n.

In humans, that means 23 chromosomes (one per pair) are present in each of the two cells instead of 46. In the figure, it means four chromosomes (two pairs) from the parent cell have become two chromosomes in the daughter cells.

Application: Non-disjunction can cause Down syndrome and other chromosome abnormalities.

If two homologous chromosomes got pulled over to the left side instead of being separated to opposite parts of the cell, the resulting nucleus on the left would have an extra chromosome and the one on the right would be missing one. This kind of event is called a non-disjunction and it produces chromosome abnormalities

Synonyms

orientation..... location/position

uncoil............ unwind/untwist

Subject vocabulary

metaphase I the stage of meiosis when homologous chromosomes pair up along the equator of the cell

random orientation a process during meiosis involving the lining up of chromosomes in an order determined by chance

anaphase I the stage in meiosis where homologous chromosomes separate

telophase I the stage in the cell cycle where chromosomes uncoil and a new nuclear membrane forms

chromosome abnormalities condition where cells contain too many or too few chromosomes, usually caused by non-disjunction during cell division in which children can be born with 45 chromosomes or 47 instead of 46. As seen in the previous section, in the case of trisomy of the 21st chromosome, non-disjunction leads to Down syndrome.

Application: Studies showing age of parents influences chances of non-disjunction

Scientists wanted to know what factors influenced the occurrence of Down syndrome. Below is a graph of the results of frequency of the syndrome compared to the mother's age at the time of birth of the child. Not surprisingly, it was concluded that after the age of 35, as the age of the mother increases, the chances of having a baby with Down syndrome increase dramatically.

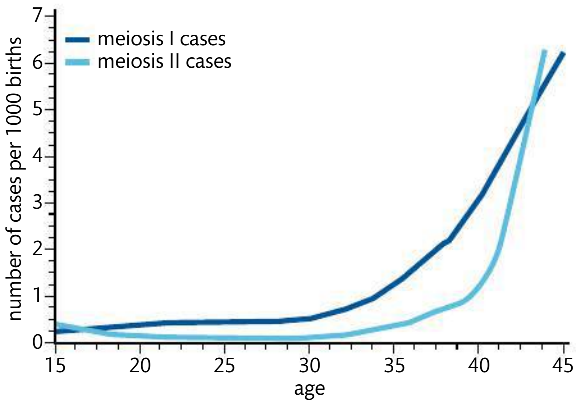


Figure 3.6 *Correlation of age of mother and occurrence of Down syndrome in children*

Source: reproduced with permission of Dr. Stephanie Sherman

Application: Description of methods used to obtain cells for karyotype analysis

One way to find out if an unborn child has a chromosome abnormality is to prepare a karyogram. One way of doing this is by **amniocentesis**. This involves removing some **amniotic liquid** that surrounds the baby. A long needle is used to collect the liquid through the mother's abdomen. **Ultrasound** technology is used to see where the baby is to ensure its safety. **Chorionic villus sampling** is another technique and is preferred earlier in the pregnancy. Here, tissue from the **placenta** is collected and cells are analysed.

Understanding: Fusion of gametes from different parents promotes genetic variation.

Meiosis II: the next four steps are to pull the chromatids apart and make a total of four nuclei, each with *n* number of chromosomes.

At the end of **telophase II**, each chromosome now consists of a single copy and the cells produced by meiosis are ready to become gametes.

The next step for gametes is to find their **complementary** partner: a sperm cell must meet an egg cell.

In determining which sperm cell will **fuse** with which egg, there is a certain amount of randomness (which egg or which sperm cells happen to have been produced at the time of fertilization) as well as a certain amount of chance (which man meets which woman and at what time fertilization happens).

The zygote, which is the first cell of what may become a new child, is unique.

The three main factors influencing variation in offspring are: (1) crossing over during prophase I, (2) random orientation during metaphase I, and (3) some of the randomness and chance involved in the process of fertilization.

Subject vocabulary

amniocentesis a test used to determine the genetic make-up of a foetus using cells collected from amniotic liquid

amniotic liquid the fluid surrounding the developing foetus

ultrasound a method used to produce an image of a baby in the uterus

chorionic villus sampling a test used to determine the genetic make-up of a foetus using cells collected from the placenta

placenta a structure found in the uterus that allows exchanges of gases, nutrients, and waste products between mother and foetus

telophase II the second telophase stage in meiosis where chromosomes uncoil and a nuclear membrane forms around the haploid nucleus to produce a gamete

fuse join together

Synonyms

complementary balancing/matching

Main idea

The **inheritance** of genes follows patterns.

Nature of science: **Making quantitative measurements with replicates to ensure reliability. Mendel's genetic crosses with pea plants generated numerical data.**

Understanding: Mendel discovered the principles of inheritance with experiments in which large numbers of pea plants were crossed.

In 1865, an Austrian monk named Gregor Mendel published the results of his experiments on how garden pea plants (*Pisum sativum*) passed on their characteristics.

Gregor Mendel used **artificial pollination** in a series of experiments in which he carefully chose the pollen of various plants to fertilize other individuals of the same species.

He used a small brush to place the pollen on the reproductive parts of the flowers, thus replacing the insects that do it naturally. This technique allows the experimenter to decide exactly which plants are fertilized by which pollen, instead of leaving it up to chance encounters with insects.

Some of the characteristics, or traits, he examined were whether the peas were yellow or green, round or wrinkled, or if the plants were tall or short.

For the genetic trait of height, one allele is dominant (***T***) for tall, and the other is recessive (***t***) for short. The table shows Mendel's results. (See last row of table for Mendel's results for height.)

Characteristics in parents	First generation produced	Second generation produced	Ratio of results seen in second generation
round × wrinkled seeds	100% round	5474 round 1850 wrinkled	2.96:1
yellow × green seeds	100% yellow	6022 yellow 2001 green	3.01:1
green × yellow pods	100% green	428 green 152 yellow	2.82:1
tall × short plants	100% tall	787 tall 277 short	2.84:1

Understanding: Gametes are haploid so contain only one allele of each **gene**.

When the male parts of a flower produce pollen, the sex cells inside the pollen contain only one copy of each pair of genes; gametes are haploid.

Subject vocabulary

inheritance passing on a trait from one generation to the next

artificial pollination process where humans control plant fertilization by transferring pollen from one specific flower to another

gene section of DNA molecule that codes for a particular trait/protein in an organism

General vocabulary

quantitative a numerical measurement

Synonyms

replicate .... copy

As a result, if the parent plant had a genotype of ***Tt***, half the gametes would contain only ***T*** and the other half would contain only ***t***. Each sex cell contains only one allele in the pair that the parent had.

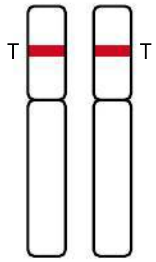


Figure 3.7 *This drawing shows you a pair of chromosomes showing a homozygous state, TT*

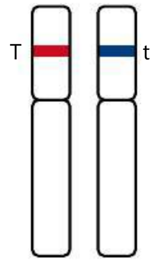


Figure 3.8 *This drawing shows you a pair of chromosomes showing a heterozygous state, Tt*

Understanding: The two alleles of each gene separate into different haploid daughter nuclei during meiosis.

The reason why there is only one allele in each gamete is because of meiosis.

During anaphase I, the two chromosomes in each homologous pair are separated so that the daughter cells only contain one of each chromosome in the pair. Remember that meiosis is considered a reduction division for this reason.

The result: the two alleles for any given trait are separated between gametes.

For example, some children from the same mother and father can be born with different hair colour or blood type. It depends on which alleles were present in the sperm cell that fertilized the egg.

Understanding: Fusion of gametes results in diploid zygotes with two alleles of each gene that may be the same allele or different alleles.

When a sperm and an egg cell meet during fertilization, the two nuclei fuse.

For example, if the egg contained a ***T*** and the sperm contained a ***t***, the resulting zygote's genotype would be ***Tt***. (Remember to read it 'big T little t'.)

The zygote is diploid. Its genotype may be the same as one or both parents but it could also be different from both parents. This is demonstrated below.

- Both parents are ***Tt***. This genotype has one dominant allele and one recessive allele. It is said to be **heterozygous**. To see what kind of offspring these parents have, we can draw a table called a Punnett grid in which the alleles in one parent's set of gametes are shown on the side and those of the other parent are shown on top.
- Notice how some of the offspring (the four genotypes in the centre) are also heterozygous, like their parents. However, there is a 1 out of 4 chance that the genotype turns out ***TT***. This is called **homozygous dominant**. The third possibility (which also represents one chance in four) is ***tt***. This is called **homozygous recessive**.
- This type of cross is called a **monohybrid cross**. It shows how one trait can be passed on.

Subject vocabulary

heterozygous possessing two different alleles of a gene at a particular locus

homozygous dominant having the same two dominant alleles for a particular gene

homozygous recessive having the same two recessive alleles for a particular gene

monohybrid cross a cross between two heterozygous parents to show how a single trait is passed on to the offspring

	T	***t***
T	***TT***	***Tt***
t	***Tt***	***tt***

Figure 3.9 *A monohybrid cross showing the possible offspring of two heterozygous parents*

Understanding: Dominant alleles mask the effects of recessive alleles but co-dominant alleles have joint effects.

The rules of dominance: in garden peas, ***TT*** (homozygous dominant) results in a tall plant. Only the allele for being tall is present.

tt (homozygous recessive) results in a short plant. Only the allele for being short is present.

Tt results in a tall plant because the dominant allele ***T***, masks the recessive allele ***t***. The result is that the recessive allele ***t*** is neither transcribed nor translated.

The steps to setting up a Punnett grid to determine the offspring of a given set of parents are as follows:

- Step 1: Choose a letter. Use capital and small case versions of the same letter to show alleles. An example is: ***T*** = allele for tall plants, ***t*** = allele for short plants.
- Step 2: Determine the parents' genotypes. It is best to write all possibilities (***TT***, ***Tt***, or ***tt***) and proceed by elimination. A short plant cannot be ***TT*** or ***Tt*** so it must be ***tt***. A tall plant cannot be ***tt***, but could be ***TT*** or ***Tt***.
- Step 3: Determine gametes.
- Step 4: Draw the Punnett grid.
- Step 5: Work out the chances of each genotype and phenotype occurring.

Here are some further examples: first cross: ***TT*** × ***tt***, second cross: ***tt*** × ***Tt***.

	t	***t***
T	***Tt***	***Tt***
T	***Tt***	***Tt***

	T	***t***
t	***Tt***	***tt***
t	***Tt***	***tt***

Analysis and interpretation:	
Genotypes of offspring:	***Genotypes of offspring:***
TT: 0% chance	***TT***: 0% chance
Tt: 100% chance	***Tt***: 50% chance
tt: 0% chance	***tt***: 50% chance
Phenotypes:	***Phenotypes:***
100% chance of being tall	50% chance of being tall
0% chance of being short	50% chance of being short

Figure 3.10 *Analysis of the two Punnet grids above*

Hints for success: Be careful when choosing letters. Nearly half the letters of the alphabet should be avoided because they are too similar in their capital and lower case forms. Don't use Cc, Ff, Kk, Oo, Pp, Ss, Uu, Vv, Ww, Xx, Yy, Zz. If the person grading your work cannot tell the difference between the two letters, they cannot give you the marks.

A test cross can be done if a plant is tall and we need to know if it is ***TT*** or ***Tt***. It is impossible to determine the genotype just by looking at the plant.

To perform a test cross, a known homozygous recessive individual is crossed with the individual that has the unknown genotype.

Subject vocabulary

test cross crossing with a homozygous recessive individual to determine the alleles of the test individual

The two possible results are shown below – if the unknown parent was ***TT***, all offspring will be tall, whereas if the unknown parent was ***Tt***, only half should be tall.

	t	*t*
T	*Tt*	*Tt*
T	*Tt*	*Tt*

	t	*t*
T	*Tt*	*Tt*
t	*tt*	*tt*

Figure 3.11 *Two possible outcomes of a test cross*

Sometimes one allele does not mask another but rather both alleles are expressed. This is called co-dominance and will be explored below.

Subject vocabulary

co-dominance alleles that have joint effects, both alleles are expressed in the organism's phenotype

recessive an allele that is only expressed when no dominant allele is present to mask it, notably when an individual is homozygous recessive

dominant an allele that is expressed in preference to another (recessive) allele

recessive autosomal genetic diseases a condition which only occurs when two recessive alleles on non-sex chromosomes are present

dominant autosomal genetic diseases diseases caused by the presence of a particular dominant allele on non-sex chromosomes

genotypes genes of an organism for a particular trait

Synonyms

pigmentation . colour

Understanding: Many genetic diseases in humans are due to **recessive** alleles of autosomal genes although some genetic diseases are due to **dominant** or co-dominant alleles.

Model sentence: Some traits are caused by alleles that have a dominant/recessive relationship, whereas other traits can show co-dominance.

The vast majority of genetic diseases are caused by genes found on chromosomes numbered 1 to 22 (the autosomes).

It is more common for genetic diseases to be caused by recessive alleles.

Examples of recessive autosomal genetic diseases or conditions are:

- Albinism – a lack of pigmentation in skin, eyes, and hair.
- Cystic fibrosis – production of excessively thick, sticky mucus, resulting in respiratory and digestive difficulties.
- Tay–Sachs disease – causes damage to nerve cells and early death in children.

It is less common for genetic diseases to be caused by dominant alleles.

Examples of dominant autosomal genetic diseases are:

- Huntington's disease – causes the degeneration of neurones, often not showing up until the age of 40 years old and causing difficulty walking and uncontrollable movements.
- Polydactyly – causes the growth of more than five fingers or toes on a hand or foot.

A small number of genetic diseases result from co-dominance. Sickle cell disease is one example (see the third example below).

Example: cystic fibrosis

If a couple wants to know what the chances are that their next child will inherit cystic fibrosis, it is important to determine the genotypes of the parents. Consider a couple in which the woman does not have cystic fibrosis but her father did. The man in the couple has cystic fibrosis. Use the five steps:

- Step 1: Use ***A*** to represent the allele for healthy mucus production, and ***a*** for the allele for cystic fibrosis. The allele that causes the disease is recessive so the only way to get it is to have the genotype ***aa***.
- Step 2: There are three possible genotypes: ***AA***, ***Aa***, and ***aa***. The mother must have at least one ***A*** since she does not have cystic fibrosis. She must have at least one ***a*** since her father was ***aa*** (he had cystic fibrosis). We can eliminate the possibility that she is ***AA*** so she must be ***Aa***. In order to have cystic fibrosis, the man in the couple cannot possess an ***A*** allele. He can only be ***aa***.

- Steps 3 and 4: Gametes (***A*** and ***a*** for the woman, ***a*** and ***a*** for the man) are placed in the side and top boxes of the Punnett grid, which is then filled in:
- Step 5: There is a 50% chance that their child will be ***aa*** and have cystic fibrosis.

	a	***a***
A	***Aa***	***Aa***
a	***aa***	***aa***

Figure 3.12 *A Punnett grid showing a heterozygous woman and a man with cystic fibrosis*

Hints for success: When answering questions about genetic outcomes for offspring, it is sometimes tempting to go straight to the Punnett grid and forget about steps 1–3. The problem is that if you do not think carefully about the information going into the Punnett grid, you could put in the wrong information.

Example: Huntington's disease – use of a pedigree chart

The diagram to the right is called a **pedigree chart** and it allows genetic experts to follow a trait from one generation to the next.

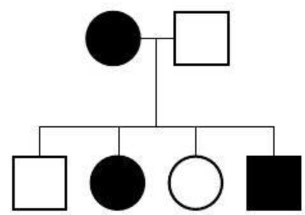


Figure 3.13 *A pedigree chart showing an affected woman, a non-affected man, and their four children*

Symbols used: filled shapes show the trait is present in the **phenotype** (in this case, Huntington's disease), whereas empty shapes show individuals who do not have the trait. Circles show females and squares show males. The children (the second row in this example) are presented in order from oldest on the left to youngest on the right. Each new row is a new generation.

This family has six individuals. The mother, the second son, and the first daughter have Huntington's disease. The father, the second daughter, and the eldest son do not.

Pedigrees are useful for establishing the genotypes of members of a family. In the case of Huntington's, ***H*** = the allele for the disease and ***h*** = the allele for healthy nerve functions.

It can be concluded that the mother must be heterozygous (***Hh***) because she had some children without Huntington's. A parent who is ***HH*** could produce only children with the disease so this is definitely not her situation.

Only the first daughter or youngest son, who are both ***Hh***, could pass on to the next generation the allele that causes Huntington's (with a 50% chance).

Example: sickle cell disease – co-dominance

Sickle cell disease is caused by a mutation of a gene that helps to make haemoglobin. The result is a misshaped haemoglobin molecule, which also causes a change in shape of the red blood cells. Instead of disc-shaped cells, elongated, curved cells with a boomerang shape are formed.

People who inherit two mutated alleles (one from the father, one from the mother) have high numbers of sickle-shaped cells and suffer severe symptoms such as fatigue and pain because the blood vessels get blocked.

People who inherit only one mutated allele but receive a healthy allele from the other parent do not have the symptoms of the disease but they are resistant to malaria.

Someone who is heterozygous is said to have **sickle cell trait**. This condition shows co-dominance or incomplete dominance. Some of the characteristics of the mutated allele are **masked** by the dominant allele but others are not.

Example: the ABO blood type system – multiple alleles and co-dominance

Until now, the examples have all been with only two alleles. The ABO blood type system is different – it has three alleles. They are written as follows:

- I^A = the allele that produces proteins for type A antigens, giving type A blood. This allele is dominant to i and co-dominant with I^B.
- I^B = the allele that produces proteins for type B antigens, giving type B blood. This allele is dominant to i and co-dominant with I^A.
- i = the allele that produces neither A nor B antigens, giving type O blood. This allele is recessive to both I^A and I^B.

Subject vocabulary

pedigree chart a diagram showing how a genetic trait is passed on from generation to generation

phenotype visible result of an organism's genotype

sickle cell trait the heterozygous condition where an individual has one healthy allele and one mutated allele coding for sickle cell disease

Synonyms

masked.......... covered/hidden

These three alleles can produce four possible phenotypes: type A blood, type B, type AB, and type O.

There are six unique combinations of these three alleles to produce the four phenotypes:

- I^AI^A or I^Ai = type A blood
- I^BI^B or I^Bi = type B blood
- I^AI^B = type AB blood (this is where co-dominance comes in)
- ii = type O blood.

Notice with the fifth combination that both alleles for A and B are present. The person will produce both A and B antigens. One allele does not mask the other – there is no such thing as recessive between A and B. The two alleles are co-dominant. Both alleles are transcribed and translated.

Understanding: Some genetic diseases are sex linked. The pattern of inheritance is different with sex-linked genes due to their location on sex chromosomes.

Model sentence: Not all genetic traits are passed on equally to males and females – sex-linked traits are distributed unequally between men and women.

When the gene responsible for a genetic disease is found on the 23rd set of chromosomes, the X or Y sex chromosomes, the disease is said to be **sex linked**.

Sex-linked traits affect one gender more frequently than another.

Examples: haemophilia and colour blindness (both found on the X chromosome) affect more males than females.

- **Haemophilia** prevents the production of certain blood-clotting proteins (factor VIII or factor IX, depending on the type of haemophilia). As a result, the person is at risk of excessive bleeding and haemorrhaging.
- **Red-green colour blindness** (affecting about 1% of males) causes deficiencies in certain types of **photoreceptors** of the retina. People with this condition have difficulty distinguishing red from green. There are several other types of colour blindness.

The allele is represented by the letter h but is written as a superscript X^h to show that it is on the X chromosome. The Y chromosome cannot carry an allele for this gene so the notation is Y. A man with haemophilia has a genotype X^hY. Note the absence of a dominant allele to mask the trait.

If a woman was X^HX^h, she would not have haemophilia. However, she would be a carrier.

Only females can be carriers for sex-linked traits whose genes are found on the X chromosome.

Subject vocabulary

sex linked a trait that is controlled by alleles located on the sex chromosomes

haemophilia a condition where certain blood clotting factors are not produced, so the blood does not clot

red-green colour blindness a sex-linked trait that affects the ability to distinguish between red and green

photoreceptors receptors in the eye that respond to light by beginning a nerve impulse

Understanding: Many genetic diseases have been identified in humans but most are very rare.

Thanks to natural selection, genetic disorders and diseases are rare, most affecting far less than 1% of the population.

There are thousands of genetic diseases and disorders.

One of the most common genetic diseases is cystic fibrosis, which affects about 1 birth in 3000 in the United States and Europe. The most rare genetic diseases only affect a limited number of people worldwide.

Do not confuse genetic diseases with chromosomal anomalies caused by **non-disjunction**. The first is caused when a mutated allele is passed on from one generation to the next but does not change the number of chromosomes. The second is caused by a new event (the non-disjunction) changing the number of chromosomes.

Understanding: Radiation and mutagenic chemicals increase the mutation rate and can cause genetic diseases and cancer.

DNA can be damaged by certain chemicals and by certain types of radiation.

These are said to be **mutagenic**, meaning they can cause mutations in DNA.

Some mutations might become new alleles that could produce a genetic variation or disease, other mutations are capable of causing **cancer**. Chemicals that can cause cancer are called **carcinogens**.

Two factors that determine how likely it is that radiation or chemicals will cause a mutation are:

- their concentrations or strength
- the length of exposure.

Mutations are more likely to be produced by high concentrations and long exposure to a mutagenic radiation or carcinogens. However, small concentrations over long time periods or very high concentrations over a short period of time can sometimes cause a mutation.

Example: results of exposure to radiation

The nuclear bombs dropped on Hiroshima and Nagasaki in Japan in 1945 killed over 100 000 people on impact but killed thousands more people in the decades to follow. Radiation sickness affected Japanese citizens in the weeks following the bombings. Symptoms show cellular damage such as gastrointestinal problems, a drop in the number of blood cells, and neurological damage.

The Chernobyl nuclear power plant accident in Ukraine in 1986 killed about 30 people immediately but exposed about 200 employees to dangerous doses of radiation. The spread of radioactive material around the explosion was extensive and hundreds of thousands of people were exposed, including citizens of the nearby city of Pripyat. It is difficult to estimate the number of radiation-related deaths in the decades since the accident, but a UN agency specializing in such exposure puts the number at approximately 4000. As for the number of people who will develop cancer from the exposure in the coming decades, estimates are in the tens of thousands.

Subject vocabulary

non-disjunction the process where two homologous chromosomes do not separate during anaphase I of meiosis, resulting in a daughter cell with one too many chromosomes and a daughter cell with one too few

mutagenic causing a mutation

cancer disease involving uncontrolled abnormal cell growth

carcinogen(s) a chemical that causes cancer

3.5 Genetic modification and biotechnology

Main idea

Biologists have developed techniques for artificial manipulation of DNA, cells, and organisms.

Nature of science: **Assessing risks associated with scientific research – scientists attempt to assess the risks associated with genetically modified crops or livestock.**

Understanding: Gel electrophoresis is used to separate proteins or fragments of DNA according to size.

Subject vocabulary

gel electrophoresis process of passing electricity through a gel matrix to separate fragments or molecules of proteins or nucleic acids

One technique used for identifying DNA is called **gel electrophoresis**. Here is how it works:

- A DNA sample is cut into fragments using specialized enzymes.
- Some of the fragments are small, some are bigger, some are highly charged, and others do not carry much of an electrical charge.
- All the fragments are put into wells at one end of a block of gel.
- An electric current is run through the gel.
- The particles are separated between the two ends of the gel by their size and electrical charge.
- This separation process leaves a pattern of bands that is different for each unique sample of DNA.

Gel electrophoresis can be used on protein molecules in the same way.

The banding patterns of a person's DNA or protein (from their hair, for example) can be used to identify that person.

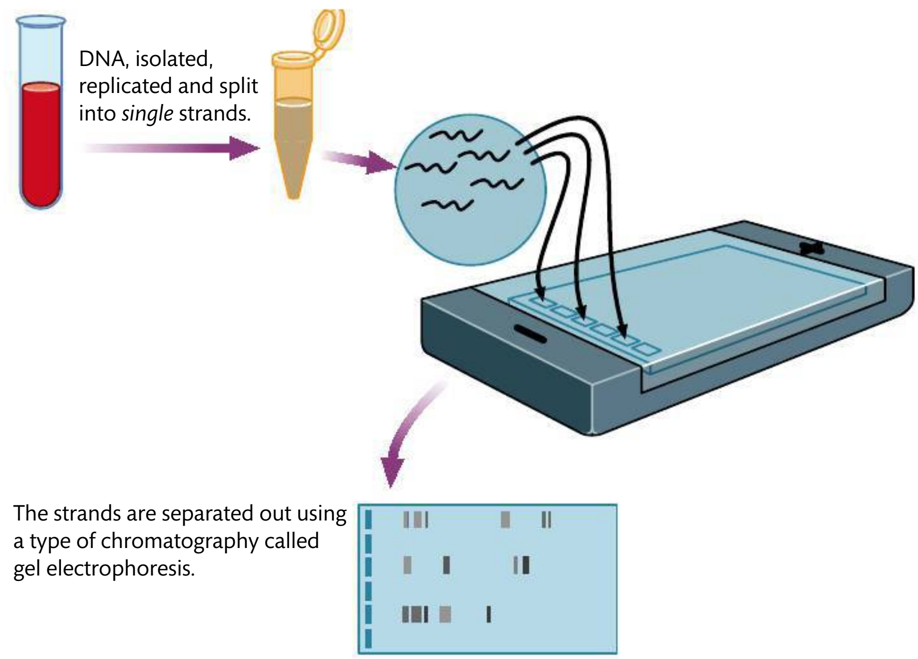


Figure 3.14 *Gel electrophoresis is used to separate DNA fragments so that they can be analysed*

Understanding: PCR can be used to **amplify** small amounts of DNA.

Model sentence: Before a DNA sample can be identified, a sample needs to be collected and amplified using PCR, and then gel electrophoresis is used to separate DNA fragments.

Gel electrophoresis is only possible if there is a certain quantity of DNA to analyse. However, sometimes at a crime scene or other situation where DNA needs to be analysed, there is only a limited quantity available.

It is possible to make millions of copies of DNA using a technique called PCR: polymerase chain reaction. Here's how it works:

- A sample of DNA is collected and isolated.
- The DNA is placed in a **thermocycler** which contains free nucleotide phosphates (containing A, T, C, and G nucleotide phosphates).
- Through a series of modifications of the temperature of the DNA fragments in the presence of enzymes, new strands of DNA are made.
- From one copy, two are made. From those two, four copies can be made. Then 8, then 16, 32, 64, and so on. Very quickly, millions of copies are being made and they are all identical to each other.

Now there is enough to analyse using other techniques such as gel electrophoresis above.

Understanding: DNA profiling involves comparison of DNA.

At a crime scene, a forensics investigator collects blood or other human tissue.

The DNA in the nuclei of the collected cells can be used to identify the victim or the attacker. Here's how:

- DNA is collected and isolated then put through PCR to make enough copies for analysis to be possible.
- The samples are put through gel electrophoresis to obtain the banded patterns characteristic of each individual's DNA.
- Comparisons are made between the banding patterns of DNA found at the scene with those on record in the police files or those prepared from suspects' DNA (see below).

If the bands from a suspect's DNA match those from DNA found at the crime scene, it suggests that the police are dealing with the same person. If no match is found, this indicates that it is unlikely to be the same person.

In addition to crime scenes, DNA profiling (sometimes called DNA fingerprinting) can be used for paternity cases (finding out who the real father of a child is) or ecological studies (constructing family connections within a population under study).

How can DNA profiling be used in paternity and forensic investigations?

- Perform gel electrophoresis on the DNA samples from the father and the child. In a criminal case, DNA found at the crime scene is compared to samples of DNA taken from various suspects.
- Line up the banded patterns to see which ones connect.

Subject vocabulary

thermocycler a machine used to produce many copies of DNA from a sample

General vocabulary

amplify make louder/stronger or increase in number

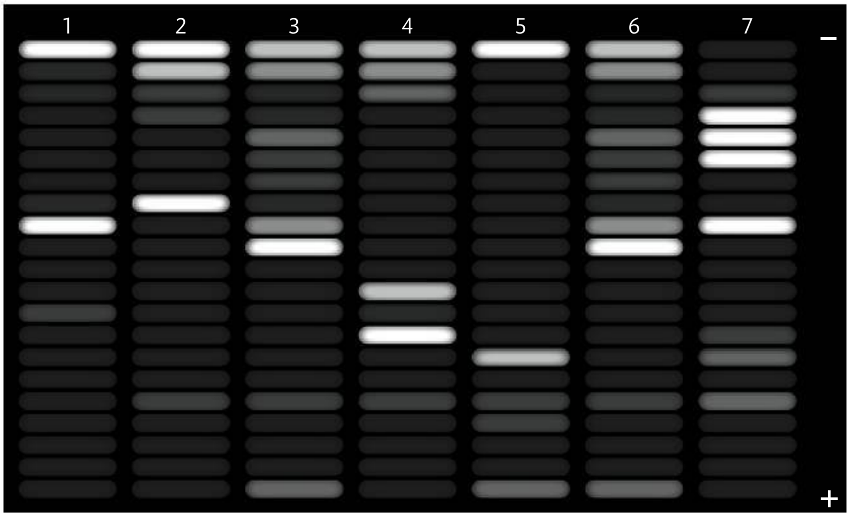


Figure 3.15 *This gel electrophoresis shows six samples – the seventh column on the right is made of known DNA fragments and is used to estimate the lengths of the unknown fragments. Samples 3 and 6 match*

- Examination of the lines in the diagram above clearly shows that rows 3 and 6 have the same banding patterns. This would suggest a match. If track 1 was the father and 6 was the child, it is unlikely they are related. However, if 3 was the DNA sample found at a crime scene and 6 was the sample of a suspect, that person has a lot of explaining to do.

Understanding: Genetic modification is carried out by gene transfer between species.

Model sentence: Because the DNA code is universal, it is possible to place a gene from one species into another and have it expressed in the host organism.

In the 1970s, scientists first developed techniques that allowed a gene from one species to be placed in another species' genome to allow the host species to express a trait that is new to it.

This is possible because DNA is **universal** – the code works for all living organisms.

One example of a **genetically modified organism (GMO)** is *Bt* corn. Here is how it works:

- Corn is often attacked by **pests** such as the corn earworm, *Helicoverpa zea*.
- Farmers do not like pests because they cannot sell corn that is **infested** and half-eaten.
- A certain soil bacterium called *Bacillus thuringiensis* has a gene that allows it to make a protein that poisons and kills pests when they eat the protein.
- The gene from the bacterium was isolated and inserted into a corn kernel. The plant that grew was in every way exactly like a regular corn plant except that it could now produce the **pesticide** protein that the bacterium makes.
- This **transgenic** species is the product of human laboratory work and is called *Bt* corn, named after the bacterium that helped it.
- Farmers can increase their **yield** because the corn is not attacked by the pests that used to eat it.

Skill: Analysis of data on risks to monarch butterflies of *Bt* crops

Monarch butterflies, *Danaus plexippus*, eat milkweed plants, *Asclepias syriaca*, on their long migration between Mexico, the United States, and Canada. Along

Subject vocabulary

universal common to all living organisms

genetically modified organism (GMO) an organism that has had a gene from another species inserted into its genome allowing it to express a new trait

transgenic having one or more genes from a different plant/animal

strain a type or variety of organism

General vocabulary

pest small animal/insect that destroys crops

infested covered in pests

pesticide poison used to treat pest infestations

resistant not affected by

Synonyms

yield.............. crop/harvest

negligible....... small

emergence..... appearance

their route, many fields are planted with genetically engineered *Bt* corn. Scientists are worried about the decline in the number of butterflies in recent decades. They wanted to find out if the pollen from the *Bt* corn, which can be blown by wind from the corn to the milkweed, was harmful to the butterflies.

These data suggest that nearly half the butterflies die after 4 days of eating milkweed leaves dusted with *Bt* corn pollen and that those that survive eat less.

However, it is difficult to reproduce natural environments in a laboratory. This study has been challenged for several reasons, including the fact that sprinkling pollen on a leaf will put many more grains of pollen on it than wind in a field could and the fact that the butterflies were not given any other choice of food. Also, one variety of *Bt* corn that showed negative results has been removed from the market. In the end, the US Department of Agriculture determined that in the field, the impact of *Bt* corn on monarch butterflies is **negligible**. So what is causing the decline in their population? Probably a combination of factors including deforestation, parasites, and the reduction of habitats where milkweed can grow.

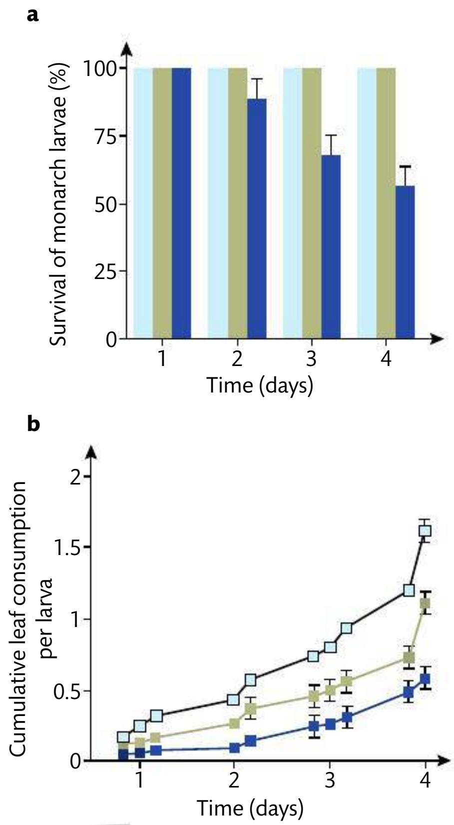


Figure 3.16 *Table of results from 1999 study.*
Legend for both graphs a and b:
Light blue = no pollen on milkweed leaves
Green = traditional corn pollen on leaves
Blue = Bt corn pollen on leaves

Application: How genetic engineering is being used today

The most commonly found genetically engineered food crops in the world today are corn, soybeans, and canola (all three of whose seeds are used for oil and animal feed).

Some animals and bacteria have alsoee been genetically engineered.

- Transgenic goats are able to produce medication in their milk for people with haemophilia.
- One **strain** of *E. coli* bacteria has had the human insulin gene inserted into it so that it can make insulin to help treat people with type I diabetes, thus saving millions of lives.

Understanding: transgenic crops have potential benefits and potential risks.

Model sentence: Like many technologies, genetic engineering has generated much debate about whether or not it is safe and worthwhile to use.

Transgenic crops – good or bad?

Potential benefits	Potential risks
increased yields – farmers can get more food from the same land	higher yields increase the problems of overproduction of crops and excess crop waste, and can drive crop prices down
improve nutritional quality, such as inserting genes for beta carotene (for vitamin A) in GM golden rice	unknown health risks to consumers such as possible allergies
pesticides grown in plants directly so fewer pesticides need to be sprayed on the crops	unknown ecological risks of the introduced genes on other organisms in the environment
some foods could be saved from viral infections by being genetically engineered, such as the GM papaya	pesticide made by *Bt* corn is consumed not only by pests but by humans and animals who eat the corn
herbicide-**resistant** crops reduce the need for mechanized weed removal and therefore reduce fossil fuel consumption on farms	**emergence** of resistant strains of pests that adapt to the new crops

Subject vocabulary

clone an organism that has exactly the same genetic make-up as its parent cell

reproductive cloning the production of new organisms that are genetically identical to the parent organism

therapeutic cloning the process of making copies of cells

stolons runners from a plant that produce cloned daughter plants

budding a type of asexual reproduction where new individuals develop from outgrowths of the original individual

wounding damaging

girdling removal of a strip of bark from around a branch or trunk

Understanding: Clones are groups of genetically identical organisms derived from a single original parent cell.

The definition of a **clone** is an organism or a group of cells that are genetically identical to the parent cell they came from.

Cloning occurs when there is no mixing of genes and DNA. In other words, the form of reproduction must be asexual (no meiosis, no gametes, no fertilization).

A clone's DNA must come directly from one parent.

This chapter deals with **reproductive cloning**, which should not be confused with **therapeutic cloning**, discussed earlier. Using stem cells to grow new tissue is considered therapeutic cloning because the objective is not to produce a new organism, only to make new copies of cells.

Understanding: Many plant species and some animal species have natural methods of cloning.

Clones are all around us.

- Bacteria clone themselves during binary fission.
- Identical twins are formed by natural cloning.
- Plants grown from the same plant material such as potato plants grown from their tubers cut into pieces are a clone. Strawberry plants send out **stolons**, also known as runners, which are horizontal projections that have new plants on the end that can grow into cloned daughter plants.
- Ginger and bamboo spread underground and grow new copies of themselves as they spread out over an area. The new plants are a clone of the old plant.
- Under certain conditions, hydra (*Hydra vulgaris*) use **budding** to make a clone.

Skill: Design of an experiment to assess one factor affecting the rooting of stem-cuttings

You are expected to be able to design an experiment to assess one factor affecting the rooting of stem cuttings.

Stem cuttings from plants can become new plants in the right conditions. In the lab, using a plant that responds well to propagation by stem cutting, set up an experiment to find out how one of the following can influence how well roots form:

- abiotic factors (light, water, temperature)
- type of medium (soil, agar, water)
- horticultural techniques such as **wounding** or **girdling**
- the presence of plant hormones such as auxins.

Understanding: Animals can be cloned at the embryo stage by breaking up the embryo into more than one group of cells.

Model sentence: Cloning has existed in nature since the beginning of life, whereas human-generated cloning of animals has been done for a century, most notably with the invention of the laboratory technique called somatic cell nuclear transfer used to make Dolly the sheep in 1996.

Scientists have been cloning embryos for decades.

It is possible to cut an embryo into smaller parts and grow them into new embryos.

The new embryos, which are all identical to one another, can be placed into the uterus of the animal that the original embryo came from.

If more than one of the animal embryos survive, they will form identical twins, triplets or quadruplets, depending on how many embryos were used and how many are successful.

Understanding: Methods have been developed for cloning adult animals using differentiated cells.

Here's how Dolly the sheep was made in 1996 using somatic cell nuclear transfer:

- A somatic cell (non-gamete cell) from the udder of the original donor sheep to be cloned was collected and cultured. The nucleus was removed from the cultured cell.
- An unfertilized oocyte was collected from another sheep and its nucleus was removed.
- Using an electrical current, the egg cell and the nucleus from the cultured somatic cell were fused together. This sets the cell cycle back to G_0 (see page 22).
- The new cell developed in vitro in a similar way to a zygote, and started to form an embryo.
- The embryo was placed in the womb of a surrogate mother sheep.
- The embryo developed normally.
- Dolly was born, and was presented to the world as a clone of the original donor sheep. One thing set her apart from her genetic mother: only the nuclear genome was copied, not the mitochondrial DNA. The mitochondrial DNA in Dolly's cells came from the surrogate mother.

Subject vocabulary

somatic cell nuclear transfer a process used in cloning where the nucleus from a non-sex cell is put into a sex cell that has had its nucleus removed and is then cultured to produce a zygote

uterus muscular organ of females where the embryo develops

oocyte the large cell that is the female's gamete

surrogate a substitute

General vocabulary

udder milk-producing structures of many mammals

4.1 Species, communities, and ecosystems

Main idea

The continued survival of living organisms including humans depends on sustainable communities.

Nature of science: Looking for patterns, trends, and discrepancies – plants and algae are mostly autotrophic but some are not.

Synonyms

discrepancies . differences/inconsistencies

Subject vocabulary

autotrophic organisms capable of producing their own food

fertile capable of reproducing

species a group of organisms which are structurally similar and able to pass their genetic traits on to their offspring

interbreed mate to produce fertile offspring

morphology the structure and shape of an organism

phylogeny family tree showing evolutionary relationships of species

asexually reproduction without fertilization and the fusion of gametes

hybrid something that has the properties of two things

infertile not capable of reproducing

populations a group of interbreeding members of a species living at the same time in the same place

synthesize a chemical reaction (or series of reactions) leading to the formation of a molecular substance

inorganic substances that do not contain carbon and are not produced by a living organism

General vocabulary

mosses small plants with no roots or water conducting vessels, often seen growing on rocks and tree trunks

Understanding: **Species** are groups of organisms that can potentially interbreed to produce **fertile** offspring.

Definition of species: a group of organisms that can **interbreed** and produce fertile offspring.

Species is the basic unit used to classify organisms. Members of a species are distinct from all other species, they have similar **morphology** and they share a common **phylogeny** (family tree).

As an example, there is only one species of humans currently living on Earth: *Homo sapiens*.

Challenges to the definition: what about bacteria or other organisms that reproduce **asexually**? In this case, morphology and phylogeny are used. What about **hybrids** such as mules (when a horse and a donkey mate) or a liger (when a lion and a tiger mate)? Since these organisms are **infertile**, no new species has been produced.

Understanding: Members of a species may be reproductively isolated in separate populations.

Through natural circumstances or through the intervention of humans, **populations** can sometimes be separated and therefore cannot interbreed anymore.

For example, a volcanic eruption might produce a lava flow or mud flow that could cut through a forest, separating a population of snails that once interbred. The construction of a major railway or a canal through the countryside could cut in two a population of **mosses** that can no longer interbreed.

Understanding: Species have either an autotrophic or heterotrophic method of nutrition (a few species have both methods).

Model sentence: Heterotrophs are organisms that cannot make their own food, whereas autotrophs are capable of synthesizing their food from sources of energy such as sunlight.

Autotrophs are capable of making their own food from **inorganic** substances. For example, photosynthetic organisms such as cyanobacteria, algae, or plants are capable of making sugar from carbon dioxide and water by using the energy from sunlight.

Heterotrophs are organisms that need to get their food from the environment; they cannot make their own food. They need to consume organic molecules that have been made by other organisms. For example, a dolphin needs to eat fish, alpaca need to eat grass, and bees need to eat nectar.

A very small number of organisms can be considered both autotrophs and heterotrophs. For example, *Euglena* feed on microscopic aquatic organisms but they also contain chlorophyll and can **photosynthesize** as well.

Understanding: Consumers are heterotrophs that feed on living organisms by **ingestion**.

- Organisms that eat other organisms are called **consumers**.
- Consumers that eat plant material are considered **herbivores**.
- Consumers that eat plant and animal material are considered **omnivores**.

Understanding: Detritivores are heterotrophs that obtain organic nutrients from detritus by internal digestion.

An organism that feeds on dead organic material is called a **detritivore**. For example, the organisms that transform dead leaves into soil, such as earthworms and soil mites, are detritivores.

These organisms play a vital role in the recycling of nutrients within an ecosystem. Without them, the return of valuable molecules to the soil would stop and the growth of plants and trees would be impossible.

Understanding: Saprotrophs are heterotrophs that obtain organic nutrients from dead organisms by external digestion.

Instead of eating food and digesting it internally, some organisms use external digestion.

How do they do this? They **secrete** digestive enzymes onto the dead organic material they consume and then absorb the digested nutrients.

Organisms that do this are called **saprotrophs**. For example, mushrooms on the forest floor can secrete enzymes onto dead wood and then absorb the nutrients that are released from the wood.

Organisms such as detritivores and saprotrophs are considered **decomposers**, since they play a vital role in the decomposition of dead organisms.

Skill: Classifying species by their mode of nutrition

You should be able to classify species using knowledge of their mode of nutrition.

What am I? Indicate 'autotroph', 'consumer', 'detritivore', or 'saprotroph' for each of the descriptions of species.

1. I move around the ocean floor looking for dead organisms to eat.
2. I sit in the sun and make food using my **chlorophyll**.
3. I swim in rivers hunting for small fish to catch and eat.
4. I secrete digestive juices onto dead organisms, then I absorb the nutrients that are released. [1]

[1] Answers: 1 detritivore, 2 autotroph, 3 consumer, 4 saprotroph

Subject vocabulary

heterotroph an organism not capable of producing its own food, requiring preformed organic compounds from other sources

photosynthesize convert light energy into chemical energy

ingestion the taking of food/substances into the body

consumer an animal that eats plants or other animals

herbivore an animal that only eats plants

omnivore an organism that eats plants and animals

detritivore an organism that eats non-living organic waste matter

saprotroph an organism which uses detritus as its energy and nutrient source

decomposer an organism that feeds on and breaks down waste organic material

chlorophyll main pigment involved in the process of photosynthesis, absorbs light energy

Synonyms

secrete .... produce/release

Understanding: A community is formed by populations of different species living together and interacting with each other.

Subject vocabulary

community all of the living organisms in an ecosystem

intertidal zone between the low and high tide water mark

quadrat an area of land marked off in order to count or study the organisms within

random sampling selecting study areas chosen by chance rather than a particular pattern

chi-squared test a statistical test to determine if two factors show independence or to show if expected values differ from observed values by chance or not

frequency how often an event happens in a fixed time

null hypothesis a default statement in statistics saying that two things are independent of each other or that there are no differences between them; the null hypothesis is challenged then rejected or not rejected

degrees of freedom the number of values in the chi-squared calculation that can vary

contingency table a reference table used to check whether a chi-squared value is significantly different from the expected value

critical value in statistical tests, a number used to determine if the null hypothesis is rejected given a certain level of statistical significance

General vocabulary

incubate keep eggs warm until the young hatch

Sometimes biologists are interested in studying a group of populations. Such a study would be at the **community** level rather than the individual or population level. Examples include a soil community, an **intertidal** community, or the community of microorganisms living in your large intestine.

Within a community, organisms depend on each other. For example, many insects depend on trees for their habitat, vampire bats depend on warm-blooded mammals for food, and cowbirds never raise their own chicks - they depend on other species of birds to **incubate** their eggs and to feed and raise their young

Skill: Testing for association between two species using the chi-squared test with data obtained by quadrat sampling

You should be familiar with the idea of sampling an ecosystem using a **quadrat** and **random sampling**. One question that might come up when studying an ecosystem is 'Is the presence of these two species together determined solely by chance?' In other words, is the fact that two species, such as a species of fern and another of moss, are often found together just a coincidence or is there something other than chance bringing them together?

A statistical test called the **chi-squared test** (χ^2) can be used to determine connections between **frequencies**. Chi is a Greek letter and it is pronounced like 'sky' without the s.

You are expected to be able to do the following:

- State the **null hypothesis** (H_0) in the given situation. The general null hypothesis is 'there is no statistically significant difference between the frequencies – they are determined by chance' and should be modified to the specific situation.
- Determine the number of **degrees of freedom** in this calculation. This is done by setting up a **contingency table** of expected and observed values as shown:

	Observed values	Expected values
first category of data		
second category of data		

Then take the number of categories minus 1. In this case, with two categories, the number of degrees of freedom is 1.

- Determine the **critical value** in order to obtain a 95% certainty that there is a statistically significant difference between these two sets of numbers. This is done by looking up the value in a table (critical value tables for the chi-squared test can be found online or in textbooks).
- Calculate the chi-squared value for these data. The general formula is below where *O* represents the observed values and *E* is for the expected values.

$$\chi^2 = \sum\frac{(O - E)^2}{E}$$

- Interpret the value calculated. Does it mean we can reject the null hypothesis or not? (See Skill below.)

Skill: Recognizing and interpreting statistical significance

If the chi-squared value is larger than the critical value, the null hypothesis is rejected. This means that the distributions in the frequencies are not due to chance.

It means that there is a statistically significant difference in the distribution of the populations. The calculation does not say what the reason is for this. It simply lets the investigator know with some certainty that something other than chance is influencing the data.

Understanding: A community forms an ecosystem by its interactions with the abiotic environment. Autotrophs obtain inorganic nutrients from the abiotic environment.

Model sentence: A group of populations interacting with each other is a community but once their non-living environment is considered, it is an ecosystem.

The term ecosystem refers to a community plus its abiotic (non-living) environment.

In a marine ecosystem such as a coral reef, the temperature, salinity, and pH of the water are going to have an impact on the communities living there. It is important that phytoplankton have access to dissolved minerals in the water so that they can grow.

On land, rainfall, air temperature, and soil chemistry will also impact the communities present. The water and inorganic substances present in an ecosystem influence the types of organisms that live there.

In the savannah, shrubs absorb inorganic materials such as nitrogen from the soil. If the quantity of nitrogen available in the soil becomes too low, plants will not be able to grow.

When plants stop growing, the organisms that rely on the plants suffer as well. It is vital for there to be organisms in the soil capable of transforming nitrogen gas from the air into usable nitrogen-rich compounds. One example of this is some types of bacteria that live in the soil or in compartments of the roots of certain plants and that transform N_2 into nitrates that plants can absorb (see Figure 14.11 on page 321).

Understanding: The supply of inorganic nutrients is maintained by nutrient cycling.

If plants, phytoplankton, and consumers are constantly taking in the inorganic substances from their environment, why is it that these materials never run out?

The answer is nutrient cycling, something ecosystems have been doing for a long time.

Nutrient cycling means that any inorganic material taken from the environment (such as nitrogen or calcium) will be returned to the environment sooner or later. Sometimes the nutrients are returned in the form of waste, other nutrients are only released back into the environment once the organism is dead and has decomposed.

Understanding: Ecosystems have the potential to be sustainable over long periods of time.

Thanks to nutrient cycling, it is possible for an ecosystem to provide inorganic substances indefinitely.

Subject vocabulary

statistically significant said of statistical tests, it means that the null hypothesis can be rejected (or not) with a certain degree of confidence, usually 95%

abiotic pertains to non-living

ecosystem the plants and animals in a region plus the non-living components of the environment

phytoplankton aquatic photosynthetic organisms that are usually microscopic

nutrient cycling the movement of nutrients through the ecosystem

General vocabulary

salinity amount of salt a substance contains

shrubs bushes

Synonyms

decomposed .. decayed

All the atoms in an organism came from the environment surrounding it. All the carbon, oxygen, and hydrogen in your body, as well as all the other atoms, came from something you ate or from the time early in your life when your mother ate something and passed on the nutrients to you.

If humans ever tried to live for a long time outside the planet Earth, such as on a space station, the Moon, or another planet, they would most likely have to take with them a sustainable ecosystem that would provide them with food, water, and air to breathe.

Until then, it is important to maintain a healthy balance in the current ecosystems that surround us on this remote space station we call Earth. If we throw the ecosystems here too far off balance, we may destroy the very thing that is keeping us alive: the **biosphere**.

Skill: Setting up sealed mesocosms to try to establish sustainability

You are asked to demonstrate that a long-term closed ecosystem can be setup and maintained without feeding it, as long as certain conditions are respected: raw materials must be introduced in the beginning along with a community of organisms that are capable of recycling the raw materials. A sealed **mesocosm** is an example of such a system and it consists of a transparent sealable container with water, nutrients, and living organisms inside that is placed in a sunny window to allow light energy to be used by the autotrophs inside. This should be set up early enough in the year to give it time to prove its **sustainability**. One version to try is called a Winogradsky column – there are lots of resources available online for how to set one up.

Subject vocabulary

biosphere all areas on and in Earth where living organisms exist

mesocosm a closed container in which a small functioning ecosystem exists

photosynthetic converts light energy into chemical energy

General vocabulary

sustainability how easy or difficult it is for an activity to continue over a long time

nourish provide food/substances needed to live and grow healthily

Synonyms

phenomena.... events/happenings

4.2 Energy flow

Main idea

Ecosystems require a continuous supply of energy to fuel life processes and to replace energy lost as heat.

Nature of science: **Use theories to explain natural phenomena – the concept of energy flow explains the limited length of food chains.**

Understanding: Most ecosystems rely on a supply of energy from sunlight.

Model sentence: Sunlight is essential to ecosystems because it provides the initial energy that will be transformed into organic molecules that will nourish the organisms.

In the previous section, we saw how nutrients are cycled so that ecosystems never run out of raw materials. In this section, we will see that it is impossible to do the same with energy.

In ecosystems, energy can be transformed but cannot be recycled. A constant supply of energy needs to enter ecosystems on Earth's surface or else they will not function.

The supply of energy for the most familiar and best-studied ecosystems on Earth is sunlight. Sunlight allows **photosynthetic** autotrophs to produce sugars and they feed the rest of the ecosystem. If the sun were to be blocked out, such ecosystems would not be able to continue at their current levels of productivity.

Understanding: Light energy is converted to chemical energy in carbon compounds by **photosynthesis**.

Photosynthesis allows for a very important transformation of energy from light energy to chemical energy.

The kind of energy found in carbohydrates such as sugar is called **chemical energy**. Chemical energy in organic substances is stored in the form of bonds between carbon, hydrogen, and oxygen.

Sunlight energy is needed by photosynthetic organisms to build the energy-rich bonds in sugars. The chemical energy is stored in the sugar until the bonds are broken during other chemical reactions such as cellular respiration.

Understanding: Chemical energy in carbon compounds flows through food chains by means of feeding.

Model sentence: In a food chain, the producers make chemical energy available in the food they make, the herbivore consumers eat it, and the carnivore consumers eat the herbivores.

Organic molecules such as sugar or lipids have many hydrogen and oxygen atoms bonded to their carbon atoms. The energy, measured in **calories** or in **joules**, depends on the number of bonds. More bonds mean more energy. Since lipids have long **hydrocarbon chains**, they contain many bonds and are therefore energy-rich compounds.

Hungry organisms will seek out energy-rich organic compounds such as sugars, starches, lipids, or proteins in order to meet their energy needs. Mayfly larvae, for example, will eat algae growing on rocks in a river. The energy flows from the algae (the producer) to the larvae (the consumer). A small fish might come along and eat one of the mayfly larvae. The energy flows to the fish. The energy will continue to flow – a kingfisher might swoop down and eat the fish and later the kingfisher might be eaten by a fox.

This flow of energy can be traced using a food chain. A **food chain** is a representation of which organisms depend on which other organisms as a source of food. The arrows between the organisms show how energy is passed on.

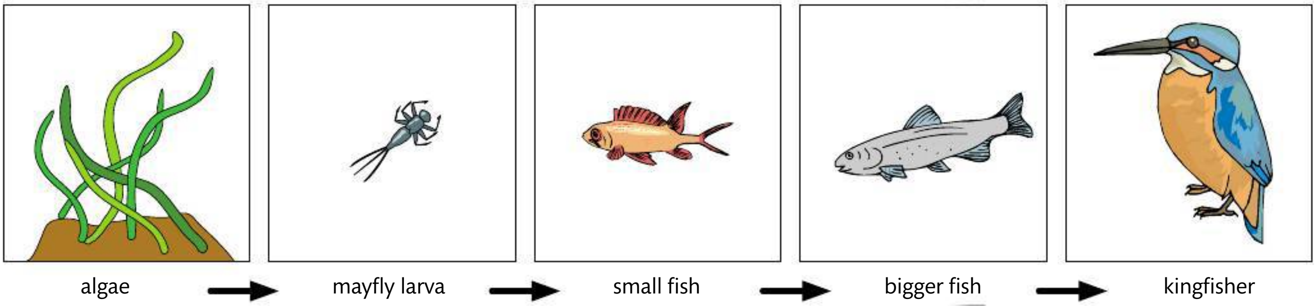


Figure 4.1 *A food chain shows the flow of energy from one organism within a community to the next*

Notice how the food chain starts with an autotroph. If the photosynthetic organism at the beginning is removed or is in short supply, all other organisms afterwards are affected.

The levels between the arrows in a food chain are called **trophic levels**.

Subject vocabulary

photosynthesis process which converts light energy into chemical energy

chemical energy energy stored in the bonds of organic molecules

calories a unit of measurement of energy

joules a unit of energy measurement

hydrocarbon chains long organic molecules formed from linked carbon atoms, hydrogen and oxygen

food chain one possible set of feeding relationships starting with a producer

trophic levels the position of an organism in a food chain

There are names for each trophic level of a food chain starting from the beginning:

- First trophic level = **producers**, made up of autotrophs.
- Second trophic level = consumers that are herbivores.
- Third and subsequent trophic levels = consumers that are carnivores.

Subject vocabulary

producer a photosynthetic organism that starts a food chain

exergonic energy releasing

Understanding: Energy released from carbon compounds by respiration is used in living organisms and converted to heat.

Some of the chemical energy from the plant and animal materials that are eaten is transferred to the organism that ate them. However, the process of transforming organic compounds into usable energy is not a very efficient process, and much of the energy is transformed into heat energy. In effect, cellular respiration is an **exergonic** reaction, a biochemical reaction that releases energy.

For example, a cow gets chemical energy from grass and the organic molecules from the grass can be used in cellular respiration in the cow. Cellular respiration generates heat, which is transferred to the environment around the cow.

Understanding: Living organisms cannot convert heat to other forms of energy.

The heat that is produced by living organisms enters the surrounding environment. Unlike light energy or chemical energy which can be useful to autotrophs, heat energy generated by cellular respiration cannot be absorbed and used by other life forms as a source of energy.

As a result, heat energy produced by living organisms is said to be lost. This means that it goes into the surrounding environment and cannot be converted into another useful source of energy by living organisms.

Understanding: Heat is lost from ecosystems.

Model sentence: Unlike minerals that can be recycled indefinitely, energy is constantly being lost from ecosystems and new energy needs to enter the system in order for it to continue.

The heat that is lost is not only considered to be unavailable for individual organisms, it is lost from the whole ecosystem. Heat will go into the water, soil, or the air and eventually will be released into space.

Again, as we have seen before, nutrients must be recycled because they are stuck within a closed cycle. Energy, on the other hand, is constantly leaving the biosphere in the form of lost heat. It cannot be recycled.

Fortunately, this is not a problem because new energy arrives every day in the form of sunlight.

Understanding: Energy losses between trophic levels restrict the length of food chains and the biomass of higher trophic levels.

Let us re-examine a food chain:

algae → mayfly larva → small fish → bigger fish → kingfisher → fox

Recall that the arrows represent the passage of chemical energy from one trophic level to the next.

At each passage of chemical energy, only about 10% of that energy is passed on. The vast majority of energy is lost due to various things:

- Heat from cellular respiration, as seen above.
- Some parts of organisms cannot be eaten.
- Some parts of food cannot be digested.
- Not all individuals in a population become food, some die without their organic molecules being passed on to the next trophic level.

This can be illustrated in an energy pyramid (see Skill).

Skill: Using pyramids of energy as quantitative representations of energy flow

Students should be able to draw a pyramid of energy based on numbers given. An example is below: the base of the pyramid shows the energy that producers require. The subsequent levels show the energy values for the consumers starting with the herbivores and the carnivores up to the top predator in the food chain concerned.

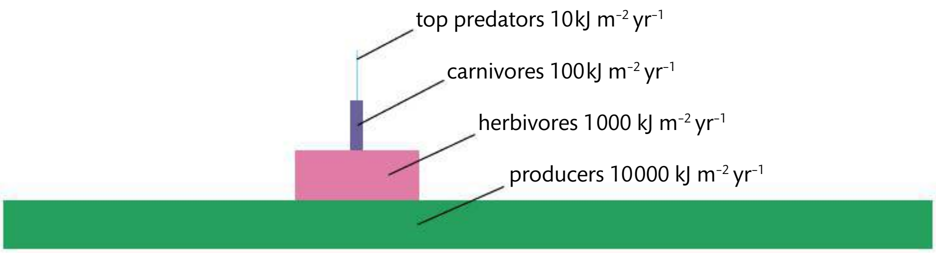


Figure 4.2 *A pyramid of energy showing a 90% loss of energy at each trophic level. Notice the units used are kilojoules of energy per metre squared per year*

4.3 Carbon cycling

Main idea

Continued availability of carbon in ecosystems depends on carbon cycling.

Nature of science: Making accurate, quantitative measurements – it is important to obtain reliable data on the concentration of carbon dioxide and methane in the atmosphere.

Understanding: Autotrophs convert carbon dioxide into carbohydrates and other carbon compounds.

Photosynthesis generates glucose. The carbon atoms found in glucose come from the CO_2 molecules they absorb. Autotrophs can convert some of the sugars they make into complex carbohydrates such as starch and cellulose.

Subject vocabulary

biomass the mass of all organisms of a particular category of organisms, e.g. the mass of all producers for a food chain

methane a biogas composed of carbon and hydrogen

General vocabulary

quantitative a numerical measurement

Understanding: In aquatic ecosystems carbon is present as dissolved carbon dioxide and hydrogen carbonate ions.

In **terrestrial** photosynthetic organisms, the CO_2 that is needed comes from the air.

In **aquatic** photosynthetic organisms, the CO_2 that is needed comes from carbon-rich substances in the water. The main sources are:

- carbon dioxide, which can dissolve in water, especially cold water
- **hydrogen carbonate ions** (written as HCO_3^-).

Understanding: Carbon dioxide diffuses from the atmosphere or water into autotrophs.

In the cells of terrestrial plants, as the CO_2 gets used up during photosynthesis, the concentration of this gas inside the cells of the autotroph decreases. This provides a **concentration gradient** allowing CO_2 to **diffuse** from the air to the cells.

Aquatic autotrophs can absorb the CO_2 from the water in order to build sugars using photosynthesis. Again, a concentration gradient forms with a low concentration inside the cells and a higher concentration outside the cells. Diffusion from outside the cell into the cell allows for the supply of CO_2 to the cell to be maintained.

Understanding: Carbon dioxide is produced by respiration and diffuses out of organisms into water or the atmosphere.

Some of the sugars that are produced by photosynthesis will be used to make ATP.

Cellular respiration produces CO_2 as a waste product. The build-up of CO_2 inside the cells creates a concentration gradient whereby there is a higher concentration of CO_2 inside the cell than outside. As a result, CO_2 will diffuse out of the cell and into the environment (surrounding air or water).

Understanding: Methane is produced from organic matter in anaerobic conditions by methanogenic archaeans and some diffuses into the atmosphere or **accumulates** in the ground.

Methane, CH_4, is an organic gas that is energy rich and highly **flammable**. It is called **natural gas** when used for industry or homes for heating or cooking. The blue flame of a Bunsen burner is made by methane.

Some microbes, notably certain **archaeans**, can produce CH_4 in **anaerobic** (oxygen free) conditions. One place such anaerobes live is inside the digestive tracts of animals. Cows, for example, host large colonies of anaerobic microbes in their guts.

General vocabulary

terrestrial living on land

aquatic living/growing in water

flammable burns easily

Subject vocabulary

hydrogen carbonate ions a negatively charged ion made of hydrogen, carbon, and three oxygen atoms

concentration gradient change in a chemical concentration between two areas

diffuse movement of a substance from an area of high concentration to an area of low concentration

natural gas methane found in petroleum deposits underground and used as fuel

archaeans members of the prokaryotic domain Archaea

anaerobic said of processes or organisms that do not require oxygen

Synonyms

accumulate .... build up

Understanding: Methane is oxidized to carbon dioxide and water in the atmosphere.

During combustion, methane, CH_4, combines with oxygen gas, O_2, from the atmosphere to yield water vapour, H_2O, and carbon dioxide gas CO_2.

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

This is an **oxidation reaction**. The reaction is accompanied by light energy and heat energy in the form of a blue flame.

Apart from O_2, all three of the other gases in this equation are considered greenhouse gases, meaning they can retain heat in Earth's atmosphere. More about these later.

Understanding: Peat forms when organic matter is not fully decomposed because of acidic and/or anaerobic conditions in waterlogged soils.

Soil is made of decomposed plant material mixed with water, inorganic minerals from rock particles and air.

When the amount of organic material in soil is high, the amount of chemical energy in it can be used as a fuel to burn.

One type of soil that has such properties is called **peat**. Peat is a dark, thick soil that forms in waterlogged areas. At least 30% of its dry mass is organic material.

The high water content of the soil prevents air from circulating and prevents decomposers from doing their work. As a result, many of the energy-rich organic molecules from the dead plant material in the soil do not get broken down.

Another effect of the high water content is that the soil becomes acidic. The high acidity levels also prevent soil organisms from decomposing. Decomposers are killed by the acidic conditions.

If peat is dug up and dried out, it can be burned as fuel. Humans in many different parts of the world have been using peat as a fuel source for generations.

Understanding: Partially decomposed organic matter from past geological eras was converted either into coal or into oil and gas that accumulate in **porous** rocks.

Coal or petroleum products, such as **crude oil** or natural gas, take millions of years to form.

All of these fuel sources, otherwise called **fossil fuels** (because of their ancient once-living origins), **originated** from photosynthetic organisms.

Just like with peat, wet **sediments** of partially decomposed photosynthetic organisms accumulated in certain regions of the world. In anaerobic conditions, full decomposition was not possible so many energy-rich compounds remained in the layers.

Subject vocabulary

oxidation reaction a chemical reaction in which electrons are lost

peat an accumulation of partially decayed plants found in wet areas that can be dried and used as a fuel

coal an organic hard, black rock formed deep below the earth from fossil remains and used as a carbon-based fuel

crude oil a thick, black petroleum-based liquid which is formed deep underground from fossilized material and which can be used to make fuels and plastics

fossil fuels a non-renewable fuel source formed by the compression of plant and animal materials in the Earth's crust over millions of years

sediments matter deposited by wind or water that has settled in an area, often forming layers

General vocabulary

porous having many small holes that liquids can slowly pass through

Synonyms

originated (from) started/ came (from)

These layers accumulated and were packed down over long stretches of geological time. The layers were pushed underground under the weight of new layers and water was squeezed out. Heat and high pressure caused molecules to rearrange and form long chains of **hydrocarbons**.

These hydrocarbon chains are rich in energy and that is what makes them valuable fuels. Remember that the more bonds an organic molecule has, the richer it is in chemical energy.

Coal is formed deep below the surface and needs to be mined from underground.

Crude oil accumulates in domes formed when porous rock layers fold due to the movements of the **crust**. Oil companies search for these deposits and drill down into the earth to pump them out.

Since gas is less dense than liquid, natural gas can accumulate above the crude oil deposits. These are also drilled for and extracted.

Fossil fuels are called **non-renewable energy** sources because once we burn them all they are gone. It is unrealistic to consider using them on a long-term basis because it takes too long for new ones to form.

Subject vocabulary

hydrocarbons organic molecules made of carbon, hydrogen, and oxygen atoms

crust the Earth's hard outer layer

non-renewable energy energy from resources, such as fossil fuels, that cannot be replaced

fermentation process where sugar is changed to alcohol

biofuels a renewable fuel resource usually based on plants or waste materials

renewable resource molecules used by humans that are able to be regenerated or recycled on a long-term basis

Understanding: Carbon dioxide is produced by the combustion of biomass and fossilized organic matter.

As we saw with the methane equation, when organic substances are burned in oxygen gas, carbon dioxide is released as a waste product.

Such is the case every time we burn fossil fuels for cooking, heating, or transportation. The human activity that produces the most carbon dioxide in the world is transportation: cars, trucks, airplanes, and ships that burn fossil fuels.

There are some sources of organic fuel that can be considered renewable. Two examples are methane, produced by biomass, and ethanol, produced by the **fermentation** of plant material.

Biomass in the context of fuel refers to things such as farm waste in the form of animal waste or plant material that cannot be eaten. Such materials are placed in a large container and special microbes (including archaeans that produce methane gas as a waste product) transform the organic material into useful fuel.

Some countries in the world, such as Brazil and the United States, have reduced their dependence on fossil fuels by mixing gasoline for cars and buses with ethanol made from the fermentation of crops such as corn.

The idea is that uneaten corn is still an energy-rich substance but not rich enough to be used as fuel. By fermenting the corn and extracting the ethanol that results from fermentation, the alcohol is rich enough in energy to be useful in combustion engines.

Biofuels are considered a **renewable resource** because the plants that provide the raw materials can be grown in a few months.

Understanding: Animals such as reef-building corals and **Mollusca** have hard parts that are composed of calcium carbonate and can become fossilized in limestone.

Photosynthesis is not the only way organisms pull carbon out of the environment. Reef builders or molluscs use a carbon compound called calcium carbonate to make shells or other body parts.

Coral reefs are made from **calcium carbonate**, $CaCO_3$. Coral polyps, the organisms that build reefs in the ocean, use two dissolved ions found in seawater to make the calcium carbonate:

$$Ca^{2+} + 2\ HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

The first ion is dissolved calcium, Ca^{2+}, the second should be familiar to you from earlier in this chapter: hydrogen carbonate, HCO_3^-. As shown in the equation, the two types of ions are combined to yield calcium carbonate, carbon dioxide gas, and water.

Calcium carbonate has chemical properties that make it as hard as rock. The coral polyps secrete it to build up the reef.

Other organisms, such as snails and clams, use calcium carbonate to make shells. Since it is a strong solid, it is a good protection.

Limestone, a rock often used by humans as a building material (such as the Ancient Egyptian pyramids or Notre Dame Cathedral in Paris), is full of fossil shells. These shells, often made by molluscs such as bivalves (i.e. clams, mussels, or oysters) are sometimes visible in stone steps and building facades made of limestone.

Model sentence: The carbon cycle shows how carbon atoms are recycled on Earth from photosynthesis to cellular respiration or burning of fossil fuels.

Skill: Construct a diagram of the carbon cycle

A diagram showing the various chemical reactions in which carbon plays a role, such as photosynthesis or cellular respiration, can be used to represent the **carbon cycle**.

Practise drawing the diagram opposite and fill in the following missing terms: carbon in decomposers, carbon in the atmosphere, carbon in producers, carbon in fossil fuels, carbon in consumers.[1]

Application: Estimation of carbon fluxes due to processes in the carbon cycle

Climatologists are interested in how the carbon cycle works and in the ways in which humans are changing the carbon cycle.

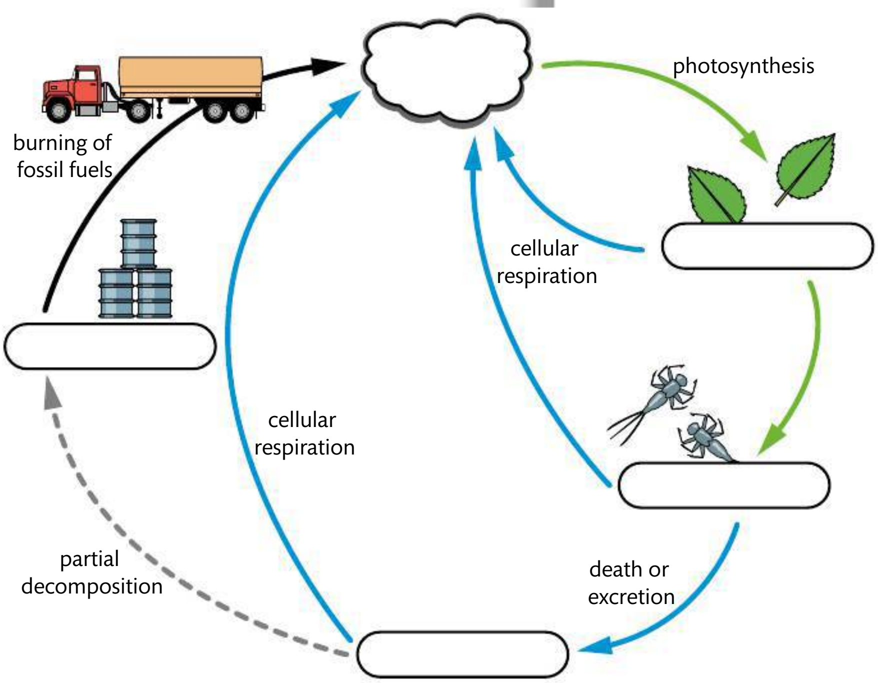


Figure 4.3 *The carbon cycle*

Subject vocabulary

Mollusca/mollusks land/sea animals with a soft body and hard shell

calcium carbonate ($CaCO_3$) a chemical used by organisms to make hard structures such as shells and reef-forming corals

carbon cycle the way carbon atoms circulate through the environment

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[1] Answers: clockwise from the top: carbon in the atmosphere, carbon in producers, carbon in consumers, carbon in decomposers, carbon in fossil fuels

One way to study this is to measure and monitor carbon dioxide levels in the atmosphere and oceans and to estimate the amounts of carbon in each part of the carbon cycle.

When carbon changes from one place to another, such as going from the atmosphere to being dissolved in the ocean, this change is called a **flux**.

Carbon fluxes are measured or estimated in **gigatons of carbon per year**, GtC yr^{-1}.

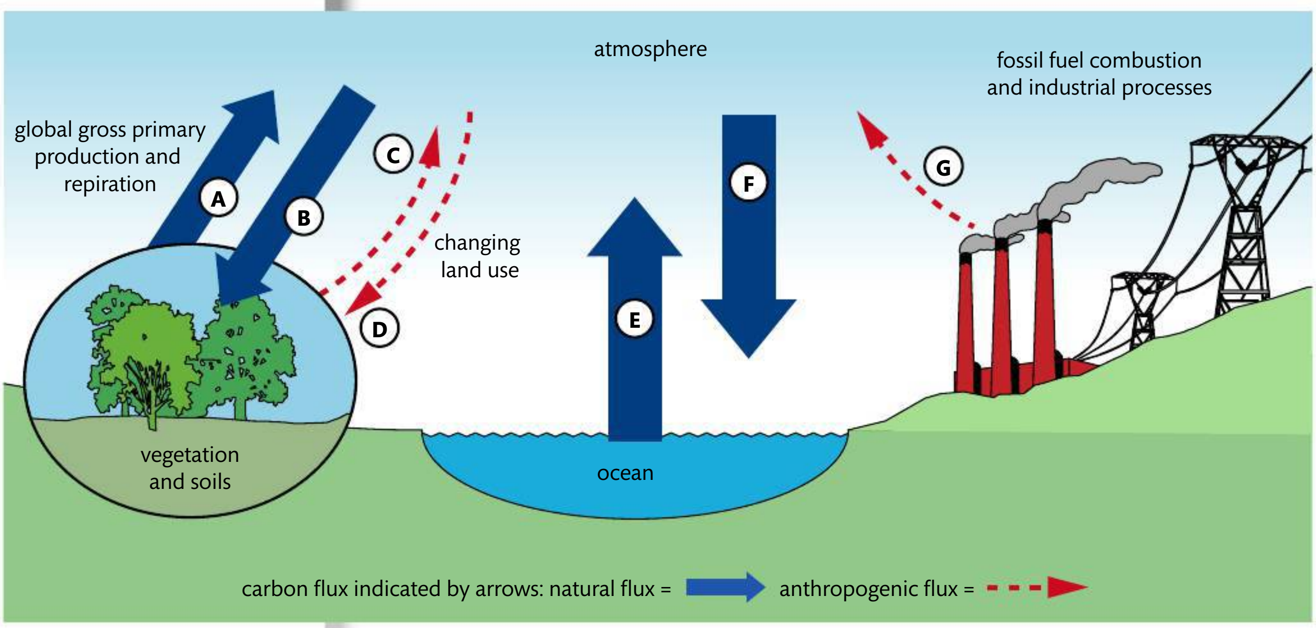
Subject vocabulary

flux the process of flowing from one place to another

gigatons of carbon per year unit of measurement of carbon fluxes

Carbon fluxes	Quantity of carbon (GtC yr^{-1})
Examples of fluxes into the atmosphere	
respiration of terrestrial organisms	120
respiration of marine organisms at the surface of the ocean	92
burning of fossil fuels (such as transport)	7.7
changes in land use (such as deforestation)	1.5
Examples of fluxes out of the atmosphere	
absorption of carbon dioxide into the water at the surface of the ocean	90
gross primary production (GPP), photosynthesis of terrestrial organisms	90
photosynthesis of marine organisms	40
changes in land use (such as growing crops in prairies)	0.5
weathering, carbon dioxide being incorporated into rocks and soils	0.2

In the diagram below replace the letters with the numbers from the table. Note: the last item in the table is not shown in the diagram.[1]



Source: adapted from NOAA Earth System Research Laboratory

Figure 4.4 *Carbon fluxes into and out of the atmosphere*

[1] Answers: A = 120, B = 90, C = 1.5, D = 0.5, E = 92, F = 90, G = 7.7. All units are GtC yr^{-1}.

Application: Analysis of data from air monitoring stations to explain annual fluctuations

The graph below shows measurements made by climatologists concerning atmospheric carbon dioxide from the beginning of 2011 to the first quarter of 2015. You could probably find a more recent one at the NOAA website.

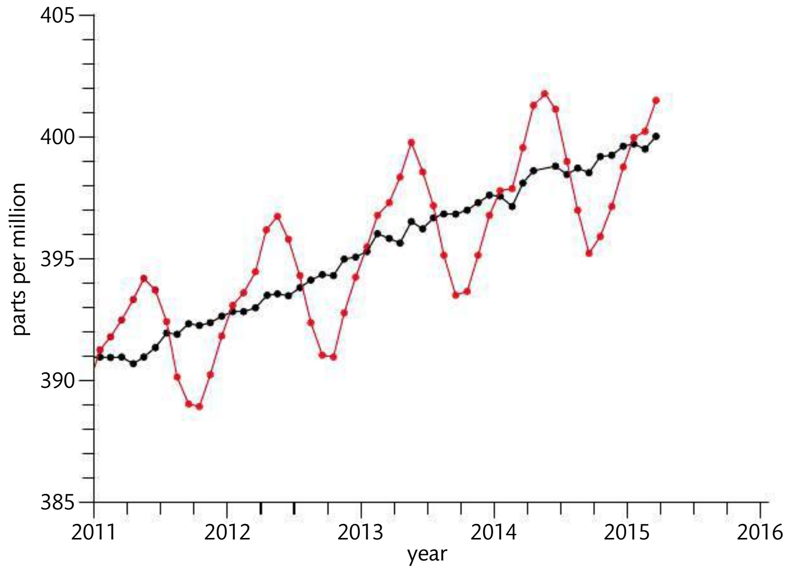


Figure 4.5 *Recent monthly CO_2 at Mauna Loa in the northern hemisphere. The red line shows direct measurements and the black line shows the average for each season*

Analysis of this graph:

- The red line **fluctuates** from season to season.
- In the coldest months of year in the northern hemisphere (January, February, March), the graph is increasing.
- In the warmest months of the year (July, August, September), the graph is decreasing.
- The cause of the seasonal increase in atmospheric carbon dioxide is due to the reduction of photosynthetic activity in the northern hemisphere in winter.
- The cause of the seasonal decrease in atmospheric carbon dioxide is due to the increase in photosynthetic activity during the summer. In effect, carbon dioxide is removed from the air by photosynthetic bacteria, phytoplankton, plants, algae, and trees during the warmer months of the year.
- The black line shows the average which has been corrected for these seasonal changes.
- This part of the graph shows an increase from 391 ppm (parts per million) at the beginning of 2011 to 400 ppm at the end of March 2015.
- That's a 2.3% increase in this 51 month period.
- As a percentage, 391 ppm is 0.00391%.

General vocabulary

fluctuate move back and forth

4.4 Climate change

Main idea

Concentrations of gases in the atmosphere affect climates experienced at the Earth's surface.

Nature of science: **Assessing claims – assessment of the claims that human activities are producing climate change.**

Understanding: Carbon dioxide and water vapour are the most significant greenhouse gases.

Subject vocabulary

greenhouse effect atmospheric trapping of heat that helps to maintain Earth's temperature

greenhouse gases gases, such as carbon dioxide, in the atmosphere that contribute to the greenhouse effect

Synonyms

phenomenon . event/happening

The **greenhouse effect** is a naturally occurring **phenomenon** in Earth's atmosphere. It helps the planet maintain a temperature that provides ideal conditions for life as we know it.

Like a glass greenhouse for growing plants, Earth is surrounded by a transparent material that lets light in, but prevents too much heat from escaping. A greenhouse uses glass or plastic, whereas Earth uses its atmosphere.

We will see later in this section how, in recent decades, certain human activities have changed the composition of the atmosphere and altered the greenhouse effect.

Many gases in the atmosphere contribute to the greenhouse effect, but two have the biggest effect:

- carbon dioxide
- water vapour.

Gases that contribute to the warming effect of the atmosphere are called **greenhouse gases**, GHGs.

Understanding: Other gases including methane and nitrogen oxides have less impact.

A gas's ability to contribute to the greenhouse effect depends on several factors including:

- the concentration of the gas in the atmosphere
- its ability to retain heat
- how long it stays in the atmosphere.

Gases such as methane and nitrous oxides are also GHGs that have an effect on global climate change. However, they contribute less to the greenhouse effect than carbon dioxide. We will find out why next.

Understanding: The impact of a gas depends on its ability to absorb long-wave radiation as well as on its concentration in the atmosphere.

Methane does not stay in the atmosphere as long as other GHGs because it tends to react with other substances present in the atmosphere and be transformed.

In addition, methane is much less concentrated in the atmosphere (approximately 1700 parts per billion, ppb) than gases such as carbon dioxide (400 000 ppb).

With an ability to retain heat 100 times stronger than that of carbon dioxide, **nitrous oxides** might be considered to have a major impact on the greenhouse effect. Instead, since they are present in very small quantities (320 ppb), they are not as much of a worry as carbon dioxide, which is present in concentrations 1000 times that of oxides of nitrogen. One characteristic of nitrous oxides is that they can stay in the atmosphere for a long time.

Scientists focus on the kinds of GHGs that are not only present in larger concentrations but can also stay longer in the atmosphere. These are two of the main reasons carbon dioxide gets the most attention.

Water vapour is an important GHG but we are not seeing the same kinds of dramatic fluctuations in its concentration in the atmosphere that we are seeing in carbon dioxide's concentrations.

Understanding: The warmed Earth **emits** longer wavelength radiation (heat).

As we have seen, energy arrives on Earth in the form of sunlight. Some of that light bounces off the surface and back into space.

On the electromagnetic spectrum, light waves have a relatively short wavelength.

The gases in the atmosphere are transparent to light waves – they have no way of trapping light waves and storing their energy.

Some of the light energy from the sunlight hitting Earth, however, is transformed into heat. Heat has longer wavelengths than light and therefore has different properties concerning **visibility** and temperature, to name just two.

The idea of transformation from short-wave energy to long-wave energy is a key concept in understanding the greenhouse effect. You have experienced such a transformation when you wear dark-coloured clothing on a sunny day or when a car is parked in the sunshine with the windows closed and it warms up inside.

Model sentence: Energy arrives on Earth as short-wave light energy and some of that energy is converted to long-wave heat energy which can remain trapped in greenhouse gases in the atmosphere.

Understanding: Longer wave radiation is absorbed by greenhouse gases that retain the heat in the atmosphere.

One property of heat energy that makes it different from sunlight is that, unlike light, heat can be trapped and stored by GHGs.

As the heat from Earth's surface (rocks, water, vegetation) radiates upwards, it warms up certain gases in the atmosphere: water vapour, carbon dioxide, methane, and nitrous oxides (the GHGs).

This is another key step in understanding the greenhouse effect: GHGs trap some heat before they escape to space.

This is what helps keep Earth's surface warm even at night when there is no more sunlight.

Subject vocabulary

nitrous oxides greenhouse gases formed from nitrogen and oxygen with the general formula NO_x

visibility ability to be seen

General vocabulary

emits sends out

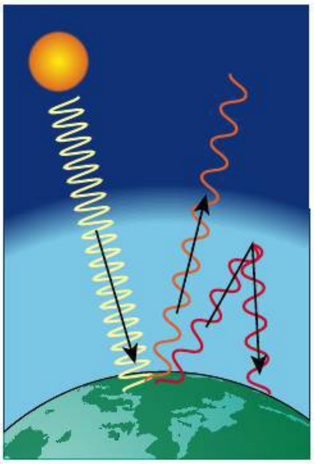


Figure 4.6 *A summary of the greenhouse effect: short-wave radiation (shown in yellow) hits the surface and some is converted into long-wave radiation (shown in orange). Some of this infrared heat escapes into space but some (shown in red) is radiated back by greenhouse gases*

Hints for success: The greenhouse effect is not a simple phenomenon to explain. To be able to explain the step-by-step process on an exam, be sure to take time to practise with drawings and text or try to explain it to a friend or family member. Remember: be concise and precise.

Understanding: Global temperatures and climate patterns are influenced by concentrations of greenhouse gases.

Subject vocabulary

correlation relationship between two occurrences

causality that one event is a direct result of another

climate the long-term pattern of weather (temperature, precipitation, and winds) of a region

proxy an indirect measurement or estimation

There is a direct **correlation** (and **causality**) that is observable in the concentrations of GHGs and global temperatures and climate.

Climate refers to long-term changes in temperature, rainfall, and cloud cover. It can be thought of as being similar to weather except instead of being on a scale of hours or days the way weather is, climate is on a scale of decades, centuries, or even millennia.

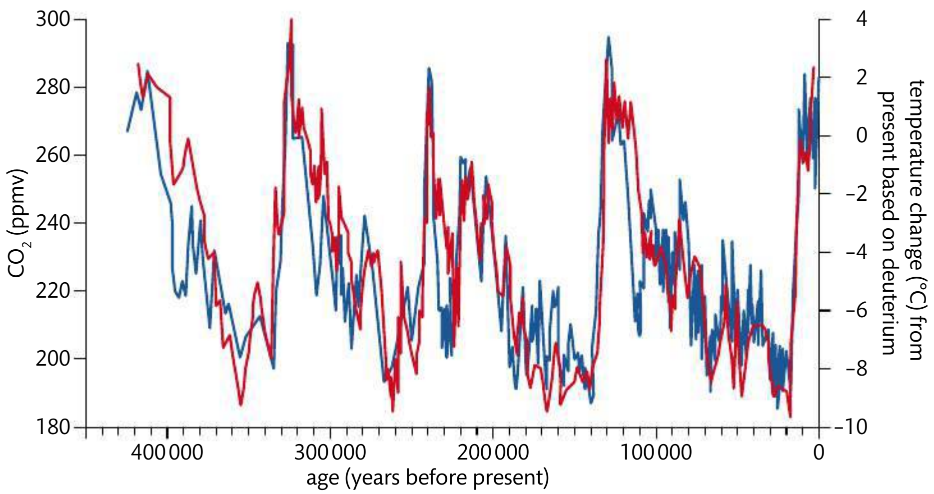
Climatologists study climate and try to understand how it works. When they look at changes in concentrations of GHGs they see that the gases can influence the kinds of climate found.

For example, sampling deeply buried layers of ice that trapped air bubbles in the past, makes it possible to measure the concentrations of gases such as CO_2 going back thousands, tens of thousands or even hundreds of thousands of years.

Analyses of these ice cores reveal interesting patterns. The colder periods correspond to the times when there were the lowest concentrations of GHGs such as CO_2. The hottest periods of Earth's past correspond with the highest concentrations of CO_2 in the atmosphere.

Getting measurements from sources such as ice cores is an example of measurement by **proxy**. Proxies are used when direct measurements are not possible.

Application: Correlations between global temperatures and carbon dioxide concentrations on Earth



Source: NOAA National Climatic Data Center

Figure 4.7 *Atmospheric CO_2 levels and atmospheric temperatures over the last 400 000 years show a correlation*

This graph from the National Oceanographic and Atmospheric Administration (NOAA) shows data going back more than 400 thousand years and was made from proxy data gained from ice core samples.

Temperature change (°C) compared to modern temperature is in blue and CO_2 levels (ppm) are in red.

The graph shows that, in general, as CO_2 levels go down, temperatures decrease, and as CO_2 levels increase, temperature increases.

This graph is mostly for palaeo (ancient) data. Current CO_2 levels are closer to 400 ppm, which would be distinctly above the line shown in the graph.

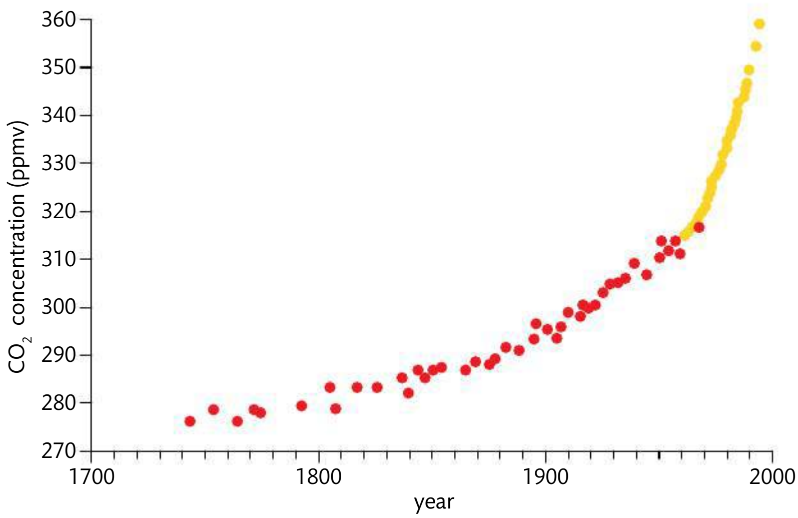
Understanding: There is a correlation between rising atmospheric concentrations of carbon dioxide since the start of the industrial revolution 200 years ago and average global temperatures.

The industrial revolution, which began in the 1800s, brought with it great advances in machinery but increased society's need for a fuel supply to keep the machines running.

Coal was a main source of fuel for many decades but little by little, other fossil fuels were exploited as well, including petroleum products, such as crude oil and natural gas (methane).

The burning of these fossil fuels produces CO_2 as a waste product. Colourless and **odourless**, CO_2 was thought for a long time to be harmless.

In recent decades, climatologists have collected enough data worldwide to see that CO_2 levels have been increasing for the last 200 years and these increases coincide with two things: increased industrialization and increases in global temperatures. In other words, there is a clear correlation between human activities such as burning fossil fuels and an increase in CO_2 levels on Earth.



Source: US Geological Survey

Figure 4.8 *Graph from the US Geological Society showing CO_2 concentrations in the atmosphere in ppmv (parts per million by volume)*

The red data points are from indirect measurements (proxy data) and the yellow points are direct measurements.

This intensification of Earth's natural greenhouse effect is called the **runaway greenhouse effect** and it causes the temperature of the atmosphere to increase.

Hints for success: Sometimes students as well as adults confuse the problem of a runaway greenhouse effect with another environmental problem: the thinning of the ozone layer. Although both are caused by human pollution, they are not the same thing. Avoid wasting time explaining the ozone layer – it is off topic for this section.

General vocabulary

odourless having no smell

Subject vocabulary

runaway greenhouse effect increasing global temperature rise due to the release by human activity of high levels of greenhouse gases into the atmosphere

Understanding: Recent increases in atmospheric carbon dioxide are largely due to increases in the combustion of fossilized organic matter.

These three increases (industrialization, burning of fossil fuel, and CO_2 levels in the atmosphere) have a connection and are more than just correlations. There is a causality, and the workings explaining the causality are explained in the following way by climatologists:

- Increased use of combustion engines for industry and transportation in recent decades has increased the consumption of fossil fuels.
- When fossil fuels are burned, CO_2 is released into the atmosphere. This explains the increase in atmospheric concentrations of CO_2 in recent decades.
- The higher CO_2 concentrations in the atmosphere are causing **climate change** as seen in increased temperatures in many parts of the world, more **drought**, more extreme weather such as severe storms, and rising sea levels.
- Statistical analysis of the data shows that climatologists are 95% sure that the atmospheric changes and therefore climate change is due to human activity rather than due to natural fluctuations.

Model sentence: The increase in the levels of atmospheric carbon dioxide from about 270 ppm before the industrial revolution to about 400 ppm today are due to human activities such as the burning of fossil fuels and deforestation.

Subject vocabulary

climate change an alteration of the weather patterns experienced in a region

coral reef bleaching the death of a coral reef due to the surrounding water becoming more acidic

General vocabulary

drought shortage of water due to dry weather

Application: Threats to coral reefs from increasing concentrations of dissolved carbon dioxide

Coral polyps, the organisms that make reefs in the ocean, are sensitive to changes in the water that surrounds them, notably the pH.

The increase of CO_2 in the atmosphere causes a concentration gradient to form between the air and the oceans, and CO_2 diffuses into the water. When water absorbs CO_2, it becomes more acidic due to the formation of carbonic acid.

If the pH of the water goes too low, it kills the coral polyps and the reef dies.

Coral reefs support a rich concentration of communities and killing them has similar consequences to deforestation of tropical rainforests – once the habitat is gone, the other organisms are no longer supported.

When reefs die, their rich colours are lost and they turn white as bone – this process is called **coral reef bleaching** and it is happening in many places all over the world at alarming rates.

Application: Evaluating claims that human activities are not causing climate change

Critics of climate change, sometimes referred to as climate change deniers or doubters, challenge the climatologists' view that humans are causing climate change.

You are expected to be able to evaluate statements such as the ones in the following list. To evaluate in this context means to judge their validity by weighing the 'for' arguments and the 'against' arguments.

Climate change critics' claims: true or false?

- **Claim 1:** Yes, the climate is changing now but it always has in the past and will continue to do so – it's a natural phenomenon and is not due to human activity.
- Counterclaim to explore: Have the changes ever happened this fast?
- **Claim 2:** There is a lot of disagreement in the scientific community – many scientists do not agree with the idea that climate change is caused by humans and can explain it in other ways such as measuring the increased output of the Sun.
- Counterclaim to explore: in recent decades, how many studies by climatologists have been published supporting the idea that climate change due to human activity is not true?
- **Claim 3:** Warmer temperatures have been due to higher solar output – it's the Sun's fault, not ours.
- Counterclaim to explore: How does the trend in solar energy output over the past 200 years compare with that of the last few decades?
- **Claim 4:** Tackling climate change would require reducing carbon emissions and that would ruin the economy. Besides, we don't have realistic alternative solutions to fossil fuels.
- Counterclaim to explore: many sustainable energy sources can be implemented to reduce carbon emissions – what role does politics play in encouraging or discouraging these technologies?

One way to evaluate the claims is to see if they are based on evidence or based on belief. Also, are the criticisms driven by economic or political concerns rather than scientific evidence?

5.1 Evidence for evolution

Main idea

There is overwhelming evidence for the evolution of life on Earth.

Nature of science: Looking for patterns, trends, and discrepancies – there are common features in the bone structure of vertebrate limbs despite their varied use.

Synonyms

discrepancies . differences/ inconsistencies

Subject vocabulary

vertebrate living creature with a backbone

limb arm or leg

heritable a genetic trait which can be passed on to offspring

theory of evolution by natural selection idea that the frequency of characteristics in a population changes due to the survival advantage they give an individual that has those traits

evolution cumulative change in the heritable characteristics of a population

allele version of a gene, differing by one or more bases

fossils petrified remains of plants or animals

extinct no longer existing

General vocabulary

cumulative gradually increasing

burrows holes

Understanding: Evolution occurs when heritable characteristics of a species change.

Model sentence: Evolution is the process of cumulative change in the heritable characteristics of a population and the process by which evolution happens is natural selection.

Charles Darwin and Alfred Russell Wallace presented the **theory of evolution by natural selection** in 1858.

Evolution is the process of cumulative change in the heritable characteristics of a population. The characteristics referred to here are genetic ones (coded in DNA).

When the combinations of **alleles** present in a population change over time, we say the population is evolving. Evolution within a population often occurs when the population's environment changes.

Understanding: The fossil record provides evidence for evolution.

Fossils are traces of parts of organisms (bones or leaf imprints) or their activities (footprints or **burrows**) left in layers of rock.

When palaeontologists dig up fossils, they try to determine the age of the fossil and the type of organism that made it.

When fossils are arranged by age, some clear patterns emerge:

- Most of the history of life on Earth was in the oceans in the form of single-celled organisms.
- Life existed on land starting about 475 million years ago (meaning that over 90% of the time that life was on Earth, it was only in the oceans).
- Life only evolved hard parts (such as shells) starting about 500 million years ago.
- Living things that are familiar to us today are relatively recent in evolutionary or geological time – such as the first flowers 130 million years ago or the first songbirds 55 million years ago. These seem like ancient events but 130 million years represents less than 4% of the existence of life on Earth.
- The majority of all species that ever inhabited Earth are **extinct**, such as the trilobites or stegosaurs – it is difficult to quantify, but the percentage of life forms that have gone extinct is much greater than 99.99%.

We can conclude that life forms are constantly changing due to evolution. We are living on a planet where staying the same is not a long-term option for most species.

Understanding: Selective breeding of domesticated animals shows that artificial selection can cause evolution.

A way to see evolution on a more familiar time scale is to look at the breeding of domesticated animals. Domesticated animals such as farm animals are produced using a process called selective breeding.

To obtain animals with the most wanted traits, farmers often do not let nature decide which males will breed with which females. The farmer chooses animals that will give offspring that possess the traits chosen by the farmer.

If a cattle farmer sees that certain individuals in the herd are more resistant to disease, those cows will be chosen for reproduction. The same can be said for milk production or body shape. Having a straight back, for example, instead of a curved back makes birthing less problematic for cows, and having longer legs makes it easier for mechanical pumps to be placed under the cow for milking.

Racing dogs, such as greyhounds, have been bred to have very long legs and thin, streamlined bodies. Like all domestic dogs, these dogs never existed in nature. They are a product of human intervention called artificial selection in the form of selective breeding.

The following are examples of animals that are in the form they are in today thanks to artificial selection: cows, sheep, pigs, chickens, camels, llamas, turkeys, and alpaca.

Understanding: Evolution of homologous structures by adaptive radiation explains similarities in structure when there are differences in function.

Model sentence: **Homologous structures in different species such as the pentadacyl limb seen in bats, whales, and humans are evidence that these species had a common ancestor.**

Homologous structures are anatomical features of organisms that show a similar structure but do not necessarily have a similar function.

Example: the pentadactyl limb

The forelimbs of many animals show the following pattern starting from the body and moving outwards – one bone, two bones, many bones, five articulated digits.

Humans have this pattern in their arms: one bone (the humerus in the upper arm), two bones (the ulna and radius in the forearm), many bones (the carpals in the wrist), and five bony articulated digits (metacarpals and phalanges in the fingers).

Bats have this pattern in their wings, dolphins in their fins, and horses used to have it but they lost all but one digit on each limb.

Notice how the anatomy shows a similar structure but the functions are different: flight for bats, swimming for dolphins, and running for horses.

The name for an arm or leg that ends in five digits is a pentadactyl limb. 'Penta' means five and 'dactyl' means digit or finger.

Evolution explains this with two ideas: speciation and adaptive radiation.

Adaptive radiation is the evolution of many different species from one species or a small number of species.

Subject vocabulary

selective breeding choosing organisms with particular traits to reproduce so that their offspring share these traits

artificial selection selective breeding for particular traits

homologous structures structures which have similar genetic and structural origin that now show obvious differences

anatomical relating to the structure of the body

forelimbs front limbs (arms, legs, or flippers) of an animal

articulated jointed

pentadactyl limb an arm or leg with five jointed digits

adaptive radiation the emergence of many diverse species from a single or small number of species

Synonyms

offspring........ young/children

digits............. finger

It is hypothesized that some of the first animals to crawl onto land from the sea were quadrupeds (four-legged). They had a new habitat unoccupied by no other **terrestrial** animals except insects.

These animals had pentadactyl limbs.

With no pre-existing competition, they were able to spread out and occupy a wide range of habitats. Each habitat had a slightly different influence on which alleles were favoured.

Over hundreds of millions of years of evolution by natural selection, organisms with pentadactyl limbs have **colonized** vast territories and become many different species that occupy the land (both over- and underground), the trees, the skies, and the waters. In effect, some pentadactyl land creatures have returned to the oceans as marine mammals – whales and dolphins are two examples.

Understanding: Populations of a species can gradually **diverge** into separate species by evolution.

Model sentence: When a population evolves in a different way to other members of the species to an extent that it can no longer produce fertile offspring with members of the original population, a speciation has occurred, meaning that a new species has evolved.

When two populations of a similar species evolve in different ways, sometimes enough differences have **accumulated** over time to make it impossible for members of the two populations to interbreed anymore. When this happens, we say that **speciation** has occurred.

Example: speciation as seen in Darwin's finches

When Charles Darwin studied birds in South America, notably finches in the Galapagos Islands, he proposed that the similarities in the birds suggested a common ancestor. And yet, the birds were different enough to constitute different species.

The 13 species of finches must have come from one species that arrived on the islands long ago. As the birds spread out over the islands, different populations adapted to different habitats. With little competition and no **predators**, the process of adaptive radiation can happen relatively quickly.

Finch populations that had larger beaks were better adapted for eating seeds, whereas those that ate insects were more successful if they had finer, more pointed beaks. If the two populations tried to mate today, fertile offspring would not be produced. Some **hybrids** might arise but, generally speaking, if they are separate species, they should not be able to produce offspring. When fertile offspring cannot be produced, we say that speciation has occurred separating two groups that once had a common ancestor. The same can be said for all 13 species of Darwin's finches.

General vocabulary

terrestrial living on land

colonized moved into a new geographical area

diverge develop in different ways so they are no longer similar

Subject vocabulary

fertile capable of reproducing

speciation process by which one species splits into two species which can no longer interbreed

predator an organism that hunts and eats other organisms

hybrid something that has the properties of two things

Synonyms

accumulated .. built up

Understanding: Continuous variation across the geographical range of related populations matches the concept of gradual divergence.

How fast does evolution happen? There are two main theories: gradualism and punctuated equilibrium.

- The theory of **punctuated equilibrium** states that populations do not evolve much over long stretches of time and then suddenly, due to a significant change in their environment, they evolve quickly over a short period.
- The theory of **gradualism** states that evolution is a steady, slow, ongoing process with no sudden changes in populations.

If major differences were found between closely related species across a geographical area, this would suggest that speciations are sudden and dramatic. If, on the other hand, the variations change by small **increments** from one geographical area to another, this would give credibility to the gradualism theory.

For example, various species of conifer trees can be found ranging from warmer climates in southern China and Japan all the way up to the much colder climates near the Arctic Circle in Siberia, with **incremental** changes in tolerances to colder temperatures as the geographical range stretches northward. This gives credibility to the idea of gradual change over long periods of time as conifer species spread out to colonize different zones.

Application: Development of melanistic insects in polluted areas

Different degrees of **pigmentation** can exist in organisms, from total lack of pigmentation (white) to extreme pigmentation (black). Genes determine the degree of pigmentation, although the environment can sometimes have an influence. When individuals possess unusually dark pigmentation, it is called **melanism**. The ability of a species to have more than one appearance is called **polymorphism**.

One insect has shown some remarkable changes in the frequency of dark and light members of its population: the peppered moth in England.

During the industrial revolution, the percentage of all-black moths was high, and when the soot and smoke were removed from the air in the 1950s, the number of melanistic moths dropped significantly and the lighter-coloured moths were seen in high percentages again.

This can be explained in the following way:

- Thrushes are birds that eat moths. When they see a dark-coloured moth on a light background such as a clean tree branch, they eat it.
- This **predator**/**prey** relationship keeps the number of dark-coloured moths low in the population.
- In the 1800s, soot and smoke from the industrial revolution darkened many surfaces, making tree branches and trunks near cities dark in colour.
- This allowed the dark moths to hide well and made it easier for birds to see the light-coloured moths.
- During the industrial revolution, the light-coloured moths were seen against the darker background and eaten, so they did not pass on their genes to the next generation. This caused a change in the population: unusually high numbers of dark-coloured moths were present. This **phenomenon** is called **industrial melanism**.
- Their numbers stayed low until the Clean Air Act removed smoke and soot from the air and trees. Now the dark-coloured moths are low in number.

Subject vocabulary

punctuated equilibrium evolution by big jumps with periods of no change in between

gradualism evolution by slow, continuous small changes

pigmentation pattern of coloration

melanism dark colouring

polymorphism having several different forms

predator an organism that hunts and eats other organisms

prey animal that is food for another animal

industrial melanism production of dark-coloured form of organism, well camouflaged in areas polluted with soot

General vocabulary

increments gradual and regular increases

incremental increasing in gradual and regular amounts

Synonyms

phenomenon . event/happening

Application: Comparison of the pentadactyl limb of mammals, birds, amphibians, and reptiles with different methods of locomotion

The **pentadactyl limb** as the 'ancestral' terrestrial vertebrate's limb plan, subsequently adapted by modification for different uses/habitats.

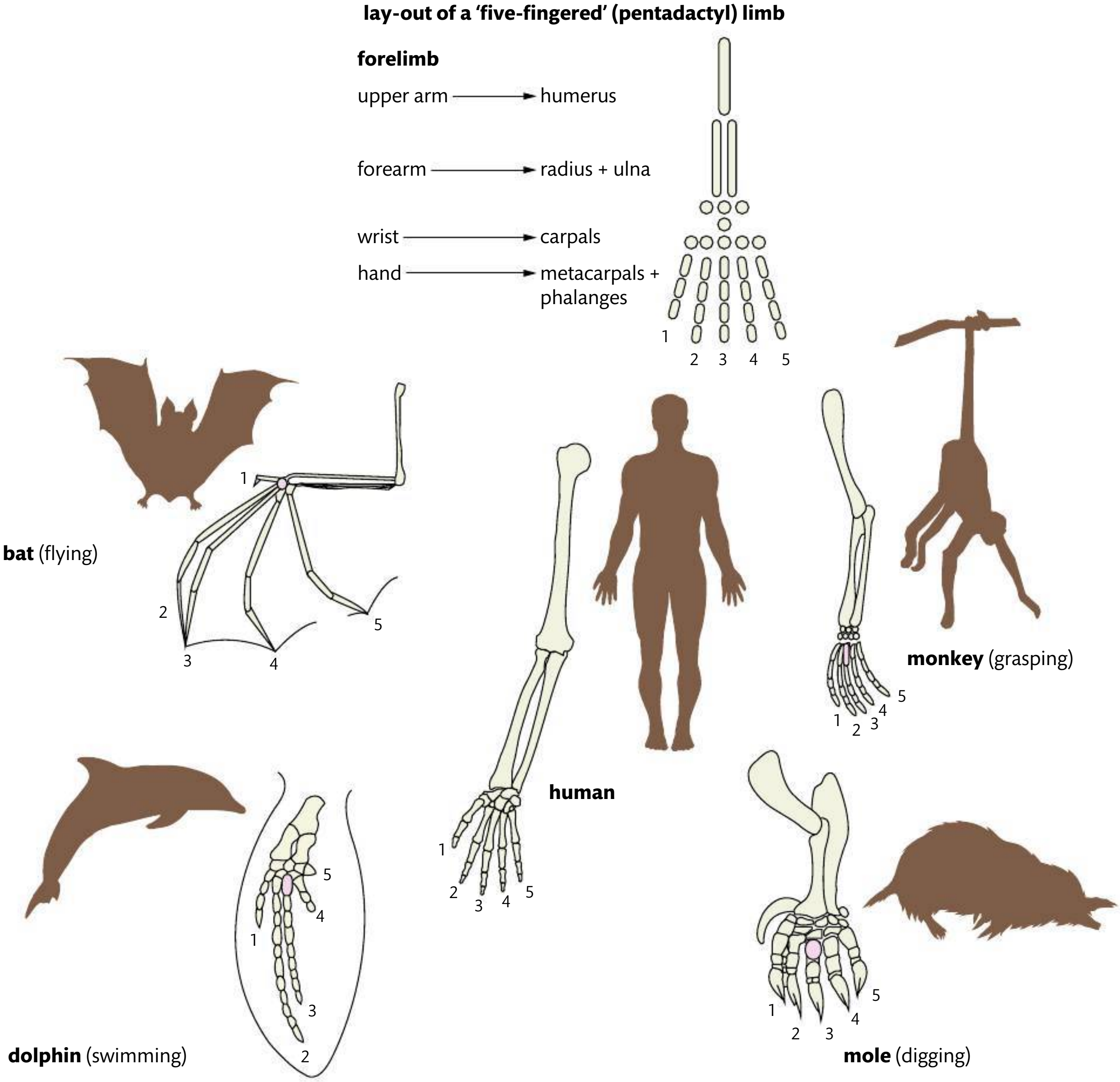


Figure 5.1 *Similarities in pentadactyl limbs are used as evidence of common ancestry*

Compare each of these organisms and identify what they do with their pentadactyl forelimbs. Which pentadactyl limbs are for swimming, flying, **grasping**?

General vocabulary

grasping holding something firmly

5.2 Natural selection

Main idea

Natural selection explains how life on Earth has become so **diverse** and how it continues to evolve.

Understanding: Natural selection can only occur if there is variation among members of the same species.

Model sentence: Natural selection is a theory to explain evolution through three main aspects: (1) overproduction of offspring that show variety, (2) a struggle for survival, and (3) the best-adapted organisms passing on their genes to the next generation.

If all the organisms in a species are identical, the species only has two options: survive or die out. It is better to have variation in the population so that some organisms survive even if others die. If and when the species' environment changes, variety in the population will help it to adapt to the changes.

Understanding: Mutation, meiosis, and sexual reproduction cause variation between individuals in a species.

There are three main sources of the variation found in a population:

1. Mutations – small changes in the genetic sequence can lead to changes in genetic traits. Mutations do not happen frequently. Examples of results of new variations that could be generated by such changes are better frost resistance in plants, changes in pigmentation that help with an animal's **camouflage**, changes in an alga's ability to grow in warmer waters.
2. Meiosis – both crossing over during prophase I and random orientation of the chromosomes during metaphase I allow for new combinations of genetic material. This makes it possible for a much greater variety in the production of sperm cells and egg cells. The more variety there is in the **gametes**, the more variety there will be in the offspring.
3. Sexual reproduction – there is a certain amount of chance involved in where and when a sperm cell can meet an egg cell. This element of chance produces new combinations and decreases the chances of the same offspring being produced twice.

Understanding: Adaptations are characteristics that make an individual suited to its environment and way of life.

The term 'adaptation' refers to characteristics of an organism's **morphology** or **innate** behaviour that improve its chances for survival.

Species that are well adapted to their environment have better chances in one or more of the following domains:

- finding resources such as food, shelter, and water
- escaping from predators

General vocabulary

camouflage way of hiding by looking like the surroundings

Subject vocabulary

gamete a sex cell, either a sperm cell or an egg cell

morphology the structure and shape of an organism

innate genetically determined, controlled by DNA

General vocabulary

mate organism of the opposite sex to reproduce with

appendages arms/legs/other body parts that extend outward from the body

larvae young immature stages of insects with soft bodies

migrate to change geographical locations from one season to another (said of populations when they change geographical locations from one season to another or said of neurones when they travel to new parts of the brain)

bioluminescent light up in the dark

nocturnal organisms that are active at night

aquatic living/growing in water

Subject vocabulary

parasite organism that uses another organism for resources and does harm to that organism

pollination transfer of pollen from the anther to the stigma of a flower, occurs before fertilization in angiosperms

- attracting a **mate**
- fighting off disease and **parasites**
- reproducing and providing for their offspring.

Examples include:

- hooks on their **appendages** that could improve the success of insect **larvae** living in fast-flowing rivers
- plant populations that can attract bees with colourful patterns on their flowers will be better adapted for successful **pollination**
- the instinct in some birds to **migrate** to a warmer climate, greatly improving survival during winter.

Some adaptations are not fully understood by biologists, such as **bioluminescent** fungi in the forest – although it is hypothesized that the light attracts **nocturnal** insects that would help spread fungal spores.

Understanding: Species tend to produce more offspring than the environment can support.

Model sentence: Because of an overproduction of offspring and limited resources, only some members of a population will survive.

Organisms tend to produce too many offspring.

For example:

- Fish produce hundreds or thousands of eggs but only a small number will survive.
- Fruit trees produce many more seeds than will ever be able to grow into new trees.
- Mushrooms produce millions more spores than will ever grow into new mushrooms.

There are not enough resources to allow all the offspring to survive. Examples of resources are water, sunlight, food, shelter, or dissolved oxygen (in **aquatic** systems).

Since there is variety in the population, some members of the population will be better adapted to survive. Some fish might hide well from predators or swim faster. A particular tree sapling might be better adapted to the soil conditions where its seed germinated.

Organisms with adaptations that help them to survive are considered fit for survival. High fitness, such as good camouflage, will improve the chances of survival. Low fitness, such as poor vision in a predator, will decrease chances of survival.

Hints for success: Avoid using human examples to illustrate the theory of natural selection. It is preferable to use plants, fungi, and non-human animals as examples. If you would like to use bacteria as an example, it is best to use the idea of resistance to antibiotics talked about later in the unit.

Understanding: Individuals that are better adapted tend to survive and produce more offspring while the less well adapted tend to die or produce fewer offspring.

Model sentence: Well-adapted organisms have a higher chance of passing on their successful genes to their offspring. Organisms with low fitness will have a greater chance of dying before being able to pass on their genetic characteristics.

Zebras have evolved to have black and white stripes and tend to gather in groups. The stripes confuse predators who try to attack the group. Female lions, for example, have difficulty determining where one zebra ends and the next one begins.

If by **mutation** or by natural variation through mixing of alleles, one zebra was all black, that individual would be easy to see in the herd. Its fitness, and therefore its chances for survival, would be greatly reduced.

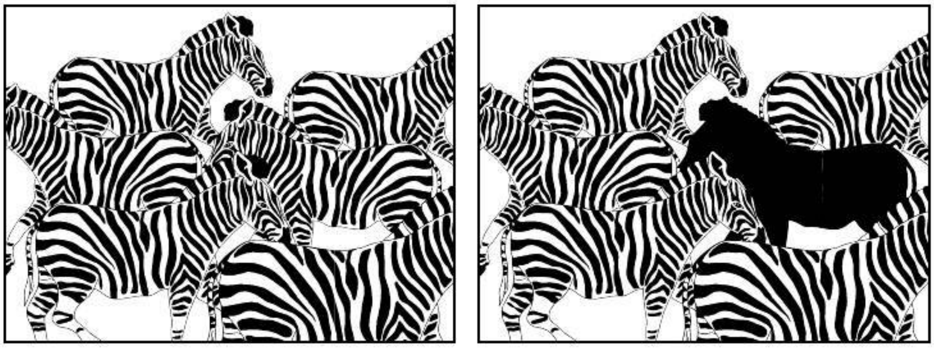


Figure 5.2 *When all zebra have stripes, it is difficult for a predator to isolate one individual from the herd. If a mutated zebra had all dark fur and no stripes, it would be at a disadvantage to the individual but also to the others since the dark fur provides a uniform background that makes the striped zebra stand out*

When a young all-black zebra is killed by a predator, its ability to pass on its genes to the next generation is reduced to zero. The frequency of alleles for all-black zebras is greatly reduced in this process. In contrast, the frequency of alleles for striped zebra increases. If all the zebra in a group are striped, then other characteristics will be used for selection. For example, if a zebra is unable to fight off parasites, it could die young and not be able to pass on its genes.

Over many generations, the frequency of successful characteristics increases and the frequency of unsuccessful characteristics decreases. This explains why most unhealthy traits such as **debilitating** genetic diseases are very rare in a population.

Understanding: Natural selection increases the frequency of characteristics that make individuals better adapted and decreases the frequency of other characteristics, leading to changes within the species.

The giant leaf insect, *Phyllium giganteum*, has an effective way of hiding from predators such as birds: it looks just like a leaf. If a bird flies nearby hunting for an insect to eat, it will think it sees a leaf and it will keep flying. It will not think it sees an insect. Having an appearance of something else is called **mimicry**.

Mimicry is an effective way of tricking organisms in the surrounding habitat. Leaf insects that look more closely like leaves hide better than those who show variations that do not make them leaf-like. This gives them higher fitness and therefore an advantage for survival.

Subject vocabulary

mutation an accidental change in a genetic sequence

mimicry a type of adaptation that gives an organism advantages of the organism being imitated

General vocabulary

debilitating having a seriously weakening effect

Synonyms

imitate .... copy

Subject vocabulary

acquired traits characteristics that are learned not inherited

General vocabulary

drought shortage of water due to dry weather

In this type of insect, the alleles for colours and shapes that **imitate** leaves are found more frequently. On the other hand, alleles for colours and shapes that poorly imitate leaves are selected out of the population. For example, if a leaf insect has a white colour instead of a green colour, a predator would see it more easily. This low fitness would increase the insect's chances of being seen and eaten. That would make it impossible for the insect to pass on its genes for white colour to the next generation.

It is important to note that if there is a change in the environment, a green colour or leaf shape might not be such a useful adaptation. If climate change causes a thinning of the forest and reduces the leaf cover, the insect's camouflage is less effective because it will be more challenging to hide.

Understanding: Individuals that reproduce pass on characteristics to their offspring.

The two examples above illustrate the importance of reproductive success. If a population shows variety and has a large population size, the chances of some of the individuals possessing successful characteristics and being able to survive and pass on their characteristics increase.

On the other hand, small populations with fewer variations have a lower chance of survival and therefore less of a chance to pass on their genes.

One of the challenging concepts of evolution is that the changes in allele frequencies occur at the level of the population and yet those who are contributing to the changes are individuals. It is important to remember that evolution happens at the population or species level, and not at the individual level. Evolution is a group phenomenon over many generations.

Characteristics that an individual develops during its lifetime, called **acquired traits**, are not passed on genetically. If a cat gets into a fight and loses an eye, for example, its future kittens will not be born missing one eye. We will see in Chapter 7 that there are some interesting exceptions to this phenomenon.

Hints for success: Here is a way for remembering the key ideas in natural selection: **VISTA**. **V**ariation, **I**nheritance, **S**election, **T**ime, **A**daptations.

Application: Changes in beaks of finches on Daphne Major

In addition to being able to explain examples like the ones above, you should be able to use the theory of natural selection to explain how the beaks of Darwin's finches changed over time, notably on the Galapagos Island called Daphne Major. Decades of studies by evolutionary biologists Peter and Rosemary Grant at Princeton University have shown how food supply and **drought** that are influenced by El Niño can affect frequencies of different alleles through natural selection.

Do some research on this subject and explain what has happened to finches on that island in the past few decades. Be sure to use the ideas of overproduction of offspring, variety in the population, a struggle for survival, and whether or not genes are passed on to the next generation.

Application: **Evolution of antibiotic resistance in bacteria**

Model sentence: Because we expose bacteria populations to high doses of antibiotics, humans have accelerated the evolution of populations of bacteria that are resistant to antibiotics.

A patient sees a doctor and gets a treatment of antibiotics for a **strep throat**.

- The treatment kills most of the bacteria. The patient feels better and stops taking the antibiotic.
- One or more bacteria in the population were naturally **resistant** to the antibiotic. This resistance could be because of a mutation or because of receiving genetic material from another bacterium through **plasmid transfer**.
- Now without competition for resources from other bacteria, this resistant bacterium **thrives** and produces a new population of resistant bacteria.
- The patient gets sick again. This time, the antibiotic treatment will not work on him because the infection is caused by a resistant **strain**. Therefore, a new antibiotic must be used.

Methicillin-resistant *Staphylococcus aureus* (MRSA) is a type of bacteria that possesses such antibiotic resistance.

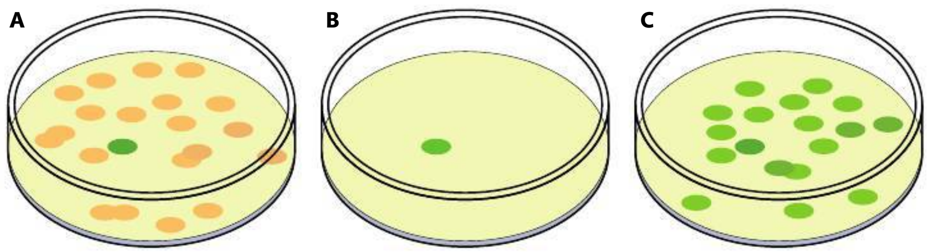


Figure 5.3 *(A) Original population of bacteria being treated with antibiotics, (B) all bacteria killed except one that is resistant, (C) new population of resistant bacteria thrives*

General vocabulary

strep throat a sore throat caused by a strain of bacterium

thrive grow/multiply well

Subject vocabulary

resistant unaffected by something

plasmid transfer a technique used by bacteria to share DNA

strain a type or variety of organism

5.3 Classification of biodiversity

Main idea

Species are named and classified using an internationally agreed system.

Nature of science: **Cooperation and collaboration between groups of scientists – scientists use the binomial system to identify a species rather than the many different local names.**

Understanding: The binomial system of names for species is universal among biologists and has been agreed and developed at a series of **congresses**.

All known species on Earth are named using the **binomial nomenclature** system. The system was perfected and generalized by the Swedish naturalist Carolus (Carl) Linnaeus. It can be referred to as the **Linnaean system**.

Binomial = ‘two names’, nomenclature = ‘naming system’. The plant *Pisum sativum* is the garden pea that Gregor Mendel used in his genetics experiments. *Pisum* is the **genus** name and *sativum* is the species name.

For modern humans, the genus and species names are *Homo sapiens*. Notice that most of the names are in Latin or Greek – sometimes the scientific name is called the Latin name.

General vocabulary

congresses fomal meetings with members of different groups

Subject vocabulary

binomial nomenclature the naming system where all organisms are given two names

Linnaean system the binomial classification system, named after Linnaeus

genus (plural: genera) a group of species with shared characteristics

The genus name is capitalized but the species name is not. When typing, the two names are in italics, when writing by hand, they should be underlined.

To make the rules about how to classify organisms and to discuss new species, specialists hold congresses on a regular basis. Each group of specialists such as **zoologists** or **botanists** will have their own meetings and discussions.

These meetings ensure that a single species does not have two different names. They also take into consideration the possibility that some species might have to be moved to different categories if new information about how they are classified becomes available. When renaming an organism, the species name must remain the same.

General vocabulary

zoologist scientist who studies animals

botanist scientist who studies wild plants

Subject vocabulary

morphological relating to structure and form

type specimen a sample displaying typical characteristics of a species

holotype a standard defining specimen of a species

taxonomist someone who classifies life into categories

hierarchical system classified in order of rank

taxa a level in the hierarchy of classifying living organisms, e.g. kingdom

phylum a taxon made up of many classes

kingdom a taxon made up of many phyla

families a group of related genera

taxonomy the study of classifying organisms

Understanding: When species are discovered they are given scientific names using the binomial system.

Model sentence: In the binomial nomenclature system, there are certain rules that must be followed about publishing the name and making an example of the organism (a holotype) available for study.

The discoverer of a new species must first prove that no one else has already named and described the organism. This is done by checking classification books and databases.

Next, the genus must be chosen based on the **morphological** and genetic characteristics that characterize that genus.

It is normal practice to use the Latin or Greek forms of words so that they are universally understood and so that there is some stability in the system worldwide.

The new name must be published in a way that is available for others to see and an example of the organism, called a **type specimen** or **holotype**, must be made available for inspection in a place such as a museum or a university collection.

What if two scientists identify the same species independently? In such as case, the first name that was given is adopted.

Understanding: **Taxonomists** classify species using a hierarchy of taxa. The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family, genus, and species.

Organizing things by having categories inside other categories (like folders inside other folders) is called a **hierarchical system**.

Such is the case for **taxa**, the word we use to describe categories of organisms that are similar to folders. Bigger categories such as a **phylum** or a **kingdom** contain many sub-categories such as **families** or genera (the plural of genus).

Taxonomy is the science of classifying organisms and a taxonomist is a specialist who classifies life into categories. They use a hierarchical system of categories and sub-categories to make sense of the natural world.

Here is what it looks like:

Kingdoms contain many phyla (plural of phylum), a phylum contains many classes, etc., until you get to a genus which will contain many species.

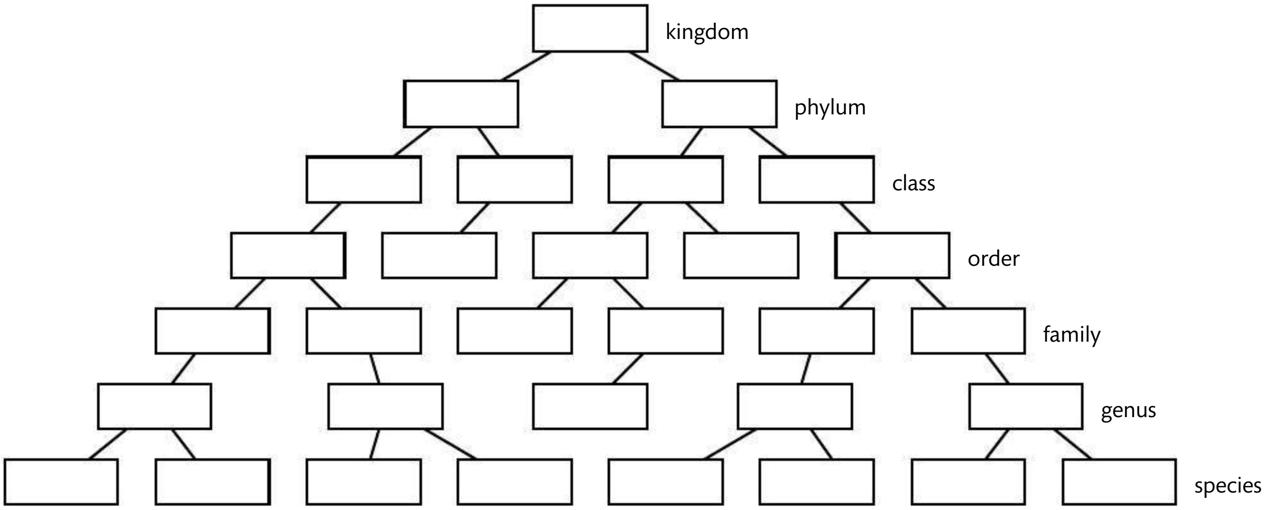


Figure 5.4 *This diagram is a very simplified way of showing the relationships between eight species from two phyla in one kingdom. It would be impossible to show the relationships of the hundreds of thousands of species in each of the kingdoms in this way. If this diagram was flipped upside down, can you see how it could be thought of as a tree? Also, remember that kingdoms can be classified under one of three domains*

Understanding: All organisms are classified into three domains.

There is one more over-arching category: a **domain**. All organisms can be placed into three domains: the Archaea domain, the Eubacteria domain, and the Eukaryote domain.

Archaea are prokaryotic single-celled organisms that have some similarities with bacteria but have very different molecular properties. For example, one type of archaean can use methane as a food source, something neither one of the other domains can do.

Eubacteria are also prokaryotes. They are the true bacteria – they are single-celled and have no membrane-bound **organelles**.

Eukaryotes have cells that possess membrane-bound organelles such as a nucleus or mitochondria. They can be single-celled such as yeast or paramecia or they can be multicellular such as plants and animals.

Subject vocabulary

domain the highest category that living things are classified into

Archaea a domain of single-celled organisms similar in size to bacteria but significantly different in biochemistry

organelles non-cellular structures within a cell which carry out organ-like processes

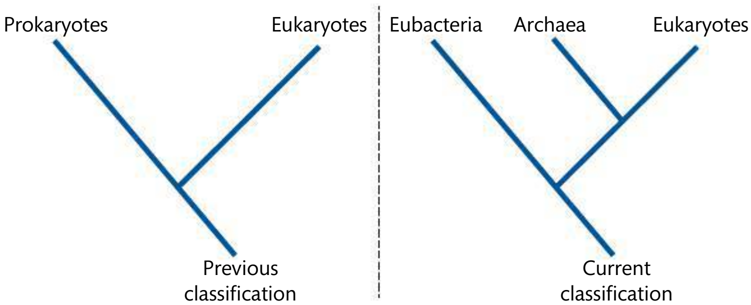


Figure 5.5 *The classification of Archaea*

Understanding: In a natural classification, the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.

The binomial nomenclature system is a **natural classification system** based on biology and ancestry.

Linnaeus was not able to use genetics because it had not yet been discovered. But by placing organisms together based on similar **morphologies**, naturalists in the 18th and 19th centuries often, without meaning to, put organisms together by how closely they were related.

With the invention of gene sequencing tools, it is now possible to confirm whether the original classifications under the Linnaean system did, in fact, group organisms by common ancestry.

On the other hand, if there are enough differences, taxonomists may choose to remove one or more species from a taxon.

Subject vocabulary

natural classification system a way of grouping organisms based on their biological similarities

morphology the structure and shape of an organism

circumscription the process of defining the characteristics of a classification group

Synonyms

ornamental .... decorative

Understanding: Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.

Some classifications have had to be adjusted based on new genetic evidence. Defining (or in this case re-defining) the characteristics for groups of taxa is called **circumscription**.

Example: circumscription

Flowering plants in the genus *Costus* are found in tropical regions and include plants used for medicinal purposes or as **ornamental** flowers.

As with many organisms, these plants were originally classified by their morphology such as the characteristics of their flowers. In *Costus*, some species have long tube-like flowers that are well adapted for hummingbirds to feed from, and others have flatter, more open flower structures for bee pollination.

DNA analysis has more recently shown that the tube-like flower structure evolved more than once along different evolutionary lineages. Using this characteristic to group species together does not conform to a natural classification because it would mean putting organisms together that have differing ancestries.

In 2006, Dr Chelsea Specht proposed breaking up up the *Costus* genus into four genera: *Cheilocostus*, *Chamaecostus*, *Paracostus*, and the original *Costus*. In addition to the flower morphology contradiction mentioned above, one of the issues this new classification resolved is that it took into account DNA differences showing that the species that evolved in Asia are on different evolutionary lineages than those found in the Americas.

Understanding: Natural classifications help in identification of species and allow the prediction of characteristics shared by species within a group.

Model sentence: Taxonomists use a natural classification system (one based on ancestry) rather than an arbitrary one (such as one based on how a plant tastes to humans).

There are several reasons to adopt a natural classification system:

- to make sense of the **biosphere** – to see that there are connections between species of living organisms
- to show how species are related to each other
- to predict characteristics shared by a group.

For this last one, imagine a specialist who has just discovered a new species of spider. It has an **exoskeleton** and four pairs of articulated legs. Without watching the spider's behaviour, the specialist can predict that this organism produces spider silk because all spiders produce it (although it is true that not all spiders use the silk to make webs).

Application: Classification of one plant and one animal species from domain to species level

Research your favourite plant and animal – can you find out how they are classified? Here are two examples:

	Ginger	Gray wolf
Domain	Eukaryote	Eukaryote
Kingdom	Plantae	Animalia
Phylum	Angiospermophyta	Chordata
Class	Liliopsida	Mammalia
Order	Zingiberales	Carnivora
Family	Zingiberaceae	Canidae
Genus	*Zingiber*	*Canis*
Species	*officinale*	*lupus*

Hints for success: To help remember the order of the taxa, a memory trick is helpful. Make a sentence using the first letters of each level, such as 'King Philip Came Over For Good Soup'. The human brain is very poorly adapted for remembering lists of words but very highly adapted for remembering stories. Transforming lists into stories is a good way to remember them.

Application: Recognition features of Bryophyta, Filicinophyta, Coniferophyta, and Angiospermophyta

Characteristics of organisms in the phylum Bryophyta:

- non-**vascular**
- very short in **stature**
- do not produce flowers
- reproduction by spores
- examples: mosses, liverworts.

Subject vocabulary

biosphere all areas on and in Earth where living organisms exist

exoskeleton a skeleton of some material that is found on the outside of an animal

vascular related to the tubes that carry liquid in animals/plants

Synonyms

stature........... size/height

Characteristics of organisms in the phylum Filicinophyta:

- no flowers
- reproduction by spores
- ferns have triangular **fronds** – made up of multiple smaller blade-like leaves
- examples: besides ferns, horsetails are also filicinophytes.

Characteristics of organisms in the phylum Coniferophyta:

- woody stems
- leaves are needle-like or in the form of scales
- cones hold the seeds
- examples: pine, spruce, cedar, juniper.

Characteristics of organisms in the phylum Angiospermophyta:

- flowers
- fruit holding a seed (or seeds) inside
- examples: rose, wheat, apple.

Application: Recognition features of Porifera, Cnidaria, Platylhelmintha, Annelida, Mollusca, Arthropoda, and Chordata

Characteristics of organisms in the phylum Porifera:

- aquatic and sessile (do not move around)
- no digestive system – food filtered out of water
- no muscle, nerve tissue, or clear internal organs
- example: sponges.

Characteristics of organisms in the phylum Cnidaria:

- no bones or shell
- **radial symmetry**
- stinging cells
- examples: coral polyps, sea jellies, hydra.

Characteristics of organisms in the phylum Platyhelmintha:

- **invertebrate**, long flat body
- **bilateral symmetry**
- two-way digestive system (only one opening)
- no **segmentation**
- examples: flatworms, such as tapeworm.

Characteristics of organisms in the phylum Annelida:

- invertebrate
- bilateral symmetry
- long thin body with one-way digestive tube (two openings)
- segmentation
- examples: earthworm, leech.

Characteristics of organisms in the phylum Mollusca:

- invertebrates, but can produce hard shells
- bilateral symmetry
- rarely segmented (exception: chitons)
- one-way digestive tube
- examples: snail, clam, octopus.

Characteristics of organisms in the phylum Arthropoda:

- invertebrates
- bilateral symmetry
- segmented
- hard exoskeleton made of chitin
- jointed limbs
- examples: insect, crab, spider.

General vocabulary

fronds leaves of a fern or palm

Subject vocabulary

radial symmetry body plan where any line through the centre of the organism produces two similar halves, e.g. sea anemone

invertebrate living creature with no backbone

bilateral symmetry one side of an organism is a mirror image of the other side

segmentation having separate parts that are joined together

Characteristics of organisms in the phylum Chordata:

- vertebrates, most produce a bony spinal column
- bilateral symmetry
- segmented
- notochord (line of cartilage going down the back)
- examples: lizard, fish, human.

Application: Recognition of features of birds, mammals, amphibians, reptiles, and fish

Characteristics of birds:

- wings with feathers (although not all birds can fly)
- bipedal
- very short tail
- eggs with hard shells
- hollow bones for a lightweight skeleton
- complex breathing system
- beaks or bills instead of teeth
- endothermic
- examples: pigeons, penguins, chickens, gulls.

Characteristics of mammals:

- hair
- females produce milk
- usually have four limbs, mostly land-dwelling
- thermoregulation
- specialized teeth
- examples: polar bear, dolphin, platypus, bat, human.

Characteristics of amphibians:

- larval stage in water (using gills), adult stage in air (using lungs)
- most have four legs
- teeth
- ectothermic (do not maintain body temperature)
- examples: frog, salamander.

Characteristics of reptiles:

- amniote egg (egg with protective membrane around it)
- scales
- ectothermic
- examples: lizard, turtle, snake.

Characteristics of fish:

- aquatic, possess gills
- limbs in the form of fins
- ectothermic
- most have bony spinal cord, some (such as sharks) have cartilaginous spines
- examples: sharks, tilapia, carp.

Skill: Construction of dichotomous keys for use in identifying specimens

A dichotomous key is a tool used for identification of unknown specimens. It starts with a pair of statements (1a and 1b, for example) that can either be true or false about the specimen. If 1a is false ('1a: feathers present', for example), then 1b must be true ('1b feathers not present').

If statement 1a is true, the investigator looks at the end of the line to find a number that refers to the next pair of statements to look at.

If statement 1a is false, the investigator looks at 1b. The end of the line will indicate which pair of statements to go to next. If the end of a line contains the name of an organism instead of a number, it is indicating the type of the specimen being identified.

You should be able to construct a dichotomous key for a set of organisms. Use the list of characteristics shown above to practise making a key.

Subject vocabulary

vertebrate living creature with a backbone

endothermic warm blooded, body maintained at a constant temperature

thermoregulation ability to maintain a certain body temperature

larva (plural: larvae) an immature form of an insect species

ectothermic cold blooded, constant body temperature not maintained

General vocabulary

bipedal can walk using two legs rather than four

scales type of skin found on snakes, fish, and reptiles

5.4 Cladistics

Main idea

The **ancestry** of groups of species can be determined by comparing their base or amino acid sequences.

Nature of science: **Falsification of theories with one theory being superseded by another – plant families have been reclassified as a result of evidence from cladistics.**

Subject vocabulary

ancestry how groups of species were related in the past

ancestor individual from which an organism is descended

cladistics the study of evolutionary relationships

clade a group of organisms that share the same ancestor

primitive traits ancient traits observed in the earliest common ancestor, also called plesiomorphic traits

plesiomorphic traits ancient traits observed in the earliest common ancestor, also called primitive traits

ancestral trait a characteristic inherited from an ancestor

apomorphic or derived traits characteristics that have evolved fairly recently

anatomy the study of the structure of the body

molecular systematics classifying organisms by genetic sequences or protein sequences

Understanding: A clade is a group of organisms that have evolved from a common **ancestor**.

- **Cladistics** is the study of **clades**. Organisms that show more recently evolved characteristics (such as the ability to produce milk) are classified differently from organisms that show a characteristic that evolved from another ancestor (such as the ability to grow feathers).
- **Primitive traits**, also called **plesiomorphic traits** or **ancestral traits**, are the traits that evolved from the earliest ancestor in the species being studied.
- **Derived traits**, also called **apomorphic traits**, are the traits that evolved more recently. In plants, flowers evolved after vascular tissue, for example.

Understanding: Evidence for which species are part of a clade can be obtained from the base sequences of a gene or the corresponding amino acid sequence of a protein.

Although traditionally biologists have used **anatomy** and morphology to help classify organisms, more recently, gene sequencing and protein analysis have been implemented.

Using genetic information or amino acid sequences in proteins to classify organisms into clades is called **molecular systematics**.

If two organisms show similar sequences in their DNA or similar patterns of amino acids in certain proteins, it suggests that they are closely related species. If there are many differences, it can be assumed that they are more distantly related.

Since large quantities of data are involved, computers often help biologists by comparing thousands, if not millions, of data points.

As an example, compare the imaginary sequences of three species below showing four codons and the amino acids that would be coded for (in parentheses).

Species X: GGGAAATTTCCC (proline – phenylalanine – lysine – glycine)

Species Y: GGGATATTTCCC (proline –**tyrosine** - lysine – glycine)

Species Z: CGGATATATCCG (**alanine** – **tyrosine** - **isoleucine** - glycine)

Notice that compared to species X, species Z has four times as many mutations (shown in red) as species Y. If the corresponding mRNA sequences are translated, we see that they code for different amino acids. This is what researchers can look at when deciding how closely related species are: species X and Y are the most closely related and species X and Z are the least closely related.

Note also that often a change in letters of the code will result in a different amino acid showing up in the polypeptide sequence, but not always. Glycine is coded for in species Y and Z even though they have different base sequences. This phenomenon is expressed in the term **degenerate code**.

Understanding: Sequence differences **accumulate** gradually so there is a positive correlation between the number of differences between two species and the time since they **diverged** from a common ancestor.

Model sentence: When analysed over millions of years, alterations in the genetic code can be used as a kind of molecular clock to estimate times when speciation events occur.

By studying mutations in DNA sequences or by causing them to happen in laboratory experiments, it has been determined that mutations are infrequent and their accumulation in a species is therefore slow.

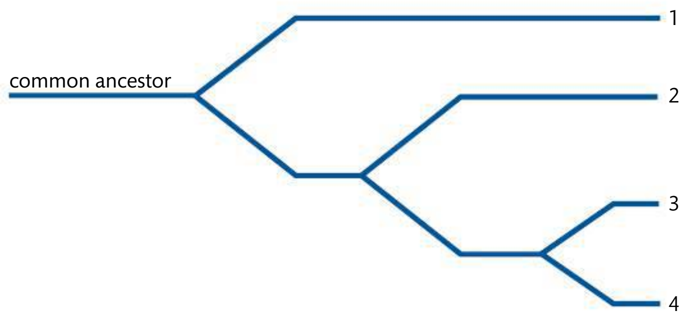


Figure 5.6 *A cladogram showing three speciation events and four species of which 3 and 4 are the most closely related to each other*

In the figure, species 3 and 4 are the most closely related, meaning that they show the most recent modifications. A speciation happened earlier to separate the species that became 3 and 4 from species 2. The first split shows how species 1 has continued to live but that subsequent speciation events (shown by the splits) have resulted from variations on the original species. The horizontal line at the left of the figure shows the common ancestor from which all four species in the diagram **descended**.

Using the idea of a biological clock, if species 2 shows ten differences in its DNA sequence compared to the original common ancestor, and species 1 shows only five differences compared to the original species and assuming that mutations happen at a steady pace, the following can be hypothesized: species 1 has existed for twice as long as species 2.

Understanding: Traits can be analogous or homologous.

Analogous traits are those that have a similar function but not necessarily a similar structure. They are found in species which do not have a recent common ancestor. Such anatomical features have different embryological origins.

Many analogous traits are the result of **convergent evolution**.

Subject vocabulary

degenerate code more than one codon coding for a given amino acid

analogous traits two traits are analogous if they have similar functions but dissimilar ancestries, for example, insect wings and bird wings

convergent evolution process by which different structures in different species develop to perform the same function

Synonyms

accumulate .... build up

General vocabulary

diverged developed in different ways so they are no longer similar

descended came from

Subject vocabulary

homologous traits two traits are homologous if they have similar ancestries but dissimilar functions, for example, pentadactyl limbs used for swimming or flying

divergent evolution process by which the same structure in different species develops to perform the different functions

cladogram branching diagram showing relationships amongst a group of organisms

node point in a cladogram where lines meet at a common ancestor showing a speciation event

sister groups groups in a cladogram that are closely related, with a recent common ancestor

outgroup a group that is not closely related to others

parsimony the principle by which the simplest and least convoluted explanation is chosen

General vocabulary

grasping holding something firmly

camouflage way of hiding by looking like the surroundings

divergence development in different ways so as to be no longer similar

Synonyms

pigments .... colours

Homologous traits are those that have a similar structure but not necessarily a similar function. They are evidence that the two species share a common ancestry. Such anatomical features have the same embryological origins.

Examples:

Analogous	Homologous
bird wings for flight and insect wings for flight	pentadactyl limbs in bats for flight evolved from a common ancestor that also gave rise to the pentadactyl limbs in monkeys for **grasping** objects
flippers in dolphins for swimming and fins in sharks for swimming	eyes with lenses in fish evolved from a common ancestor that also gave rise to eyes in birds
spots of **pigments** on moths for **camouflage** and spots of pigments on mammal fur for camouflage	brains in lizards evolved from a common ancestor that also gave rise to brains in primates

Homologous traits that look different are the result of **divergent evolution**.

Homologous characteristics are useful for cladistics, whereas analogous characteristics are not. Taxonomists would not put into the same taxon all organisms that have stripes, for example, zebra, certain insects, certain flowers.

Understanding: **Cladograms** are tree diagrams that show the most probable sequence of **divergence** in clades.

Model sentence: Cladograms allow for the visualization of how species emerged from common ancestors.

To visualize the genetic similarities between species in clades, diagrams called cladograms are used.

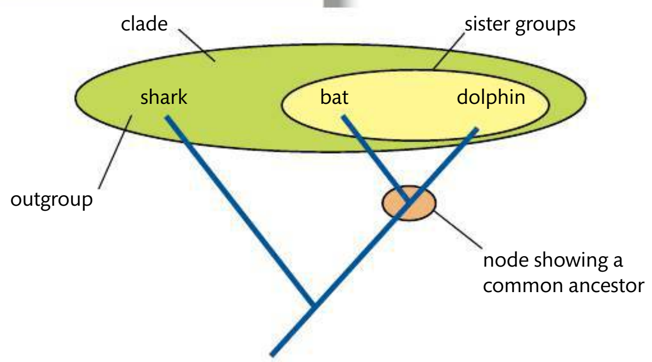


Figure 5.7 *A cladogram showing three taxa organized into a clade, of which two are sister groups and one is an outgroup. Nodes show a common ancestor for the descendants that appear above them in this cladogram*

A cladogram is made up of lines showing lineage (ancestry) and each **node** (each Y-shaped branch) represents the common ancestor after which a speciation event occurred. Everything above a node is a clade.

Groups that are very closely related are called **sister groups**. The group that is the most distantly related to the others is considered an **outgroup**.

All cladograms are to be considered as proposed hypotheses. There is no one single 'correct' cladogram. Depending on the characteristics chosen, more than one cladogram could be proposed for the organisms being considered.

However, there is a rule to be followed: the principle of **parsimony**. Parsimony is the practice of adopting the simplest and most probable explanation while rejecting more complex and less probable explanations.

Hint for success: Do not overinterpret these diagrams. Cladograms are only supposed to show more ancient ancestors towards the base of the diagram and more recently developed species towards the ends of the branches. When analysing cladograms, you should not talk about 'progress', 'improvement', or 'more highly evolved species'. Evolution works by natural selection rather than following some kind of path towards perfection. All species alive today have evolved for the same number of years.

Understanding: Evidence from cladistics has shown that classifications of some groups based on structure did not correspond with the evolutionary origins of a group or species.

Some cladograms have been proved false. A cladogram that does not show the similarities and differences in genetic sequences correctly cannot be accepted. Putting two distantly related species next to each other above the same node on a cladogram when other species are clearly more closely related does not follow the principle of parsimony.

In the past, some organisms were wrongly classified as being closely related due to their similar morphologies. Later it was shown that the two species were more distantly related than originally thought. In this case, a new cladogram and therefore a new classification are proposed.

The opposite can also happen: birds have always been placed in a class of their own but the more we study them and study dinosaurs called theropods, it is clear from a cladistics point of view that birds are, in fact, theropods. The features that they share include backward-pointing knees, fused clavicle bones (the Y-shaped 'wishbone'), and eggs with hard shells.

Application: Cladograms including humans and other primates

Example of a cladogram including humans and chimpanzees. The numbers represent the following: (1) vertebrates, (2) **quadruped**, (3) hair, (4) **opposable thumb** (thumb that can be used to grasp), (5) **bipedalism** (ability to walk on two legs).

Application: Reclassification of the figwort family using evidence from cladistics

There is a family of flowering plants called figworts which have traditionally been classified in the family called Scrophulariaceae. This classification was based on the morphology of parts of the plants such as the nectaries (where sweet nectar is produced) or the type of aestivation. **Aestivation** in plants refers to how the flower's petals are arranged before the bud opens.

Taxonomists have analysed zones of DNA markers such as the nuclear ribosomal **internal transcribed spacer** (ITS) and found that figworts with the morphological similarities listed above did not show expected similarities in their DNA sequences. This means that plants that were originally thought to be **monophyletic** (sharing a recent common ancestor) were in fact **polyphyletic** (on a different lineage).

One example of a figwort that has been reclassified is the foxglove. These flowering plants are now in the family called Plataginaceae, which is the same family as plantains.

General vocabulary

quadruped an animal with four legs

Subject vocabulary

opposable thumb a digit arranged opposite the other digits which allows objects to be grasped

bipedalism ability to walk on two legs

aestivation the arrangement of flower petals within a bud

internal transcribed spacer a marker in DNA used to check similarities between species

monophyletic having one common ancestor

polyphyletic said of two or more clades that have different common ancestors

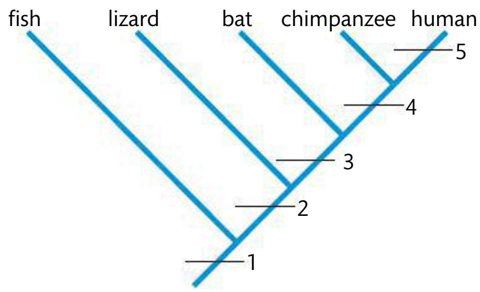


Figure 5.8 *A cladogram showing the relationship of humans to four other vertebrates. Cladograms are helpful in showing that we are more closely related to chimpanzees than to fish. But notice that there is no judgement of how evolved an organism is. Fish are just as highly evolved as humans, only they have adapted well to living underwater whereas we have not*

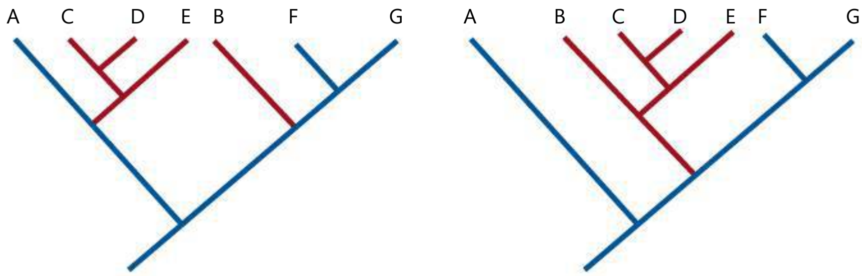


Figure 5.9 *Rearranging a cladogram based on new DNA evidence. The clade that included species C, D, and E on the left was moved from the branch that included species A, and placed on the branch with species B instead, because C, D, and E show a common ancestry with species B. In the old cladogram on the left, B, C, D, and E are shown as being* ***paraphyletic****, whereas the new cladogram on the right is showing them as monophyletic*

Subject vocabulary

paraphyletic a group containing some but not all of the descendants of a common ancestor

Skill: Analysis of cladograms to determine evolutionary relationships

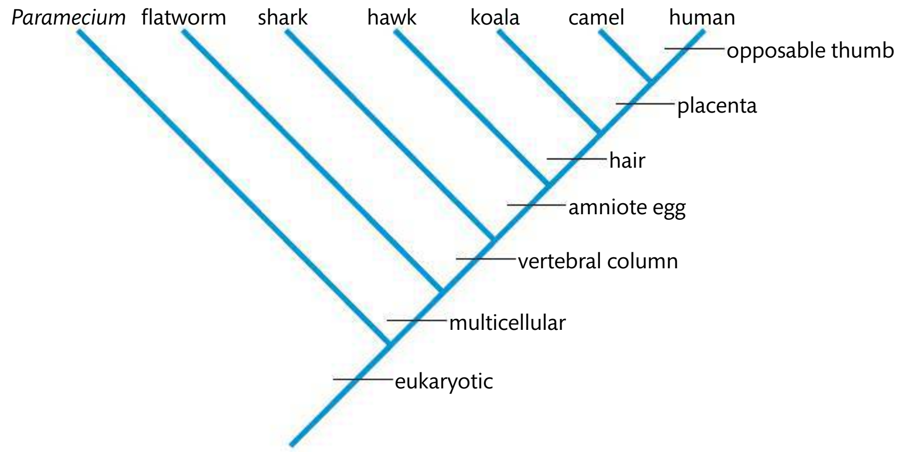


Figure 5.10 *A cladogram showing the evolutionary relationships between seven organisms*

1 What is the primitive characteristic in the cladogram shown in Figure 5.10?

2 Name the members of the mammal clade in this cladogram.

3 What is the outgroup when considering the clade of multicellular organisms?

4 Do shark eggs have a protective membrane (the amnios) around them?

5 Explain why there are no bacteria shown in this diagram.

Hints for success: To help you remember the difference between analogous and homologous, remember that these terms refer to anatomy (the flesh and blood) and that an analogy is used to compare very different things. The term 'homo' means 'same', so homologous refers to anatomically similar things.

[1] Answers:
1 Being eukaryotic is the primitive characteristic shared by all.
2 koala, camel, human
3 *Paramecium*
4 No. Sharks are not amniotes.
5 Because the primitive characteristic requires the organisms to have a nucleus. If bacteria were to be added to this cladogram, a new primitive characteristic would need to be chosen.

6.1 Digestion and absorption

Understanding: The contraction of circular and longitudinal muscle of the small intestine mixes the food with enzymes and moves it along the gut.

Model sentence: Food within the small intestine is mixed with enzymes and is kept moving due to contractions of two layers of intestinal muscles.

Ingested food moves along a 'tube' called the alimentary canal.

The interior cavity of the alimentary canal is called the lumen.

The small intestine is the longest part of this tube.

Enzymes needed for digestion are added to the food at various places along the tube.

Two layers of muscle that make up the wall of the tube contract in order to:

- mix the food with the enzymes
- keep the food moving from beginning to end.

Food moves by way of a process called peristalsis. Peristalsis is muscle contractions just behind the food mass so that the food mass continues moving in one direction.

The two layers of muscle are called the circular muscle layer and the longitudinal muscle layer. Both of these muscle layers are controlled by areas of the brain that control activities at the subconscious level. The type of muscle controlled at the subconscious level is called smooth muscle.

Skill: Drawing the digestive system

You should be able to draw a diagram of the human digestive system and give the functions of each major part. The figure to the right would be good practice for doing this. Add functions as you learn them from various sections of this part of the text.

Skill: Identifying tissue layers from a sectioned view of the small intestine.

The following figure will help you to learn these layers.

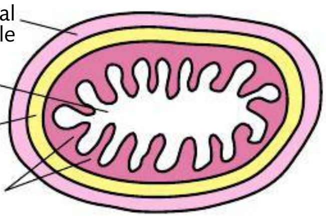


Figure 6.1 *This drawing shows a sectioned view of a part of the small intestine. Notice that the outer layer of muscle is called the longitudinal layer and under that layer is the circular layer. You will learn about the villi in an upcoming section*

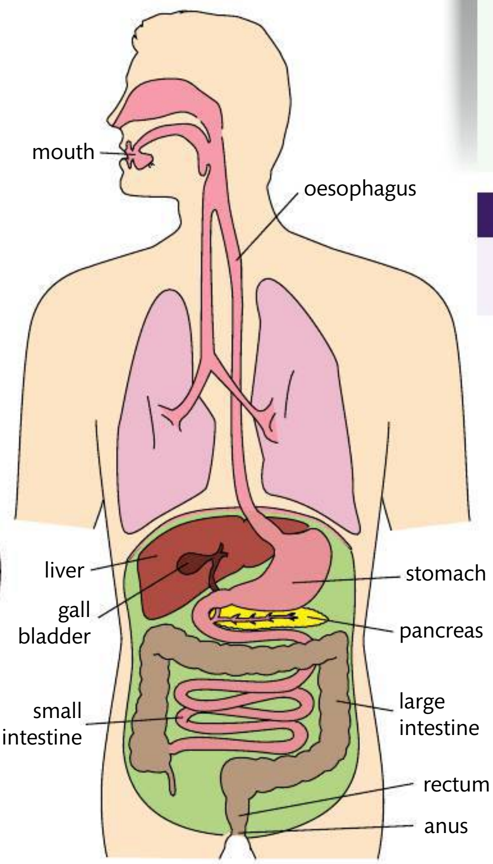


Figure 6.2 *The human digestive system*

General vocabulary

contraction tightening and narrowing

sectioned 'cut-away' view

Subject vocabulary

enzyme a protein that acts as a catalyst

ingested food/substances taken into the body

alimentary canal the tube that carries food while it is being digested

lumen area within surrounding walls or membranes; usually used for the cavity of a tubular structure such as a blood vessel

digestion a chemical process whereby large molecules undergo reactions in order to become a molecular size that can be absorbed into the blood

peristalsis contractions of smooth muscle in the alimentary canal that moves the food from mouth towards anus

circular muscle layer the inner layer of smooth muscle of the alimentary canal

longitudinal muscle layer outer layer of smooth muscle of alimentary canal

smooth muscle muscle that contracts to move something in the body besides a bone or heart chamber

Synonyms

gut................ alimentary canal

cavity............ space (within)

Subject vocabulary

pancreas an organ within the body that has many functions including production of three important digestive enzymes and production of two hormones that regulate glucose

substrate substance which begins a chemical reaction or process

hydrolyses splits a larger molecule into two smaller molecules through a chemical reaction

digest a reaction that hydrolyses or splits a molecule into a smaller form

macromolecules large, complex organic molecules

monomer a 'building block' unit of a macromolecule

villus (plural: villi) a small finger-like projection that extends into the lumen of the small intestine

epithelium cell layer that often forms a covering or outer cell layer of a structure (formed of epithelial cells)

capillary smallest blood vessels; all substances moving in or out of the bloodstream pass through the walls of these small vessels

Synonyms

secrete .... produce/release

absorption ..... taking in

General vocabulary

projection something that extends outward from a surface

Understanding: The pancreas secretes enzymes into the lumen of the small intestine.

Model sentence: Digestive enzymes are sent into the cavity of the small intestine from the pancreas.

The table shows three enzymes that are produced by the pancreas and sent to the small intestine.

Enzyme	Substrate	Action
lipase	lipids (fats and oils)	hydrolyses lipids into glycerol and fatty acids
amylase	starch	hydrolyses starch into smaller carbohydrates
trypsin	proteins	hydrolyses proteins into smaller sections

Understanding: Enzymes digest most macromolecules in food into monomers within the small intestine.

Model sentence: The large molecules found in food are digested into smaller molecular forms by enzymes in the small intestine.

Most people think of foods as meats, breads, fruits, and vegetables. Each of these foods is made up of very large molecules called macromolecules. The macromolecules are too large to be absorbed into our blood. The function of enzymes is to digest the macromolecules into smaller forms called monomers. The small intestine can then absorb the monomers into the bloodstream.

Food example	Macromolecule form	Monomer form
meat (chicken)	protein	amino acids
bread	starch	glucose
cooking oil	triglycerides	fatty acids and glycerol
fruit (orange)	nucleic acids	nucleotides

Understanding: Villi increase the surface area of epithelium over which absorption is carried out.

Model sentence: The small intestine contains many small projections called villi that increase the surface area for absorption.

The lumen (inner cavity) of the small intestine is lined by cells called epithelial cells. This lining is not smooth. Instead, it is composed of a great many finger-like projections called villi. Each villus creates a great deal of surface area for absorption as compared to a smooth walled surface. In addition, the cells that make up each villus have many even smaller projections that also greatly increase surface area. These projections from each cell are called microvilli. After the food monomers enter a villus, they are most often taken into the smallest of all blood vessels called a capillary.

Understanding: Villi absorb monomers formed by digestion as well as **mineral ions** and **vitamins**.

Model sentence: Vitamins and mineral ions are absorbed by villi in addition to food monomers.

Here is a partial list of the important substances that are absorbed from the small intestine into our bloodstream:

- water
- glucose
- amino acids
- mineral ions (e.g. sodium, potassium, calcium)
- vitamins (e.g. vitamin B, vitamin C).

Subject vocabulary

mineral ions the charged form of inorganic substances like sodium (Na^+)

vitamins organic compounds needed in small amounts in our diet

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Understanding: Different methods of membrane transport are required to absorb different nutrients.

Model sentence: The nutrient monomers absorbed through the villi membranes use a variety of membrane transport methods.

Each villus that extends into the lumen of the small intestine is made up of many epithelial cells. The epithelial cells have plasma membranes that the food monomers must pass across in order to reach a capillary. The figure illustrates three of the common transport methods.

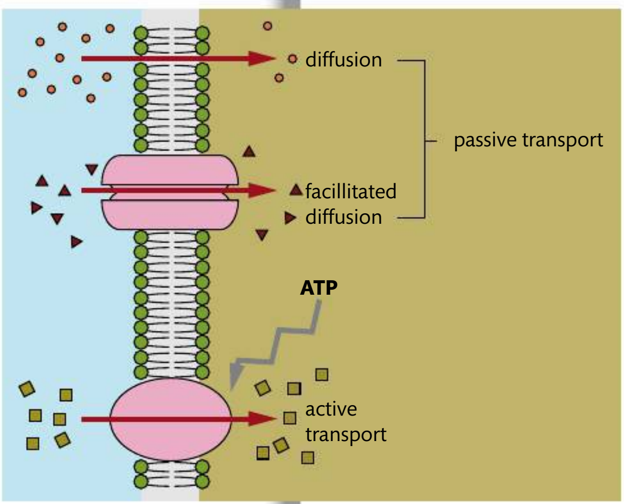


Figure 6.3 *Schematic view of three of the more important mechanisms used by cells of the villi epithelium to absorb nutrients from the lumen of the intestine. The mechanism used depends on the size and polarity of the molecule transported. Not shown is endocytosis where a portion of the plasma membrane invaginates to take in many molecules at one time*

6.2 The blood system

Understanding: Arteries convey blood at high pressure from the **ventricles** to the **tissues** of the body.

Model sentence: Ventricles are the heart chambers that pump high pressure blood through arteries to tissues in the body.

- The heart is composed of four chambers.
- The upper two chambers collect incoming blood and are called **atria.**
- The lower two chambers pump blood out and are called ventricles.
- Any blood vessel that takes blood away from the heart is an artery.
- The ventricle on the left side of the heart pumps blood to the body tissues.
- The ventricle on the right side of the heart pumps blood to the lungs.

Subject vocabulary

ventricles the lower two chambers of the heart

tissues a collection of cells in the body that serve a common purpose

artery any blood vessel that carries blood away from the heart

atria the upper two chambers of the heart (singlular - atrium)

Synonyms

composed (of) made up (of)

General vocabulary

coronary relating to the heart

rigid stiff/not moving or bending

contract tighten and narrow

permeable allows one or more substances to pass through

Subject vocabulary

plaque build-up of cholesterol and other substances on the inner wall of arteries or biofilm on the surface of teeth

occlusion a condition where a blood vessel no longer carries enough blood due to plaque build-up

elastic fibre a protein found in the wall of arteries that can expand and contract

blood pressure the pressure exerted by blood on the inner wall of a blood vessel

lumen area within surrounding walls or membranes; usually used for the cavity of a tubular structure such as a blood vessel

capillary smallest blood vessels; all substances moving in or out of the bloodstream pass through the walls of these small vessels

nutrient chemical material a cell or organism needs

Application: Causes and consequences of occlusion of the coronary arteries

Some of the most important arteries in the body are the arteries that feed blood directly into the muscle tissue of the heart. These arteries are called coronary arteries. Over a long period of time substances can build up in the inner walls of the coronary arteries. These substances are called **plaque**. Eventually plaque begins to block blood from flowing freely through one or more coronary arteries. This block is called an **occlusion**. Occlusions can lead to the heart muscle experiencing a lack of oxygen and may result in a heart attack.

Understanding: Arteries have muscle cells and elastic fibres in their walls.

Model sentence: An artery is not a rigid tube carrying blood as its walls have muscle cells and elastic fibres that allow the wall to move and be flexible.

Arteries must have the strength to withstand the high blood pressure provided by the pumping action of each ventricle. Thus, the wall of an artery is relatively thick. Much of this thickness is made up of a type of muscle called smooth muscle.

Arteries also have flexible fibres made of protein that stretch when a ventricle first pumps blood into an artery. These flexible proteins are capable of stretching something like a coiled spring.

Understanding: The muscle and elastic fibres assist in maintaining blood pressure between pump cycles.

Model sentence: During the brief time period when ventricles are not pumping, blood pressure is maintained with the help of smooth muscle and elastic fibres.

The smooth muscle that makes up the wall of an artery does **contract** at times. You are never aware when this is happening. The contraction causes changes in the size of the inside cavity of the artery. This inside cavity is called the **lumen** of the artery. Changes in the size of the lumen help control blood pressure.

Arteries also have flexible fibres made of protein that stretch when a ventricle first pumps blood into an artery. Between pumps these elastic fibres return to their original length. This action helps maintain blood pressure even when the ventricle is not pumping.

Understanding: Blood flows through tissues in **capillaries.** Capillaries have **permeable** walls that allow exchange of materials between cells in the tissue and blood in the capillary.

Model sentence: Capillaries are the only blood vessels that have walls permeable to materials entering or leaving the blood.

- Blood enters a capillary from a very small branch of an artery.
- Each capillary wall is only one cell layer in thickness.
  - This makes the capillary permeable to many molecules.
  - Oxygen and **nutrients** typically leave the blood and move into surrounding cells.

- Carbon dioxide and sometimes other **wastes** leave the cells and move into the blood.
- Blood cells are not able to leave from the capillary.

- Blood leaves the capillary and goes into a very small **vein**.

Understanding: Veins collect blood at low pressure from the tissues of the body and return it to the atria of the heart.

Model sentence: Blood is returned to the atria of the heart through veins that carry low-pressure blood leaving the capillaries of the body.

When blood leaves the ventricles of the heart through an artery it is under high pressure. This pressure is a result of each ventricle acting as a pump. When the blood enters capillaries it must slow down as the blood cells move through the small capillaries one cell at a time. As a result, much of the blood pressure is lost while in the capillaries.

When this low-pressure blood enters a vein it is still under low pressure. It is this blood that makes its way back to the heart through larger and larger veins. The slow-moving blood is carried back to the atria of the heart to begin another **pumping cycle.**

Understanding: Valves in veins and the heart ensure circulation of blood by preventing backflow.

Model sentence: The heart and veins have valves to keep blood moving in a single direction.

Veins have one-way valves that stay open when blood is moving back towards the heart. The valves close if the blood attempts to move in the other direction. The heart has four internal valves that prevent backflow of blood. This keeps blood moving in a single direction.

Skill: Identification of blood vessels as arteries, capillaries, or veins from the structure of their walls

As described in the previous sections, arteries will have the thickest walls. Veins will have thin walls, but not thin enough for substances to enter or leave. Capillaries will have extremely thin walls composed of a single cell layer.

Inside of the heart there are four valves that keep blood moving in a single direction. There are valves located between each atrium and ventricle. These two valves are called the **atrioventricular valves**. There are also valves located where blood is pumped out of the ventricles. The valve on the left side is called the left **semilunar valve**. The valve on the right side is called the right semilunar valve.

Subject vocabulary

wastes molecules produced by body cells that need to be carried away

vein a blood vessel that collects blood from capillaries and returns that blood to the heart

pumping cycle the muscular contractions of both atria and then both ventricles

valves structures that allow a one-way fluid flow

atrioventricular valves valves located between each atrium and ventricle

semilunar valves valves located where blood exits each ventricle

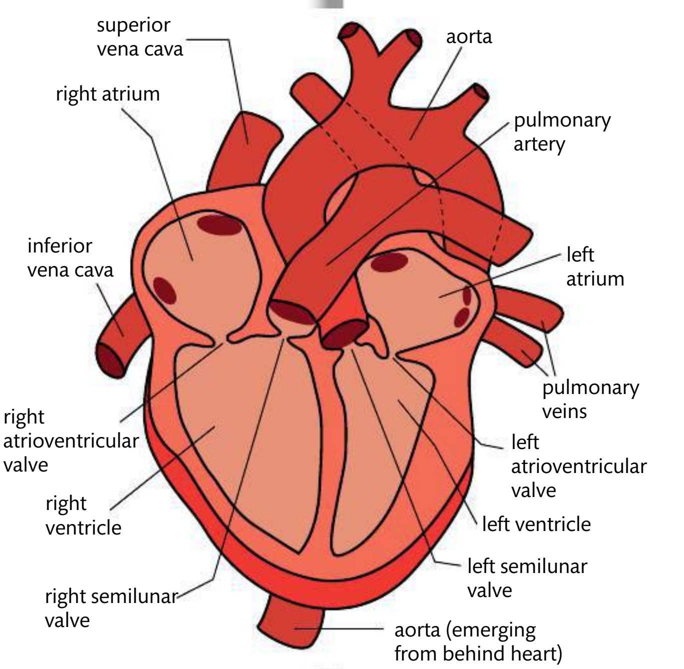
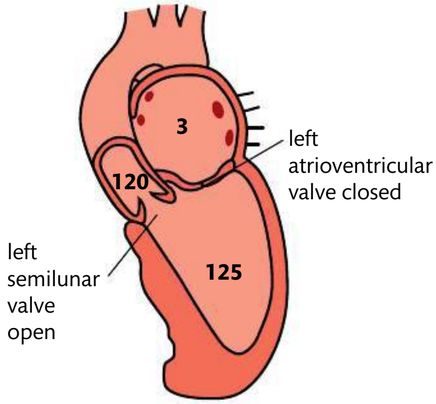


Figure 6.4 *Human heart anatomy*

Skill: **Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure**

You may want to study the names and positions of the chambers and valves of the heart from a dissected animal heart. If not, you can learn this information from many heart diagrams including the figures provided in this text.

Application: **Pressure changes in the left atrium, left ventricle, and aorta during the cardiac cycle**



'Late' ventricular systole

Figure 6.5 *Blood pressure produced by the left ventricle. The numbers shown in this figure are pressure readings in mm Hg. The left ventricle exerts enough pressure to open the semilunar valve sending blood out of the aorta. This pressure also keeps the atrioventricular valve closed*

The numbers shown in this figure are pressure readings in millimetres of Hg (mm Hg). The left ventricle exerts enough pressure to open the semilunar valve sending blood out into the aorta. This pressure also keeps the atrioventricular valve closed.

Understanding: There is a separate **circulation** for the lungs.

Model sentence: **The heart acts as two pumps with one of the two pumps sending blood to the lungs.**

The left side of the heart pumps oxygen-rich blood out to the body. This blood leaves the left ventricle and flows through the aorta. The aorta then branches into many smaller arteries.

The right side of the heart pumps oxygen-poor blood to the lungs. This blood leaves the right ventricle and flows through the pulmonary artery. Since you have two lungs the pulmonary artery branches into two large arteries. Oxygenated blood is returned to the heart through the pulmonary veins.

Application: **William Harvey's discovery of the circulation of the blood with the heart acting as a pump**

It was not until the 17th century that people learned that blood was being pumped through the body by the heart. William Harvey showed this by dissection of many human cadavers and living animals.

Subject vocabulary

cardiac involving the heart

aorta the largest artery in the body, taking oxygenated blood away from the left ventricle of the heart

pulmonary artery large artery leaving the heart taking blood to the lungs

pulmonary associated with the lungs

pulmonary veins veins that return blood to the heart from the lungs

cadaver a dead human body

General vocabulary

circulation a pathway that leads back to a starting point

dissection to cut up the dead body of an organism to study it

Synonyms

oxygen-rich.... oxygenated

oxygen-poor .. deoxygenated

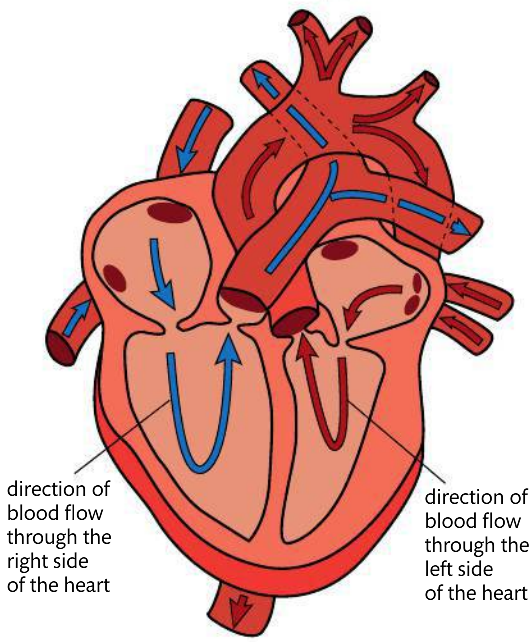


Figure 6.6 *Blood flow through the human heart. Blue arrows show oxygen-poor blood and red arrows show oxygen-rich blood*

Understanding: The heart beat is **initiated** by a group of specialized muscle cells in the right atrium called the **sinoatrial node.**

Model sentence: The sinoatrial node is composed of specialized muscle cells in the right atrium that begin each heart beat.

The cells that make up the sinoatrial node have features that make them muscle cells. They also have features that make them nervous system cells.

The sinoatrial node is often abbreviated as SA node.

Understanding: The sinoatrial node acts as a **pacemaker.**

Model sentence: By acting as the pacemaker, the sinoatrial node sets the rate at which our heart beats.

A single heart beat is when both atria contract at the same time followed by both ventricles contracting at the same time. These two sets of contractions are followed by a brief rest period until the next heart beat occurs. When a person is 'at rest' (not being physically active) the sinoatrial node initiates each heart beat at its own pace.

Understanding: The sinoatrial node sends out an electrical signal that stimulates contraction as it is **propagated** through the walls of the atria and then the walls of the ventricles.

Model sentence: The electrical signal initiated by the sinoatrial node results in contraction of both atria and then is transferred to the walls of both ventricles.

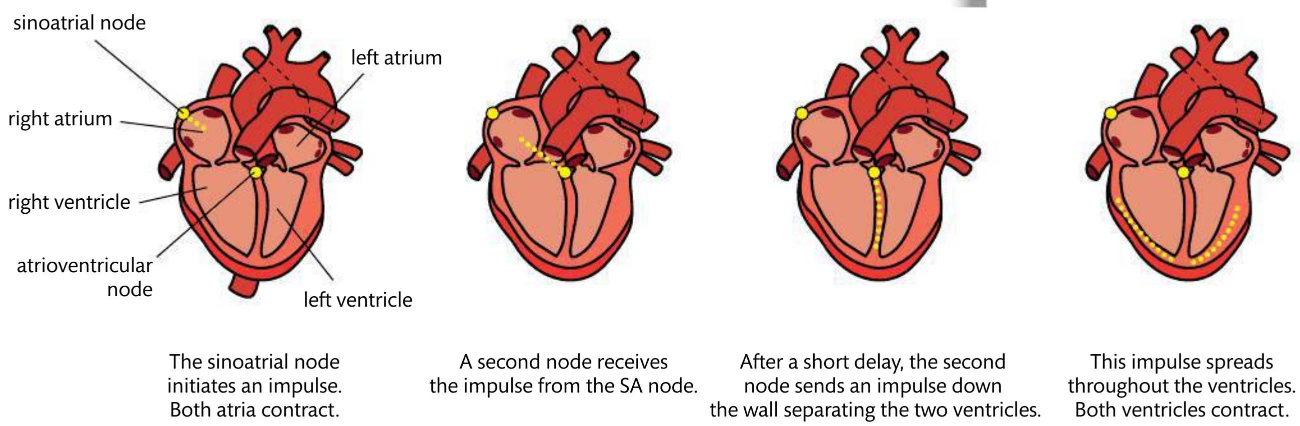


Figure 6.7 *Electrical activity of the heart initiated by the atrioventricular node*

Synonyms

initiated......... started/begun

Subject vocabulary

sinoatrial node a specialized group of cells in the heart that send out spontaneous electrical signals leading to a resting heart rate

pacemaker something that determines a rate for one or more events

General vocabulary

propagated caused to spread out

Synonyms

medulla of the brain........ medulla oblongata

General vocabulary

subconscious mental activities that one is not aware of

vigorous done with great energy

Subject vocabulary

accelerans nerve nerve that carries impulses from the medulla to SA node in order to increase heart rate

vagus nerve nerve that carries impulses from the medulla to the SA node in order to decrease heart rate

epinephrine hormone secreted from the adrenal glands

secretion release of a substance from a cell, tissue, or gland

adrenal glands glands located on top of each kidney

mucous membrane living tissue that secretes a mucous protection

pathogens disease-causing agents such as viruses and bacteria

infectious capable of causing an infection

Understanding: The heart rate can be increased or decreased by impulses brought to the heart through two nerves from the **medulla of the brain.**

Model sentence: The medulla of the brain can increase or decrease heart rate by sending impulses through two nerves that connect to the sinoatrial (SA) node of the heart.

- The medulla of the brain is part of the brainstem.
- The medulla controls many physiological factors in the body that occur at the **subconscious** level.
- During exercise, the medulla sends impulses through a nerve called the **accelerans nerve** to increase heart rate.
- After exercise, the medulla sends impulses through a second nerve called the **vagus nerve** to decrease heart rate.
- Both nerves connect into the SA node.
- The SA node stills sends impulses to the atria but the rate is being controlled by the medulla of the brain.

Understanding: **Epinephrine** increases the heart rate to prepare for **vigorous** physical activity.

Model sentence: Humans are capable of increasing their heart rate through secretion of the hormone epinephrine.

Epinephrine is a hormone secreted by two glands in the body called the **adrenal glands**. When needed the adrenal glands secrete epinephrine into the bloodstream. This can result in a dramatic increase in heart rate above the resting rate.

6.3 Defence against infectious disease

Understanding: The skin and **mucous membranes** form a primary defence against **pathogens** that cause **infectious** disease.

Model sentence: Most pathogens never get a chance to enter the body and cause disease because of the actions of skin and mucous membranes.

The outer layer of human skin is a layer of dead waterproofed cells. This helps protect us from many infectious diseases that can only infect living cells.

Mucous membranes line the openings of many body openings like the mouth and nose. This living tissue produces a layer of mucus. This mucus helps trap and eliminate many pathogens.

Understanding: Cuts in the skin are sealed by blood clotting.

Model sentence: Blood loss is kept to a minimum by blood clotting when blood vessels in the skin are cut.

Capillaries and other small blood vessels are opened whenever one accidently cuts through their skin. Our blood system has a response to that situation called clotting. Clotting involves both cells and chemicals that are found in our bloodstream.

Understanding: Clotting factors are released from platelets.

Model sentence: Small fragments of blood cells, called platelets, release chemicals called clotting factors in response to a cut.

- Platelets are blood cell fragments.
- Platelets are regularly produced in bone marrow.
- In response to a damaged blood vessel, platelets release chemicals.
- These chemicals are called clotting factors.
- Clotting factors are needed in order to clot blood at the cut area.

Understanding: The cascade results in the rapid conversion of fibrinogen to fibrin by thrombin.

Model sentence: A blood clot is a result of a cascade of reactions ultimately changing fibrinogen to fibrin by the enzyme thrombin.

A blood clot is accomplished by a set of reactions called a cascade. This is because one step of the reaction leads to another, then another, and so on. Fibrinogen and the inactive enzyme prothrombin are always circulating in the blood waiting to be used if needed to form a clot.

The clot is the fibrin mesh that acts somewhat like a spider web in that it traps blood cells to help seal the cut area.

Application: Causes and consequences of blood clot formation in coronary arteries

Note: the coronary arteries are the blood vessels that feed oxygenated blood directly into the heart muscle.

Causes of blood clot formation	Consequences of clots in coronary arteries
Deposits of cholesterol and fat build up over time inside the arteries. These deposits are called plaque.	Blood being provided to specific areas of the heart becomes limited.
Plaque narrows the inside opening of the blood vessel.	The areas with limited blood supply become weak.
Plaque in one area can break off and become lodged in another area where the vessel is smaller.	If enough blockage occurs a heart attack may result.

Subject vocabulary

blood clotting a body response to minimize blood loss from small blood vessels

clotting factors chemicals that help the clotting process

platelets cell fragments in the blood that release clotting factors

bone marrow soft tissue which fills the inner, hollow spaces of certain types of bones

fibrinogen the inactive form of the blood-clotting protein called fibrin

fibrin the active form of fibrinogen that forms the mesh of a blood clot

thrombin the enzyme that converts fibrinogen to fibrin

Synonyms

fragments ...... pieces

lodged........... stuck

General vocabulary

cascade a sequence of events, each one causing the next

conversion change from one form to another

mesh a structure that works like a net

blockage something that stops movement

Subject vocabulary

phagocytic a cell capable of phagocytosis

non-specific immunity actions by the immune system based on the pathogen only being identified as 'not self'

phagocytosis active transport in which larger particles and substances are brought into the cell

not self a foreign invader to the body such as a virus or bacterium, often called an antigen

antibody a protein produced by our immune system in response to an antigen

lymphocytes white blood cells capable of producing antibodies, often referred to as B lymphocytes or B cells

antigen substance which stimulates the production of antibodies in vertebrates

specific immunity actions by the immune system based on a specific pathogen having been identified

Understanding: Ingestion of pathogens by phagocytic white blood cells gives non-specific immunity to diseases.

Model sentence: The human body contains white blood cells that ingest disease-causing agents (pathogens) by identifying the agent as foreign to the body.

White blood cells are also called leukocytes. There are many types of leukocytes in the body.

Some leukocytes are capable of phagocytosis (phagocytic white blood cells). Some phagocytic white blood cells recognize molecules making up pathogens as being 'not self' or foreign to the body. If a pathogen is recognized as 'not self' it is ingested by phagocytosis and destroyed. This type of immunity is called non-specific as the pathogen is not identified, it is only determined to be 'not-self'.

Understanding: Production of antibodies by lymphocytes in response to particular antigens gives specific immunity.

Model sentence: Specific immunity is provided by white blood cells known as lymphocytes when they recognize antigens and produce antibodies.

Lymphocytes are another type of leukocyte. They are capable of producing specifically shaped proteins called antibodies. Each type of antibody is a molecule that recognizes specific molecules found on pathogens called antigens.

For example:

- A specific virus infects an individual.
- The protein coating of the virus acts as the antigen(s).
- Lymphocytes produce and secrete antibodies that bond to the virus antigen(s).
- The virus is more readily eliminated from the body.

This is called specific immunity because the pathogen has been identified and a specific response (the antibody) has been used to fight the infection.

Application: Effects of HIV on the immune system and methods of transmission

HIV is a virus that infects specific white blood cells of a person's immune system. Those cells are important for cellular communication to other white blood cells. When HIV kills enough of the communicating cells, a person's immune system stops functioning properly.

HIV is transmitted when a body fluid of an infected person is transmitted to someone else. This can happen when:

- Body fluids are exchanged during sex.
- Hypodermic needles are used on an HIV patient and then someone else uses the same needle.
- Donated blood products are used without testing for the presence of HIV.

Understanding: Antibiotics block processes that occur in prokaryotic cells but not in eukaryotic cells

Model sentence: Chemicals called antibiotics help fight bacterial infections by blocking cellular processes that are unique to prokaryotic cells.

It is common for people to receive an antibiotic from a doctor when they have an infection. Antibiotics are chemicals that selectively target cell processes that occur only in prokaryotic cells (bacteria). The antibiotic will then either kill the pathogenic bacteria or at least stop their growth. The antibiotic has no harmful effect on body cells as body cells are eukaryotic.

Application: Florey and Chain's experiments to test penicillin on bacterial infections in mice

In the first half of the 20th century, Howard Florey and Ernst Chain tested the antibiotic penicillin. They infected eight mice with a deadly strain of bacteria and then injected four of them with penicillin. The four not injected with penicillin died within a day. The four injected with penicillin lived for several days.

Understanding: Viruses lack a metabolism and cannot therefore be treated with antibiotics.

Model sentence: Antibiotics are not useful treatments against viruses as viruses are not prokaryotic cells and lack their own metabolism.

- Viruses are made up of a protein coat surrounding either DNA or RNA.
- Viruses are not cells and are not alive.
- Viruses do not have their own metabolism.
- Antibiotics do not work against infections caused by viruses.

Understanding: Some strains of bacteria have evolved with genes that confer resistance to antibiotics, and some strains of bacteria have multiple resistance.

Model sentence: There are some strains of bacteria that have developed a resistance to one or more types of antibiotics.

A single species of bacteria can exist in different strains. Each strain has a slightly different metabolism. Those bacteria that have a natural variation that give them some resistance to a specific antibiotic have a better chance of surviving when that antibiotic is used. Those that do survive reproduce in large numbers, where all of the bacteria now are resistant. There are some strains of bacteria that have evolved a resistance to many antibiotics. These strains are very difficult to treat with antibiotics.

Hints for success: On examinations, avoid using the term immunity as a synonym for resistance. The term immune or immunity refers to protection given by an organism's immune system. Resistance to an antibiotic by a bacterial strain is due to natural selection of existing genes.

Subject vocabulary

antibiotic chemical used to kill or stop the growth of bacteria

prokaryotic cells bacterial cells

eukaryotic cells all cells that are not bacteria

penicillin an antibiotic

strain a type or variety of organism

metabolism sum total of all reactions in a cell or organism

variation a form of a gene that makes one organism different than another

Subject vocabulary

ventilation the act of breathing in and out to refresh air in the lungs

concentration gradient change in a chemical concentration between two areas of chemical concentrations

alveoli the many tiny air sacs making up each lung

diffuse movement of a substance from an area of high concentration to an area of low concentration

type I pneumocytes cells of the alveoli that aid in gas exchange

surface tension attraction forces that exist at the surface of a liquid

Synonyms

spherical........ round

General vocabulary

moist slightly wet

adhering sticking to

Understanding: Ventilation maintains concentration gradients of oxygen and carbon dioxide between air in alveoli and blood flowing in adjacent capillaries.

Model sentence: The correct concentration gradients of oxygen and carbon dioxide are maintained between the air in alveoli and blood in nearby capillaries by the continuous action of ventilating the lungs.

- The lungs are composed of numerous tiny air sacs called alveoli.
- Each alveolus has one or more nearby capillaries.
- Air is continuously refreshed in each alveolus when we breathe in and out. Breathing in and out is called ventilation.
- The air we breathe in has a higher concentration of oxygen as compared to the oxygen level in the nearby capillary. Thus, oxygen will **diffuse** from the alveolus into the capillary.
- The blood in the capillary has a higher concentration of carbon dioxide as compared to the carbon dioxide level in the alveolus. Thus, carbon dioxide will diffuse from the blood to the alveolus. Blood is continuously refreshed in the lung capillaries.

Hint for success: In an examination, remember that oxygen and carbon dioxide concentrations and movements are the reverse of those shown above when the blood gets to the body tissues.

Understanding: Type I pneumocytes are extremely thin alveolar cells that are adapted to carry out gas exchange.

Model sentence: Each alveolus is composed of two types of cells, one of those types is the type I pneumocytes that are very thin and are used for the exchange of gases.

A single alveolus is a very small **spherical** structure that is composed of two types of cells. The most numerous of those cell types are the type I pneumocytes. These cells form most of the spherical shape and are thin and flat. This helps with the diffusion of oxygen and carbon dioxide between the air in the alveolus and the blood in a nearby capillary.

Understanding: Type II pneumocytes secrete a solution containing surfactant that creates a moist surface inside the alveoli to prevent the sides of the alveolus adhering to each other by reducing surface tension.

Model sentence: A second type of cell making up alveoli are the type II pneumocytes that secrete a solution that prevents alveoli from sticking to each other by reducing surface tension.

All alveoli also contain a less numerous type of cell. These cells are called type II pneumocytes. Their function is to produce and secrete a solution called a **surfactant** to the outside of the alveolar cells. This is helpful when cells of one alveolus touch cells of another alveolus during ventilation. The surfactant prevents the two alveoli from sticking to each other by reducing the surface tension of each.

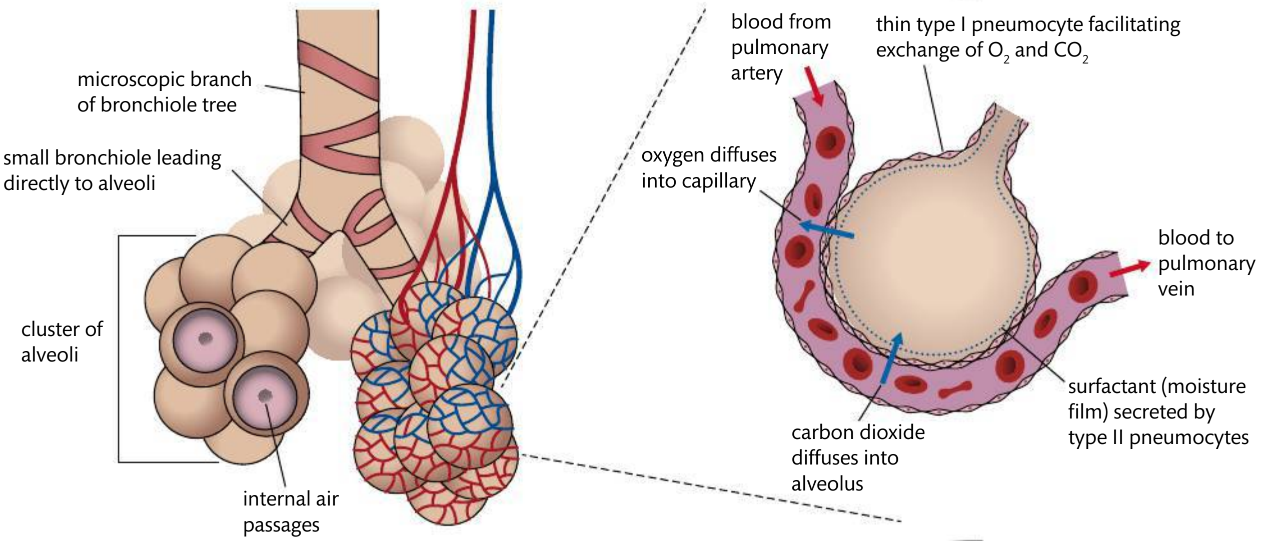


Figure 6.8 *Microscopic view of a small area inside a human lung. Each cluster of alveoli is surrounded by a capillary bed for efficient gas exchange. The inset shows a sectioned drawing of a single alveolus and the structures that make gas exchange efficient*

Hint for success: In examinations, you should be able to draw and label the structure of an alveolus and a nearby capillary. This view is being shown on the right side of figure above.

Understanding: Air is carried to the lungs in the **trachea** and **bronchi**, and then to the alveoli in **bronchioles**.

Model sentence: When you breathe in, the air passes down your trachea to a right and left bronchi and is eventually carried to the alveoli by small bronchioles.

Subject vocabulary

surfactant a solution that reduces surface tension

trachea tube of the respiratory system that carries air to both lungs

bronchi (bronchus singular) respiratory structures (branches of the trachea) which carry air from the trachea into the lungs

bronchioles microscopic sized branches of the bronchi

microscopic too small to be seen without magnifying

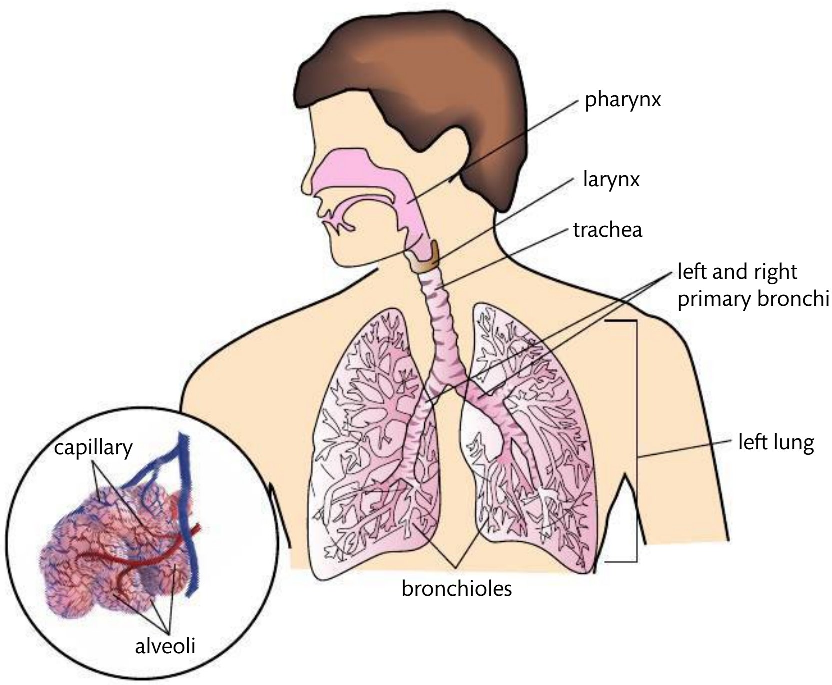


Figure 6.9 *Air is taken in by your mouth or nose. This air goes down the trachea to either the left or right bronchus. The left or right bronchus branches many times until the branches become* ***microscopic****. These very small branches are called bronchioles. The bronchioles lead to the alveoli surrounded by capillaries*

Subject vocabulary

emphysema a lung disease where alveoli become damaged, typically due to smoking

muscular composed of muscle

inspiration the act of breathing in

expiration the act of breathing out

inspire breathe in

rib cage the collection of all ribs that form a shape around the lungs

diaphragm the muscle below the lungs that rises and lowers

General vocabulary

fatal causes death

elastic able to stretch

deflate lose air

inflate gain air

Synonyms

thorax .... chest cavity

Application: Causes and consequences of emphysema

Emphysema is a slowly progressing disease where the alveoli of the lungs become destroyed. What is left behind are huge holes where alveoli used to be. This greatly decreases the surface area for oxygen and carbon dioxide to diffuse. The most common reason people develop emphysema is long-term smoking of cigarettes.

The consequences of emphysema take time to become serious. A person would first experience 'shortness of breath' when they exercise. As the disease progresses, the 'shortness of breath' will occur at all times. As time goes on, the disease is **fatal**.

Application: Causes and consequences of lung cancer

Lung cancer is a cancerous growth that typically begins in the lungs. Although anyone can develop lung cancer, it is most frequent in people who smoke. There are substances in cigarette smoke that are known carcinogens. When inhaled, a carcinogen can result in an internal lung cell becoming cancerous. Lung cancer can also spread to other parts of the body.

The consequences of lung cancer largely depend on how early it is detected and whether the cancer has spread to other body areas. The disease is often fatal unless detected and treated early.

Understanding: Muscle contractions cause the pressure changes inside the **thorax** that force air in and out of the lungs to ventilate them.

Model sentence: Pressure changes inside the chest cavity caused by muscle contractions result in air being forced into and out of the lungs resulting in ventilation.

- The lungs are not **muscular** and cannot move themselves.
- The lungs are **elastic** and will tend to **deflate** themselves (a little like a balloon deflates).
- The lungs are inside the chest cavity, also known as the thorax.
- When pressure in the thorax is high, the pressure pushes on the lungs and makes them smaller. This will force air out of the lungs
- When pressure in the thorax is low, the lungs are able to **inflate** to their full size. This creates a low pressure area inside of the lungs. Air enters the lungs to fill this low pressure area.
- Muscles of the thorax create these pressure changes.

Understanding: Different muscles are required for **inspiration** and **expiration** because muscles only do work when they contract.

Model sentence: A variety of muscles are needed for breathing in and out as any one muscle can perform only one action when it contracts.

When you **inspire** (breathe in), your **rib cage** rises and moves somewhat outward in order to make your thorax larger. The following muscles are involved in this action:

- The **diaphragm** (under your rib cage) contracts and flattens out.

- A group of muscles between your ribs contract (these are called the external **intercostal muscles**).
- One set of muscles in your **abdomen** contract.

When you **expire** (breathe out), your rib cage lowers and moves somewhat inward in order to make your thorax smaller. The following muscles are involved:

- The diaphragm relaxes and forms the shape of a dome.
- A different group of muscles between your ribs contract (called the internal intercostal muscles).
- A second set of muscles in your abdomen contract.

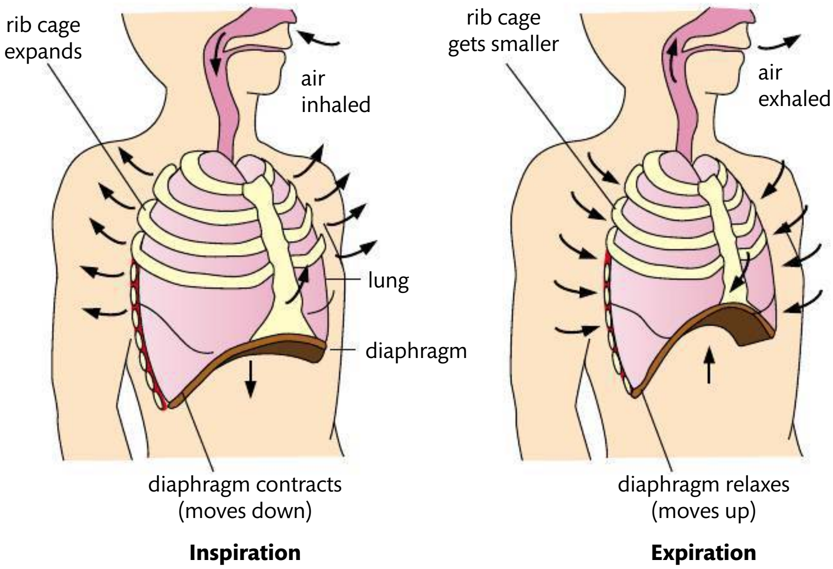


Figure 6.10 *The mechanisms for inspiration and expiration (ventilation)*

Application: External and internal intercostal muscles, and diaphragm and abdominal muscles as examples of antagonistic muscle action

Muscles can only perform one action when they contract. For that reason, they typically exist in pairs. Each of the pair of muscles achieve the opposite actions. This is often described as being antagonistic to each other. This is illustrated in the pairs of muscles involved in breathing in and breathing out.

Subject vocabulary

intercostal muscles muscles surrounding your ribs: external intercostal muscles contract when breathing in; internal intercostal muscles contract when breathing out

expire breathe out

antagonistic performing opposite actions

Synonyms

abdomen .... lower/hind body cavity

6.5 Neurones and synapses

Understanding: **Neurones** transmit electrical impulses.

Model sentence: The nervous system cells that transmit electrical impulses are called neurones.

Neurones are often very long cells. This helps to transmit impulses long distances when necessary.

Neurones have three main areas:

- **Dendrites** – receive electrical impulses from other neurones.
- **Cell body** – contains nucleus and other organelles.
- **Axon** – long extension from cell body that gives length to a neurone.

Subject vocabulary

neurones cells of the nervous system that transmit electrical impulses

impulse an electrical signal

dendrites short extensions from the neurone cell body which receive impulses

cell body area of neurone that contains a nucleus and other organelles

axon long extension of a neurone that carries an impulse away from cell body

Neurones carry electrical impulses in a single direction. The impulse begins at a dendrite, then continues to the cell body, and finally down the axon to the terminal buttons.

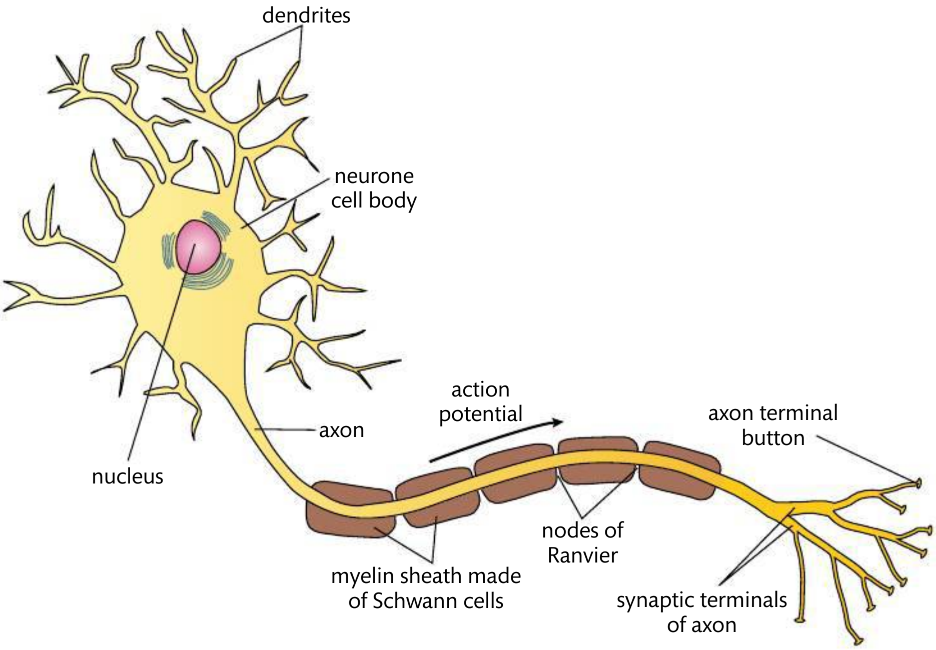


Figure 6.11 *The structure of a neurone. Some structures shown in this figure will be described in the upcoming sections*

Subject vocabulary

myelination production of myelin sheath around an axon

saltatory conduction impulse skipping from one node of Ranvier to the next

myelin sheath an insulation layer around the axon of neurones composed of multiple layers of Schwann cells

Schwann cell one of the cells helping to form a myelin sheath

node of Ranvier the gap area between Schwann cells of a myelin sheath

resting potential a neurone that is ready to send an electrical impulse

actively transporting moving substances through a membrane using energy in the form of ATP

Synonyms

nerve fibres.... axons (of neurones)

General vocabulary

insulation the addition of a material to keep an electrical impulse from going in or out

Understanding: The **myelination** of **nerve fibres** allows for **saltatory conduction**.

Model sentence: Neurones that have a myelin sheath are capable of faster transmission of the electrical impulse called saltatory conduction.

The figure of a neurone above shows several cells that wrap themselves around the axon of the neurone. These cells are called **Schwann cells**. Each Schwann cell wraps itself around the axon many times. This creates an **insulation** where the electrical impulse cannot occur. There are gaps between Schwann cells. Each gap is called a **node of Ranvier**. The entire area of the axon wrapped many times by Schwann cells is called the myelin sheath.

An electrical impulse is able to jump from one node of Ranvier to the next node of Ranvier when it travels down the axon. This greatly increases the speed at which an impulse is able to travel. When an impulse travels from one node of Ranvier to the next it is called saltatory conduction.

Understanding: Neurones pump sodium and potassium ions across their membranes to generate a **resting potential**.

Model sentence: Neurones prepare themselves to send an electrical impulse by actively transporting sodium and potassium ions across their membranes.

A neurone that is ready to send an impulse is said to be at its resting potential. The resting potential is achieved by pumping sodium ions out of the neurone and potassium ions into the neurone through the cell membrane. Pumping sodium and potassium ions is an active transport mechanism.

Understanding: An action potential consists of depolarization and repolarization of the neurone.

Model sentence: An electrical impulse is also called an action potential and consists of a depolarization followed by repolarization of the neurone membrane.

- An electrical impulse starts when sodium ions diffuse through channels in the neurone membrane.
- Sodium ions diffuse from outside the cell membrane to inside the cell membrane. This is called a depolarization.
- This is followed by potassium ions diffusing in the opposite direction (from inside to outside the cell membrane) through their own channels in the axon.
- In order for this neurone to send another impulse the sodium and potassium ions must be actively transported back to their resting potential positions. This is called repolarization.

Understanding: Nerve impulses are action potentials propagated along the axons of neurones.

Model sentence: Action potentials travel from one end of a neurone to the other starting with the dendrites and then along the axon.

Any one neurone can only send impulses in a single direction. The action potentials are propagated along the neurone starting at the dendrite end and moving towards the end of the axon.

Understanding: Propagation of nerve impulses is the result of local currents that cause each successive part of the axon to reach the threshold potential.

Model sentence: Specific areas of a long axon are being affected by an action potential at slightly different times and are successively stimulated to depolarize by reaching their threshold potential.

The long axon of a neurone does not depolarize all at the same time. Each area of an axon that may currently be depolarized is affecting the next area of the membrane to soon depolarize. This is known as a 'local current'. The entire movement of the nerve impulse is a series of chain reactions. A membrane will stay at its resting potential until an event causes it to reach a threshold potential. Then and only then will that area of the membrane begin an action potential. The event that does this is the area of the neurone nearby that is going through an action potential.

Subject vocabulary

active transport cellular transport requiring energy (ATP) from the cell

action potential the depolarization of a neurone membrane

depolarization sodium ions diffusing from outside to inside the neurone membrane

repolarization pumping of sodium and potassium ions back to their resting potential positions

local current an area of a neurone that is undergoing an action potential

threshold potential the minimum intensity signal needed to begin a nerve impulse

General vocabulary

successive following in order with no break between

chain reaction one event leading to the next event

Subject vocabulary

synapse an area where one neurone comes close to another cell in order to send a chemical message

receptor specialized structure in an organism which allows response to a stimulus

effector cell a muscle cell

presynaptic neurone neurone sending a chemical communication to postsynaptic neurone

postsynaptic neurone neurone receiving a chemical communication from a presynaptic neurone

receptor cell a cell that begins an impulse by being stimulated by an external factor, e.g. a touch receptor stimulated by pressure

neurotransmitter a chemical released from a presynaptic neurone into a synaptic gap

synaptic gap the fluid-filled space between a presynaptic neurone and a postsynaptic neurone

acetylcholine a common neurotransmitter

cholinergic synapse a synapse that uses acetylcholine as the neurotransmitter

neonicotinoid insecticides insecticides that work by blocking receptor proteins that normally bind acetylcholine

paralysis inability to use muscles

General vocabulary

junctions area where two things join or come close to joining

insecticide chemical used for killing insects

Synonyms

binding.......... attachment

bind.............. attach

Understanding: Synapses are junctions between neurones and between neurones and receptor or effector cells.

Model sentence: Neurones communicate with other cells by chemical connections called synapses.

The following are examples of neurone to cell communications:

- one neurone sending a communication to another neurone along a chain of neurones
  - the neurone sending the communication is called the presynaptic neurone
  - the neurone receiving the communication is called the postsynaptic neurone
- a receptor neurone cell sending a communication to the second neurone of a chain of neurones
- a neurone sending a communication to an effector (muscle) cell.

Understanding: When presynaptic neurones are depolarized they release a neurotransmitter into the synapse.

Model sentence: The chemical communication released by a presynaptic neurone is called a neurotransmitter.

There is always a narrow, fluid-filled space between the end of a presynaptic neurone and the dendrites of a postsynaptic neurone. This space is called a synaptic gap.

The presynaptic neurone releases a chemical into the synaptic gap. This chemical is called a neurotransmitter.

The neurotransmitter affects the postsynaptic neurone causing it to begin an action potential.

Application: Secretion and reabsorption of acetylcholine by neurones at synapses

One of the more common neurotransmitters used in the body is called acetylcholine. Acetylcholine is released by a presynaptic neurone and diffuses across the synaptic gap. Acetylcholine binds to receptor proteins on the postsynaptic neurone. This causes the postsynaptic neurone to begin a nerve impulse. An enzyme in the synaptic gap degrades acetylcholine. Finally, the neurotransmitter 'pieces' are released and reabsorbed back into the presynaptic neurone.

Application: Blocking of synaptic transmission at cholinergic synapses in insects by binding of neonicotinoid insecticides to acetylcholine receptors

When acetylcholine is released into a synaptic gap it must bind to a receptor protein on the postsynaptic neurone. Synapses that use acetylcholine as a neurotransmitter are called cholinergic synapses. If acetylcholine does not bind, the nerve impulse is not continued.

Researchers have recently come up with a new type of insecticide. These insecticides are called neonicotinoid insecticides. Neonicotinoid molecules fit the receptor proteins on the postsynaptic neurones that normally fit and accept acetylcholine. Thus, the insecticide molecules prevent the synapse from working correctly and the insect dies of paralysis.

Understanding: A nerve impulse is only initiated if the threshold potential is reached.

Model sentence: Each neurone has a minimum strength stimulus, called a threshold potential, that is needed to begin an impulse.

Each type of receptor neurone responds to a different type and intensity of a stimulus. For example, there are photoreceptors in your retina that only begin a nerve impulse if they receive red light. In addition, the intensity of that red light must be high enough to initiate the action potential. This minimum intensity of a particular stimulus type is called the threshold potential of that stimulus.

If the threshold stimulus is not reached no nerve impulse is sent. A nerve impulse from any one receptor is an 'all or nothing' event. In other words, an impulse is either sent or not.

6.6 Hormones, homeostasis, and reproduction

Understanding: Insulin and glucagon are secreted by β cells and α cells in the pancreas, respectively, to control blood glucose concentration.

Model sentence: The pancreas contains beta (β) cells that produce insulin and cells called alpha (α) cells that produce glucagon to help regulate the glucose concentration in the blood.

The pancreas is an endocrine gland. An endocrine gland produces hormones. These hormones are distributed to body cells by the bloodstream.

One hormone produced by the pancreas is insulin. Insulin is produced by beta (β) cells in the pancreas. Insulin results in body cells taking in glucose from the blood. This lowers the concentration of glucose in the blood.

A second hormone produced by the pancreas is glucagon. Glucagon is produced by α cells in the pancreas. Glucagon results in the liver releasing a stored form of glucose. This increases the concentration of glucose in the blood

Application: Causes and treatment of type I and type II diabetes

Diabetes is a disease where the body does not effectively regulate the level of glucose in the bloodstream and the amount of glucose provided to body cells. There are two types of diabetes:

- Type I diabetes – people are born with type I diabetes. This is a genetic disease where the cells that produce insulin are destroyed by one's own immune system. Treatment is regular injections of insulin when appropriate.
- Type II diabetes – this is a type of diabetes that develops during one's lifetime. Insulin is being produced but body cells do not respond. Treatment is control of one's diet and a healthy lifestyle.

Subject vocabulary

photoreceptors receptors in the eye that respond to light by beginning a nerve impulse

homeostasis steady or controlled state

beta (β) cells cells in the pancreas that produce and secrete the hormone insulin

alpha (α) cells cells in the pancreas that produce and secrete the hormone glucagon

endocrine gland a gland that produces a hormone

type I diabetes a genetic disease where insulin is not being produced by the pancreas in sufficient amounts

type II diabetes a form of diabetes where one develops a resistance to the normal function of insulin

Synonyms

initiate........... start/begin

Subject vocabulary

thyroxin hormone that results in an increase in cell metabolism

thyroid gland endocrine gland that produces thyroxin

metabolic rate sum total of all cell and organism chemical reactions including cell respiration

leptin hormone produced by body fat that lowers the appetite

adipose tissue body fat

hypothalamus a region of the brain that controls pituitary gland secretions and other autonomic functions

melatonin hormone produced by the pineal gland

pineal gland small gland located within the brain

circadian rhythm a cycle of something based on a 24-hour time period

Synonyms

secreted .... produced/released

inhibit .... prevent/reduce

General vocabulary

regulate to adjust the degree or rate of something

obesity being overweight in an unhealthy way

Understanding: Thyroxin is secreted by the thyroid gland to regulate the metabolic rate and help control body temperature.

Model sentence: The thyroid gland produces a hormone called thyroxin that helps regulate body metabolism including the control of body temperature.

The thyroid gland is an endocrine gland located in the neck area. It produces the hormone thyroxin.

Thyroxin increases the metabolic rate of all cells. Increased metabolic rate will generally increase internal body temperature:

- To lower body temperature – body decreases thyroxin production.
- To raise body temperature – body increases thyroxin production.

Hints for success: In an examination, you should know that humans have a nearly constant internal body temperature of 37 °C.

Understanding: Leptin is secreted by cells in adipose tissue and acts on the hypothalamus of the brain to inhibit appetite.

Model sentence: Adipose tissue secretes leptin, a hormone that targets the hypothalamus of the brain to help lower one's appetite.

Leptin is a hormone produced by fat stored in the body.

The production of leptin is high after eating. Leptin travels in the bloodstream to the brain, where it affects cells in the hypothalamus of the brain. The effect is to lower the appetite.

Application: Testing of leptin on patients with clinical obesity

Leptin is a hormone produced by adipose tissue (body fat). Leptin should decrease appetite. Logic says that obese people should have lowered appetites. This has not been shown to be the case. One theory says that the function of leptin is only evident in those people with very low body fat. The theory says that those people produce very little leptin and increase their appetite in order to gain body fat.

Understanding: Melatonin is secreted by the pineal gland to control circadian rhythms.

Model sentence: The pineal gland secretes a hormone called melatonin that helps regulate our 24-hour sleep-wake cycle.

The pineal gland is a very small gland located within the interior of the brain. It secretes the hormone melatonin.

Levels of melatonin change over a 24-hour time period. A repeating pattern that occurs over a 24-hour time period is called a circadian rhythm.

The changes in melatonin help us to fall asleep and wake up.

Application: Use of melatonin to alleviate jet lag

Jet lag is the term used when someone flies a long distance and their destination is a time zone that is far different from where they started. This upsets the circadian rhythm and the sleep–wake cycle. Some people report that taking pills with melatonin help lessen the symptoms of jet lag.

Understanding: A gene on the Y chromosome causes embryonic gonads to develop as testes and secrete testosterone.

Model sentence: The Y chromosome of male embryos has a gene that results in formation of testes that soon begin secreting testosterone.

Females have the chromosome pattern of XX and males XY. Thus, females do not have a Y chromosome. The Y chromosome contains a gene that causes embryonic gonad tissue to become testes. This gene is called the *SRY* gene. The *SRY* gene produces a protein that helps to regulate other genes that are important in becoming a male. The testes soon begin producing and secreting the hormone testosterone.

Understanding: Testosterone causes prenatal development of male genitalia and both sperm production and development of male secondary sexual characteristics during puberty.

Model sentence: Before birth testosterone results in the formation of male sex organs; at puberty, testosterone results in sperm production and formation of secondary sex characteristics.

Testosterone is a hormone that causes male reproductive structures to form. The male reproductive structures are often called the male genitalia. The development of male genitalia is called prenatal as it happens before birth.

When a young man becomes a teenager he enters a stage of life called puberty. At this time, the testes begin a higher secretion of testosterone. This leads to sperm production and development of male secondary sexual characteristics.

Some male secondary sex characteristics are:

- increase in muscle growth
- increase in height
- deeper voice
- body hair in armpits and pubic region.

General vocabulary

alleviate to make something less severe

Subject vocabulary

jet lag disruption of the sleep–wake cycle

Y chromosome a chromosome only found in males

embryonic early development after fertilization

gonads the tissue that produces sperm in males and eggs in females (testes and ovaries)

testosterone hormone produced by the testes of males

testes male organs where spermatogenesis occurs

***SRY* gene** a gene located on the Y chromosome that leads to an embryo becoming male

prenatal before birth

genitalia sex organs such as the penis

secondary sexual characteristics body characteristics that begin at puberty

puberty age in males and females where reproduction is first possible

Synonyms

pubic............. groin

Skill: Annotate a diagram of the male reproductive system to show names of structures and their functions

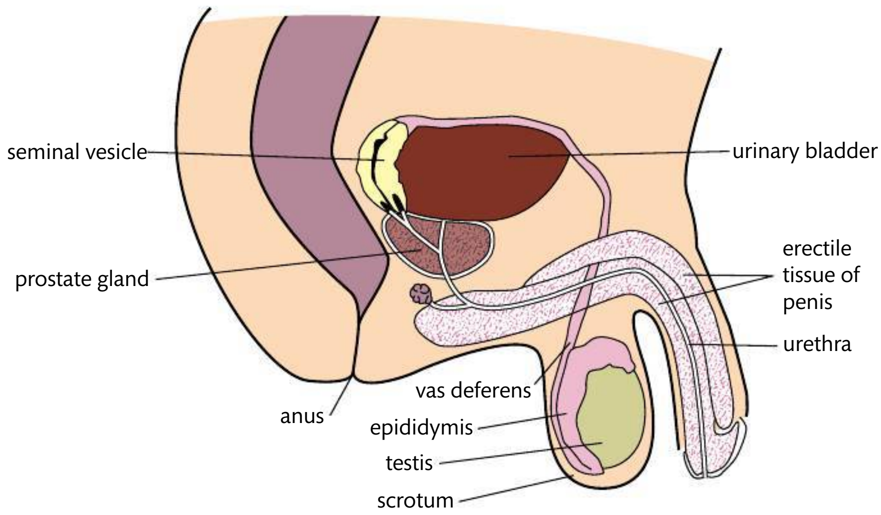


Figure 6.12 *Male reproductive structures and their functions*

Structure	Function
testis	sperm are produced here and testosterone is produced here
epididymis	area where sperm are stored
scrotum	sacs that hold the testes outside of the body
vas deferens	a tube that carries sperm
seminal vesicle	small glands that add fluid to the sperm
prostate gland	another gland that adds fluid to the sperm
penis	a structure capable of becoming erect during sex
urethra	the tube in which semen leaves the body during sex

Understanding: Oestrogen and progesterone cause prenatal development of female reproductive organs and female sexual characteristics at puberty.

Model sentence: Before birth, oestrogen and progesterone result in the formation of female sex organs; at puberty, these two hormones result in the formation of female sex characteristics.

Oestrogen and progesterone are hormones produced during the prenatal development of females. These two hormones are responsible for the formation of the female genitalia.

Subject vocabulary

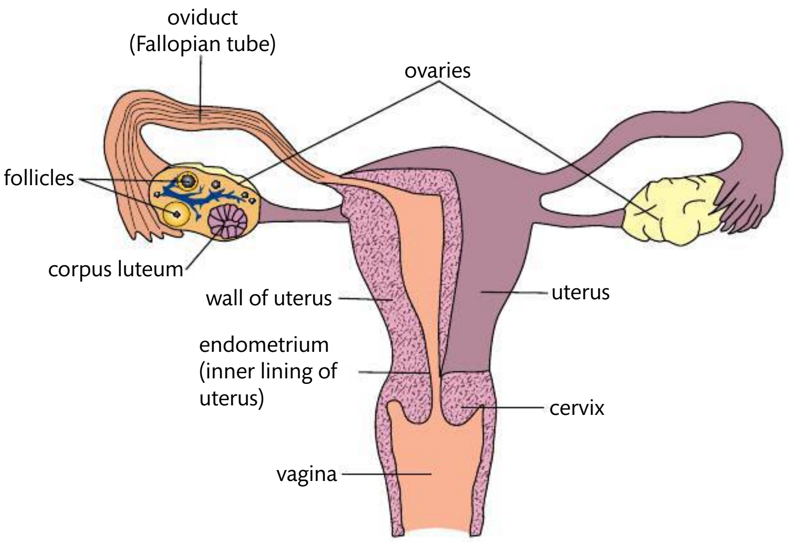
oestrogen one of two hormones produced by the ovaries of a female

progesterone hormone produced initially by ovaries / signals endometrium of uterus to remain ready to receive an embryo

At the age of puberty the increased levels of these two hormones result in the formation of the female secondary sex characteristics. Some female secondary sex characteristics are:

- development of breasts
- body hair in armpit and pubic region
- increase in height
- **menstrual cycle** begins.

Skill: Annotate a diagram of the female reproductive system to show names of structures and their functions



Structure	Function
ovaries	organ that produces and releases ovum and hormones
Fallopian tubes	ducts that can carry an early embryo to the uterus
uterus	muscular organ where an embryo can develop
endometrium	inside lining of the uterus
cervix	opening from vagina to inside of uterus
vagina	semen is deposited here during sex

Understanding: The menstrual cycle is controlled by negative and positive feedback mechanisms involving **ovarian** and **pituitary hormones**.

Model sentence: The pituitary gland and the ovary both secrete hormones that control the timing of the menstrual cycle by negative and positive feedback mechanisms.

The female menstrual cycle is a series of events that lead to the release of an egg from an ovary. At the same time, the uterus must be prepared to receive a young embryo if the released ovum is fertilized. Many of these events are controlled by the release of specific hormones at specific times.

Subject vocabulary

menstrual cycle a cycle of events in females that results in release of an egg from an ovary

ovarian hormones hormones produced by an ovary (oestrogen and progesterone)

pituitary hormones those hormones produced by the pituitary gland (FSH and LH)

Figure 6.13 *Female reproductive structures and their functions*

Here is a summary of the hormonal events of the menstrual cycle:

Hormone	Secreted from	Effect of hormone
FSH	pituitary gland	prepares ovum within a **follicle** for release (**ovulation**)
LH	pituitary gland	prepares ovum for release (ovulation)
oestrogen	follicle cells of the ovary	prepares female uterus to receive young embryo if a fertilization occurs
progesterone	**corpus luteum** of ovary (only after ovulation)	maintains the uterus to receive a young embryo if a fertilization occurs

Positive feedback is when one event increases the level of another event. An example of this in the menstrual cycle is the effect that oestrogen increase has. When oestrogen is secreted at relatively high levels from the ovary this increases the amount of FSH secreted by the pituitary gland.

The menstrual cycle also shows negative feedback control. Negative feedback is when one event decreases the level of another event. An example of this is when the ovary increases levels of progesterone. This leads to decreased FSH and LH secreted by the pituitary.

Application: The use in IVF of drugs to suspend the normal secretion of hormones, followed by the use of artificial doses of hormones to induce superovulation and establish a pregnancy

Some people make use of a reproductive technique abbreviated as **IVF** in order to have children. IVF stands for 'in vitro fertilization'. The technique requires an **oocyte** to be taken from a female. This oocyte is then placed into a glass dish where it is fertilized by the father's sperm. After the fertilized egg develops into a young embryo, the embryo is placed into the mother's uterus for development.

IVF has a much higher success rate if several embryos are produced at the same time. Thus, it is common for the mother to be treated with hormones that will cause what is called a superovulation. This is where the ovaries produce and ovulate many eggs during one menstrual cycle. Many eggs can then be collected to be fertilized for the IVF procedure.

Application: William Harvey's investigation of reproduction in deer

William Harvey was most famous for his experimental work that showed how blood circulates in the body. He also did many dissections on deer. This work showed many of the developmental stages of mammals. He was not able to study the early embryonic stages as the microscopic was not yet in use in the early 1600s when he was carrying out his investigations.

Subject vocabulary

follicle an egg surrounded by numerous follicle cells

ovulation release of a follicle from the ovary

corpus luteum a gland that forms in the ovary in the location where an ovum is released

IVF a technique for fertilization of eggs outside of the body

oocyte the large cell that is the female's gamete

7.1 DNA structure and replication

Main idea

The functions of DNA are possible because of its structure.

Understanding: Nucleosomes help to supercoil the DNA.

Model sentence: Structures called nucleosomes allow DNA to fit within the nucleus of a cell.

A single chromosome is a molecule of DNA. This molecule of DNA may be as long as 4 cm.

Each species of organism with eukaryotic cells has a specific number of chromosomes. The human species has 46 chromosomes normally.

Coiling is necessary for all the chromosomes of a eukaryotic cell to fit in the cell nucleus. This coiling is extensive and is referred to as supercoiling. The supercoiling occurs around spherical molecules of a group of proteins called histones.

A section of DNA coiled around a core of eight histone molecules is called a nucleosome.

A ninth histone molecule holds the DNA coiling in place around the core histone molecules.

Nucleosomes are connected by linker DNA. Linker DNA is a short section of DNA.

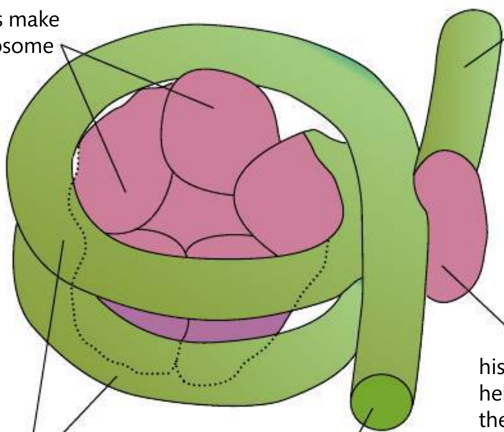


Figure 7.1 *Histones and DNA together form nucleosomes*

Skill: Utilization of molecular visualization software to analyse the association between protein and DNA within a nucleosome

There are many sites on the internet where a model of a nucleosome can be seen. Observe some of these to gain an understanding of how the folding of DNA occurs. Watch videos from several different sites showing examples of the DNA folding process.

Subject vocabulary

nucleosome structure found in eukaryotic chromosomes consisting of a strand of DNA wrapped around eight histone molecules

chromosomes structures on which DNA occurs within a cell

species a group of organisms which are structurally similar and able to pass their genetic traits onto their offspring

eukaryotic cells all cells that are not bacteria

supercoiling a process in which intense folding and coiling of a structure occurs

histones proteins associated with DNA in eukaryotic chromosomes

linker DNA short section or strand of DNA which occurs between adjacent nucleosomes

General vocabulary

extensive wide ranging

Synonyms

spherical........ round

Understanding: DNA structure suggested a **mechanism** for DNA **replication**.

Model sentence: With the finding of the structure of DNA came a logical way to explain how DNA may make copies of itself.

Many scientists from all over the world were involved in the early studies of DNA. Findings of these studies led to the explanation of the detailed structure of DNA.

Research done by Alfred Hershey and Martha Chase provided evidence that DNA was the actual genetic material of the cell.

Rosalind Franklin and Maurice Wilkins **conducted X-ray diffraction** studies of DNA.

Erwin Chargaff analysed data involving the **nitrogenous** bases of DNA.

Francis Crick and James Watson used information provided by Franklin, Wilkins, Chargaff, and other world scientists to produce the model of the structure of DNA we recognize today.

The **base pairing** between the two strands which make up the DNA model was a major factor in the **semi-conservative** explanation of DNA **replication**.

Application: Rosalind Franklin's and Maurice Wilkins' investigation of DNA structure by X-ray diffraction

Rosalind Franklin and Maurice Wilkins provided some key findings concerning the structure of DNA. They used X-ray diffraction studies of DNA. Their investigations gave the following results:

- The distance between the two DNA **strands** is consistent all through the molecule.
- The DNA molecule is a **double helix**.
- The distance between the twists of the helix was determined. This distance was found to be consistent throughout the molecule.
- The DNA molecule is made up of repeating units.

Skill: Analysis of results of the Hershey and Chase experiment providing evidence that DNA is the genetic material

Alfred Hershey and Martha Chase carried out experiments that helped confirm that DNA is the genetic material. They used **radioisotopes** of sulfur and phosphorus in their experiments. Radioisotopes give off **radiation** which can be detected. These radioisotopes are said to be **radioactive**. Hershey and Chase used **viruses** labelled with these radioisotopes to infect **bacterial cultures** in their work. Study the figure below which summarizes their experiment:

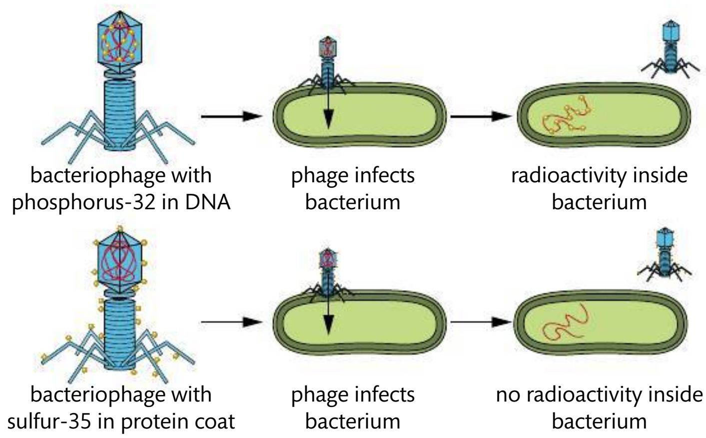


Figure 7.2 *The Hershey–Chase experiment used radioisotopes as markers to label the DNA and protein of T2 bacteriophages. The basic procedure and findings are shown here*

Synonyms

mechanism .... way/process

conducted...... undertook

Subject vocabulary

replication process of producing a copy of a molecule or structure

X-ray diffraction bending of X-rays as it passes through a substance

nitrogenous containing nitrogen

base pairing process in DNA replication and protein synthesis in which nitrogenous base pairing is very specific

semi-conservative type of replication in DNA in which each new DNA molecule has one original strand of the parent molecule

replication process of producing a copy of a molecule or structure

double helix three-dimensional shape of DNA involving a double spiral

radioisotope an isotope which is radioactive

radiation particles given off by a substance which allow its tracking

radioactive element or isotope which gives off energetic particles

virus infectious particle composed of protein and nucleic acid not able to replicate itself outside a cell

bacterial cultures a laboratory collection or association of bacteria maintained for study

General vocabulary

strands single thin pieces of matter

Key points from the experiment:

- When the virus, a **bacteriophage**, was labelled with the radioisotope phosphorus-32, radioactivity was measureable within the bacterium.
- When the virus was labelled with the radioisotope sulfur-35, no radioactivity was measureable within the bacterium.
- Radioactive phosphorus was found in the region of the bacterial cell where the genetic material was known to exist. Radioactive sulphur was not.
- Since DNA contains phosphorus and not sulfur, DNA was shown to be the genetic material.

Subject vocabulary

bacteriophage a type of virus which infects bacteria

nucleotides smaller units chemically bonded to form nucleic acids

primer some process or structure needed to begin a specific task

Understanding: DNA polymerases can only add **nucleotides** to the 3′ end of a **primer**.

Model sentence: The strand produced during DNA replication is lengthened by adding nucleotides to the 3′ end only.

DNA is a double stranded molecule. The strands are anti-parallel to one another.

The 5′ and 3′ refer to which carbon of the nucleotide deoxyribose is on the end of the strand.

The strand being produced in semi-conservative replication always has nucleotides added to its 3′ end. A type of **DNA polymerase** is the enzyme that causes nucleotides to be added only on the 3′ end. DNA replication, therefore, occurs in the 5′ to 3′ direction.

Prokaryotic DNA is a single, relatively short, and circular chromosome. Prokaryotic DNA has only one site which serves as the **origin of replication**. Replication in the prokaryotic chromosome proceeds in both directions around the loop from the origin of replication.

Eukaryotic DNA is not circular. Eukaryotic DNA involves multiple chromosomes of relatively large size. Each eukaryotic chromosome has many sites serving as origins of replication. This allows for a much faster replication process.

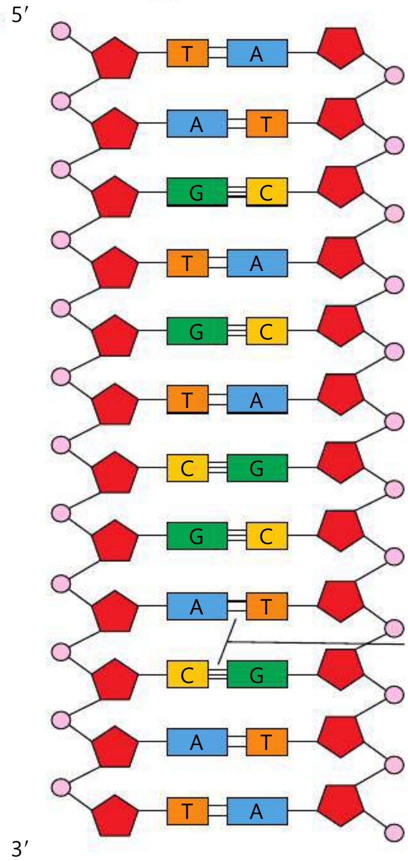


Figure 7.3 *The antiparallel strands in DNA run in opposite directions*

Hints for success: To understand the position of growth of a DNA strand, draw a single DNA nucleotide including its three major parts. It should look similar to the following diagram.

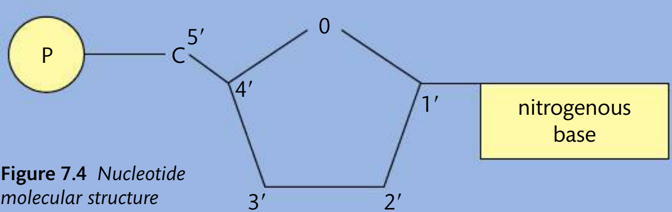


Figure 7.4 *Nucleotide molecular structure with carbons labelled*

Nucleotides are added to the carbon of deoxyribose labelled 3′ in DNA replication. DNA polymerase can only bring about the addition of nucleotides at the 3′ end of the DNA chain.

Nucleotides are added to the 3′ end of an existing DNA chain by a **covalent bond**. This covalent bond is specifically called a **phosphodiester bond**.

Subject vocabulary

DNA polymerase group of enzymes which are involved in DNA replication

prokaryotic bacterial cells

origin of replication point on a DNA molecule which opens to begin the replication process

covalent bond chemical bond in which electrons are shared

phosphodiester bond type of covalent bond in DNA and RNA which involves two hydroxyl groups and one phosphate group

Understanding: DNA replication is continuous on the leading strand and discontinuous on the lagging strand.

Model sentence: The two strands of DNA are different in how they are replicated because they are antiparallel to one another.

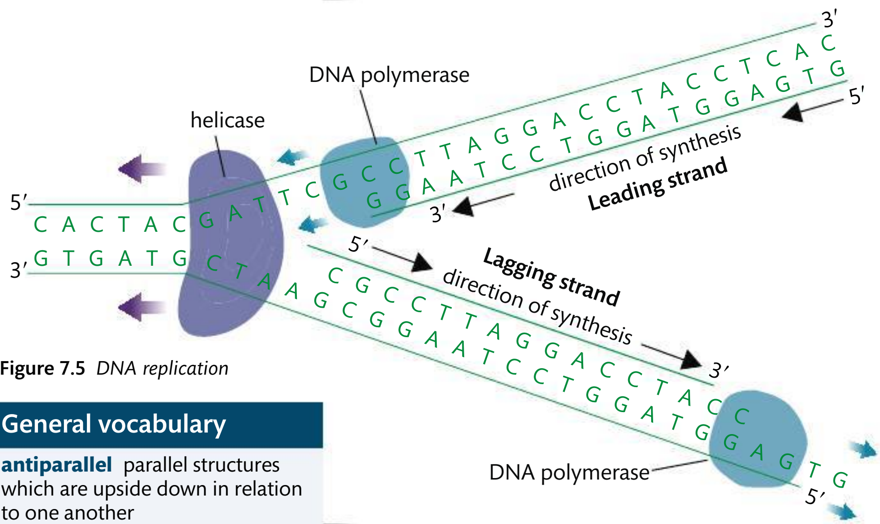


Figure 7.5 *DNA replication*

Both strands of DNA must be replicated to produce two molecules of DNA from the original DNA molecule.

These strands are **antiparallel**. Antiparallel means the two strands of DNA are upside down when compared to one another. One strand of the DNA molecule has the 5′ carbon on the top of the chain and the 3′ carbon on the bottom. The other strand has the 3′ carbon on top and the 5′ carbon on the bottom. Each strand may only be built in the 5′ to 3′ direction due to DNA polymerase.

One strand is built continuously from the origin of replication site. This strand is called the **leading strand**. The other strand is not built continuously. It is built in **fragments**. This strand is called the **lagging strand**. Study the diagram above.

Note: there are several reasons for a leading and a lagging strand in DNA semi-conservative replication. These reasons include:

- DNA polymerase may only allow nucleotide additions to a DNA strand at the 3′ end.
- The two strands of DNA are antiparallel to one another.
- The leading strand requires fewer steps to completion and will finish replicating before the lagging strand.

Understanding: DNA replication is carried out by a complex system of enzymes.

Model sentence: There is a large number of enzymes involved in the control of DNA replication.

Enzyme	Role
helicase	unwinds the double helix at the **replication forks** (sites of replication origin) by breaking hydrogen bonds
DNA gyrase (DNA topoisomerase)	acts to decrease the helical strain just ahead of helicase activity, stabilizes the single strands
primase	synthesizes **RNA primer** which is necessary to begin the **synthesis** of a strand (leading strand) or **Okazaki fragment** (lagging strand)

General vocabulary

antiparallel parallel structures which are upside down in relation to one another

Subject vocabulary

leading strand in DNA replication the strand produced continuously

lagging strand in DNA replication the strand produced in segments called Okazaki fragments

helicase enzyme which opens the DNA double helix in the replication process

replication forks the point at which the helix of DNA unwinds to allow replication

DNA gyrase (DNA topoisomerase) enzyme which lessens the strain of the DNA helix just ahead of helicase activity

primase synthesizes RNA primer which is necessary to begin the synthesis of a DNA strand or fragment in DNA replication

RNA primer a short length of RNA that forms the starting point for DNA synthesis

synthesis constructing complex molecules from smaller, simpler ones

Okazaki fragment segments of DNA produced on the lagging strand in DNA replication

Synonyms

fragments ...... pieces

Enzyme	Role
DNA polymerase III	allows the building of the new DNA strand by adding DNA nucleotides onto RNA primer or onto the 3′ end of the existing DNA segment
DNA polymerase I	removes the RNA primer and replaces it with DNA nucleotides
DNA ligase	joins the ends of DNA segments and Okazaki fragments

Single-stranded binding proteins are not enzymes. However, they are involved in the replication process by keeping the DNA strands apart until these strands are copied.

Hints for success: The diagram below shows the location and function of each of the enzymes involved in DNA replication in prokaryotic cells. DNA gyrase would be placed **adjacent** to the helicase on the unopened DNA double helix.

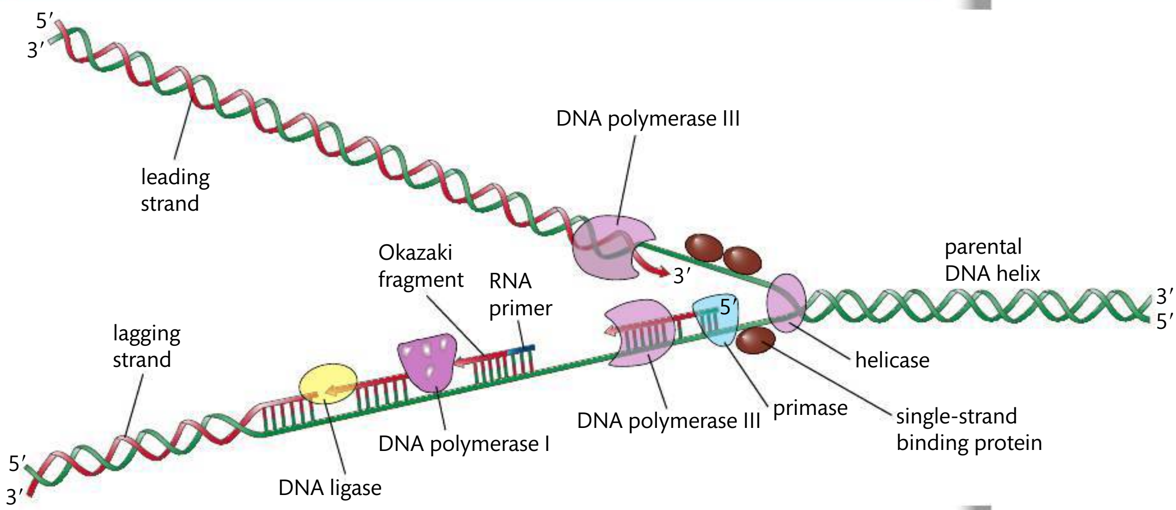


Figure 7.6 *DNA replication in prokaryotic cells*

Subject vocabulary

DNA polymerase III enzyme which adds DNA nucleotides to the RNA primer or the 3′ end of the DNA strand

DNA polymerase I enzyme which removes the RNA primer and replaces it with DNA nucleotides in DNA replication

DNA ligase enzyme which joins the ends of Okazaki fragments to produce a continuous strand

General vocabulary

adjacent next to

Understanding: Some regions of DNA do not code for proteins but have other important functions.

Model sentence: Many nucleotide sequences within a DNA molecule have functions other than coding for protein production.

Most of the DNA nucleotide sequences in eukaryotic cells do not code for protein formation. These non-protein coding sequences include:

- **Telomeres** which occur on the ends of chromosomes and have a protective function. Telomeres also shorten with each chromosomal replication. They seem to play a role in the number of reproductive cycles a cell may go through.
- Areas which act as regulators of gene expression.
- Areas which code for **tRNA** molecules.
- **Highly repetitive sequences** of nucleotides which include transposable elements capable of changing their position within a chromosome. The **centromere** region and the telomeres of chromosomes are actually examples of highly repetitive sequences. However, these two regions of highly repetitive sequences are not transposable.

Subject vocabulary

telomeres repeated DNA sequences which occur at the tip of chromosomes which shorten with cell divisions

tRNA transfer RNA, the molecule that carries an amino acid to the ribosome in protein production

highly repetitive sequences short DNA nucleotide repeats typically not transcribed

centromere region where sister chromatids attach

- **Short tandem repeats** are chromosomal regions of variable numbers of repeats of nucleotide sequences. These short tandem repeats occur in specific **loci** of a species' chromosomes.

Application: Tandem repeats are used in DNA profiling

These short tandem repeats are unique for each individual. Analysing regions of short tandem repeats allows identification of family relationships, possible criminal activity, and identification of disaster victims. DNA analysis involves the use of **restriction enzymes** and **gel electrophoresis**. **DNA fragment bands** are produced when restriction enzymes and gel electrophoresis are used. The unique position of these fragment bands on the gel is then analysed to determine relationships.

Application: Use of nucleotides containing dideoxyribonucleic acid to stop DNA replication in preparation of samples for base sequencing

Special nucleotides containing **dideoxyribonucleic acid** are used to stop DNA replication in preparation for **base sequencing** in DNA profiling. There are four different nucleotides with each containing a dideoxyribonucleic acid. Each of these four special nucleotides have a different **fluorescent marker** attached to them. Observing the position of these florescent markers allows the sequencing of a segment of DNA since they stop the DNA replication process at the exact position they are added.

7.2 Transcription and gene expression

Main idea

The DNA code must be copied onto **mRNA** if it is to be involved in protein synthesis.

Understanding: Transcription occurs in a 5′ to 3′ direction.

Model sentence: mRNA produced by transcription is formed by adding RNA nucleotides to the 3′ end of the existing chain.

mRNA is a single-stranded molecule produced by **complementary base pairing** of the **template strand** of DNA. This template strand of DNA is also known as the **antisense strand**. The **sense strand** of DNA is not used to produce mRNA. However, the sense strand does contain the same code as the mRNA produced on the template strand.

Application: The promoter as an example of non-coding DNA with a function

DNA has **promoter regions** on the template strand. The promoter is a non-coding region of the DNA molecule which binds with **RNA polymerase** to begin the process of transcription of a particular DNA segment (gene).

The enzyme known as RNA polymerase starts transcription by attaching to the DNA strand at a promoter. RNA polymerase aids the addition of the 5′ end of a free RNA nucleotide to the 3′ end of an existing mRNA molecule. Transcription then continues in a 5′ to 3′ direction until a **terminator sequence** is **encountered**. The RNA polymerase detaches from the template strand at the terminator sequence. This ends the transcription process at this DNA location.

Subject vocabulary

short tandem repeats repeating sequence of 1–5 nucleotides which varies in number of repeats for different individuals

locus (plural: loci) the specific place where a gene is found on a chromosome

tandem repeats segments of DNA composed of particular sequences of repeating DNA nucleotides

DNA profiling method of studying DNA using restriction enzymes and gel electrophoresis

restriction enzymes enzymes which cut DNA at particular nucleotide sequences

gel electrophoresis process using electricity passing through a gel matrix to separate fragments or molecules of proteins or nucleic acids

DNA fragment bands DNA bands of different size produced by restriction enzymes which migrate at different rates in gel electrophoresis

dideoxyribonucleic acid component in nucleotides used to stop DNA replication at specific locations

base sequencing process in which the exact sequence in a DNA fragment or molecule is produced

fluorescent marker used to allow identification in DNA studies

mRNA messenger RNA carries the DNA code from the nucleus to the cytoplasmic ribosomes for specific production of proteins

transcription the process of creating RNA from DNA

complementary base pairs nitrogenous bases which pair together in nucleic acids, A–T, A–U, C–G

template strand DNA strand, also known as the antisense strand, where complementary base pairing occurs to produce mRNA

antisense strand DNA template strand in transcription

sense strand DNA strand not transcribed in the production of mRNA, contains the same code as the mRNA which is produced on the template strand

promoter region non-coding DNA region which binds with RNA polymerase to begin the transcription process

RNA polymerase enzyme involved in the transcription process

terminator sequence sequence of DNA which stops the transcription process for a particular protein

Synonyms

encountered..... met/reached

Understanding: Nucleosomes help to regulate transcription in eukaryotes.

Model sentence: The packaging of DNA that occurs at nucleosomes serves as a regulator of transcription in eukaryotic cells.

DNA wrapped around histones in nucleosomes is inaccessible to transcription enzymes. This wrapping prevents transcription of this part of DNA from occurring.

DNA wrapped around the histones of a nucleosome is also subjected to chemical changes that affect its ability to be transcribed. These chemical changes often involve the addition of acetyl or methyl groups.

Skill: Analysis of changes in the DNA methylation patterns

Analysis of changes in the DNA methylation patterns has produced some very interesting observations. Many cancer cells have either a larger amount of methylation or a lower amount of methylation than non-cancerous cells. The presence of methyl groups also seems to play a role in the maternal or paternal expression of a gene. The analysis of methylation patterns has shown changes in an organism's amount of methylation as they go through the ageing process.

Understanding: Eukaryotic cells modify mRNA after transcription.

Model sentence: The mRNA produced by transcription in eukaryotic cells goes through several changes before it leaves the nucleus to enter the cytoplasm.

Changes to mRNA produced by transcription before exiting the nucleus:

- Segments of non-coding mRNA called introns are cut and removed from the original mRNA strand produced. The original mRNA strand is known as the pre-mRNA strand.
- Small nuclear RNAs (snRNAs) known as spliceosomes bring about this cutting and removal. This process is called splicing.
- The mRNA segments remaining after splicing are called exons.
- The exons are then chemically connected to one another.
- A cap is added to the 5′ end of the mRNA segment.
- The 3′ end of mRNA segment then has a poly-A tail added.
- The final product is called mature mRNA. It then leaves the nucleus to enter the cytoplasm.

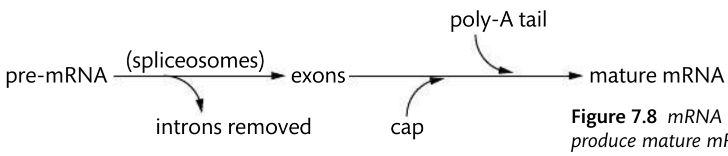


Figure 7.8 *mRNA modification to produce mature mRNA*

Hints for success: The modification of the original strand of mRNA is necessary for many reasons. The intron portions are not involved in protein synthesis at the ribosomes and must be removed by the splicing process. The cap and poly-A tail serve to protect mature mRNA as it moves through the pores of the nuclear membrane into the cytoplasm. The cap and poly-A tail also seem to enhance or help the translation process at the ribosome.

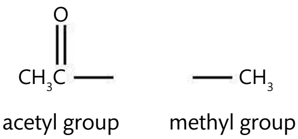


Figure 7.7 *Molecular groups involved in DNA regulation*

Subject vocabulary

methylation patterns refers to the methyl groups which occur on DNA of organisms

cancerous of or involving cancer

introns non-coding regions of DNA which are transcribed onto the mRNA molecules, they are removed before leaving the nucleus

pre-mRNA strand original, unprocessed strand of mRNA produced in transcription

small nuclear RNAs snRNAs also known as spliceosomes

snRNAs small nuclear RNAs involved in the cutting of pre-mRNA strands to remove introns

spliceosomes also known as snRNAs which remove introns from pre-mRNA

splicing the removal of introns from mRNA

exons sections of mRNA containing the protein coding nucleotide sequences

cap protective structure added to the 5′ end of mRNA after processing before the mRNA leaves the nucleus

poly-A tail protective structure added to the 3′ end of mRNA after processing before the mRNA leaves the nucleus

mature mRNA final product of mRNA processing which occurs in the nucleus and will be translated at the ribosome

General vocabulary

maternal relating to being a mother

paternal relating to being a father

Synonyms

pore................ hole/opening

Understanding: Splicing of mRNA increases the number of different proteins an organism can produce.

Model sentence: The modification of mRNA in the splicing process allows a larger number of proteins to be produced at the cell's ribosomes.

The splicing process allows a gene to produce several different proteins. Different proteins are produced when exons are **removed** in the splicing process. It is also possible for exons to change position in the splicing process. This will allow the production of different proteins. In some higher eukaryotes, different sections of a gene may act as introns at different times. Again, this will result in the production of different proteins.

General vocabulary

removed taken away

Subject vocabulary

sequence a series of bases in the genetic code in a particular order

promoter region non-coding DNA region which binds with RNA polymerase to begin the transcription process

transcription activator proteins which cause looping of DNA and increase expression of a gene

activator transcription factor which causes transcription of a gene

repressor proteins bind to segments of DNA and prevent transcription and gene expression

silencer segment of DNA to which a repressor protein binds

enhancers parts of DNA that speed up transcription by binding to certain proteins

genotype genes of an organism for a particular trait

phenotype visible result of an organism's genotype

pigmentation pattern of coloration

Understanding: Gene expression is regulated by proteins that bind to specific base **sequences** in DNA.

Model sentence: Proteins which bind to DNA have a controlling factor in gene expression.

There are several types of proteins which have an effect on gene expression in the cell. These proteins bind to certain base sequences of DNA to cause their effect. Examples include:

- Proteins which assist the binding of RNA polymerase at the **promoter region** to bring about a higher rate of transcription.
- **Transcription activators** are proteins which cause looping of DNA. The looping of DNA may result in a shorter distance between the **activator** and the promoter regions of a gene. This will increase the expression of that gene.
- **Repressor proteins** may bind to segments of DNA known as **silencers**. This prevents transcription and gene expression.

Enhancers are sections of DNA which proteins may combine with to increase the rate of transcription of a particular gene. Silencers are sections of DNA to which proteins may attach. This decreases the rate of transcription of a gene.

Understanding: The environment of a cell and of an organism has an impact on gene expression.

Model sentence: The environment of an organism has an effect on the expression of genes of that organism's cells.

Organisms with the same **genotypes** often express different **phenotypes** when in different environments.

Identical twins are often used in studies to prove the effect of different environments.

Examples of this include:

- The gene which produces fur **pigmentation** in Himalayan rabbits is only active at temperatures between 15 and 25 °C.
- When the larval form of the *Vanessa urtica* butterfly is placed in red light, it produces intensely coloured wings. When a larva of the same species is placed in green light, dark colourless wings are produced.

7.3 Translation

Main idea

Translation involves the transfer of the DNA code into an amino acid sequence.

Understanding: Initiation of translation involves assembly of the **components** that carry out the process.

Model sentence: Translation begins with the binding of a mature mRNA strand with the two subunits of a ribosome.

The process called translation occurs at the ribosome. Translation uses the base sequence of the DNA code to produce a specific **polypeptide** which may become a protein. A protein has a much more detailed structure than a polypeptide. Proteins may be made up of one or more polypeptides. Proteins differ from one another by the number and the sequence of amino acids of which they are composed. The sequence of the steps involved in cellular protein synthesis is:

DNA (gene) $\rightarrow$ transcription (mRNA) $\rightarrow$ translation $\rightarrow$ protein

Translation involves the following components:

- ribosome
- mature mRNA
- tRNA
- amino acids.

A **ribosome** must bind with a mature mRNA strand before tRNA can begin bringing amino acids to the **complex**. The complex is the combination of the ribosome and the mRNA strand. This formation of the **ribosome–mRNA complex** is the initiation or beginning of the translation process.

The sequence of events to initiate translation is:

- The mature mRNA strand attaches first to the small subunit of the ribosome.
- A tRNA carrying the amino acid **methionine** attaches to an mRNA binding site.
- The large ribosomal subunit then attaches to these parts.

Skill: The use of molecular visualization software to analyse the structure of eukaryotic ribosomes and a tRNA molecule.

Utilizing websites which show the molecular structure of eukaryotic ribosomes is essential to understand their function. Examining a website showing the molecular structure of a eukaryotic ribosome will show the following key points:

- Ribosomes are composed of protein and rRNA molecules.
- Ribosomes are composed of one larger subunit and one smaller subunit.
- Each ribosome has three binding sites to which tRNA may attach.

Subject vocabulary

translation process of protein production which occurs at the ribosome in cells, DNA language is changed into the language of proteins

polypeptide polymer of many amino acids combined by peptide bonds

ribosome organelle within cells where polypeptides are formed

ribosome-mRNA complex combination of ribosome and mRNA which must occur for translation to begin

methionine particular type of amino acid which begins the production of a polypeptide in translation

Synonyms

components … parts

General vocabulary

complex a larger structure made up of smaller parts

Utilize websites to view the molecular structure of tRNA. Some key points of your observations should include:

- tRNA includes areas where base pairing creates a double strand.
- Loops are apparent in three areas.
- One loop contains the **anti-codon** of the molecule.
- Has a single-strand 3′ end with the base sequence CCA which is the amino acid attachment site.

Skill: Identification of polysomes in electron micrographs of prokaryotes and eukaryotes

Observe the cytoplasm in electron micrographs of prokaryotic and eukaryotic cells. Structures which appear as a number of beads attached to a single string are called **polysomes** or polyribosomes. Each bead is a ribosome. The single string is one mRNA molecule. The polysome produces many copies of the same polypeptide.

Subject vocabulary

anti-codon group of three nucleotides on tRNA which base-pair with the codon of mRNA

polysomes group of ribosomes attached to a single strand of mRNA all producing the same polypeptide

tRNA binding sites the A, P, and E sites on the small subunit of ribosomes that connects with the amino acid carrying tRNA molecules

polypeptide chain large sequence of amino acids chemically combined by covalent bonds called peptide bonds

Synonyms

discharged ..... released

cavity .... space (within)

General vocabulary

sequentially in order

Understanding: Synthesis of the polypeptide involves a repeated cycle of events.

Model sentence: There is a repeated cycle of events in the production of polypeptides at the ribosome.

There are three **tRNA binding sites** on the small subunit of the ribosome. They are labelled A, P, and E. The following table explains the action at each binding site.

Ribosomal binding site	Function
A (entry site)	holds the tRNA carrying the next amino acid to be added to the polypeptide chain
P (peptide bond formation site)	holds the tRNA carrying the growing polypeptide chain
E (exit site)	site at which tRNA that has lost its amino acid is **discharged** from the ribosome

Polypeptide chains are assembled in the **cavity** between the two ribosomal subunits. tRNAs carrying specific amino acids move **sequentially** through the three ribosomal binding sites; first the A site, then the P site, and finally the E site.

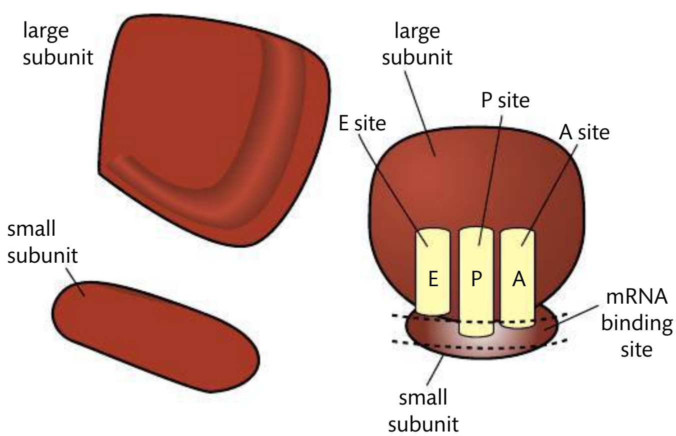


Figure 7.9 *This model shows the arrangement of subunits and binding sites in a ribosome*

tRNAs come to the A site so that base pairing of their anti-codon with the mRNAs **codon** occurs. This base pairing creates the exact sequence of amino acids called for in the cell's genetic code. **Peptide bonds** between the amino acid and the growing polypeptide chain occur at the P site. A continuous repetition of the cycle of events occurs at the A, P, and E sites until the full polypeptide chain is assembled. The ribosome moves from the 5′ to the 3′ end of the mRNA strand to build the polypeptide.

The polypeptide chain produced at the ribosome is assembled by a repeated cycle of events. Amino acids are added one at a time as a result of base pairing between mRNA codons and tRNA anticodons. The initiation of a polypeptide chain assembly occurs with the combining of a tRNA carrying the amino acid methionine with the mRNA codon AUG. This methionine carrying tRNA has the anticodon, UAC. The growth of the polypeptide chain continues until a stop codon is **encountered**. The polypeptide is then released.

Application: tRNA-activating enzymes illustrate enzyme–substrate specificity and the role of phosphorylation

Certain enzymes work with certain **substrates** and this is demonstrated by the enzymes necessary to allow the attachment of an amino acid to its specific tRNA. There are 20 different amino acids. Therefore, there are 20 different tRNAs. There are also 20 different enzymes needed to aid in the attachment of each different amino acid to the proper tRNA. The addition of a phosphate and its accompanying energy from ATP is also necessary for the attachment of an amino acid to its proper tRNA. This is known as **phosphorylation**. The tRNA attached to a specific amino acid is now said to be activated. It may then be involved in translation. The energy in the bond connecting the amino acid to the tRNA is used in the attachment of the amino acid to the growing polypeptide chain in the translation process at the ribosome.

Translation is a two-step process:

- tRNA-activating enzymes attach the appropriate amino acid to the correct tRNA (based on the tRNA anticodon)
- the tRNA anticodon binds with the correct complementary mRNA code.

Understanding: **Disassembly** of the components follows termination of translation.

Model sentence: The polypeptide is released and the mRNA-ribosomal complex splits apart once the stop codon is encountered during translation.

Polypeptide synthesis ends at a ribosome when that ribosome comes to the 3′ end of an mRNA strand. The mRNA-ribosomal complex involved in the translation process breaks into its individual parts. The polypeptide produced goes free to be used for cellular needs. The mRNA is released into the cytoplasm. The ribosome splits into its two subunits. This ribosome is then available to attach to a different mRNA strand coming from the nucleus so that a new translation process may occur.

Subject vocabulary

codon a group of three bases that together code for a single amino acid

peptide bonds covalent bond which occurs between the amino group of one amino acid and the carboxyl group of another

substrate substance which begins a chemical reaction or process

phosphorylation process of adding a phosphate group to a molecule, usually includes the addition of energy as well

disassembly breaking something down into the parts of which it is made

Synonyms

encountered… met/reached

Understanding: Free ribosomes synthesize proteins for use primarily within the cell.

Model sentence: Ribosomes in the cytoplasm which are not attached to the endoplasmic reticulum usually produce proteins which are used within the cell.

The polypeptides produced by translation at free ribosomes in the cell usually become proteins or become parts of proteins needed within the cell. Free ribosomes are not attached to the endoplasmic reticulum. Whether a ribosome is attached to the endoplasmic reticulum or not seems to be determined by a signal sequence of specific amino acids called for on the mRNA strand coming from the nucleus.

Subject vocabulary

endoplasmic reticulum organelle involved in transport within the cell

free ribosomes ribosomes in the cytoplasm of the cell which are not connected to the endoplasmic reticulum

signal sequence group of amino acids coded by mRNA which controls whether a ribosome is attached to the endoplasmic reticulum or not

secretion release of a substance from a cell, tissue, or gland

lysosome eukaryotic cell organelle involved in hydrolytic or breakdown processes within the cell

bound ribosomes ribosomes which are connected to the endoplasmic reticulum

General vocabulary

interior the inner part or inside of something

Understanding: Bound ribosomes synthesize proteins primarily for secretion or for use in lysosomes.

Model sentence: Bound ribosomes are attached to the cell's endoplasmic reticulum and produce proteins most often used for secretion from the cell or for use in lysosomes.

Ribosomes will become attached to the membrane of the cell's endoplasmic reticulum when a certain signal sequence of amino acids is present in a polypeptide or protein being assembled. These ribosomes are then called bound ribosomes. Polypeptides or proteins produced by these bound ribosomes then enter the interior of the endoplasmic reticulum. Once inside the endoplasmic reticulum, transport occurs of these polypeptides or proteins through the cell's membrane system. The membrane system includes the endoplasmic reticulum, the Golgi apparatus, vesicles, lysosomes, and the plasma membrane. Most often these polypeptides or proteins will be secreted outside the cell or will be used in the cell's lysosomes.

Understanding: Translation can occur immediately after transcription in prokaryotes due to the absence of a nuclear membrane.

Model sentence: Translation occurs more rapidly after transcription in prokaryotes because there is not a nuclear membrane present.

The speed of protein synthesis in prokaryotic cells is faster than in eukaryotic cells. This is due to two factors:

- Non-coding sequences do not exist in prokaryotic DNA. Therefore, there is no need to process the mRNA produced by transcription to remove introns.
- Prokaryotic cells do not have a nucleus. Therefore, in these types of cells mRNA does not have to move through the nuclear membrane to attach to a ribosome.

Hints for success: Prokaryotic cells will start the translation process immediately after transcription. Eukaryotic cells have a delay between transcription and translation. This delay is due to the need for mRNA to be processed and to move through the nuclear membrane.

Understanding: The sequence and number of amino acids in the polypeptide is the **primary structure**.

Model sentence: The primary level of protein structure refers to the unique sequence of amino acids present.

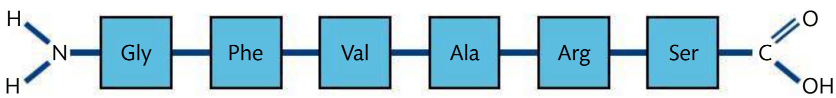


Figure 7.10 *This figure represents a primary structure. Each blue box represents a particular amino acid. The lines connecting these amino acids represent a covalent bond called a peptide bond. The peptide bond is formed between an amino group of one amino acid and the carboxyl group of the other amino acid*

The figure shows the primary structure of a protein. The primary structure refers to the unique sequence of amino acids present. There are 20 different amino acids which make up proteins. These 20 different amino acids vary in the R-groups which they contain. The **R-group** is often called the side chain. The figure shows the general formula of an amino acid.

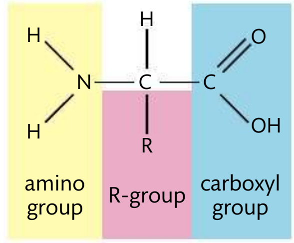


Figure 7.11 *General structure of an amino acid*

> **Hints for success:** The primary structure of proteins produced in a cell by translation is determined by the cell's DNA code. The primary structure of a protein determines the secondary, tertiary, and quaternary levels of protein structure. Only **covalent bonding** is involved in primary structure.

Understanding: The secondary structure is the formation of alpha helices and beta pleated sheets **stabilized** by hydrogen bonding.

Model sentence: Hydrogen bonding produces the secondary structure of proteins which includes alpha helices and beta pleated sheets.

Hydrogen bonds occur between oppositely charged polar regions of the **carboxyl** and **amino groups** of amino acids in a polypeptide. The result of these hydrogen bonds is the **secondary structure** of proteins. The secondary structure takes two major forms.

- The **alpha helix** is a coiled form.
- The **beta-pleated sheet** is a folded form.

The hydrogen bonds form between the relatively positively charged hydrogen **regions** of the amino groups and the relatively negatively charged oxygen regions of the carboxyl group.

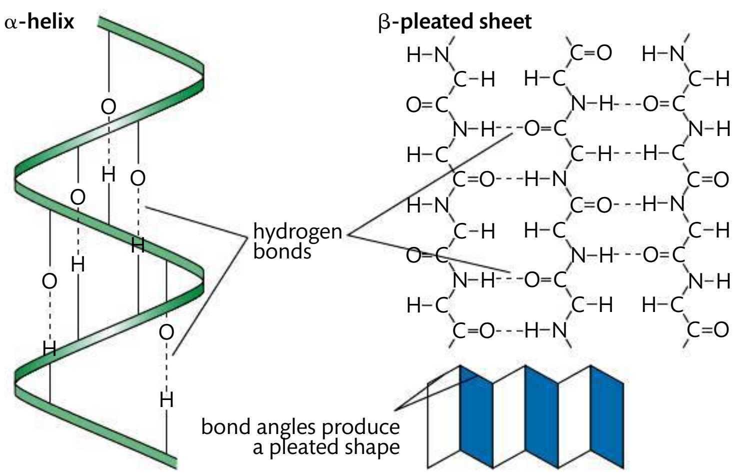


Figure 7.12 *Protein secondary structure*

General vocabulary

stabilized made stable

Subject vocabulary

primary structure sequence of amino acids forming the polypeptide chain of a protein

R-group the portion of each of the 20 amino acids that is different from one another

covalent bond chemical bond in which electrons are shared

carboxyl group -COOH

amino group $-NH_2$

secondary structure alpha helices and beta-pleated sheets which are produced in polypeptides due to interactions between carboxyl and amino groups

alpha helix secondary structure possible for polypeptide chain involving a helical structure

beta-pleated sheet one of the possible shapes formed in the secondary structure of a polypeptide

Synonyms

regions .... particular parts

Understanding: The tertiary structure is the further folding of the polypeptide stabilized by interactions between R-groups.

Model sentence: **The tertiary structure of proteins is due to the complex folding of the polypeptide as a result of disulphide bridges, weak hydrogen bonds, ionic interactions, and hydrophobic or hydrophilic interactions between amino acid R-groups.**

The folding of a protein to create the **tertiary structure** is quite specific based on interactions of the amino acid R-groups present.

Amino acids with non-polar R-groups are hydrophobic. Amino acids with polar R-groups are hydrophilic.

Hydrophobic amino acids will move to the interior of the folded molecule where contact with water is less likely. Hydrophilic amino acids will move toward the exterior of the folded molecule where contact with water is more likely.

Polar and non-polar amino acids are important in determining the tertiary structure of a protein. The tertiary structure of proteins is especially important when the protein is an enzyme. The active site of an enzyme is mostly due to tertiary structure. Substrates which 'fit' specific active sites must have a similar shape and proper polar and non-polar charges.

A protein's primary and secondary structures do not change when it folds to form the tertiary structure. This folding is three dimensional and is quite specific. The same sequence of amino acids will always produce the same tertiary structure.

Subject vocabulary

disulphide bridges covalent bond which occurs between two sulfur atoms of the same or different molecules

tertiary structure three-dimensional folding of a polypeptide chain due to multiple interactions amongst the parts of the amino acids present

quaternary structure protein level of organization which includes more than one polypeptide chain

prosthetic group non-protein group which occurs in the quaternary structure of some proteins

conjugated protein a protein which contains at least one prosthetic group

denatured protein protein to which a permanent shape change has occurred with loss of original function

Understanding: The quaternary structure exists in proteins with more than one polypeptide chain.

Model sentence: **Proteins with a quaternary structure have multiple polypeptide chains combined to form a single structure.**

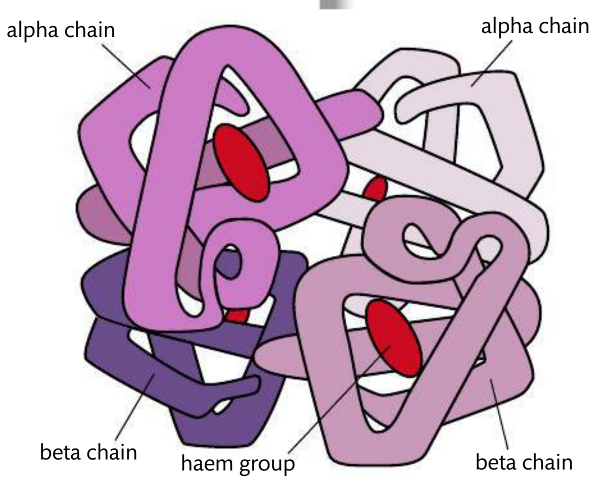


Figure 7.13 *This 'sausage' model of haemoglobin contains four polypeptide chains. Each polypeptide chain has a haem group associated with it*

Only proteins with more than one polypeptide chain are said to have **quaternary structure**.

Bonding to create quaternary structure involves all the bonds present in the primary, secondary, and tertiary structures.

Proteins with quaternary structure often include non-polypeptide components. These non-polypeptide groups are also called **prosthetic groups**. Proteins with prosthetic groups are called **conjugated proteins**. An example of a conjugated protein is haemoglobin. Haemoglobin contains two alpha polypeptide chains, two beta polypeptide chains, plus four haem groups which contain iron atoms for oxygen attachment. The adjacent figure shows a 'sausage' model of haemoglobin.

Hints for success: The function of a protein in an organism is directly related to its primary, secondary, tertiary, and quaternary structure. Environmental factors such as temperature and pH may permanently alter the shape of a protein. This shape change will result in the loss of that protein's function. The protein is then said to be **denatured**.

8.1 Metabolism

Main idea

The metabolic activities of the cell are maintained to meet the needs of the cell.

Understanding: Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.

Model sentence: Enzymes catalyse each step of all metabolic pathways within cells.

Metabolism includes all chemical reactions which occur within a cell or an organism.

General types of metabolism include:

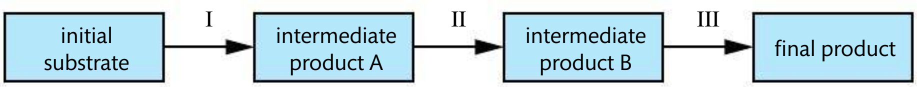
- **Anabolism** – uses energy and smaller compounds to build complex molecules useful to the cell or organism.
- **Catabolism** – breaks down complex molecules and releases energy in the process.

Metabolism usually occurs in a series of small steps with each step catalysed by a particular enzyme.

The small steps which occur in a single metabolic process make up a **metabolic pathway**.

Metabolic pathways take two forms:

1 Chain – a straight-line series of small reactions in which several **intermediate** products are formed between the initial substance or reactant and the final product.



I, II, and III represent different enzymes

Figure 8.1 *General representation of a chain metabolic pathway*

2 Cycle – circular type of metabolic pathway in which an initial substance or reactant is also the final product of the pathway.

Each step in both forms of metabolic pathways is catalysed by a unique enzyme.

Subject vocabulary

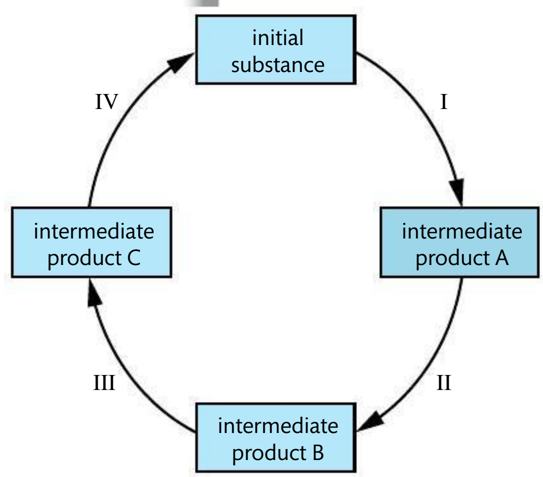
anabolism type of metabolism in which smaller compounds are used to build larger compounds in organisms

catabolism type of metabolism in which larger compunds are broken down with the release of energy

metabolic pathway a chemical pathway in which a series of enzymes produces intermediate compounds on the way to producing a final product needed by the organism

General vocabulary

intermediate between



I, II, and III represent different enzymes

Figure 8.2 *General representation of a cycle type of metabolic pathway*

Understanding: Enzymes lower the activation energy of the chemical reactions that they catalyse.

Model sentence: Enzymes catalyse reactions by lowering activation energy.

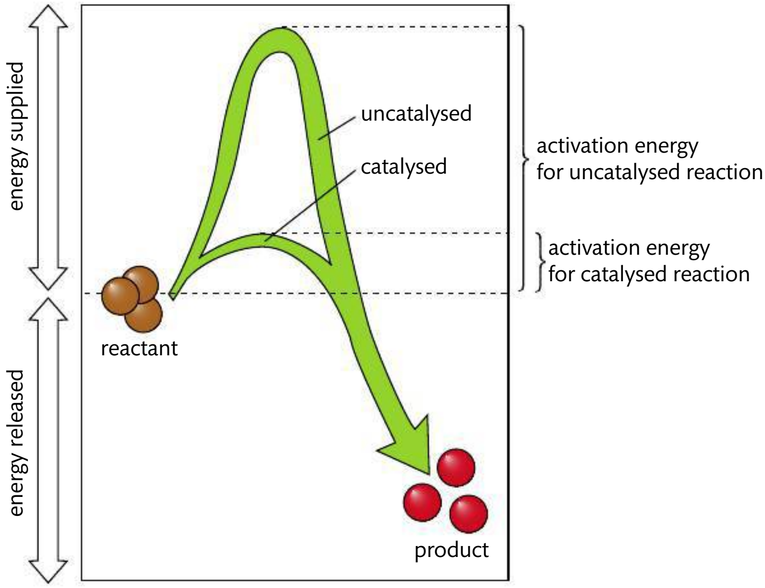


Figure 8.3 *Enzymes accelerate reactions by lowering the activation energy required for a reaction to occur*

Key points:

1. **Activation energy** is needed to **destabilize** the chemical bonds in the reactant or initial substance.
2. The upper curve shows the activation energy needed when no enzyme is present.
3. The lower curve shows the activation energy needed when an enzyme is present.

The material on which an enzyme acts is referred to as the **substrate**.

Mechanism of the **induced-fit model** of enzyme action:

1. The surface of the substrate contacts the active site of the enzyme.
2. The enzyme's active site and the substrate **conform** so that a close fit occurs between the two. The result is a **temporary** complex called the **enzyme–substrate complex**.
3. The activation energy necessary to change the substrate is lowered. The reaction occurs more rapidly.
4. The changed substrate or product is released from the active site.

The induced-fit model of enzyme action is a more accurate description of enzyme action than the more simple lock-and-key model.

Subject vocabulary

activation energy energy needed to begin a chemical reaction

substrate substance which begins a chemical reaction or process

induced-fit model the idea that enzymes change shape to better match the shape of the substrate when they come into contact making the reaction more efficient

enzyme-substrate complex combination of enzyme and substrate which occurs at the active site of the enzyme

General vocabulary

destabilize to make less stable

conform matching of shape

temporary continuing for only a limited period of time

Understanding: Enzyme **inhibitors** can be competitive or non-competitive.

Model sentence: Enzyme inhibitors decrease enzyme activity and are grouped as either competitive or non-competitive.

The following table compares competitive and non-competitive enzyme inhibitors.

Competitive enzyme inhibitor	Non-competitive enzyme inhibitor
decreases enzyme activity	decreases enzyme activity
decreases substrate's encounters with the enzyme's active site	prevents the substrate's ability to fit and combine with the enzyme's active site
attaches to the active site of the affected enzyme and blocks substrate attachment	usually attaches to a site of the enzyme other than the active site, called the **allosteric site**
increasing the substrate concentration will increase the rate of enzyme activity	increasing the substrate concentration will not increase the rate of enzyme activity
active site does not change shape	active site does change shape

An example of a competitive enzyme inhibitor is sulphanilamide which attaches to the active site of the enzyme which converts paraminobenzoic acid (PABA) to folic acid in certain types of bacteria. This prevents the formation of folic acid. These bacteria will die when folic acid is not present.

Examples of non-competitive enzyme inhibitors are some nerve gases which prevent the action of an enzyme to break down a neurotransmitter at the junction of two neurones. These types of nerve gas attach to an allosteric site of the enzyme. This changes the shape of the enzyme's active site. The result is a continuous action of the muscle to which a nerve attaches. This may cause death in humans due to heart or lung **malfunction**.

Skill: Calculating and plotting rates of reaction from raw experimental results

You should develop the skill of producing graphs for enzyme reaction rates from raw data. Hydrogen peroxide breaks down over time to produce water and oxygen. This reaction is shown below:

$$2H_2O_2 \rightarrow 2H_2O + O_2 \text{ (gas)}$$

The enzyme known as catalase will significantly increase the rate of this reaction. Raw data from this reaction showing the amount of oxygen produced over time or amount of hydrogen peroxide broken down over time may be used to calculate the reaction rate of catalase. These raw data collected over a series of times may also be used to produce a graph representing the enzyme's reaction rate over the full time period.

Skill: Distinguishing different types of inhibition from graphs at specified substrate concentration.

You must be able to **distinguish** different types of enzyme inhibitors from graphs which indicate specific substrate concentration. Competitive and non-competitive inhibition produce characteristic graphs of substrate concentration and enzyme activity.

Subject vocabulary

inhibit to lower

competitive enzyme inhibitor substance which decreases enzyme activity by directly competing with a substrate for an enzyme's active site

non-competitive enzyme inhibitor substance which affects an enzyme's activity by combining with an allosteric site of the enzyme and altering the enzyme's active site shape

allosteric site a site that is not the active site on an enzyme to which a non-competive enzyme inhibitor attaches

General vocabulary

malfunction failure to function well

distinguish to recognize the difference

Synonyms

raw .... unprocessed

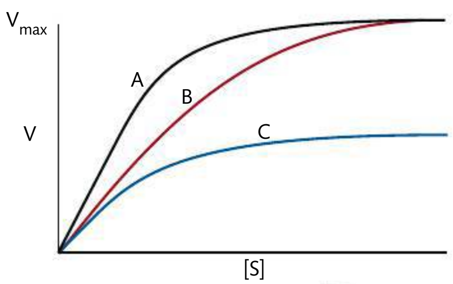


Figure 8.4 *Enzyme inhibition. [S] = substrate concentration; V = reaction rate; V_{max} = maximum reaction rate*

Study the following example:

Curve A in the example is the curve showing the reaction rate of an enzyme as substrate concentration increases. For curve A, there is no inhibition of the enzyme occurring.

Curve C in the example represents **non-competitive inhibition**. This is because:

- Curve C shows a lower maximum reaction rate due to attachment of the product to the enzyme's allosteric site.
- Curve C shows the reaction rate of the enzyme does not increase as the substrate concentration increases.

Curve B in the example represents **competitive inhibition**. This is because:

- Curve B shows the reaction rate of the enzyme increasing as the substrate concentration increases.
- Curve B will reach the maximum reaction rate if the substrate concentration becomes high enough.

Subject vocabulary

non-competitive inhibitor a substance which changes the shape of an enzyme's active site by combining with an allosteric site on the enzyme

competitive inhibiton reaction in which inhibition occurs due to competition for an enzyme's active site

General vocabulary

inhibition the slowing or prevention of a process, reaction or function

Understanding: Metabolic pathways can be controlled by end-product **inhibition**.

Model sentence: End-product inhibition is a common way by which metabolic pathways in cells may be controlled.

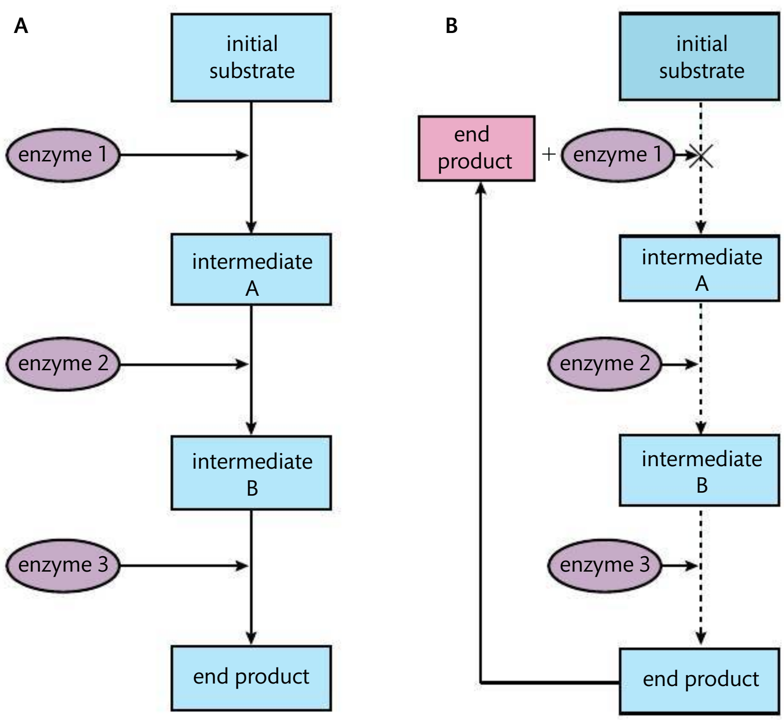


Figure 8.5 *A short pathway of metabolic reactions with a specific end product that, when in sufficient quantity, causes end-product inhibition. This is also a form of negative feedback. The intermediates are essential molecules produced in the step-by-step pathway to achieve the end product.* ***A*** *represents a normal pathway with several enzymes producing intermediate compounds along the way.* ***B*** *represents feedback inhibition. In this condition a large amount of end product is present. The end product inhibits enzyme 1 in the pathway. The result is that the pathway is halted*

Hints for success: End-product inhibition is an example of negative feedback. Inhibition of a pathway occurs when the concentration of the pathway's end-product is high. This inhibition occurs when the end product binds to the enzyme catalysing the first reaction in the metabolic pathway. The inhibition of the first enzyme in the pathway prevents the production of more of a product than is needed. Also, inhibition of the first enzyme prevents a build-up of pathway intermediates.

Application: End-product inhibition of the pathway that converts threonine to isoleucine

Escherichia coli, a type of bacterium, has a pathway which allows the conversion of threonine to isoleucine. Isoleucine is necessary for growth in this bacterium. The generalized pathway is presented in the figures.

In this example, isoleucine attaches to an allosteric site of enzyme 1 in the pathway. This attachment prevents the formation of intermediate A. The result is that the pathway will no longer occur. This is a negative feedback system. Higher concentrations of isoleucine will result in more combinations of isoleucine with enzyme 1. The result of increasing concentrations of isoleucine will be lesser amounts of isoleucine being produced by the pathway.

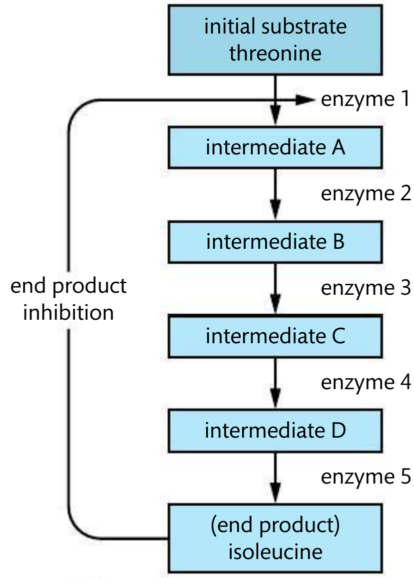


Figure 8.6 *End-product inhibition of the threonine to isoleucine pathway*

Application: Use of databases to identify potential new anti-malarial drugs

Scientists are using a relatively new field of biology called bioinformatics to determine potential new anti-malarial drugs. Bioinformatics uses databases contributed to by multiple researchers to search for unique events and patterns. This approach has led to the discovery of a group of compounds which may be successful in treating or preventing malaria in the future.

8.2 Cell respiration

Main idea

Cell respiration allows the conversion of energy into a usable form in cells and organisms.

Understanding: Cell respiration involves the oxidation and reduction of electron carriers.

Model sentence: Oxidation and reduction of electron carriers occurs in cell respiration to produce usable energy for the cell and organism.

Oxidation	Reduction
loss of electrons	gain of electrons
gain of oxygen	loss of oxygen
loss of hydrogen	gain of hydrogen
results in many carbon to oxygen covalent bonds	results in many carbon to hydrogen covalent bonds
results in a compound with lower potential energy	results in a compound with higher potential energy

The major electron carriers of cell respiration which are oxidized and reduced are NAD and FAD.

General vocabulary

converts changes something into a different form

conversion change from one form to another

Subject vocabulary

bioinformatics branch of biology which uses computers in an effort to understand biological processes

oxidation reaction a chemical reaction in which electrons are lost

reduction reaction a chemical reaction in which electrons are gained

electron carriers specialized chemicals with the ability to form temporary bonds with freed electrons

Understanding: Phosphorylation of molecules makes them less stable.

Model sentence: Molecules which have a phosphate chemically added to them are more likely to break down.

Phosphorylation is the process by which a phosphate group (PO_4^{3-}) is added to a molecule.

Phosphorylated molecules are more likely to enter into reactions than non-phosphorylated molecules.

ATP is very often the source of the phosphate group when phosphorylation occurs in cells.

ATP ⟶ ADP + phosphate + energy

The energy released when ATP splits away a phosphate may be used to aid in the phosphorylation of a molecule.

Hints for success: Most phosphorylated molecules are more likely to enter into chemical reactions than non-phosphorylated molecules.

Subject vocabulary

phosphorylation process of adding a phosphate group to a molecule, usually includes the addition of energy as well

phosphorylated molecules molecules to which phosphate groups have been added resulting in a decrease of stability of the molecules

glycolysis first stage of cell respiration in which oxygen is not required and glucose is broken down into two pyruvate molecules

pyruvate 3-carbon compound formed by the breakdown of glucose in glycolysis, the first stage of cell respiration

triose phosphate 3-carbon carbohydrate with a phosphate group attached produced in the glycolysis pathway

---

Understanding: In glycolysis, glucose is converted to pyruvate in the cytoplasm.

Model sentence: Glycolysis results in the formation of pyruvate in the cytoplasm.

- The first series of reactions in cell respiration is called glycolysis.
- Glycolysis usually begins with the monosaccharide known as glucose.
- Glycolysis occurs in the cytoplasm of the cell. Glycolysis does not require organelles.
- Glycolysis occurs in prokaryotic and eukaryotic cells.
- The reactions of glycolysis are controlled by enzymes.
- 6C in the diagram means a 6-carbon compound. 3C in the diagram means a 3-carbon compound.

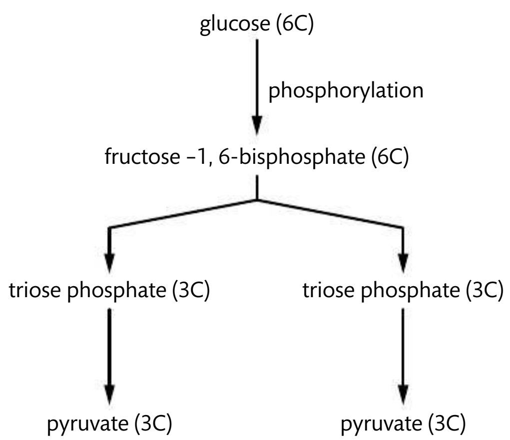


Figure 8.7 *General diagram of glycolysis*

Hints for success: Phosphorylation of glucose makes it an unstable molecule. The result of the instability is the formation of two triose phosphates. Each triose phosphate goes through a series of reactions to produce one pyruvate molecule. Two pyruvate molecules are produced from one glucose molecule in the process of glycolysis.

Understanding: Glycolysis gives a small net gain of ATP without the use of oxygen.

Model sentence: There is a net gain of two ATP molecules in the process of glycolysis.

Glycolysis does not require oxygen to occur. Study the general diagram of glycolysis with ATP usage and gain.

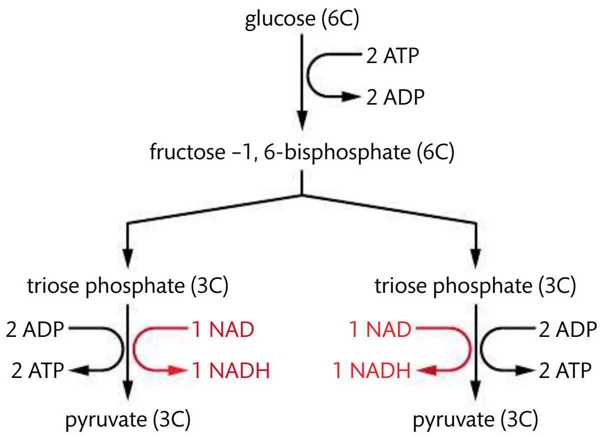


Figure 8.8 *Overview of glycolysis*

Notice from the diagram that two ATP molecules are necessary to phosphorylate glucose so it becomes reactive. Each triose phosphate (three carbon molecules) goes through a series of reactions to produce two ATP molecules. Two ATP molecules are used in glycolysis but four ATP molecules are directly produced. Therefore, there is a net gain of two ATP molecules due to glycolysis. Note the red NAD and NADH molecules. Be aware you will often see the reduced form of NAD written as $NADH^+ + H^+$. They will be discussed in a later part of cell respiration.

Understanding: In aerobic cell respiration pyruvate is decarboxylated and oxidized, and converted into acetyl compound and attached to coenzyme A to form acetyl coenzyme A in the link reaction.

Model sentence: The first stages of aerobic cell respiration involve the decarboxylation and oxidation of pyruvate in the link reaction to form an acetyl compound.

The presence of oxygen in the cell allows aerobic cell respiration to occur.

Aerobic cell respiration occurs in the mitochondria of cells. Prokaryotic cells do not have mitochondria. Therefore, the process of aerobic cell respiration does not occur in prokaryotic cells.

The presence of oxygen brings about the active transport of pyruvate into the matrix of the mitochondrion.

Subject vocabulary

decarboxylation process of removing a carbon from a compound

link reaction aerobic cellular respiration pathway in which a carbon is removed from pyruvate and acetyl CoA is formed

mitochondrion (plural: mitochondria) cell organelle(s) involved in cell respiration

Subject vocabulary

mitochondrial matrix region of a mitochondrion within the inner membrane filled with a cytosol-like material

acetyl group 2-carbon organic compound group formed in the link reaction

coenzyme A molecule which combines with and carries the link reaction acetyl group into the Krebs cycle

acetyl CoA compound moving from the cellular respiration link reaction to the Krebs cycle

Krebs cycle cyclic metabolic pathway of aerobic cellular respiration occurring in the mitochondrial matrix producing ATP, carbon dioxide, and reduced NAD and FAD

Synonyms

coupled to...... joined with/ paired with

liberating....... freeing/releasing

Enzymes are present in the **mitochondrial matrix** to control the link reaction. The link reaction is a series of reactions which begins aerobic cell respiration. The major events of the link reaction are:

1. Pyruvate loses a carbon atom. This loss is referred to as decarboxylation. This carbon atom combines with oxygen to form carbon dioxide. The carbon dioxide is released from the cell.
2. When pyruvate loses a carbon atom, it forms an **acetyl group**. The acetyl group contains two carbons.
3. The acetyl group then combines with **coenzyme A** (CoA) to form **acetyl CoA**.
4. The acetyl CoA then enters the next stage of aerobic cell respiration called the **Krebs cycle.**

Oxidation in the link reaction occurs with the loss of hydrogen atoms/high energy electrons from pyruvate to form NADH from NAD. The NADH produced then enters the electron transport chain of the aerobic cell respiration process.

Hints for success: Study the following representation of the major steps of the aerobic cell respiration's link reaction:

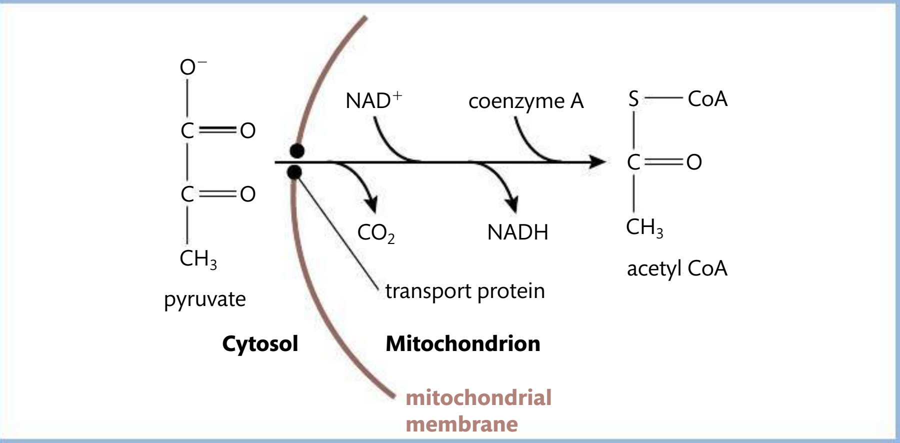


Figure 8.9 *Link reaction of cell respiration*

- Notice the loss of CO_2 from the pyruvate which occurs inside the mitochondrion.
- Also, notice the loss of hydrogen/electrons from pyruvate to form NADH from NAD.

The loss of CO_2 is referred to as decarboxylation. The loss of hydrogen and energized electrons to form NADH from NAD is referred to as oxidation.

Understanding: In the Krebs cycle, the oxidation of acetyl groups is **coupled to** the reduction of hydrogen carriers, **liberating** carbon dioxide.

Model sentence: The Krebs cycle involves the decarboxylation and oxidation of acetyl groups to form reduced hydrogen carriers and carbon dioxide.

Study the following overview of the Krebs cycle.

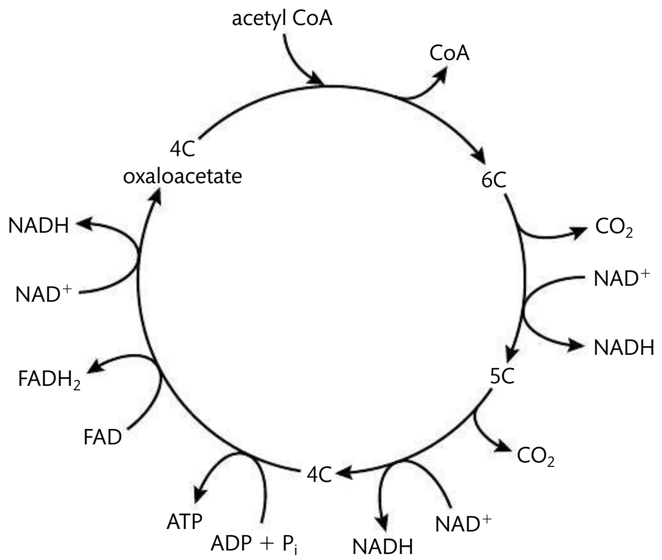


Figure 8.10 *Overview of the Krebs cycle*

Notice the following from the above figure.

- Each acetyl CoA which enters the Krebs cycle results in the formation of three NADH molecules and one $FADH_2$ molecule. The acetyl group is oxidized to form these reduced molecules. The formed NADH and $FADH_2$ molecules move to the aerobic cell respiration electron transport chain.
- Two molecules of carbon dioxide are produced. These two molecules of CO_2 are due to the decarboxylation of the acetyl group which enters the Krebs cycle.
- One molecule of ATP is produced as oxidation of the acetyl group occurs.

Skill: Analysis of diagrams of the pathways of aerobic respiration to deduce where decarboxylation and oxidation reactions occur

You must be able to work out where **decarboxylation** and oxidative reactions occur from a diagram showing the pathways of aerobic respiration. Look at the figure above.

1 Where does decarboxylation occur?

2 Where is oxidation occurring?

Decarboxylation is occurring just prior to the release of CO_2 from the 6-carbon (6C) and the 5-carbon (5C) compounds in the cycle. Oxidation of the cycle compounds is occurring just before the three reductions of NAD to NADH, just before the reduction of FAD to $FADH_2$, and just before the production of ATP from ADP.

Hints for success: A glucose molecule entering glycolysis results in two pyruvate molecules. Therefore, the two pyruvates produced from a single glucose molecule results in the following products when the Krebs cycle occurs twice, once for each pyruvate molecule:

- Two ATP molecules.
- Six molecules of reduced NAD (NADH).
- Two molecules of reduced FAD ($FADH_2$).
- Two molecules of reduced NAD (NADH), produced in the link reaction before the Krebs cycle began.
- Four molecules of carbon dioxide, which are released from the cell as waste.

Subject vocabulary

pathways means of getting from one substance or position to another

decarboxylation process of removing a carbon from a compound

Understanding: Energy released by oxidation reactions is carried to the cristae of the mitochondria by reduced NAD and FAD.

Model sentence: NAD and FAD carry the energy released by oxidation reactions to the mitochondrial cristae in cell respiration.

- Oxidation of one glucose molecule in glycolysis results in the reduction of two NAD molecules to form NADH.
- Oxidation of two acetyl groups occurs in the link reaction and results in the reduction of two NAD molecules to form NADH.
- Oxidation of two acetyl CoA molecules in the Krebs cycle results in the reduction of six NAD and two FAD molecules to form NADH and $FADH_2$.
- The NADH and $FADH_2$ molecules move from the mitochondrial matrix to the mitochondrial cristae.
- These reduced forms of NAD and FAD molecules are high in energy as they move to the cristae.

Subject vocabulary

mitochondrial cristae inner membranes of the mitochondria with a shelf-like appearance

pumping active means of changing a particle's or substance's position

electron transport chain chain involving specialized molecules used to transport electrons due to different attractions for the electrons

cytochromes type of proteins which act as carriers in many electron transport chains

oxidative phosphorylation process of adding a phosphate group to ADP using energy received from an electron transport chain

---

Understanding: Transfer of electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton **pumping**.

Model sentence: Transfer of electrons paired with proton pumping occurs between carriers of the cristae's electron transport chain.

The transfer of electrons and the pumping of protons occur together at the mitochondrial cristae. These two processes are said to be coupled. This transfer of electrons and the pumping of protons is known as the electron transport chain.

The electron transport chain utilizes specialized molecules called carriers in the cristae membrane to produce ATP from ADP. These carriers are mostly types of proteins called cytochromes.

Electrons are passed from carrier to carrier based on the specific amount of energy they possess. A small amount of energy is released at each electron passage or exchange from one carrier to the next. This released energy is used to pump protons across membranes.

These small released amounts of energy along with the proton pumping are used to add a phosphate to ADP to produce ATP. Producing ATP from ADP using an electron transport chain is called oxidative phosphorylation.

Hints for success: The pumping of protons across membranes using the energy released from electron transfers from carrier to carrier allows the formation of ATP from ADP in the electron transport chain.

Understanding: In chemiosmosis protons diffuse through ATP synthase to generate ATP.

Model sentence: Chemiosmosis is the process in which ATP production occurs as a result of protons diffusing through an enzyme of the cristae membrane called ATP synthase.

Study the following drawing of a mitochondrion to understand the location of the major processes of chemiosmosis.

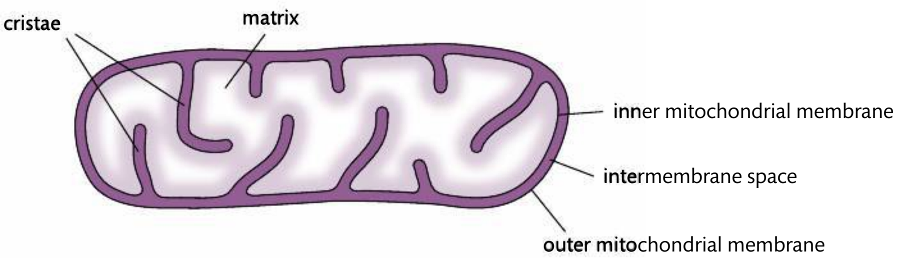


Figure 8.11 *Structure of a typical mitochondrion*

Key points of chemiosmosis:

- Small amounts of energy are released as electrons move from carrier to carrier in the electron transport chain. These carriers are present in the inner mitochondrial membrane which projects inward to form the cristae.
- This released energy is used to pump hydrogen ions by active transport out of the mitochondrial matrix into the space between the membranes of the cristae. In the figure above, this space is labelled the intermembrane space. Note the relatively small volume of the intermembrane space. This low volume is important in allowing a high hydrogen ion volume to develop.
- This hydrogen pumping creates a higher concentration of hydrogen ions in the intermembrane space than in the matrix. This is a concentration gradient involving hydrogen ions.
- The concentration gradient of hydrogen ions results in the passive flow of hydrogen ions from the intermembrane space into the mitochondrial matrix. The passive flow of hydrogen ions across the cristae membrane occurs through channels of the enzyme ATP synthase.
- The passive flow of hydrogen ions through ATP synthase results in energy available to allow the formation of ATP. ATP is formed by the phosphorylation of ADP. This form of phosphorylation by chemiosmosis is called oxidative phosphorylation.

Understanding: Oxygen is needed to bind with the free protons to maintain the hydrogen gradient, resulting in the formation of water.

Model sentence: The final acceptor of protons and electrons at the end of chemiosmosis is oxygen resulting in the formation of water.

The electrons which move down the electron transport chain in chemiosmosis combine with oxygen at the very end of the chain. The energy that these electrons carried from the earlier phases of aerobic cell respiration has been removed.

This electron-enriched oxygen immediately combines with the free hydrogen ions in the mitochondrial matrix to form water. Water formed in this way is referred to as water of metabolism.

Subject vocabulary

chemiosmosis process in which ATP is produced due to protons diffusing through ATP synthase in thylakoid and cristae membranes

ATP synthase enzyme of thylakoid and cristae membrane which allows phosphorylation of ADP to form ATP

intermembrane space space between membranes such as between the membranes of the cristae and the thylakoids in which a build-up of hydrogen ions occurs

acceptor receiver of particles or substances

water of metabolism water produced when the de-energized hydrogens of the aerobic cellular respiration electron transport chain combine with available oxygen

Synonyms

diffusing .... spreading

General vocabulary

gradient 'area of difference' involving a factor

The free hydrogen ions in the mitochondrial matrix are the result of the passive flow of these hydrogen ions through ATP synthase. It is essential these free hydrogen ions combine with oxygen to form water. The formation of water of metabolism in the mitochondrial matrix keeps the hydrogen ion concentration relatively low. The low hydrogen concentration in the matrix maintains the hydrogen ion concentration gradient between the intermembrane space and the mitochondrial matrix. This allows the **maintenance** of the passive flow of hydrogen ions through ATP synthase and the continued production of ATP in chemiosmosis.

General vocabulary

maintenance the act of making a state or situation continue

Subject vocabulary

cytosol the fluid part of the cell that surrounds and supports organelles

Understanding: The structure of the mitochondrion is adapted to the function it performs.

Model sentence: The mitochondrial structure allows for the efficient formation of ATP in the process of aerobic cell respiration.

Mitochondrial structure or feature	Function
outer mitochondrial membrane	a membrane which separates the contents of the mitochondrion from the rest of the cell
matrix	an internal **cytosol**-like area that contains enzymes for the link reaction and the Krebs cycle
cristae	tube-like projections of the inner membrane into the mitochondrial matrix which allow added membrane surface area for oxidative phosphorylation
inner mitochondrial membrane	a membrane that contains the carriers for the electron transport chain and ATP synthase for chemiosmosis
intermembrane space	space into which hydrogen ions are pumped using energy from the electron transport chain

Skill: Annotation of a diagram of a mitochondrion to indicate the adaptations to its function

Students must be able to label and add notes to a mitochondrial diagram to show the relationship of structure to function. Obtain several electron micrographs or drawings of mitochondria. Annotate these with the names and functions of the mitochondrial parts.

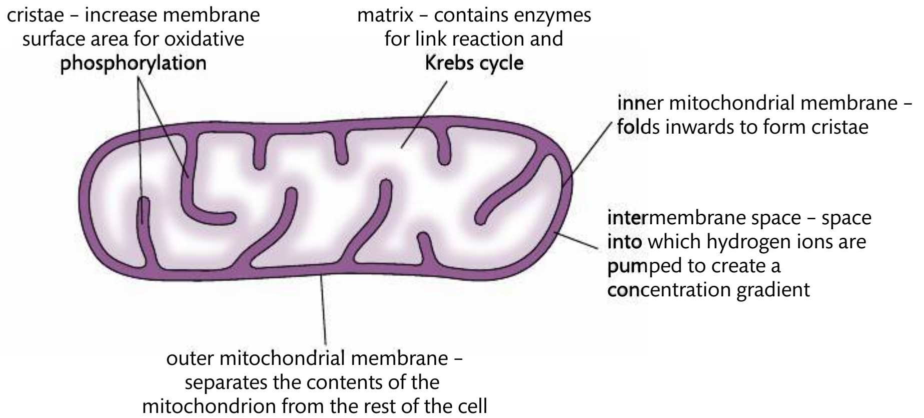


Figure 8.12 *General functions of the parts of a mitochondrion*

Application: Electron tomography used to produce images of active mitochondria

Electron tomography studies are being used by scientists to help determine the detailed internal structure of an active mitochondrion. This technique is similar to **CAT (computerized axial tomography) scans** which are used for medical purposes to study internal organs and body structures. Scientists study computerized images of mitochondria produced by this method at various times to develop a better understanding of the internal structure and actions of this essential organelle to aerobic cell respiration.

8.3 Photosynthesis

Main idea

Photosynthesis is a process which converts light energy into chemical energy.

Understanding: Light-dependent reactions take place in the intermembrane space of the **thylakoids**.

Model sentence: The light-dependent reactions of photosynthesis occur on the thylakoid membrane and within the thylakoid intermembrane spaces.

Review the parts of a chloroplast presented in the figure below.

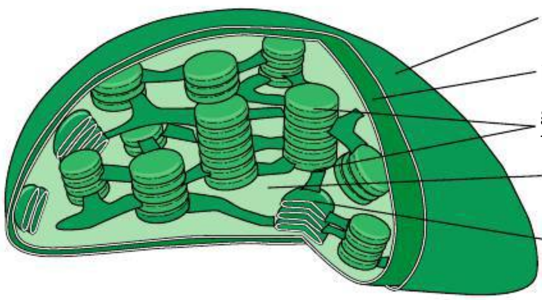


Figure 8.13 *Basic structure and parts of a chloroplast*

Photosynthesis includes two separate, yet connected, reactions. They are:

1 light-dependent reaction

2 light-independent reaction.

These two reactions occur in different parts of the chloroplast.

The light-dependent reaction occurs in the thylakoids of the chloroplast. Notice in the drawing above a thylakoid looks like a flattened sac. A membrane provides the outer most part of the thylakoid. A space known as the intermembrane space occurs within the membrane.

It is important to note from the drawing that thylakoids usually occur in stacks called **grana** (**granum** is singular). The thylakoid membranes contain **pigments** which are involved in the absorption of light energy.

Subject vocabulary

electron tomography studies computerized images of active mitochondria to determine the reactions taking place

CAT (computerized axial tomography) scans computerized internal scans used in medical tests to determine body structures

thylakoids flattened sacs which, when stacked, form grana within chloroplasts

light-dependent reactions reactions of photosynthesis in which light energy is directly needed

granum (plural: grana) stack of thylakoids in the chloroplast

Synonyms

pigments .... colours

Subject vocabulary

light-independent reactions reactions of photosynthesis in which light energy is not directly needed, this reaction uses the products of the light-dependent reactions

photosystems complexes of pigments and a protein matrix occurring on the thylakoid membranes involved in the light-dependent reactions of photosynthesis

photosystem I photosystem of the light-dependent reaction of photosynthesis involved in production of NADPH

photosystem II photosystem of the light-dependent reaction of photosynthesis involved in production of ATP and photolysis

General vocabulary

corresponds is very similar or the same

Understanding: Light-independent reactions take place in the stroma.

Model sentence: A chloroplast's stroma is where the light-independent reactions of photosynthesis occur.

Notice the location of the stroma in the drawing of the chloroplast presented in the previous understanding. The stroma is the cell cytosol-like region of the cell. It corresponds to the matrix of the mitochondrion.

The light-independent reaction of photosynthesis occurs in the stroma of the chloroplast. There are no pigments involved with light absorption in the stroma. The products of the light-dependent reaction are involved in the light-independent reaction.

Understanding: Reduced NADP and ATP are produced in the light-dependent reactions.

Model sentence: The products of the light-dependent reaction which are important to the overall process of photosynthesis are reduced NADP and ATP.

The overall equation representing both reactions of photosynthesis is:

$$6CO_2 + 12H_2O + \text{light energy} \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

Molecules called pigments are present in specialized regions of the thylakoid membrane. These specialized regions are called photosystems. The pigments of the photosystems are quite efficient at absorbing light energy.

The light-dependent reaction of photosynthesis first involves the absorption of light energy. The absorbed light energy is then used to produce these products:

- reduced NADP or NADPH
- ATP.

These two products are necessary for the light-independent reaction of photosynthesis to occur.

Understanding: Absorption of light by photosystems generates excited electrons.

Model sentence: Energized electrons are produced when photosystems on the thylakoid membranes absorb light energy.

There are two types of photosystems which occur on thylakoid membranes. They are:

- photosystem I
- photosystem II.

Bacteria have only one type of photosystem, photosystem I. Most modern-day plants have both types of photosystems.

Both types of photosystem are composed of the following:

- a protein supporting region or matrix
- a pigment called **chlorophyll *a***
- pigments other than chlorophyll *a* involved in light absorption.

Chlorophyll *a* and the other pigments are **embedded** in the protein matrix of the photosystem. The pigments of the photosystems are involved in the absorption of light. Light is absorbed in packets of energy referred to as photons.

Steps in the light-dependent reaction involving the production of excited electrons:

1. One of the pigments of the photosystem absorbs a photon.
2. The energy of a photon is passed to chlorophyll *a* which is present in the **reaction centre.**
3. Electrons of chlorophyll *a* become excited. The chlorophyll *a* is now said to be **photo-activated.**
4. These excited electrons move to a higher energy electron shell. There is one photon of light necessary for each electron energized.
5. The excited electrons are then received by the primary acceptor of the reaction centre.

Both types of photosystems follow the same steps in the absorption of light energy to produce energized electrons.

Subject vocabulary

chlorophyll *a* type of chlorophyll often found in the reaction centre of a chloroplast

photons units or packets of light energy

reaction centre specific part of a photosystem which has electrons energized to a higher level and moved to an electron transport chain

photo-activated process in which light causes electrons to be energized and moved to a higher level

primary acceptor compound of the reaction centre which receives the energized electrons of chlorophyll *a* and passes them to an electron transport chain

photolysis process in photosynthesis where water molecules are split using the energy from light

General vocabulary

embedded positioned firmly and deeply

splitting dividing or separating something

Understanding: Photolysis of water generates electrons for use in the light-dependent reactions.

Model sentence: Electrons from the photolysis of water are used in the light-dependent reaction of photosynthesis.

Water is split by an enzyme to produce free electrons, hydrogen ions, and an oxygen atom.

$$H_2O \rightarrow 2H^+ + 2e^- + \tfrac{1}{2}O_2$$

The splitting of water is driven by the energy provided by light, and is called photolysis. The free electrons are taken up by the chlorophyll *a* molecules which lost their electrons when they were energized. Oxygen is also a product of photolysis and leaves the chloroplast as a waste gas. The hydrogen ions or protons, which are a product of photolysis, add to the protons which exist in the thylakoid space. These protons are also available for reduction reactions occurring in the area.

The presence of light allows two processes to occur in the light-dependent reaction:

1. Electrons of chlorophyll *a* are excited and captured by the primary acceptor of the reaction centre.
2. Photolysis of water occurs resulting in replacement of electrons in chlorophyll *a*. The **splitting** of water due to light occurs over and over so that chlorophyll *a* can continuously have electrons available to be excited or energized.

It is important to note that photolysis only occurs with photosystem II. This indicates that the structures and chemicals necessary for the photolysis process are not present in photosystem I.

Understanding: Transfer of excited electrons occurs between carriers in thylakoid membranes.

Model sentence: Energized or excited electrons pass through an electron transport chain involving carriers which exist in the thylakoid membranes.

Electrons of chlorophyll *a* excited by light are transferred to the primary acceptor in the reaction centre known as plastoquinone.

Plastoquinone carries the excited electrons from the reaction centre to the electron transport chain. The electron transport chain is outside the reaction centre. This chain consists of a series of carriers in the thylakoid membranes which includes a centre region referred to as the **cytochrome complex**.

The electron transport chain allows energy to be released in small amounts from the excited electrons as the electrons are transferred from one carrier to another.

These steps occur in photosystem II. The steps of photosystem I will be discussed later.

Subject vocabulary

plastoquinone compound which carries excited electrons from the reaction centre to the electron transport chain in photosystem II

cytochrome complex centre group of carriers in the photosystem II electron transport chain involved with the generation of ATP

proton (H^+) gradient concentration gradient involving protons inside an intermembrane space and outside the membrane which occurs in chemiosmosis

Understanding: Excited electrons from photosystem II are used to contribute to the generation of a proton gradient.

Model sentence: The excited electrons of photosystem II which move through a thylakoid membrane electron transport chain provide the energy to produce a concentration gradient of protons.

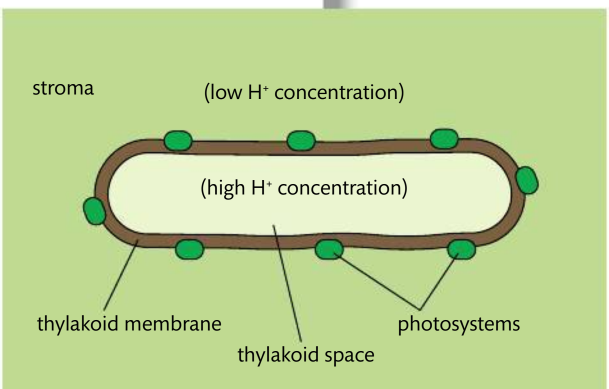


Figure 8.14 *The structures and conditions needed for chemiosmosis in the light-dependent reaction*

The figure shows a single thylakoid surrounded by stroma in a chloroplast. Notice that many photosystems are present on the thylakoid membrane. The photosystems are embedded in the phospholipid bilayer of the membrane.

Note the **proton (H^+) gradient** between the thylakoid space and the stroma that surrounds the thylakoid. This gradient is the result of the pumping of protons (H^+) from the stroma into the thylakoid space. Energy for this pumping action comes from the release of energy in small amounts as excited electrons move down the electron transport chain. Photolysis occurs in the cytosol-like fluid of the thylakoid space and also provides protons (H^+) to the space.

This proton (H^+) gradient is essential to the next process of the light-dependent reaction called chemiosmosis which allows the generation of ATP.

Understanding: ATP synthase in thylakoids generates ATP using the proton gradient.

Model sentence: The proton (H^+) gradient between the thylakoid space (intermembrane space) and the stroma allows the passive transport of protons (H^+) through ATP synthase to generate ATP.

Chemiosmosis occurs and generates ATP when a gradient of protons exists between the thylakoid space (intermembrane space) and the stroma just outside the thylakoid membrane. The small volume of the thylakoid intermembrane space allows a high concentration of protons to be achieved quickly.

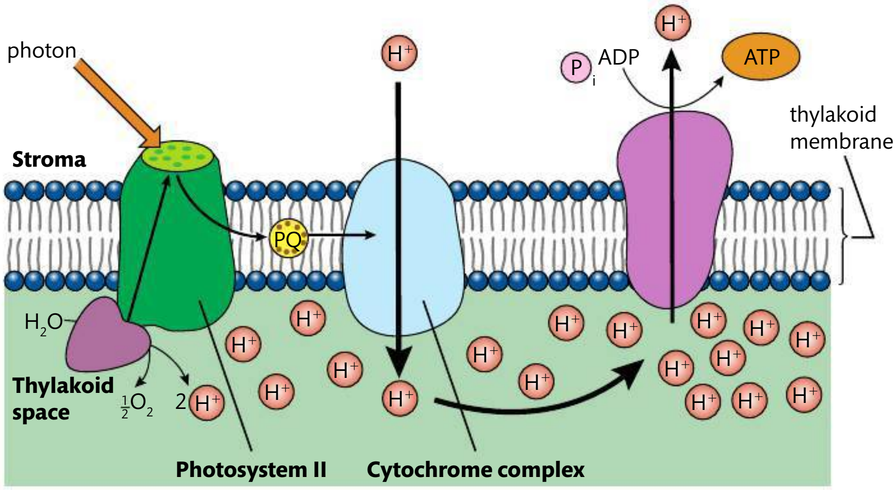


Figure 8.15 *Chemiosmosis at the thylakoid of a chloroplast*

The chemiosmosis which occurs at the thylakoid is very similar to the chemiosmosis which occurs at the mitochondrion. Note that in the diagram above hydrogen ions (protons) move passively from the thylakoid intermembrane space through ATP synthase into the stroma of the chloroplast. The passive transport occurs due to the concentration gradient of hydrogen ions (protons) between the inside thylakoid and the surrounding stroma. As the hydrogen ions pass through the ATP synthase, energy is made available which is used to phosphorylate ADP to form ATP. This type of phosphorylation is referred to as **photophosphorylation** since light is the actual energy source.

The energized electrons which enter the electron transport chain release all the extra energy they received from a photon of light. At the end of the chain they are received by an electron carrier called **plastocyanin**. The plastocyanin will carry these de-energized electrons to photosystem I. The plastocyanin, carrying de-energized electrons from the electron transport chain of photosystem II to photosystem I, allows a connection between the processes which occur in these two photosystems.

Understanding: Excited electrons from photosystem I are used to reduce NADP.

Model sentence: Photons of light in photosystem I are used to excite electrons in order to reduce NADP.

The following events occur in the thylakoid involving photosystem I:

1. A photon of light is absorbed by a pigment in photosystem I.
2. This energy is transferred to a chlorophyll *a* molecule.
3. Electrons of chlorophyll *a* are moved to a higher energy level.
4. These higher energy level electrons are transferred to a primary electron carrier.
5. From the primary electron carrier, the electrons move down a short electron transport chain combining with **ferredoxin** at the end.
6. An enzyme known as **NADP reductase** catalyses the transfer of the electrons from ferredoxin to NADP to allow the formation of NADPH.

The energized (excited) electrons of photosystem I which move away from chlorophyll *a* are replaced by the de-energized electrons carried by

Subject vocabulary

photophosphorylation process of adding phosphate to a molecule using the energy from light

plastocyanin compound which carries de-energized electrons from photosystem II to photosystem I

ferredoxin final carrier of the photosystem I electron transport chain of the photosynthesis light-dependent reaction

NADP reductase enzyme which catalyses the transfer of electrons from ferredoxin to NADP to allow formation of NADPH in the photosystem I electron transport chain plastocyanin from photosystem II. The de-energized electrons of photosystem II replacing the energized (excited) electrons of photosystem I links these two photosystems together.

Hints for success: Study the following figure showing the major processes of photosystems II and I. Notice the linking of the two photosystems by the passing of electrons from photosystem II to photosystem I.

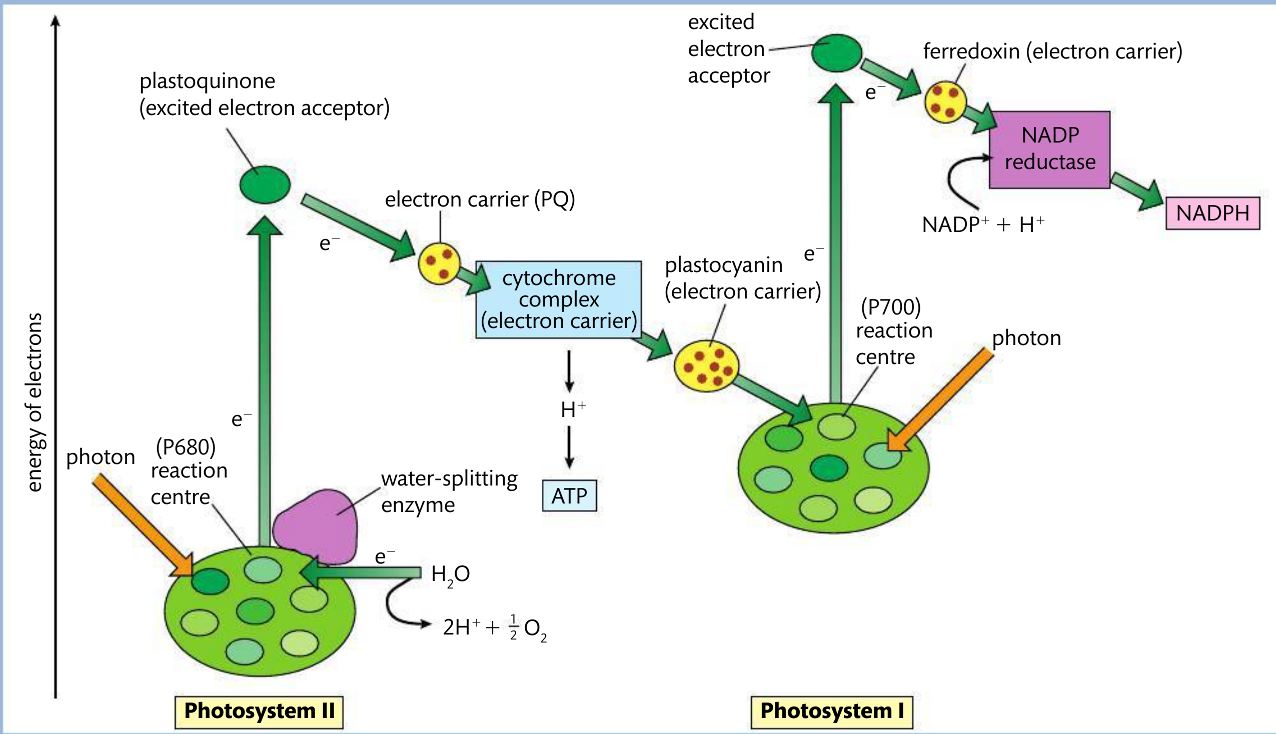


Figure 8.16 *The light-dependent reaction of photosynthesis*

This figure represents the light-dependent reaction of photosynthesis. It is especially important to note the two major products of this reaction: ATP and NADPH. These two products are essential to the light-independent reaction of photosynthesis.

Subject vocabulary

ribulose bisphosphate first compound of the Calvin cycle of the light-independent reaction, also known as RuBP

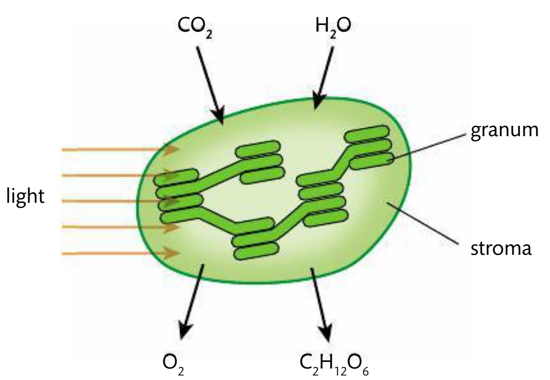


Figure 8.17 *The process of photosynthesis*

Understanding: In the light-independent reactions a carboxylase catalyses the carboxylation of ribulose bisphosphate.

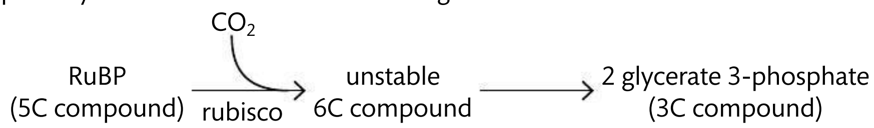
Model sentence: The light-independent reaction begins with the addition of carbon to ribulose bisphosphate.

The light-independent reaction of photosynthesis occurs within the stroma of the chloroplast. The ATP and NADPH produced by the light-dependent reaction provide the energy and reducing power for the light-independent reaction to occur.

Oxygen was released from the chloroplast as a result of photolysis in the light-dependent reaction. The light-dependent reaction did not produce glucose ($C_6H_{12}O_6$). The ATP and NADPH from the light-dependent reaction is used to produce glucose in the light-independent reaction.

The light-independent reaction involves the Calvin cycle. The Calvin cycle begins and ends with the same substance, ribulose bisphosphate.

The first reaction of the Calvin cycle is the addition of carbon to ribulose bisphosphate. Ribulose bisphosphate is often abbreviated as **RuBP**. This process of adding a carbon to a compound is called **carboxylation**. A carboxylase enzyme, **RuBP carboxylase**, catalyses the carboxylation of the ribulose bisphosphate. RuBP carboxylase is usually referred to as **rubisco**. The carbon used in the carboxylation reaction comes from carbon dioxide, which along with water are the raw materials of photosynthesis. This is shown in the diagram below.



RuBP is a 5-carbon (5C) compound. Adding one carbon from carbon dioxide to RuBP produces an unstable 6-carbon compound. This addition of carbon to RuBP is called carboxylation. Rubisco is the enzyme which catalyses the carboxylation process. The unstable 6-carbon compound immediately breaks down into two compounds of glycerate 3-phosphate. Glycerate 3-phosphate is a 3-carbon compound.

Subject vocabulary

RuBP ribulose bisphosphate

carboxylation process in which a carbon is added to another compound

RuBP carboxylase enzyme which catalyses the addition of carbon from carbon dioxide onto RuBP in the Calvin cycle, also known as rubisco

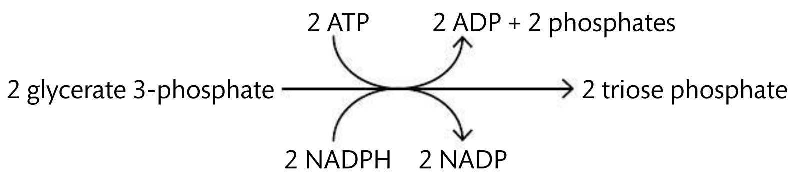
rubisco RuBP carboxylase

glycerate 3-phosphate 3-carbon compound formed immediately after splitting of the unstable 6-carbon compound formed after carboxylation of RuBP in the Calvin cycle

triose phosphate 3-carbon carbohydrate with a phosphate group attached produced in the glycolysis pathway

Understanding: Glycerate 3-phosphate is reduced to triose phosphate using reduced NADP and ATP.

Model sentence: NADPH and ATP from the light-dependent reaction are used to reduce glycerate 3-phosphate to triose phosphate in the Calvin cycle.

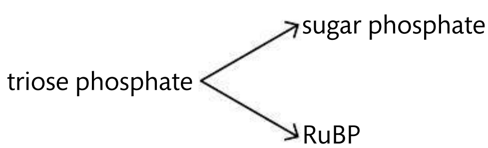


The two **glycerate 3-phosphate** molecules formed from the carboxylation of RuBP are reduced to form two **triose phosphate** molecules in the Calvin cycle. ATP provides the energy for this reduction to occur. NADPH provides the hydrogen which is needed to convert glycerate 3-phosphate to triose phosphate. The ATP and NADPH come from the light-dependent reaction of photosynthesis.

The importance of this reduction process is to get the hydrogen to oxygen ratio in triose phosphate to 2:1. This will allow the production of a carbohydrate from triose phosphate molecules.

Understanding: Triose phosphate is used to regenerate RuBP and produce carbohydrates.

Model sentence: The production of triose phosphate in the Calvin cycle allows for the regeneration of RuBP and the formation of carbohydrates.



Subject vocabulary

hexose 6-carbon monosaccharide

Triose phosphate formed in the Calvin cycle may be used to produce sugar phosphate or RuBP. The sugar phosphate produced is a **hexose**. It may be used to form a more complex carbohydrate such as starch. The sugar phosphate also allows the formation of the most recognized product of photosynthesis which is glucose.

Understanding: Ribulose bisphosphate is reformed using ATP.

Model sentence: Triose phosphate from the Calvin cycle allows the reformation of RuBP using ATP.

Any metabolic pathway which is a cycle must begin and end with the same compound. The Calvin cycle begins and ends with RuBP. Most of the triose phosphate molecules produced in the Calvin cycle are used to reform RuBP. Triose phosphate molecules must go through a series of enzyme-catalysed reactions to reform RuBP. ATP is essential to provide the energy necessary for these catalysed reactions.

Study the figure below to understand the Calvin cycle. The figure also shows how RuBP is reformed from triose phosphate. In the figure, circles represent carbon atoms.

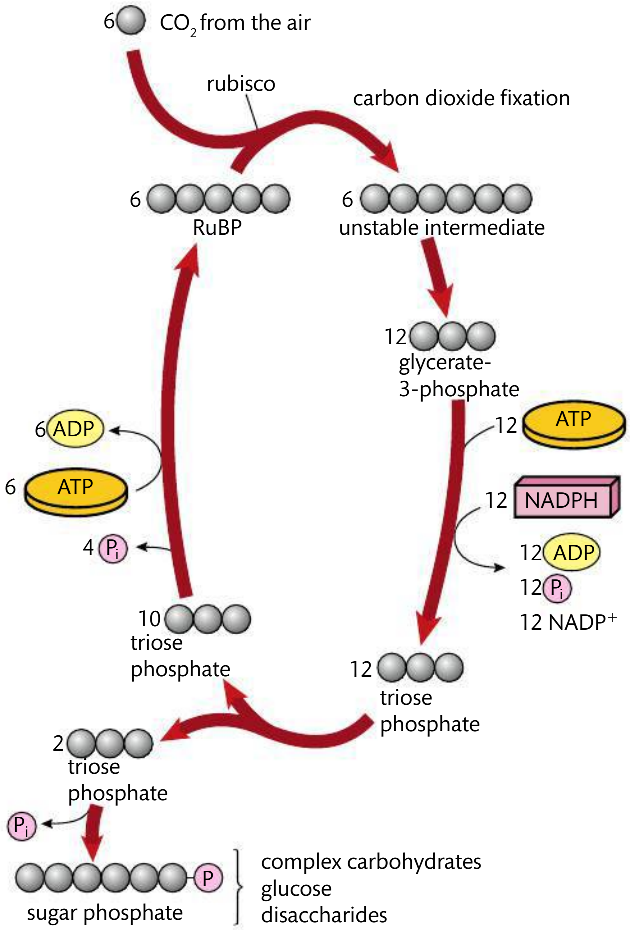


Figure 8.18 *The Calvin cycle*

Notice in the figure that most of the triose phosphate molecules are used to reform RuBP. This allows the Calvin cycle to continue over and over again. Only 2 out of 12 triose phosphates are used to produce the sugar phosphate. Careful observation of the figure will show that it takes six turns of the Calvin cycle to produce one sugar phosphate.

Application: Calvin's experiment to elucidate the carboxylation of RuBP

Melvin Calvin and his team used chromatography, radioactive tracers, and autoradiography to discover the details of the cycle which produced carbohydrates in the light-independent reaction of photosynthesis. He and his team used a 'lollipop' apparatus and a type of green alga to determine the compounds produced at various stages of the cycle. Techniques developed by his team and earlier researchers were applied to allow the determination of these compounds. Because of his work, the carbon fixation cycle of the light-independent reaction of photosynthesis was named the Calvin cycle.

Understanding: The structure of the chloroplast is adapted to its function in photosynthesis.

Model sentence: The functions of the various parts of the chloroplast in photosynthesis are directly related to their structure.

The following table summarizes the relationship of chloroplast structure to function.

Chloroplast structure	Function allowed
extensive membrane surface area of the thylakoids	allows greater absorption of light by photosynthesis, also allows more surface area for the photosystems and the electron transport chains
small space (lumen) within the thylakoids	allows for faster accumulation of protons (H^+) to create a concentration gradient
stroma region similar to the cytosol of the cell	allows an area for the enzymes necessary for the Calvin cycle to be stored and to work in
double membrane on the outside	isolates the working parts and enzymes of the chloroplast from the surrounding cell cytosol

Skill: Annotation of a diagram to indicate the adaptations of a chloroplast to its function

Add notes to the following diagram of a chloroplast explaining the adaptations of the chloroplast to its function.

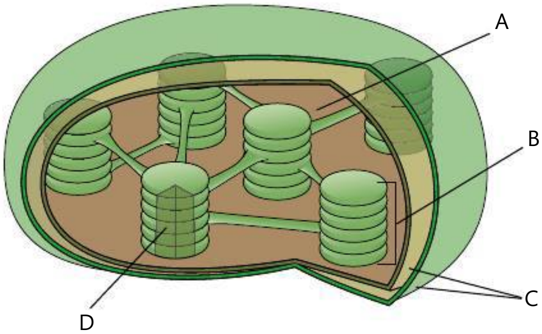


Figure 8.19 *Basic structure of a chloroplast*

Answers: A Stroma allowing for the storage and function of enzymes involved in the Calvin cycle
B Granum or stack of thylakoids allowing more membranes and thylakoid spaces for the light-dependent reaction to occur
C Double membrane to isolate the working parts and enzymes of the chloroplast from the surrounding cell cytosol
D Small lumen within thylakoid allowing for a more rapid build-up of H^+ so that chemiosmosis may occur to generate ATP

Subject vocabulary

radioactive tracers elements or compounds giving off radioactivity and are used in studying organism reactions

autoradiography study of radioactive substances and images produced from them

carbon fixation cycle Calvin cycle in which carbons are fixed to RuBP

lumen area within surrounding walls or membranes; usually used for the cavity of a tubular structure such as a blood vessel

Synonyms

accumulation . build up

General vocabulary

adaptation(s) change(s) which make(s) something more suitable for a situation

9.1 Transport in the xylem of plants

Main idea

The **xylem** is able to carry out its functions efficiently due to its structure.

Subject vocabulary

xylem tissue which conducts water and minerals in plants

transpiration loss of water vapour from leaves and other aerial parts of the plant

stoma (plural: stomata) opening, usually on the underside of leaves, through which gas exchange and transpiration occur

guard cells specialized leaf cells involved in transpiration control

solute molecules dissolved in a solvent (water)

photosynthesis process which converts light energy into chemical energy

General vocabulary

adaptation change which makes something more suitable for a situation

Understanding: Transpiration is the inevitable consequence of gas exchange in the leaf.

Model sentence: The exchange of carbon dioxide and oxygen between the leaf interior and the surrounding environment includes transpiration.

Transpiration is the loss of water vapour from leaves and other parts of the plant that are above the ground. Most transpiration occurs through leaf structures called **stomata** (singular: **stoma**). Most of the leaf stomata are on the underside of the leaf. The underside of the leaf receives less light. Less light results in a lower temperature. Lower temperatures result in decreased transpiration. The positioning of stomata on the leaf underside is one plant **adaptation** which decreases water loss. **Guard cells** are a second plant adaptation which decreases water loss. Note the drawing of a stoma and its two accompanying guard cells.

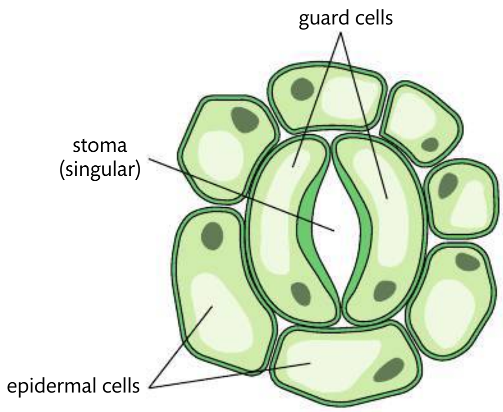


Figure 9.1 *A leaf stoma and its guard cells*

The guard cells control the size of the stoma. When the guard cells are enlarged due to increased amounts of water, the stoma gets larger. Guard cells with little water result in a small opening or stoma. Stomata which are smaller or closed decrease water loss from the leaf. In many plants, guard cells close stomata during the warmer parts of the day to decrease water loss.

A disadvantage of plants having stomata is loss of water through transpiration. The water movement in transpiration is good for the plant because it allows **solute** distribution throughout the plant. These solutes were initially absorbed by the roots. However, the stomata are essential for the exchange of gases between the inside and the outside of the leaf. Carbon dioxide and oxygen are the two gases of **photosynthesis** that are maintained at the correct level for photosynthetic activity due to movement through the stomata.

Skill: Design of an experiment to test hypotheses about the effect of temperature or humidity on transpiration rates

You need to know how to measure transpiration rates using a **potometer**. A potometer is a rather simple device used to measure transpiration rates in plants. There are several ways a potometer may be constructed. One way is presented in the following figure.

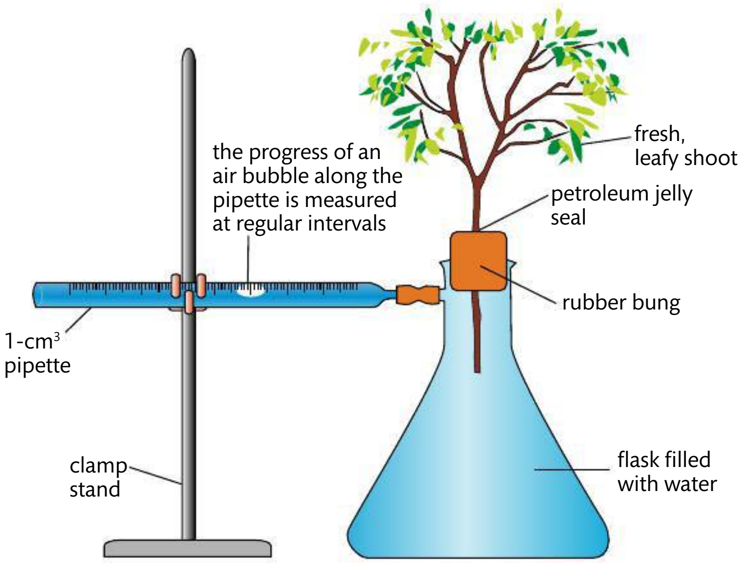


Figure 9.2 *An example of a potometer used to measure transpiration rate*

You are to design an experiment to measure the effects of temperature or humidity on transpiration rates in a plant species using your constructed potometer. Some findings you would expect from carrying out this procedure should include:

- The rate of transpiration increases as the surrounding temperature rises.
- The rate of transpiration increases as the surrounding **humidity** decreases.

Other environmental factors which usually affect transpiration rates include:

- Wind usually increases transpiration rates by carrying humid air away from the stomata.
- Low soil water content may result in more water lost by transpiration than the water brought in by the roots. This will result in less water in the guard cells and stomata closing.
- High carbon dioxide levels around the plant leaves usually cause the guard cells to close due to loss of water pressure (**turgor**) in the guard cells.

Application: Adaptations of plants in deserts for water conservation

Plants that survive in the desert have adaptations for water conservation. Plants that survive in the desert are referred to as **xerophytes**. These adaptations include:

- Smaller leaves which brings about a decrease in the number of stomata.
- Stomata located in pits or crypts on the leaf to increase humidity near the opening and minimize transpiration.
- Thick, waxy leaf coverings called a **cuticle**.
- A period of **dormancy** or even a **shedding** of leaves during the driest months.
- Hair-like structures on the leaf near stomata which trap water vapour. This maintains a higher humidity near the stomata.
- Using a different photosynthetic pathway in which the stomata are open at night and closed during the day. These are called **CAM plants**. They use a unique 4-carbon compound to attach to and release carbon dioxide in the photosynthesis process.

Subject vocabulary

potometer specialized device used to measure transpiration rates in plants

turgor water pressure within a cell

xerophytes plants with specialized adaptations to survive in the desert

cuticle waxy, protective, water-conserving layer on some leaves

dormancy inactivity

CAM plants plants carrying out a type of photosynthesis that is an adaptation to arid environments

General vocabulary

humidity the amount of water in the air

Synonyms

shedding........ dropping/loss

Subject vocabulary

halophytes plants with specialized adaptations to survive in high saline areas

succulents plants which possess fleshy, water-storing leaves

vacuoles cell storage structures especially visible in plants

General vocabulary

cohesion attraction of one water molecule for another, two like materials stick together or attach to one another

adhesion process where two different substances stick together or attach to one another

Application: Adaptations of plants in saline soils for water conservation

Plants which survive and grow in saline soils are referred to as **halophytes**. These adaptations include:

- Plants store large amounts of water in their tissues becoming **succulents**. This large store of water serves to dilute the salt concentration.
- Storing the salts present in **vacuoles** stops the salts from negatively affecting the functions of the plant.
- Leaf surface area is reduced.
- Stomata are sunken into the surface of the leaf in pits or crypts.
- Thickened cuticles.
- Plants possess structures which allow excretion from the cells of the salts brought in from the soil.
- A period of dormancy or loss of leaves when environmental conditions would result in high transpiration rates.

Hints for success: It is extremely important for a plant to have adaptations to minimize loss of water through its stomata. The stomata may pose a problem in water loss from the plant. However, they are essential for gas exchange in the process of photosynthesis.

Understanding: Plants transport water from the roots to the leaves to replace losses from transpiration.

Model sentence: Water lost from the plant by transpiration is replaced by water supplied from the roots.

Transpired water has to be replaced by the intake of water at the roots. There is a continuous stream of water from the roots to the upper parts of a plant. This upward, continuous stream of water through the plant provides both the water and the minerals necessary for the life of the plant.

The stream of water from the roots occurs in the xylem of the plant. **Cohesion**, **adhesion**, and the active uptake of minerals allow the maintenance of this stream of water in the xylem.

Understanding: The cohesive property of water and the structure of the xylem vessels allow transport under tension.

Model sentence: Two features that allow water transport in plants are cohesive properties between water molecules and the structure of xylem vessels.

Two features which allow water transport in plants are:

- cohesion
- structure of xylem vessels.

Cohesion in this case involves water molecules. Water is a polar molecule. The oxygen regions of the water molecule have a relatively negative charge. The hydrogen regions of the same molecule have a relatively positive charge.

Opposite electrical charges attract. In water the negatively charged regions are attracted to the positively charged regions of other water molecules. This attraction helps maintain the continuous columns of water in plants which occur in the xylem vessels.

Xylem vessels are formed when living cells arranged in long columns die and the contents break down. The ends of the cells which connect to one another develop large **pores** or perforations. This creates continuous, relatively uninterrupted tubes for water. The xylem vessel cell walls are thickened due to the addition of a material called **lignin**. The lignin is combined with the existing **cellulose** of the cell walls of the xylem to create a strong supporting part of the plant. The thick xylem walls are also necessary to withstand a negative pressure due to tension, which occurs within them due to water loss from transpiration.

There are regions of these xylem cell walls that are **hydrophilic**. The water of the xylem is attracted to these regions. This attraction between different molecules due to electrical charge differences is called adhesion. Adhesion also plays a role in the passage of water upward in a plant.

Skill: Drawing the structure of primary xylem vessels in sections of stems based on microscope images

You should be able to draw xylem vessels as they would appear in plant stem microscopic images.

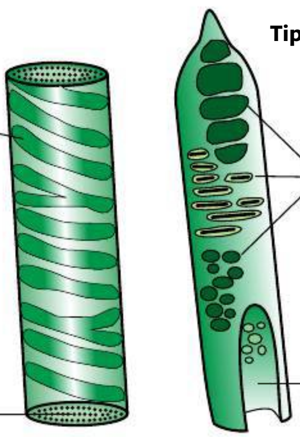


Figure 9.3 *Representation of plant xylem*

Understanding: The adhesive property of water and **evaporation** generate tension forces in leaf cell walls.

Model sentence: The evaporation of water and the polar attraction of water to surrounding structures create forces of tension within leaf cells.

The **intercellular spaces** in leaves normally have a high concentration of water molecules. It is the water molecules of the leaf intercellular spaces that have the potential to move to the leaf stomata. Molecules of water lost by evaporation through the stomata are replaced by water moving out of the xylem vessels and into the leaf intercellular space. This is partly due to the cohesion forces which exist between water molecules. However, there are adhesion properties at work as well. Water is attracted to polar regions of the leaf cell walls. A molecule of water lost by evaporation will **initiate** adhesion forces between water molecules and the cell walls to bring the next water molecule to the location. This adhesion force that

Subject vocabulary

xylem vessels columns of dead xylem forming cells without cytoplasm and with pores on their ends

lignin complex polymer combined with the cellulose of xylem cell walls which provides strength

cellulose complex carbohydrate present in plant cell walls

hydrophilic 'water loving', substances that dissolve in water

Synonyms

pore.............. hole/opening

Subject vocabulary

evaporation water changing from a liquid to a gaseous state

intercellular space space between cells

Synonyms

initiate........... start/begin

pulls the next molecule into position is referred to as tension. The pull of the water molecules towards the stomata creates a tension called **transpirational pull**. This transpirational pull exists in the xylem and the leaf intercellular spaces all the way from the stomata of the leaves to the very lowest root structures. The column of water in the xylem is maintained by cohesion amongst the water molecules.

Hints for success: Cohesion and adhesion are both at work in order to allow a continual supply of water necessary for the plant to carry out photosynthesis and remain alive. These forces are strong enough to ensure continuous columns of water in the plant xylem vessels all the way from the deepest root structures to the tallest stem and leaf structures. Root pressure is also involved in maintaining these columns of water.

Understanding: Active uptake of mineral **ions** in the roots causes **absorption** of water by **osmosis**.

Model sentence: The osmosis of water from the soil into a plant's root cells is due to the active uptake of mineral ions into the root.

A major function of roots is the uptake of water and mineral ions. Roots are efficient at this uptake function because of an extensive branching pattern and because of specialized **epidermal** structures called **root hairs**. The extensive branching pattern and the root hairs increase the surface area over which water and mineral ions may be absorbed.

Water moves into the root hairs from the soil because root cells have a higher mineral ion concentration and a lower water concentration than the surrounding soil. The build-up of the mineral ion concentration within the root hairs is due to active transport of the various ions from the soil into the root cells. This active transport involves very **specific** **protein pumps** for each ion in the root cell **plasma membranes**.

There is a **mutualistic relationship** between some plants' roots and a fungus. The fungus helps the plant by moving some mineral ions into the root. The plant helps the fungus by providing sugars and possibly other **nutrients**.

Water moves into the root cells by osmosis because of the high mineral ion concentration within the root cells.

Note that both active and passive transport are involved in the movement of water from the soil into the root system of plants. Active transport occurs when mineral ions are moved into the cell through protein carriers. Passive transport occurs when water moves by osmosis into the root cells.

Application: Models of water transport in xylem

Use all the available information to produce a model which represents water transport in the xylem of plants. **Capillary tubing** could be used in your model to represent the xylem with **continuous** columns of water in plants. Both adhesion and cohesion may be demonstrated using the capillary tubing. You could use a container of a measured amount of water into which one end of the capillary tubing is placed. Filter paper or some other type of **absorbent** paper could be used to draw the column of water out of the container and upward into the capillary tubing. The construction of your model will depend on the materials you have available. A model constructed correctly will provide a very good demonstration of how water moves upward in plants.

Subject vocabulary

transpirational pull pull or tension exerted on xylem columns of water as a result of transpiration

ion charged atom or group of atoms

osmosis movement of water through a membrane along a concentration gradient

epidermal of, or related to, the outer surface or epidermis

root hairs specialized extensions of root epidermal cells which increase the surface area of these cells for added water and mineral uptake

protein pumps proteins of the cell membrane involved in the transport of specific materials with the use of energy

plasma membrane membrane which surrounds the cell

mutualistic relationship relationship between two organisms in which both are helped

nutrient chemical material a cell or organism needs

capillary tubing glass tubing with small lumen used to demonstrate adhesion and cohesion

Synonyms

absorption ..... taking in

specific .... particular

General vocabulary

continuous continuing to happen or exist without stopping

absorbent able to easily take in liquids

Hints for success: Study the following figure which provides an overview of the mechanism for upward movement of water in land plants.

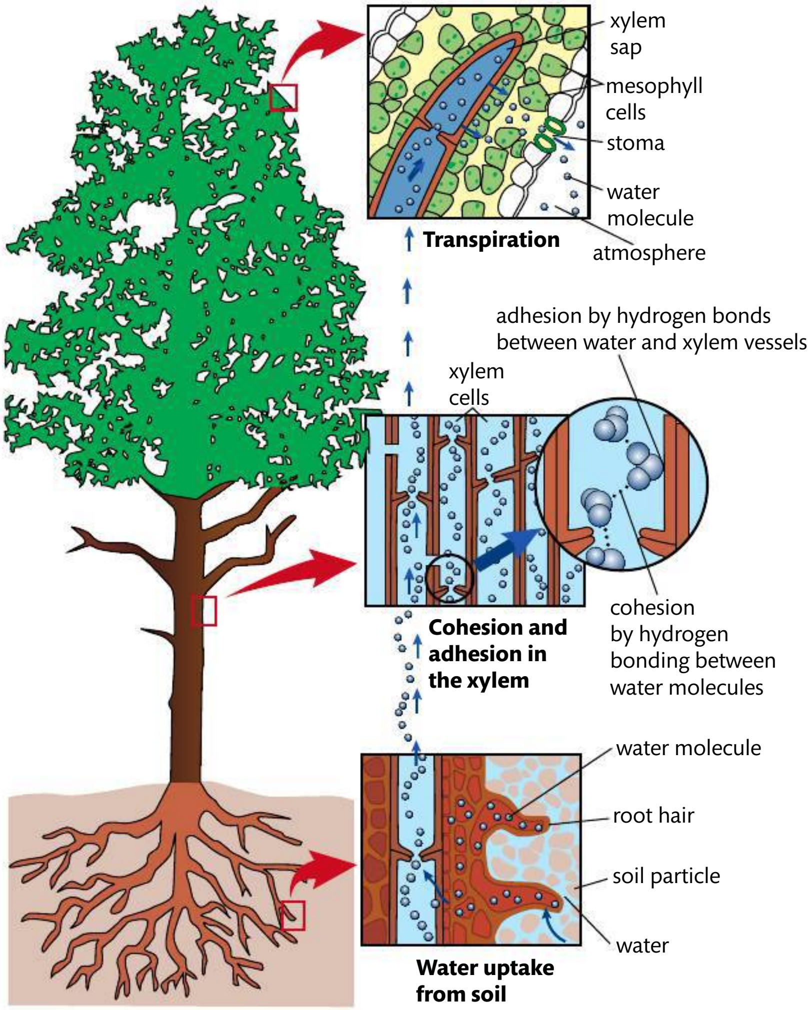


Figure 9.4 *Upward movement of water in land plants*

9.2 Transport in the phloem of plants

Main idea

The phloem is able to carry out its functions efficiently due to its structure.

Understanding: Plants transport organic compounds from sources to sinks.

Model sentence: The phloem of plants transports organic compounds such as sugars and amino acids from source areas to sink areas.

Xylem and phloem are the two major types of transport tissue in plants. Xylem transports water and minerals. Phloem transports organic compounds. Phloem is mostly made up of sieve tube members, also known as sieve tube elements, and

Subject vocabulary

phloem vascular tissue type in plants involved with transport of organic substances from sources to sinks

source area of high organic substance concentration in the pressure-flow hypothesis of phloem transport

sink area of low organic substance concentration in the pressure-flow hypothesis of phloem transport

sieve tube members cells of the phloem connected to one another by sieve plates to form sieve tubes

General vocabulary

compounds a combination of two or more parts, substances, or qualities

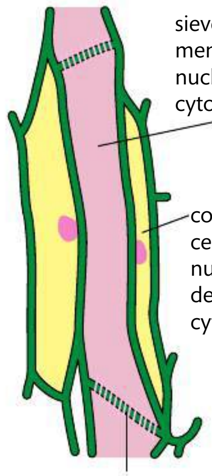


Figure 9.5 *The structure of phloem, including the sieve tube member and accompanying companion cell*

Subject vocabulary

companion cells living cells in the phloem involved in maintaining phloem functions

sieve tubes functional columns of the phloem through which the phloem sap flows, also known as sieve elements

sieve plates structures with pores connecting adjacent sieve tube members

cytoplasm region of the cell within the plasma membrane in which the cell organelles exist

bulb storage region of nutrients in the plant root region, serving as a source of nutrients in seasons with early growth

translocation movement of organic compounds in plants

phloem sap contents of the fluid within the phloem sieve elements often containing sugars and amino acids as well as water

Synonyms

pore.............. hole/opening

General vocabulary

sap the watery substance that carries food through a plant

their **companion cells**. Sieve tube members are connected to one another by sieve plates to form **sieve tubes**. Study the figure.

Notice the **sieve plates** have pores at the ends of sieve tube members. These **pores** allow the movement of water and dissolved organic molecules from one sieve tube member to another. The sieve tube members lack nuclei and have only small amounts of **cytoplasm**. However, they are alive and are able to maintain a functional cell membrane. The companion cells are also alive and aid in the transport process which occurs in the sieve tubes.

Phloem tissue transports organic compounds from sources to sinks within the plant.

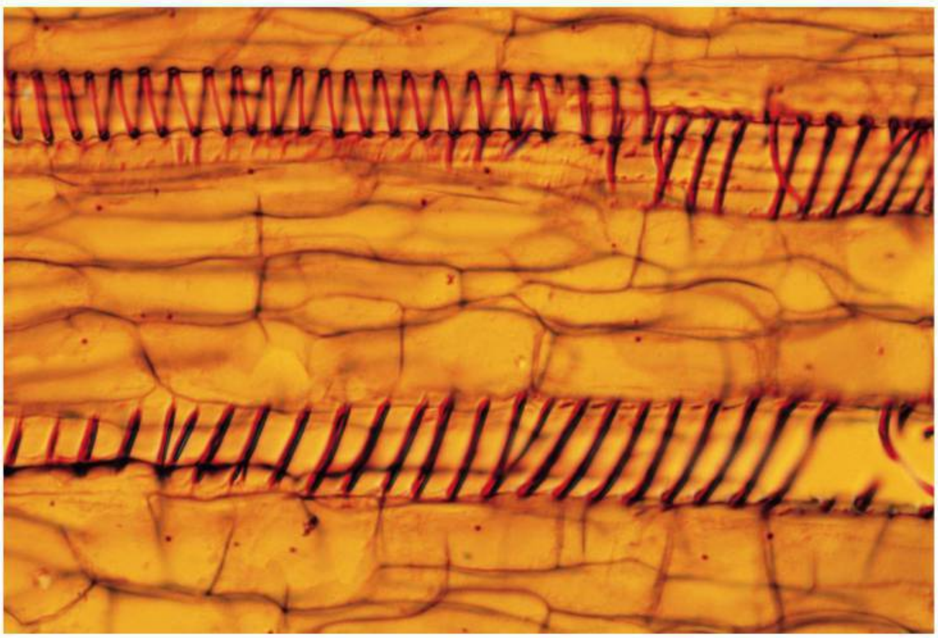
- A source is a plant organ or region that is a net producer or storage area of a particular organic compound.
- A sink is a plant organ or region that uses or stores a particular organic compound.

Sugars, usually sucrose, are among the most common organic compounds transported from source to sink by phloem tissue. It is possible for some plant structures to be both sources and sinks at different times. **Bulbs** are structures which are associated with the roots of some plants. Bulbs often act as a sink in the summer as they store sugar produced during photosynthesis. These same bulbs may act as a source in the early spring as they provide sugar for stem and leaf development.

The movement of organic compounds in plants is called **translocation**. These organic compounds are dissolved in water. The combination of water and organic compounds in phloem sieve tubes is called **phloem sap**. Sugars and amino acids are the most common compounds of phloem sap. Other compounds found in the phloem **sap** are plant hormones and small RNA molecules.

Skill: Identification of xylem and phloem in microscope images of stem and root

It is essential for you to be able to identify xylem and phloem tissue in microscope images of plants. Below are two micrographs showing xylem and phloem tissue.



Source: Science Photo Library / Astrid & Hanns-Frieder Michler

Figure 9.6 *Light micrograph of pumpkin tissue showing the lignin of the xylem vessel elements*

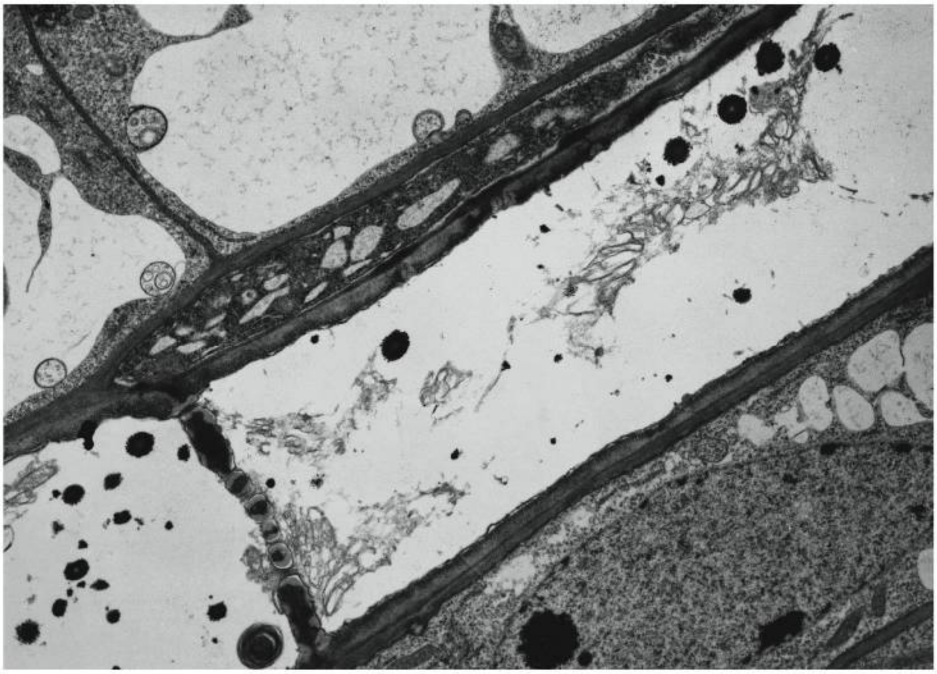


Figure 9.7 *TEM of a phloem sieve tube and its companion cell*

Study the examples above and search for other micrographs on the internet to develop your skills in identifying xylem and phloem tissue.

Microscopic cross-sections of stems and roots will usually show xylem cells are larger than phloem cells. **Vascular bundles** will usually have phloem cells closer to the outside of the plant than xylem cells. Analyse microscope cross-sections of roots and stems to verify these statements.

Understanding: Incompressibility of water allows transport along hydrostatic pressure gradients.

Model sentence: Phloem sap moves from areas of high pressure to areas of low pressure within the plant.

Water has many properties which makes it essential to the everyday functions of life. One property is that it is relatively **incompressible**. Two factors especially important in causing this incompressibility are:

- Water has a rather dense molecular structure as a liquid. Even when water is cooled to form ice, the ice has a lower density than liquid water.
- The numerous interactions amongst the water molecules. An example of the interactions are hydrogen bonds, which form between oppositely charged regions of the individual molecules.

It is this incompressibility which allows water to easily flow through tubes. The incompressibility of water also allows water to flow from areas in the plant of high water pressure to areas in the plant of low water pressure.

The **hydrostatic pressure** of water in a plant refers to the pressure water and its dissolved contents places on its confining structure such as the phloem sieve tubes. A **hydrostatic pressure gradient** in a plant's phloem refers to areas in the sieve tubes having different pressures pushing against the walls. Water movement in plant phloem occurs along hydrostatic pressure gradients.

Subject vocabulary

vascular bundles groups of vascular cells found together in stems and roots of some plants

hydrostatic pressure pressure of water and its dissolved contents on their confining structures such as on the cell walls of the phloem sieve tubes

hydrostatic pressure gradient two areas connected in which one area has a higher hydrostatic pressure than the other, fluids will flow from the high pressure area to the low pressure area

General vocabulary

incompressible not able to be pressed together any closer

Understanding: Active transport is used to load organic compounds into phloem sieve tubes at the source.

Model sentence: Source areas in phloem sieve tubes use active transport of sucrose to produce high hydrostatic pressure regions.

The sugar **sucrose** is the form of carbohydrate most often carried from source to sink in phloem sieve tubes. Sucrose is the major organic compound loaded into phloem sieve tubes by active transport at source areas of a plant. The loading of sucrose into the sieve tubes at the source involves **proton pumps** and specialized membrane proteins called **cotransport proteins**. This loading is an example of **chemiosmosis**, a type of active transport.

The companion cells which accompany the phloem sieve tubes are involved with this active transport process. It is the companion cells which provide the **ATP** for the loading to occur.

Subject vocabulary

sucrose disaccharide of glucose and fructose

proton pumps protein in the cell membrane which uses ATP to transport hydrogen ions out of a cell against a concentration gradient

cotransport proteins proteins of the cell membranes which aid in the transport of compounds across the cell membrane

chemiosmosis process in which ATP is produced due to protons diffusing through ATP synthase in thylakoid and cristae membranes

ATP a molecule used as a source of chemical energy

solute molecules dissolved in a solvent (water)

active transport cellular transport requiring energy (ATP) from the cell

hypertonic solution a solution with a higher concentration of solute(s) and a lower concentration of water (the solvent)

hypotonic solution a solution with a lower concentration of solute(s) and a higher concentration of solvent (water)

passive transport cellular transport not requiring cellular energy, occurs along a concentration gradient

Understanding: High concentrations of **solutes** in the phloem at the source lead to water uptake by osmosis.

Model sentence: The active transport of sucrose creates a hypertonic solution at the phloem source areas which causes passive water flow into these areas.

Study the following sequence of events which occur at the phloem source:

- **Active transport** of sucrose into the phloem source area occurs.
- A **hypertonic solution** in the phloem results from this active transport with a relatively lower water concentration than the surrounding fluid.
- Water then moves from the surrounding fluid into the phloem source area attempting to equalize the water concentration inside and outside the phloem sieve tubes.

The water moving in this system from an area of higher water concentration to an area of lower water concentration is a passive process. The movement of water is an example of osmosis.

Hints for success: Water moves by osmosis from a **hypotonic solution** across cell membranes to a hypertonic solution without the need of energy from the cell. This **passive transport** of water into the source only occurs after sucrose has been actively transported into the same source area.

Understanding: Raised hydrostatic pressure causes the contents of the phloem to flow towards sinks.

Model sentence: Movement along hydrostatic pressure gradients in the phloem sieve tubes results in the flow from source to sink.

Both active and passive transport occurs at phloem sources to cause increased hydrostatic pressures. Sucrose is removed from the phloem sap in the sink areas. This sucrose may be used for metabolic needs in the sink area or it may be stored in the form of starch in the vacuoles of surrounding cells. The continuous removal of sucrose from the sink results in the maintenance of a relatively low hydrostatic pressure at this location. It is this hydrostatic pressure gradient which results in the flow of phloem sap from source to sink.

The relatively pure water left after the removal of sucrose at the sink is moved along a concentration gradient into xylem vessels to enter the xylem transpirational stream or to be used at another plant source site.

This complete process explaining the movement of phloem sap through plants is known as the **pressure-flow hypothesis**.

The following figure provides an overview of the pressure-flow hypothesis of phloem sap movement.

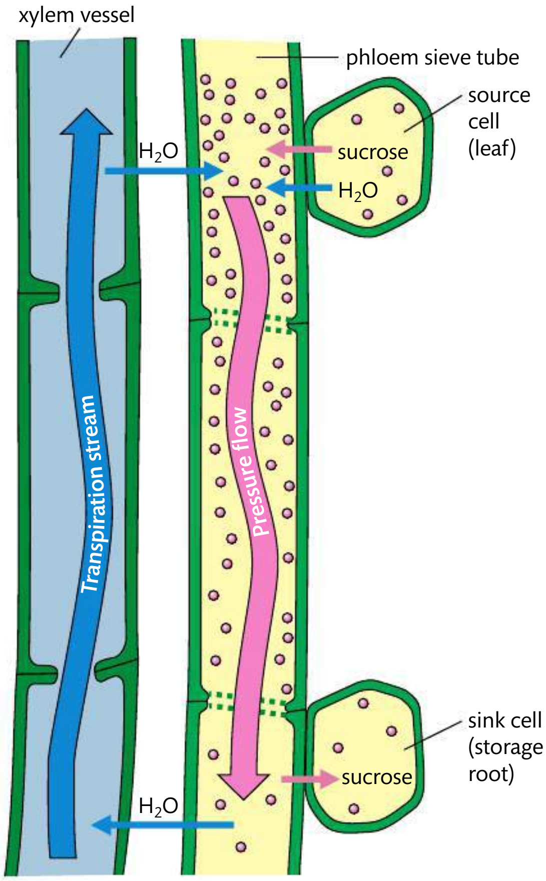


Figure 9.8 *The pressure-flow hypothesis*

Application: Structure–function relationships of phloem sieve tubes

There are several structural features of phloem tissue which allow it to carry out its functions. The table below summarises the functions of the structures.

Phloem structure or feature	Function allowed by structure or feature
living sieve tube cells	ensures the presence of a cell membrane to allow osmosis and the active transport of organic compounds, mostly sucrose, into the sieve tube source areas
companion cells	have numerous **mitochondria** to produce the ATPs necessary for active transport in sucrose loading at the source areas help in the maintenance of the sieve tube cells
proton pump proteins and cotransport proteins in the sieve tube cell membranes	help in the loading of sucrose and other organic compounds into the phloem sieve tubes which occurs at the source
rigid cell walls of the sieve tube cells	allows the development of the hydrostatic pressures essential to the pressure-flow hypothesis for plant phloem sap transport
pores in the ends of the sieve tube cell walls	allows increased flow between the connecting sieve tube members (elements) in a sieve tube
decreased cytoplasm in the sieve tube members	allows increased flow between the connective sieve tube members (elements) in a sieve tube

Subject vocabulary

pressure-flow hypothesis presently most accepted hypothesis of water and content movement within the phloem of plants

mitochondrion (plural: mitochondria) cell organelle involved in cell respiration

General vocabulary

rigid stiff/not moving or bending

Synonyms

pore.............. hole/opening

Subject vocabulary

aphid stylets extensions of an aphid's mouth which penetrate and obtain nutrients from a source

radiation particles given off by a substance which allow its tracking

undifferentiated cells cells without specific structure or function

meristem region in plants which allows growth

determinate growth growth occurring to definite limits involving stage, size, or age

indeterminate growth growth which continues throughout the life of an organism, such as in plants

primary growth growth in length of a plant or plant structure

secondary growth plant growth involving increase in width

apical meristems/primary meristems regions of growth at the tips of plants

cork cambium meristematic tissue which produces new cork/bark cells

Synonyms

penetrate....... go through

Skill: Analysis of data from experiments measuring phloem transport rates using aphid stylets and radioactively labelled carbon dioxide

Evidence for the pressure-flow theory of phloem sap movement can be provided by analysis of data from procedures involving **aphid stylets**. Stylets are extensions from an aphid's mouth which the insect uses to **penetrate** a single sieve tube in a plant. The stylet inserted into the sieve tube provides nutrients to keep the animal alive. If the aphid is **anaesthetized** and removed from the stylet, the contents and the pressure of the fluid continuing to come out of the stylet may be analysed. Data analysis should show:

- Pressure decreases in the sieve tube as the stylet is inserted further from the source.
- The lowest pressure is nearest the sink.
- Sucrose levels are substantially lower in the sink than in the source.

Analysing fluid from the stylets coupled with the use of radioactively labelled carbon dioxide demonstrates how carbohydrates produced in photosynthesis are transported throughout the plant to multiple areas for many different uses. The radioactively labelled carbon dioxide can be tracked in the plant because it gives off traces of **radiation**.

9.3 Growth in plants

Main idea

Plant growth shows **adaptation** to environmental conditions.

Understanding: Undifferentiated cells in the meristems of plants allow indeterminate growth.

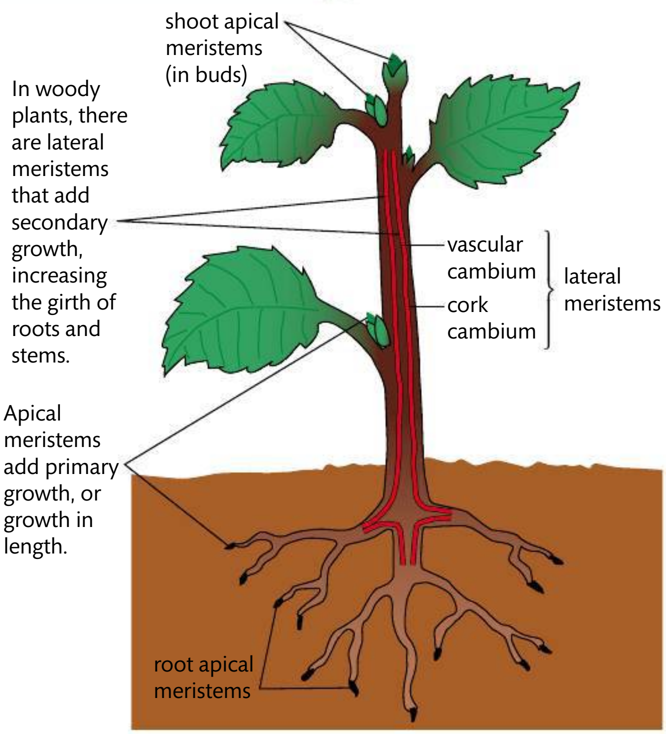


Figure 9.9 *An overview of primary and secondary growth*

Model sentence: Cells of meristem regions of plants allow growth throughout a plant's life.

Types of growth in organisms include two major types:

- **Determinate growth** occurs in most animals and in some plant organs such as flowers. Organisms with this type of growth stop growing at a particular stage, size, or age.
- **Indeterminate growth** occurs in most plants. Organisms with this type of growth show continued growth throughout their life.

Meristems are regions of plants which contain specialized cells allowing continual growth. **Primary growth** is growth in length of a plant or plant structure. **Secondary growth** is growth in width of a plant or plant structure. Stems and roots show primary growth due to meristematic tissue at their tips. Meristems occurring at the tips of plants are called **apical meristems** or **primary meristems**. Lateral meristems allow growth in the thickness of plants or plant structures. Examples of lateral meristems are **vascular cambium** and **cork cambium**. These lateral meristems are common in trees and shrubs known as woody plants.

Understanding: **Mitosis** and cell division in the **shoot apex** provide cells needed for extension of the stem and development of leaves.

Model sentence: The shoot apex of plants carries out rapid and continuous cell division to provide the cells needed for primary stem growth and leaf development.

The **meristematic tissue** at the tips of roots and stems is composed of many small cells which are continuously going through mitosis and **cytokinesis** cell division. These small cells show no **differentiation** into a particular plant cell type. When a **meristematic cell** divides the result is the following:

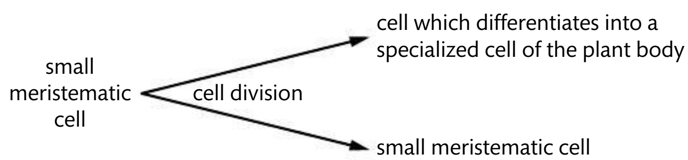


Figure 9.10 *Division of a meristematic cell*

The products of this meristematic cell division produce cells for plant growth while maintaining the meristematic tissue necessary for future and ongoing growth.

The apical meristem and its surrounding developing plant tissue at the tip of a stem is known as the shoot apex. Differentiation of cells produced by cell division of meristematic tissue allows the production of all the different cells necessary for plant elongation or growth. This cell differentiation from the shoot apex also allows the formation of the cells necessary to form new leaves in the plant growth process. The table below shows what early shoot apex structures become in the mature plant.

Shoot apex structure	Mature plant part
protoderm	epidermis
leaf primordia	leaf
procambium	vascular tissue and **lateral** meristem

Understanding: Plant hormones control growth in the shoot apex.

Model sentence: Growth and cell division within the shoot apex are controlled by chemical messengers called plant hormones.

Factors which affect plant development and growth include:

- environmental factors, such as day length and water availability
- receptors, which allow the plant to detect certain environmental factors
- the genetic make-up of the plant
- **hormones** of several types produced in various plant regions.

Plant hormones are produced in very small amounts. They have the potential to bring about effects in many parts of the plant. The plant hormones normally move through the phloem transport system or from cell to cell. The cells upon which hormones have an effect are called **target cells**.

Subject vocabulary

mitosis cell division where one diploid cell becomes two diploid cells

shoot apex apical meristem and its surrounding developing plant tissue at the tip of a stem

meristematic tissue tissue of the meristem which allows continual growth

cytokinesis division of the cytoplasm in cell division

differentiation series of changes which transforms unspecialized cells into specialized cells and tissues in multicellular organisms

meristematic cell undifferentiated cell of plant meristems

protoderm early shoot apex area which becomes the mature plant epidermis

leaf primordia early shoot apex area which become the leaf

hormone chemical messenger produced in very small amounts by an endocrine gland

target cell cells that respond to a particular hormone

General vocabulary

anaesthetized given a drug to prevent the feeling of pain

adaptation change which makes something more suitable for a situation

lateral related to the sides or movement to the side

A plant hormone will have varying effects depending on the target cell's location within the plant. It is also common for various plant hormones to interact with one another to produce a particular response within a plant.

Auxins are a group of plant hormones which have a very large effect on shoot apex growth and development. These auxins may also affect leaf and fruit development. Other common plant hormones and their general effect are shown in the table below.

Hormone	General effect
gibberellin	promotes seed germination and stem growth
cytokinin	promotes root growth and maintains leaf health
abscisic acid	closes stomata, maintains seed dormancy
ethylene	promotes fruit ripening

Hints for success: It is especially important to note the role of auxins in promoting shoot apex growth and development.

Application: Use of micropropagation for rapid bulking up of new varieties, production of virus-free strains of existing varieties, and propagation of orchids and other rare species

Scientists are using the present understanding of plant meristems and plant hormones in **micropropagation** procedures to produce large numbers of plant offspring which have desired characteristics. Micropropagation uses cells from the shoot apex of desired plants. The propagation of new plants from these cells involves sterile cultures grown on nutrient gels. The addition of specific plant hormones such as an auxin or cytokinin to the sterile cultures is necessary to obtain the new plants from the shoot apex cells. Scientists are making use of the fact that plant cells retain the ability to differentiate into any plant part in this procedure.

This method also allows them to obtain plants which are virus-free or which are new varieties of an existing plant. Orchids and other rare species of plants are produced in laboratories by micropropagation.

Understanding: Plant shoots respond to the environment by tropisms.

Model sentence: Plant tropisms occur in response to environmental stimuli.

Tropisms refer to plant growth or movement in response to directional stimuli in the immediate environment. **Positive tropisms** bring about growth or movement toward environmental stimuli. **Negative tropisms** refer to growth or movement away from environmental stimuli. Common stimuli for plant tropisms are:

- chemicals
- light
- gravity
- touch.

Growth or movement in plants due to gravity is called **gravitropism**. Most plant roots show **positive gravitropism**. The stems of most plants show **negative gravitropism**. **Phototropism** is growth or movement of a plant towards or away from light. In general, roots are **negatively phototropic**. Stems are usually **positively phototropic**.

Subject vocabulary

auxins group of plant hormones affecting plant growth and development

gibberellin plant hormone which promotes seed germination and stem growth

cytokinin plant hormone which promotes root growth and maintains leaf health

abscisic acid plant hormone which closes stomata and maintains seed dormancy in some plant species

ethylene plant hormone involved in promoting fruit ripening

micropropagation process of culturing cells from the shoot apex of plants on nutrient gels to produce desired plants

tropism plant growth or movement to directional stimuli in the immediate environment

positive tropism plant growth toward a specific environmental stimulus

negative tropism plant growth away from a specific environmental stimulus

gravitropism growth or movement in plants due to gravity

positive gravitropism plant growth toward gravity such as roots show

negative gravitropism plant growth away from gravity

phototropism plant growth or movement towards or away from light

negatively phototropic plant growth away from light

positively phototropic plant growth toward light

Understanding: Auxin efflux pumps can set up **concentration gradients** of auxin in plant tissue.

Model sentence: Auxin efflux pumps move auxins out of plant cells in a region which is closest to light creating cells with different auxin concentrations.

The figure opposite shows the effect of sunlight on a typical stem shoot. There is a higher concentration of auxin on side B. The higher concentration of auxin on side B causes increased **elongation** of the cells on this side compared to side A. As shown, the result is growth towards the light.

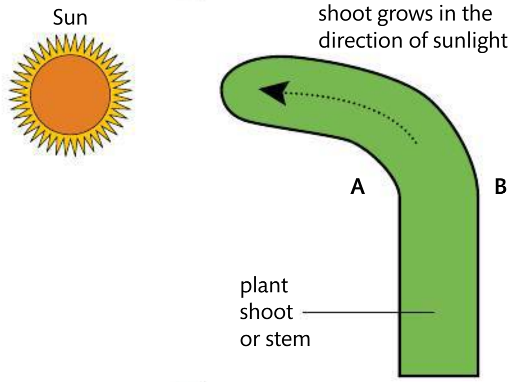


Figure 9.11 *Effect of auxin on some plant stems*

This figure demonstrates positive phototropism. Auxin is actually being produced in all cells of the region of plant shown. It is specialized membrane proteins called auxin efflux pumps that move the auxins out of the cells closer to the light to cells which are further from the light. The specialized proteins of the auxin efflux pumps are known as **PIN3 proteins**. ATP is the energy source that allows the auxin efflux pumps to function. The position of the PIN3 proteins (auxin efflux pumps) may be altered to affect the direction of auxin movement.

Sequence of events in plant **phototropism**:

1. Auxin is produced by all cells in the plant shoot region exposed to light.
2. Auxin efflux pumps move auxin out of cells on the shoot side closest to the light and into the intercellular space.
3. Auxin is moved to the intercellular space of the shoot cells further away from the light.
4. The auxin activates proton pumps in the cell membranes of the shoot cells further from the light.
5. The proton pumps cause a build-up of hydrogen ions in the intercellular space.
6. Increased hydrogen ions in the intercellular space causes a decrease in pH.
7. A decrease in pH breaks hydrogen bonds in the cellulose of the cell walls of cells away from the light.
8. The result of breaking cellulose hydrogen bonds is elongation of cells on the darker side and bending toward the light.

The particular auxin involved in this elongation process of phototropism is called **indole-3-acetic acid** (IAA).

Subject vocabulary

concentration gradient difference in chemical concentrations between two regions

auxin efflux pump PIN3 proteins of plant cell membranes involved in moving auxins in plant tissues

PIN3 proteins proteins making up auxin efflux pumps

phototropism plant growth or movement towards or away from light

indole-3-acetic acid specific plant auxin involved in elongating plant stems in response to light

transcription the process of creating RNA from DNA

transcriptional repressors protein which binds to DNA and prevents transcription of a particular region or gene

General vocabulary

elongation to grow longer

Understanding: Auxin influences cell growth rates by changing the pattern of gene expression.

Model sentence: The hormones known as auxins are able to alter transcription in certain plant cells and alter growth rates.

Current research shows that auxins combine with specific plant cell receptors which target **transcriptional repressors** of genes that respond to auxins in the plant cell

DNA. There are repressors in certain plant stem cells that **inhibit** the transcription of growth-stimulating genes. Growth is very slow when these repressors are present. The ways auxins affect gene expression and plant growth are as follows:

1. When auxin comes into contact with receptors on the nuclear membrane of these repressor-containing cells, an **auxin-receptor complex** is formed.
2. This complex moves to and binds with the repressor of the DNA that codes for growth-stimulating genes.
3. The binding with the repressor results in the breakdown of the repressor.
4. Growth-stimulating genes are transcribed when the repressor is no longer present.
5. The transcription of the growth-stimulating genes causes growth.

Subject vocabulary

auxin-receptor complex combination of an auxin and a transcriptional repressor which leads to breakdown of the repressor and transcription occurring

angiosperms largest taxonomic group of plants in which flowers are involved in their reproductive process

pollination transfer of pollen from the anther to the stigma of a flower, occurs before fertilization in angiosperms

pollen produced by the anther of the stamen and carries the male gametes in angiosperms

stigma upper most part of the flower's female structure which receives the pollen

vegetative non-reproductive, non-flowering

repression the act of preventing or decreasing the chances

9.4 Reproduction in plants

Main idea

The living and non-living environment of flowering plants greatly affects reproduction in the plants.

Understanding: Flowering involves a change in gene expression in the shoot apex.

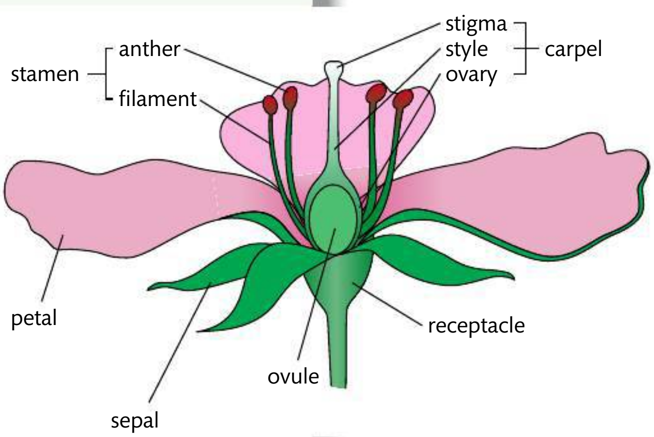


Figure 9.12 *Half-views of animal-pollinated flower*

Model sentence: A change in gene expression must occur in the shoot apex to cause flowering in an angiosperm.

Plants which produce flowers are known as **angiosperms**. The flowers produced by different species of angiosperms differ greatly. A typical flower is shown in the figure.

This flower has features which allow **pollination** by animals. There are differences in flower structure when pollination is by wind or water. Pollination involves the placing of **pollen** (containing male sex cells) on the **stigma** of the carpel (female flower part).

The flower develops from the shoot apex. The shoot apex usually allows a **vegetative** or growth mode in the plant. At certain times the vegetative or growth mode of the shoot apex switches to a reproductive mode. Environmental factors which may be involved in the change from vegetative to reproductive mode in flowering plants include:

- day/night length
- temperature.

Some flowering plants seem to have an 'internal clock' which **initiates** the production of flowers.

Whatever the cause of the switch to the reproductive mode, the result is a **cascade** of changing gene expression. **Repression** of vegetative-focused genes and initiation of reproductive-focused genes occurs. Even the flower organs are formed in an exact order and location based on which genes are being expressed at certain times in the shoot apex.

Synonyms

inhibit(s)........ prevent(s)/reduce(s)

initiate(s)....... start(s)/begin(s)

General vocabulary

cascade a sequence of events, each one causing the next

Skill: Drawing of half-views of animal-pollinated flowers

You must be able to draw and label a half-view of a typical animal-pollinated flower, such as the one opposite. Be certain the flower parts are in the correct location in relation to one another. Also, make sure the flower parts are scaled correctly. You may also be asked to label a drawing of a flower. Observe several examples of flower half-views on the internet to develop your skill. Be certain the flowers you look at are animal-pollinated flowers.

Understanding: The switch to flowering is a response to the length of light and dark periods in many plants.

Model sentence: Many plants switch from vegetative to flowering mode in response to length of light and dark periods.

Photoperiodism is the response of a plant to light involving the relative lengths of day and night. Day and night length control flowering in many plants. There are two categories of plants which flower according to the lengths of day and night. They are:

- Long-day plants, which flower when days are longest and nights are shortest.
- Short-day plants, which flower when days are shorter and nights are longer.

Flowering in plants known as day-neutral plants does not depend on day length. Long-day and short-day plants are actually responding to night length and not day length.

Photoperiodism depends on the presence of a blue-green pigment called phytochrome. Phytochrome occurs in the leaves of the plant. There are two forms. They are:

- P_r – an inactive form of phytochrome
- P_{fr} – an active form of phytochrome.

The following figure shows the interconversion of the phytochrome molecule and its two possible forms. This mechanism promotes or inhibits flowering in many plants.

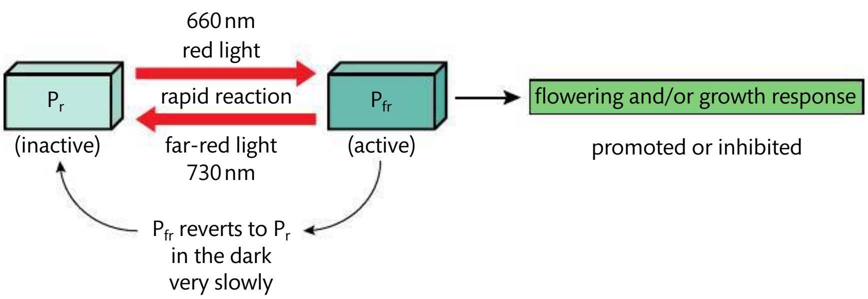


Figure 9.13 *Interconversion of phytochrome*

Notice that P_r is converted to P_{fr} in the presence of red light which has a wavelength of 660 nm. This is a relatively rapid conversion. P_{fr} may be converted to P_r in two ways:

1. When P_{fr} is exposed to far-red light which has a wavelength of 730 nm, it is rapidly converted to P_r.
2. Darkness causes the very slow conversion of P_{fr} to P_r.

In long-day plants the remaining P_{fr} at the end of a short night stimulates the plant to flower by acting as a promoter to genes which bring about flowering.

Subject vocabulary

photoperiodism response of a plant to light involving the relative lengths of day and night

long-day plants plants which flower when days are longest and nights are shortest

short-day plants plants which flower when days are shorter and nights are longer

phytochrome blue-green pigment occurring in plant leaves and involved in photoperiodism

P_r inactive form of phytochrome involved in photoperiodism

P_{fr} active form of phytochrome involved in photoperiodism

interconversion the way a molecule changes between its possible forms

In short-day plants the P_{fr} acts as an inhibitor to the genes which bring about flowering. For these short-day plants, enough P_{fr} has to be converted to P_r for inhibition of the flowering genes to stop. This conversion can only happen with long nights.

Hints for success: P_{fr} is referred to as the active form of phytochrome since it is the form that may either inhibit or promote flowering. It inhibits flowering in short-day plants. It promotes flowering in long-day plants. Night length which allows the slow conversion of P_{fr} to P_r is the actual cause of photoperiodism.

Application: Methods used to induce short-day plants to flower out of season

Scientists apply photoperiodism in *Euphorbia pulchemrrima*, the poinsettia plant, to produce large numbers of the plant with colourful displays commercially. Poinsettia plants are short-day plants in which P_{fr} acts as an inhibitor of flowering. These plants are grown in large **greenhouses** in which light is controlled. Plants kept in the dark for at least 14 hours will produce the brightly coloured displays consumers want. The bright displays of colour are not actually due to the flowers. The coloured structures are **bracts** (a form of leaf) which are produced at the same time as the plant's tiny flowers. Many other plants can be stimulated to flower by altering periods of darkness **artificially**.

General vocabulary

greenhouse a glass building used for growing plants needing warmth, light and protection

artificially not in a real way

Subject vocabulary

bracts unique structures produced in some plants which are a form of leaves

stamen male reproductive structure of the flower

pollen produced by the anther of the stamen and carries the male gametes in angiosperms

anther stamen structure in which pollen is produced and matures

self-pollination pollen is transferred from anther to stigma of the same flower or of the same plant

Understanding: Success in plant reproduction depends on pollination, fertilization, and seed dispersal.

Model sentence: Pollination, fertilization, and seed dispersal are all essential for success in plant reproduction.

Pollination

Pollination is the process by which pollen is transferred from the male **stamen** to the female stigma in flowering plants.

Pollen contains the male sex cells and is produced in the **anther** part of the stamen.

The first step in successful sexual reproduction in a flowering plant is the transfer of pollen from the anther to the stigma of the same plant species.

Locate the anther and the stigma in the drawings below:

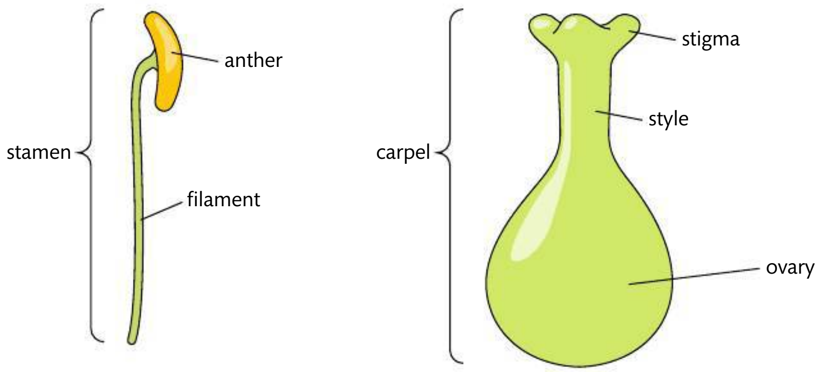


Figure 9.14 *The reproductive structures of a flowering plant: the stamen and the carpel*

In **self-pollination**, pollen is transferred from anther to stigma of the same flower or another flower of the same plant.

Subject vocabulary

cross-pollination pollen transferred from anther to stigma of flowers on different plants

haploid a cell that has only one chromosome of each homologous pair

diploid zygote fertilized egg with the diploid chromosome condition

stigma upper most part of the flower's female structure which receives the pollen

pollen tube growth structure from a germinating pollen grain which contains the male gametes

Cross-pollination occurs when pollen is transferred from anther to stigma of flowers on different plants.

There are three major factors called vectors involved in pollination. They are:

- wind
- water
- animals.

Animals are the most commonly involved vector in pollination. Water is the least commonly involved.

Fertilization

Fertilization occurs after pollination. It is the union of haploid male and female sex cells to form a diploid zygote.

Pollen which falls on the stigma of a flower produces a pollen tube which grows through the style of the carpel to the ovary.

The growing pollen tube carries the male gametes to the ovules (the female gametes) of the ovary.

Fertilization in flowering plants is actually a double fertilization. One sperm combines with an ovule egg nucleus. Another sperm from the same pollen tube combines with two polar nuclei in the ovule to produce the endosperm. The endosperm is $3n$, triploid, and provides the nutrients for the new plant that develops from seed germination.

Fertilization in flowering plants results in the formation of a seed.

Seed dispersal

The final factor in the successful sexual reproduction of flowering plants is seed dispersal.

Seeds must have some means to move from the parent plant. Successful seed dispersal lessens competition for resources around the parent plant. It also allows the species to spread from a single location.

Some common factors which allow seed dispersal include water, wind, or animals. Seeds have specific adaptations that allow them to be successfully dispersed by one of these three means.

Seeds must go through germination to produce new plants. Seeds contain an embryonic plant which goes through development as a result of germination. There are many factors which may affect seed germination. These factors are investigated in the Skill activity below.

Skill: Drawing internal structure of seeds

You should practise drawing and labelling the structures of seeds. Adjacent is a figure showing a bean seed and its structures.

Cotyledons are seed leaves which contain the nutrients of the bean seed. Bean seeds have two cotyledons and are said to be dicotyledonous. Some seeds have one cotyledon and are said to be monocotyledonous.

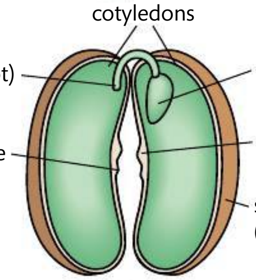


Figure 9.15 *Structure of a typical dicotyledonous seed*

Subject vocabulary

style structure which connects the stigma to the ovary in the carpel of a flower

carpel female sex organ of a flower

gamete(s) a sex cell, either a sperm cell or an egg cell

ovules female gametes which occur in the ovary of the carpel, will become seeds when fertilized by male gametes

double fertilization plant fertilization when one male gamete combines with an egg nucleus of an ovule and another combines with two polar nuclei

polar nuclei occur in an ovule and form the endosperm when a male gamete combines with them

endosperm part of the seed which provides the nutrients for the developing plant after seed germination

seed structure produced after fertilization in plants which allows the formation of a new plant

seed dispersal transport of seed from the parent plant to a new location

germination early growth or sprouting of a seed

embryonic plant early plant which occurs inside the seed

cotyledons seed leaves which provide nutrients early in a plant's life

dicotyledous plant seed with two seed leaves

monocotyledous plant seed with one seed leaf

General vocabulary

union the act of joining things together

adaptation change which makes something more suitable for a situation

Skill: Design of experiments to test hypotheses about factors affecting germination

Design an experiment to test a hypothesis about a factor which affects seed germination. Water amounts, periods of seed dormancy, oxygen levels, temperature, and pH are possible factors to investigate. You will need to decide on a particular seed type. Rapidly germinating seeds will produce results sooner. With rapidly germinating seeds, there will also be less chance of fungal growth. Be certain to keep all factors constant in your procedure except for the one factor you are investigating. Vary the factor you want to examine. It is essential to plan the collection of data so that a correct and meaningful conclusion may be obtained.

Understanding: Most flowering plants use mutualistic relationships with pollinators in sexual reproduction.

Model sentence: Most flowering plants have developed mutualistic relationships with pollinators to bring about successful sexual reproduction.

Common **pollinators** of flowering plants include bats, birds, and, especially, insects. A **mutualistic relationship** often develops between the pollinator and the flowering plant. In a mutualistic relationship, both of the organisms involved benefit. Pollinators gain food in the form of **nectar** when they carry out pollination of many flowering plants. An example of this is the honey bee. The honey bee gains food in the form of nectar while carrying out pollination of a flower. Both honey bee and plant are helped by this association.

It is important to maintain our pollinator populations in order to allow the continued existence of our flowering plants. Much of our food supply comes either directly or indirectly from these plants.

Subject vocabulary

pollinators organisms which are involved in the process of pollination

mutualistic relationship relationship between two organisms in which both are helped

nectar high sugar substance produced by plant flowers which is beneficial to pollinators

10.1 Meiosis

Main idea

Meiosis leads to independent **assortment** of chromosomes and unique composition of alleles in daughter cells.

Nature of science: **Making careful observations – careful observation and record keeping turned up anomalous data that Mendel's law of independent assortment could not account for. Thomas Hunt Morgan developed the notion of linked genes to account for the anomalies.**

Understanding: Chromosomes **replicate** in **interphase** before meiosis.

To prepare for meiosis, the chromosomes replicate while they are still in interphase. This causes single chromosomes to develop a sister chromatid resulting in two identical sister chromatids attached at the centromere.

The extra copies of DNA will ensure that the desired quantity of genetic information gets to the daughter cells that will be produced in the various phases of meiosis.

Hints for success: When looking at chromosomes in the early stages of meiosis, do not confuse two sister chromatids as two chromosomes. Be sure to learn to identify the difference between sister chromatids and homologous chromosomes.

Understanding: Crossing over is the exchange of DNA material between non-sister **homologous chromatids**.

Homologous chromosomes are matched in pairs. One in each pair is from the person's father and the other is from the person's mother.

The first pair contains the longest homologous chromosomes, for example. Remember that homologous chromosomes are similar but not necessarily identical because they can possess different alleles for the same genes.

When the homologous pairs pair up during prophase, crossing over can occur. This allows for the exchange of alleles between non-sister homologous chromatids. In other words, the maternal chromosome 1 could exchange a piece of one of its chromatids with the equivalent piece of the paternal chromosome 1.

Understanding: Crossing over produces new combinations of alleles on the chromosomes of the **haploid** cells.

Model sentence: **Without the process of crossing over, paternal chromosomes and maternal chromosomes would remain unchanged and would not show as much variety.**

Crossing over can increase the genetic variety of the sperm cells and egg cells that will be produced. Because the exchange happens between maternal and paternal chromosomes, there is a possibility of introducing alleles that were present in the

Subject vocabulary

meiosis cell division where one diploid cell becomes four haploid cells

interphase stage in the life of a cell in which it is carrying out activities other than cell division

homologous chromatids chromatids of the same shape and size that carry corresponding alleles in the same positions

alleles versions of a gene, differing by one or more bases

prophase a stage of the cell cycle during which the nuclear envelope breaks down and chromatin fibres coil to form chromosomes which form and attach to the mitotic spindle

haploid a cell that has only one chromosome of each homologous pair

Synonyms

assortment..... variety

anomalous..... different/ unexpected/ unusual

replicate........ copy/repeat

Synonyms

vice versa....... the opposite of

Subject vocabulary

bivalent/tetrad a pair of homologous chromosomes lined up during metaphase I of meiosis

chiasma (plural: chiasmata) the point at which two chromosomes cross each other during crossing over

meiosis I first part of meiosis during which homologous chromosomes separate to produce two diploid cells

diploid a cell which has chromosomes in homologous pairs

anaphase I the stage in meiosis where homologous chromosomes separate

paternal line but never present in the maternal line or **vice versa**. When the sperm and eggs form, they will possess combinations of alleles that were not present in their original chromosomes.

Understanding: Chiasmata formation between non-sister chromatids can result in an exchange of alleles.

When two homologous chromosomes line up during meiosis, they form what is called a **bivalent** or **tetrad**. This pairing up is unique to meiosis and not seen in mitosis.

Once they are matched up, crossing over can take place. The chromosomes do this by twisting around each other in such a way that a cross shape can sometimes be seen under an electron microscope.

The word **chiasma** (plural **chiasmata**) is used to refer to this formation.

Skill: Drawing diagrams to show chiasmata formed by crossing over

You should be able to draw the process of crossing over. An example can be found below. In examinations, drawings without labels or annotations do not earn any points.

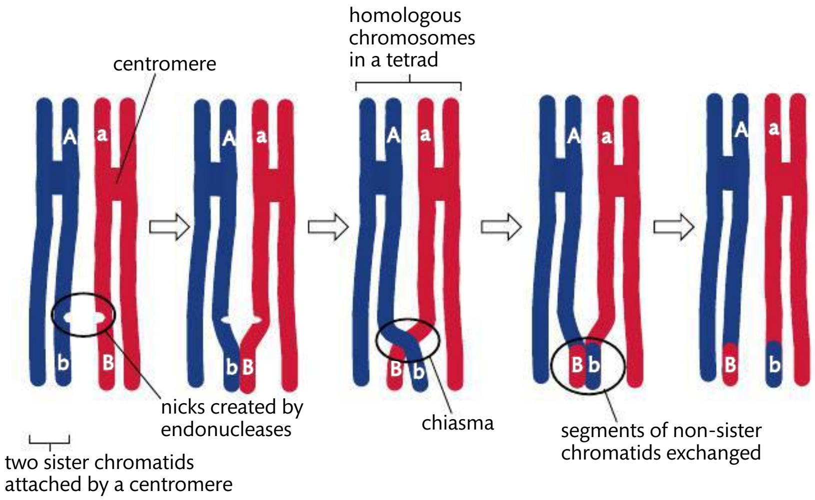


Figure 10.1 *How an allele* **B** *from a maternal chromosome (in red) can be switched with an allele* **b** *on a paternal chromosome (in blue)*

Understanding: Homologous chromosomes separate in meiosis I.

Model sentence: During meiosis I, the number of chromosomes is halved and the diploid nucleus of the parent cell becomes two haploid nuclei in the daughter cells.

Once crossing over is complete, the homologous chromosomes can separate. This is done during **anaphase I**. Each chromosome of the pair is pulled to opposite ends of the cell and two daughter cells can now be formed.

Note that at this phase (during meiosis I), the chromosomes are still carrying copies of themselves. In other words, two sister chromatids are attached at the centromere.

What is different is that some of the sister chromatids are no longer identical copies due to crossing over.

During meiosis I, the cells are converted from diploid to haploid.

Anaphase I

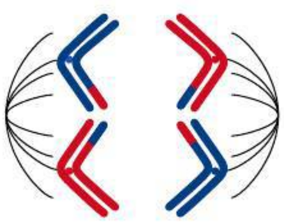


Figure 10.2 *Anaphase I, during which homologous chromosomes (bivalents) are separated. Notice the swapped tips of chromosomes where crossing over has happened*

Understanding: Sister chromatids separate in meiosis II.

Model sentence: In meiosis II, the two attached chromatids of the single chromosomes in the haploid cells are pulled apart so that any gametes produced will have a single copy of each chromosome.

To complete meiosis, a second division occurs. This second division pulls apart the sister chromatids so that they can each occupy one of four daughter cells.

It is important to notice that when the two sister chromatids become separated, they change names. We can now call them individual chromosomes. Before separation, they are sister chromatids, whereas after separation (thanks to anaphase II), they are considered individual chromosomes.

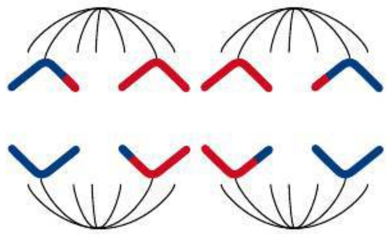


Figure 10.3 *Anaphase II, during which sister chromatids are pulled to opposite poles of the cells*

Understanding: Independent assortment of genes is due to the random orientation of pairs of homologous chromosomes in meiosis I.

Increasing the ways in which genetic variation can be introduced will increase a population's ability to survive and adapt to new situations.

An interesting phenomenon ensures the maximization of variation in gametes and therefore in the population: random orientation.

Random orientation refers to the way in which chromosomes align by chance along the equator of the cell during metaphase I. Like rolling dice, the chromosomes can align in a different way each time a cell gets ready for metaphase I.

Imagine an organism with six pairs of chromosomes ($n = 6$, $2n = 12$). Although it is relatively unlikely, there is a possibility that the chromosomes could line up in order of their size: 1, 2, 3, 4, 5, and 6. In fact, mathematically there are 2^n possible combinations, or 2^6 in this case, which is 64 possible combinations. So for six pairs of chromosomes there is a 1 in 64 chance that they could line up in this order. Others could show the following random orientations:

- 6-1-3-2-5-4
- 3-6-1-4-2-5
- 2-4-6-1-3-5.

The orientation of each of the maternal and paternal halves of the pair of homologous chromosomes determines the combination of the alleles. This sends different combinations to the gametes.

Humans have 23 pairs of chromosomes so the total number of combinations is much greater. Mathematically there are 2^n, or 2^{23}, which is over 8 million, possible combinations. But that number does not take into account crossing over, which makes the calculation more difficult but certainly guarantees a much greater number than 8 million.

The law of independent assortment states that when gametes are formed, the separation of one pair of alleles between the daughter cells is independent of the separation of another pair of alleles. This means that just because one allele is passed on to the next generation does not mean that another one must follow it. Each allele has an equal chance of being passed on or not.

Subject vocabulary

meiosis II second part of meiosis during which sister chromatids separate to produce four haploid cells (gametes)

gamete(s) a sex cell, either a sperm cell or an egg cell

anaphase II the stage in meiosis where sister chromatids separate

random orientation a process during meiosis involving the lining up of chromosomes in an order determined by chance

law of independent assortment the idea that the way one pair of alleles separates into daughter cells does not depend on the way any other pair separates

Synonyms

align.............. line up

orientation..... location/position

Main idea

Genes may be linked or unlinked and are inherited accordingly.

Synonyms

discrepancies . differences/inconsistencies

offspring........ young/children

Subject vocabulary

locus (plural: loci) the specific place where a gene is found on a chromosome

trait a characteristic that distinguishes one individual from another such as blood type

phenotype visible result of an organism's genotype

dihybrid cross a cross that considers the inheritance of two different traits

heterozygous possessing two different alleles of a gene at a particular locus

Nature of science: **Looking for patterns, trends, and discrepancies – Mendel used observations of the natural world to find and explain patterns and trends. Since then, scientists have looked for discrepancies and asked questions based on further observations to show exceptions to the rules. For example, Morgan discovered non-Mendelian ratios in his experiments with *Drosophila*.**

Understanding: Gene loci are said to be linked if on the same chromosome.

Until now, the only kinds of genes that have been discussed have been ones that determine traits that are passed on independently. There are some traits, however, that can be passed on together. In humans, the genes for haemophilia and for red–green colour blindness are linked genes and get passed on together more frequently than predicted in Punnett grids.

Linked genes are ones whose loci are on the same chromosome. In the example above, haemophilia and red–green colour blindness are determined by genes found on the X chromosome. So if a mother possesses alleles for both conditions on one of her two X chromosomes, she will pass both traits to any of her sons who receive that chromosome. Two traits caused by linked genes can be passed on together and both will be seen in the phenotype of the offspring.

Model sentence: **A dihybrid cross is one that considers two genetic traits and the Punnett grid used to show it can use up to 16 squares to show the possibilities for the offspring.**

Application: **Completion and analysis of Punnett squares for dihybrid traits**

A dihybrid cross is one that examines two genetic traits at a time. The calculation in a dihybrid cross is a little more complicated than in a monohybrid cross, but the rules are not much different.

Let us examine two traits in an organism. The alleles can be written as follows:

A = dominant allele for trait 1

a = recessive allele for trait 1

B = dominant allele for trait 2

b = recessive allele for trait 2

The dihybrid cross is between the following parents who are heterozygous for both traits: ***AaBb*** × ***AaBb***.

A dihybrid cross is a 4 × 4 cross showing 16 possibilities for the offspring. The female parent's eggs are shown across the top (see following table). Notice that instead of one allele shown in each box (as for monohybrid crosses), there are two alleles. Similarly, the contents of the male's sperm cells are shown along the left-most column, each box showing alleles for both traits being studied.

A systematic way of setting up the alleles must be used so that no combinations are left out. One way to write the letters in the boxes is to use the 'FOIL' rule: write the First letters of each genotype, then the Outside letters, then the Inside letters and finish with the Last letters. This has been done on the top row and left column of the dihybrid Punnett grid below.

	AB	*Ab*	*aB*	*ab*
AB	*AABB*	*AABb*	*AaBB*	*AaBb*
Ab	*AABb*	*AAbb*	*AaBb*	*Aabb*
aB	*AaBB*	*AaBb*	*aaBB*	*aaBb*
ab	*AaBb*	*Aabb*	*aaBb*	*aabb*

Analysis of the **genotypes** above can lead us to the phenotypes shown below. Count how many there are of each. When looking at two traits, do you get a 3:1 ratio the way we did for a monohybrid cross? What about if you only look at one trait?

	AB	*Ab*	*aB*	*ab*
AB	dominant trait 1, dominant trait 2	dominant trait 1, dominant trait 2	dominant trait 1, dominant trait 2	dominant trait 1, dominant trait 2
Ab	dominant trait 1, dominant trait 2	dominant trait 1, recessive trait 2	dominant trait 1, dominant trait 2	dominant trait 1, recessive trait 2
aB	dominant trait 1, dominant trait 2	dominant trait 1, dominant trait 2	recessive trait 1, dominant trait 2	recessive trait 1, dominant trait 2
ab	dominant trait 1, dominant trait 2	dominant trait 1, recessive trait 2	recessive trait 1, dominant trait 2	recessive trait 1, recessive trait 2

Skill: Calculation of the predicted genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes

Using the example above, we can see the following pattern in the results for the possible genotypes:

- Four out of the 16 possibilities are ***AaBb***, like their parents.
- There are two each of the following: ***aaBb***, ***Aabb***, ***AaBB***, and ***AABb***.
- And there are four unique genotypes: ***AABB***, ***AAbb***, ***aaBB***, and ***aabb***.

This gives the following results for the phenotypes:

- **9** out of 16: dominant phenotype for both traits
- **3** out of 16: dominant trait 1, recessive trait 2
- **3** out of 16: recessive trait 1, dominant trait 2
- **1** out of 16: recessive phenotype for both traits.

A dihybrid cross predicts the ratio of offspring to be **9:3:3:1**. It is perfectly acceptable for there to be slight **deviations** from this ratio but if there are significantly different proportions found in offspring, it can be concluded that something else is influencing the distribution of the alleles. One possible cause of this could be that the traits being studied are genetically linked.

Subject vocabulary

genotypes genes of an organism for a particular trait

autosomal all chromosomes except the sex chromosomes

Synonyms

deviation .... difference

Synonyms

segregate....... separate

Subject vocabulary

mutation an accidental change in a genetic sequence

reciprocal cross a pair of crosses of a male of type A with a female of type B and a male of type B with a female of type A

sex linked a trait that is controlled by alleles located on the sex chromosomes

Understanding: Unlinked genes **segregate** independently as a result of meiosis.

Most genes are not linked because any two genes picked at random are likely to be on separate chromosomes. As a result, when they are passed on to the next generation, they do so without depending on each other.

Genes found on different chromosomes follow the law of independent assortment. As a result, they follow the patterns of inheritance that are mathematically predicted by Punnett grids. In such cases, when considering any two traits ***A*** and ***B***, we would expect to find that ***AaBb*** × ***AaBb*** will give a ratio of offspring showing the 9:3:3:1 ratio.

Application: Morgan's discovery of non-Mendelian ratios in *Drosophila*

Model sentence: Thomas Hunt Morgan was able to make multiple discoveries about genetics by breeding fruit flies and finding exceptions to Mendel's law of independent assortment.

What if the ratio obtained in a breeding experiment does not give the expected ratio of 9:3:3:1 in a dihybrid cross or 3:1 in a monohybrid cross? Remember that Gregor Mendel's work breeding peas showed clear patterns of proportions of offspring with specific characteristics such as tall or short plants. Heterozygous tall parents produced a 3:1 ratio of tall to short offspring, for example.

In the early 1900s, following the work of William Bateson, Edith Saunders, and Reginald Punnett, Thomas Hunt Morgan did similar breeding experiments with *Drosophila* fruit flies. One of the traits that is easy to observe is eye colour. Flies with naturally occurring traits are said to be 'wild-type' flies and their natural eye colour is red. In 1910, Morgan's team found a **mutation** never seen before in the wild-type flies: white eyes.

For some crosses with eye colour, his team of researchers found Mendelian ratios such as the 3:1 ratio mentioned above. But for other crosses, they got some unexpected results.

When breeding a mutant white-eyed female fly with a wild-type male fly that had red eyes (in a cross called a **reciprocal cross**), Morgan got a surprising result: 50% had red eyes, which is a 1:1 ratio. Stranger still, all the male offspring had white eyes and all the females had red eyes.

When an unexpected ratio is found in one gender compared to another, it can be explained by the fact that the trait is **sex linked** (see Section 3.4). This means that the gene that determines the trait is found on the sex chromosomes. In fruit flies, the eye colour gene is found on the X chromosome but absent from the Y chromosome.

When a male fruit fly receives a mutant allele from his mother for white eye colour, he has no second allele on his Y chromosome, so he inherits only the information for white eyes. When a female fly receives a white-eyed allele from one parent, she will have a good chance of receiving a red-eyed allele from the other parent. In Morgan's experiment above, the females all got one allele for red eyes from their red-eyed fathers.

Morgan's team discovered sex linkage in *Drosophila* and also used the frequency with which certain combinations occur to show how frequently crossing over events happen. This information was used in 1913 to make the first maps of chromosomes by working out how close or far genes were to each other by how often certain unexpected combinations of alleles occurred.

Model sentence: When two genes are found on the same chromosome they are said to be linked and they often do not follow the law of independent assortment.

Skill: Identification of recombinants in crosses involving two linked genes

Let us examine a cross with two linked genes in *Drosophila*: body colour (grey or black) and length of wings (short or long). Both genes are found on chromosome 2 of the fly. The alleles can be written as follows:

- ***G*** = dominant allele for grey-coloured body
- ***g*** = recessive allele for black-coloured body
- ***L*** = dominant allele for long wings
- ***l*** = recessive allele for short wings (also called **vestigial** wings)

The cross is between these two parents: ***GgLl*** × ***ggll***.

Since the genes are on the same chromosome, the following notation is needed to indicate how they are linked:

$\frac{G \quad L}{g \quad l}$ and $\frac{g \quad l}{g \quad l}$

The horizontal bars are used to represent the chromosomes. In this example, they show that ***G*** and ***L*** are on the same chromosome.

Since the ***ggll*** parent can only give one allele for each trait, the Punnett grid does not need to be 4 × 4, it can be 1 × 4 as follows:

	GL	Gl	gL	gl
gl	GgLl $\frac{G \quad L}{g \quad l}$	Ggll $\frac{G \quad l}{g \quad l}$	ggLl $\frac{g \quad L}{g \quad l}$	ggll $\frac{g \quad l}{g \quad l}$
		R	R	

Notice that the genotypes are shown in two ways for each offspring: with and without linkage notation.

The two offspring in the middle have different configurations along the bars that represent the chromosomes. They are labelled R because they are known as **recombinants**. You should be able to figure out the process that generates these new combinations: crossing over during meiosis.

Hints for success: It is impossible to acquire skills from simply reading about them. Being able to set up a Punnett grid and analyse it can only be learnt by practice. You should be able to take the information about the parents and construct your own Punnett grid on a blank sheet of paper.

Understanding: Variation can be discrete or continuous.

Discrete variation is when the variety of phenotypes that alleles can produce can be put in distinct categories. They are either one or the other and do not show intermediate or transitional variants in between. Blood type (A, B, AB or O) is a good example of a trait that shows discrete variation.

Continuous variation is when there is a wide variety of intermediate versions of a trait from one extreme to another. It is difficult to distinguish one phenotype from the other because of smooth transitions. The genetic aspects of human skin colour or height are examples of continuous variation. There is a wide range of possibilities rather than a small number of distinct categories. We often oversimplify by saying 'tall', 'short', 'black' or 'white', but in fact both traits have a wide variety of possible intermediate phenotypes.

Subject vocabulary

vestigial said of body parts that are significantly smaller than normal and usually functionless

recombinant organism that posses a different combination of alleles to its parents

discrete variation distinct categories of phenotypes with no intermediate forms

continuous variation a range of different phenotypes for a trait, e.g. human height

Continuous variation can be plotted on a graph as a curve or histogram, often showing a bell-shaped distribution around a mean. The placing of the measurements along the x-axis is not **arbitrary** – items must go from one extreme to the other. Discrete variation, on the other hand, can be shown as a bar chart with no transitions between the bars. The items can be placed in an arbitrary way along the x-axis.

Synonyms

arbitrary........ random

Subject vocabulary

polygenic traits characteristics that are controlled by several genes

chi-squared test a statistical test to determine if two factors show independence or to show if expected values differ from observed values by chance or not

Understanding: The phenotypes of polygenic characteristics tend to show continuous variation.

One way to obtain continuous variation is by having the trait in question controlled by more than one gene. Remember that when there is only one gene with two possible alleles, the phenotype will either show the dominant or the recessive trait (assuming the alleles are not co-dominant).

As we saw with the ABO blood type system, however, a single gene can sometimes have multiple alleles. This gives greater variety in the phenotypes but it still does not give continuous variation.

If, on the other hand, several genes control the trait, the slight differences created by the numerous possible combinations can generate continuous variation. Multiple genes explain the wide variation in human skin colour, for example. Traits controlled by many genes working together are called **polygenic traits**.

Application: Polygenic traits such as human height may also be influenced by environmental factors

It is estimated that human height is about 80% genetic and 20% environmental. The environmental factors that promote height include good nutrition, physical activity, and healthy sleep patterns.

If identical twins had very different lifestyles, they might not grow to the same height even though their genes for height are identical. If one twin had poor eating habits and never got any exercise, there is less of a chance that he or she would reach his or her full height.

Understanding: **Chi-squared tests** are used to determine whether the difference between an observed and expected frequency distribution is statistically significant.

Often the results of an experiment are different from the predicted mathematical values. One difficulty researchers have is determining whether the difference between the expected values and the values obtained are due to chance or if they are due to something else. There is a mathematical test for this which we saw in Chapter 4: the chi-squared (χ^2) test.

To carry out the χ^2 test, the following are needed:

- The expected values (E), which are predicted using mathematical models. In this case, the expected values will be predicted by the Punnett grid.
- The observed values (O), which are the results of the experiment.
- The value for χ^2, as determined by this equation:

  $$\chi^2 = \Sigma\frac{(O - E)^2}{E}$$

- The null hypothesis (H_0) is the result assuming that there is no unexpected factor acting on the experiment's results. In this case, H_0 = the results will follow the expected ratios and any deviation from the expected results will be due to chance rather than due to an external factor.

- The **degrees of freedom (d.f.)**. To determine the degrees of freedom, take the number of classes into which the data can be categorized and subtract 1.
- Lastly, the critical values. These can be looked up on tables of critical values for chi-squared tests.
- Look at the skill below to see a worked example.

Skill: Use of a chi-squared test on data from dihybrid crosses

A test cross with two traits: ***GLgl*** × ***glgl***

	LG	*Lg*	*lG*	*lg*
lg	*LlGg*	*Llgg*	*llGg*	*llgg*

The phenotypes are shown in the four possibilities below. Notice how it is not necessary to repeat *lg* four times, since each line would be identical.

	LG	*Lg*	*lG*	*lg*
lg	long wings, grey body	long wings, black body	short wings, grey body	short wings, black body

The Punnett grid above predicts that the ratio of each type of offspring is 1:1:1:1. This means that there should be equal proportions of each. These are *E*, the expected values. The cross was performed by Morgan's team on fruit flies and *O*, the obtained values, are below:

283	grey long wing
1294	grey short wing
1418	black long wing
241	black short wing
3236	total

Using the total number of offspring, it is possible to calculate the number of flies that should have been produced: 3236/4 = 809.

Putting these results into the chi-squared test as explained in Chapter 4 gives the following:

	Grey body, long wings	Grey body, short wing	Black body, long wing	Black body, short wing	Total
Observed phenotypes (*O*)	283	1294	1418	241	3236
Expected proportions	1 out of 4	1 out of 4	1 out of 4	1 out of 4	
Expected phenotypes (*E*)	809	809	809	809	3236
Difference ($O - E$)	-526	485	609	-568	
Difference squared $(O - E)^2$	276 676	235 225	370 881	322 624	
$(O - E)^2 / E$	342	291	458	399	1490

Subject vocabulary

degrees of freedom the number of values in the chi-squared calculation that can vary

- From the above table, we see that the value for χ^2 is 1490.
- The null hypothesis (H_0), is: 'The results will follow the expected 1:1:1:1 ratio and we should have approximately 809 of each type of fly.'
- There are three degrees of freedom (d.f.) since there are four classes of data.
- By looking at a table of critical values for χ^2 when $p = 0.05$ we get 7.815.
- The calculated value of χ^2 is greater than the critical value so we can confidently reject the null hypothesis. This means that something other than chance is influencing the data. We can formulate a new hypothesis: 'The ratios of traits are giving results that are statistically significantly different from the expected values because the two genes are linked.'

Hints for success: You need to become comfortable with using the steps of the chi-squared test. You do not need to memorize the tables for *p* values. However, it is recommended that you practise with several different problems so that you understand how it works.

10.3 Gene pool and speciation

Main idea

Gene pools change over time.

Nature of science: **Looking for patterns, trends, and discrepancies – patterns of chromosome number in some genera can be explained by speciation due to polyploidy.**

Subject vocabulary

genus (plural: genera) a group of species with shared characteristics

speciation process by which one species splits into two species which can no longer interbreed

polyploidy having more than two sets of chromosomes per cell instead of the usual two (diploidy)

gene pool all of the alleles of all of the genes that exist in a population

allele frequency number of versions of a particular gene found in a population

Understanding: A gene pool consists of all the genes and their different alleles, present in an interbreeding population.

All the genes available within an interbreeding population is called a **gene pool**.

- A population that shows wide variety possesses a large gene pool.
- A population showing little variety possesses a small gene pool.

Understanding: Evolution requires that allele frequencies change with time in populations.

Model sentence: **A key to quantifying how fast a population is evolving is to examine changes in allele frequency – no change suggests no evolution and significant change suggests significant evolution.**

Examine the population in the following figure. Count the number of dominant alleles ***T*** in the population. What percentage is this? Of the 32 alleles present, 16 are ***T*** and 16 are ***t***. Therefore, the **allele frequency** in this case can be expressed as 0.50 or 50%.

If this percentage remains stable over time, it means that the population is not evolving. On the other hand, if the allele frequencies change over time, the population is evolving.

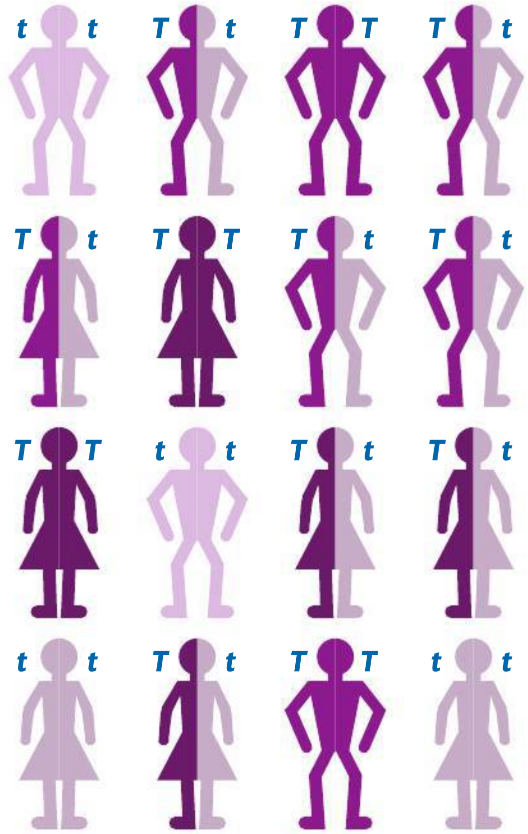


Figure 10.4 *In this gene pool, the frequencies of each allele **T** and **t** is 50%*

The allele frequency can change due to several things, including the following:

- Mutations, which generate new alleles.
- Introduction of new alleles into the gene pool from contact with a new population or individuals that join the population (immigration).
- Loss of an old allele when the last members of the population that possess it die off by natural selection or leave the population (emigration).
- Mating choices.

One way of quantifying the changes in allele frequencies is by using the Hardy–Weinberg equation (see Skill below about comparing allele frequencies).

Understanding: Reproductive isolation of populations can be temporal, behavioural, or geographic.

- **Temporal isolation** happens when members of a population can no longer interbreed due to a timing issue. For example, if one subset of a population of flowers produces pollen at a different time than the optimal or best time for pollination, their alleles will not be passed on.
- **Behavioural isolation** happens when members of a population are prevented from breeding together due to differences in behaviour. For example, if a subset of a population of birds has a different mating call than other birds, only a small number of mates might be attracted by that call.
- **Geographic isolation** happens when members of a population are prevented from breeding due to physical barriers such as mountains or rivers. If a population of rats get onto a boat and are brought to a distant island, they will no longer be able to breed with members of their original population on the mainland.

Subject vocabulary

temporal isolation members of a population prevented from interbreeding by timing, e.g. flowering at different times

behavioural isolation making one subgroup of a population unavailable for breeding due to changes in the way they behave, e.g. being nocturnal

geographic isolation members of a population prevented from interbreeding by location, e.g. separated by rivers or mountain ranges

In all three cases, the isolation can lead to a speciation. How? If the isolated population breeds only with others in the isolated population, the gene pool is different since it is only a subset of the original population. As a result, the number of possible combinations is different and certain combinations of alleles in the new population will come up more often than in the original.

In addition, the isolated population sometimes occupies a different habitat, such as the rats on the distant island mentioned above. This new environment can have very different selective pressures and lead to **adaptations** that are very different from the original population.

If there are enough differences between the old and the new populations, speciation can happen. The two populations will no longer be able to breed together. They are now two separate species.

Speciation can be gradual or **abrupt**, as we will see next when we look at the two theories about speciation: gradualism and punctuated equilibrium.

General vocabulary

adaptation change which makes something more suitable for a situation

divergence development in different ways so as to be no longer similar

increments gradual and regular increases

Synonyms

abrupt........... sudden

Subject vocabulary

gradualism evolution by slow, continuous small changes

punctuated equilibrium evolution by big jumps with periods of no change in between

stasis no change over a period of time

adaptive radiation speciation by adjusting to conditions in a new area

Understanding: Speciation due to **divergence** of isolated populations can be gradual.

Model sentence: There are two theories about the rate of speciation and evolution: (1) gradualism, which states that changes were slow and steady and (2) punctuated equilibrium, which states that changes were sudden followed by long periods of no change.

Gradualism is a theory of speciation that states that evolution is a slow and steady process with changes happening constantly but in small **increments**.

For example, this theory explains that vision in animals is not something that evolved in a short period. On the contrary, it took many millions of years for photoreceptors to evolve little by little and then to develop into complex eyes with lenses.

Understanding: Speciation can occur **abruptly**.

Punctuated equilibrium is a theory of speciation that states that evolution is a process marked by very little change over long periods of time (**stasis**) followed by sudden evolution due to changes in the environment.

Some organisms have changed very little in hundreds of millions of years – sharks, horseshoe crabs, and cockroaches are three examples of organisms whose fossils are strikingly similar to modern-day individuals.

On the other hand, the mammals that are successful today have evolved more recently. The sudden mass extinction that destroyed the dinosaurs 65 million years ago changed the ecological balances of habitats in the oceans and on land. This allowed for an abrupt branching out, or **adaptive radiation**, of many new species, notably mammals.

Application: Identifying examples of directional, stabilizing, and disruptive selection

- **Directional selection** is when natural selection favours one extreme phenotype over the opposite extreme or over any intermediate forms, if they exist. Over time, a population that once had two extreme versions of a trait and perhaps one or more intermediate versions will show a higher frequency of one trait over another. For example, male peacocks (*Pavo cristatus*) and male Astrapian sicklebills (*Astrapia nigra*) are birds known for their unusually long tail feathers. Birds of these species born with more modest feathers would be selected against because female birds would not be attracted to them.
- **Stabilizing selection** is when natural selection favours an intermediate phenotype over one of the extremes. Human height is an example. Individuals who are extremely short or extremely tall do not have an advantage over individuals of average height. On the contrary, the rarity of exceptionally tall or short people shows that such extremes have a negative selective pressure.
- **Disruptive selection** is when natural selection favours two extreme phenotypes rather than an intermediate phenotype. In Darwin's finches, beak sizes vary dramatically. Since they all evolved from one or a small number of species of finches, there must have been a stage in their evolution when one population favoured two extreme beak sizes. Eventually the differences between the individuals were so great that a speciation split occurred. This happened multiple times generating the 13 species we find on the Galapagos today.

The following table summarizes the three types of selective pressures:

	One extreme phenotype	Intermediate phenotype	Both extreme phenotypes
directional	selected for	selected against	selected against
stabilizing	selected against	selected for	selected against
disruptive	selected for	selected against	selected for

Application: Speciation in the genus *Allium* by polyploidy

The genus *Allium* includes plants such as onions, shallots, leeks, and garlic, as well as some popular ornamental flowers.

When examining their chromosomes in karyograms, it is clear that hybrids have formed between species and some show polyploidy. Remember that haploid cells have a single set of the standard number of chromosomes for the species in question and diploid have a double set. Polyploid cells contain more than two sets. This is very rare in animals but quite common in hybrid plants.

The most commonly cultivated species of onion is *Allium cepa*, but this species can have many varieties and the varieties can have **strains**. For example, the vast majority of strains of the *viviparum* variety of *A. cepa*, known as the Egyptian walking onion, are diploid. However, there is a strain called Ljutika, grown in Croatia along the coast of the Adriatic Sea, that has been found to be **triploid**.

Analysis of various karyotypes has revealed that the Egyptian walking onion, *A. cepa* var. *viviparum*, is a hybrid between two *Allium* species: *A. fistulosum* and *A. cepa*.

This is an example of new varieties being formed by polyploidy. If the varieties are isolated and continue to evolve separately, they could completely split and become two distinct species, no longer able to produce fertile offspring.

Subject vocabulary

directional selection selection for one extreme phenotype over the other extreme or intermediate phenotypes

stabilizing selection selection for the intermediate phenotype rather than either of the extreme phenotypes

disruptive selection selection for two extremes of phenotype rather than intermediate forms

strain a type or variety of organism

triploid having three sets of chromosomes

Skill: Comparison of allele frequencies of geographically isolated populations

The Hardy–Weinberg equation can be used to calculate and compare allele frequencies between two populations. The equation is as follows:

$$p^2 + 2pq + q^2 = 1$$

Where:

- p = the frequency of the dominant allele (***T***)
- p^2 = the frequency of homozygous dominant phenotypes (***TT***) in the population
- q = frequency of the recessive allele (***t***)
- q^2 = the frequency of homozygous recessive phenotypes (***tt***) in the population
- $2pq$ = the frequency of heterozygous phenotypes in the population (***Tt***)

To determine frequencies, it is useful to know that $p + q = 1$. So if the frequency of ***T*** is 0.50, then the frequency of ***t*** must be 0.50. If p is 0.50, then p^2 is 0.25. This means that 25% of the population has a genotype ***TT***. We can do the same for q to find that 25% of the population has a genotype ***tt***. Knowing these two parts of the equation, the only part missing ($2pq$) can be solved because we know that all three parts of the equation must add up to 1. So $2pq$ must equal 0.50 to make 0.25 and 0.25 add up to 1. This means that 50% of the population is ***Tt***. Notice how there is no need to split up $2pq$; just leave it as a single entity.

Hints for success: When solving the Hardy–Weinberg equation, put in any of the values given in the question and any values you can calculate knowing that $p + q = 1$. The most advanced mathematics you need is squaring or taking the square root of a number. You do not need to do this in your head – use a calculator.

Example

Population 1 has the following characteristics. Of 301 flowering plants, 142 produce large flowers (***F***) and 159 produce small flowers (***f***). A subgroup, population 2, has split away and is now geographically isolated from the original population. Of 48 plants, 33 have small flowers. Use the Hardy–Weinberg equation to compare the allele frequencies for ***F*** and ***f*** in the two populations.

Answer: It is best to start with looking at the number of plants producing small flowers because we are certain of their genotype (***ff***). Once we know ***ff***, we know q^2 and can work out q. In population 1, there are 159 out of 301 small-flowered plants, which is about 53%. The square root of 0.53 gives 0.73 meaning that q is 73%, or that 73% of the alleles in the gene pool are ***f***. We can use what we have calculated so far to determine that p is 27% and therefore p^2 is 7%. When adding 53% and 7%, 40% is missing in order to add up to 100% so therefore $2pq$ must be 40%. Here is a table of the same types of calculations with population 2:

			%	Plants
allele frequencies	recessive ***f***	q	57%	N/A
	dominant ***F***	p	43%	N/A
genotype frequencies	homozygous recessive ***ff***	q^2	69%	33
	heterozygous ***Ff***	$2pq$	12%	6
	homozygous dominant ***FF***	p^2	19%	9

Description of the changes in ***F*** and ***f*** between the two populations: ***F*** has gone from 27% to 43% and ***f*** has gone from 73% to 57%. This shows that there has been a change in the allele frequencies between the geographically isolated groups meaning that population 2 is evolving differently than population 1.

11.1 Antibody production and vaccination

Understanding: Every organism has unique molecules on the surface of its cells.

Model sentence: The plasma membranes of the cells of each organism contain unique molecules.

Remember from your previous study of cell membranes that proteins are **embedded** into and sometimes through plasma membranes. These proteins serve a variety of purposes. One of those purposes is to provide identification for the cell. Each cell of any one organism has the same set of proteins that act as the identifying proteins. These proteins will identify a cell as being 'self' as opposed to 'not-self'. Many molecules that are found to be 'not-self' will be regarded as **antigens**. Antigens are molecules that stimulate the **immune system** to begin a response.

Application: Antigens on the surface of red blood cells stimulate antibody production in a person with a different blood group

Red blood cells have a variety of proteins on the surface of their plasma membranes. Three of the protein types must be matched if a person receives a **transfusion** of blood. Those three proteins are:

- A protein
- B protein
- Rh protein.

There are two different blood identification categories based on the presence or absence of these three proteins.

The first category is called the A–B–O blood group:

- A person who has only the A protein is type A.
- A person who has only the B protein is type B.
- A person who has both the A and B protein is type AB.
- A person who has neither the A or B protein is type O.

The second category is called the Rh blood group:

- A person who has the Rh protein is Rh^+.
- A person who does not have the Rh protein is Rh^-.

When receiving blood in a transfusion a person cannot receive a protein that they do not already have. A patient that does receive one of the proteins that is 'not-self' to them will regard the new protein as an antigen. They will begin a primary immune response using the new protein as an antigen. This will lead to **agglutination** problems within their blood. You can see how correct transfusions are done from the chart at the top of the next page.

Subject vocabulary

plasma membrane membrane which surrounds the cell

antigen substance which stimulates the production of antibodies in vertebrates

immune system the system within our body that protects us from diseases

antibody a protein produced by our immune system in response to an antigen

transfusion the blood of one person is transferred to another person

agglutination clumping of blood cells due to antibodies

General vocabulary

embedded positioned firmly and deeply

If your type is	You can receive							
	O–	**O+**	**B–**	**B+**	**A–**	**A+**	**AB–**	**AB+**
AB+	yes	yes	yes	yes	yes	yes	yes	yes
AB–	yes		yes		yes		yes	
A+	yes	yes			yes	yes		
A–	yes				yes			
B+	yes	yes	yes	yes				
B–	yes		yes					
O+	yes	yes						
O–	yes							

Figure 11.1 *Chart showing blood transfusion possibilities*

Subject vocabulary

pathogens disease-causing agents such as viruses and bacteria

B lymphocytes leukocytes that produce antibodies

activated a chemical notification sent from one leukocyte to another leukocyte

T lymphocytes leukocytes that can activate other types of leukocytes

Synonyms

leukocyte....... white blood cell

Understanding: Pathogens can be species-specific although others can cross species barriers.

Model sentence: Disease-causing agents typically infect only one species but a few can infect more than one species.

Pathogens are those things that are capable of causing a disease. Two of the most common types of pathogens are some viruses and some bacteria. Usually, a specific virus or bacterium are pathogens to only one type of organism. There are exceptions to this as shown in the table below:

Caused by a virus	Caused by a bacterium
influenza caused by H1N1	tuberculosis
SARS	salmonella

Hints for success: In an examination, remember that a virus is not a living thing. Viruses are not cells.

Understanding: B lymphocytes are activated by T lymphocytes in mammals.

Model sentence: White blood cells known as T lymphocytes activate other leukocytes called B lymphocytes in mammals.

There are many types of white blood cells (also known as leukocytes). Leukocytes have a variety of functions related to the immune system. Each type of leukocyte specializes in one of the functions.

One specialized type of leukocyte is called T lymphocytes. The T lymphocytes known as helper T lymphocytes recognize antigens on pathogens. Antigens are molecules that make up a pathogen. Each pathogen has its own unique set of antigens. Once a helper T lymphocyte recognizes a specific antigen it chemically communicates with (activates) another type of leukocyte. This type of leukocyte is called a B lymphocyte.

Understanding: Activated **B cells** multiply to form clones of **plasma cells** and memory cells.

Model sentence: B cells that have become activated will divide by mitosis many times and become clones called plasma cells and memory cells.

When cells divide by mitosis each resulting cell is a clone of the other. Imagine a cell that undergoes mitosis many times in a short period of time. A small army of clones would be formed. This is what happens when B cells become activated. The resulting army of cells is of two types:

1. Plasma cells – plasma cells are B cells that immediately begin producing molecules called antibodies.
2. Memory cells – memory cells are B cells that live for a very long period of time and are capable of producing antibodies. Memory cells typically wait for a second infection of the same pathogen before becoming active.

Understanding: Plasma cells **secrete** antibodies.

Model sentence: Antibodies are produced and secreted by plasma cells.

Each different type of B cell produces a single type of antibody. Each antibody is a protein that will bind to one antigen. The plasma cells that are cloned during an infection are cells that produce only one type of antibody. Each cell is like a protein factory as it produces many of that type of antibody.

Understanding: Antibodies aid the destruction of pathogens.

Model sentence: Antibodies are an important step in the immune response by helping to destroy a pathogen.

Each antibody is a 'Y' shaped protein molecule. At the two upper ends of the 'Y' are two identical **binding sites**. These binding sites stick to a specific antigen. Most likely the antigen is a protein molecule on the surface of a pathogen (like a virus or bacterium).

Antibodies help to destroy pathogens by:

- marking the pathogen for destruction by leukocytes
- sticking antigens together by using the two binding sites on different antigen molecules (this is called agglutination).

Understanding: White cells release **histamine** in response to **allergens**.

Model sentence: Certain antigens cause some leukocytes to release chemicals called histamines.

Histamines are chemicals that are released from leukocytes called mast cells. When the antigen is first encountered, B cells produce an antibody called **IgE**. The IgE antibodies bind to leukocytes called mast cells. Whenever that same antigen is encountered again, the antigen will find the IgE molecules on the mast cells. The mast cell will then release histamine into the surrounding area.

Synonyms

B cells............ B lymphocytes

secrete .... produce/release

Subject vocabulary

plasma cells B cells that immediately begin antibody production during an infection

mitosis cell division where one diploid cell becomes two diploid cells

binding sites the area of an antibody that can stick to an antigen

histamine chemicals released by leukocytes called mast cells

allergen a substance capable of initiating an allergic response

IgE a type of antibody produced by some B cells

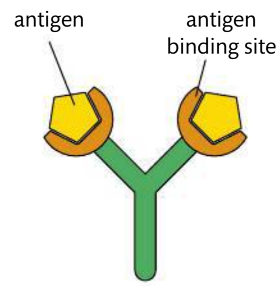


Figure 11.2 *Antibody molecule showing two identical binding sites*

Subject vocabulary

allergic symptoms sneezing, itchiness, etc., that are common with an allergy

allergy reaction to an antigen as if it were part of a pathogen

mast cells leukocytes that release histamines during an allergy episode

dilate inner portion of a tube getting larger

Understanding: Histamines cause allergic symptoms.

Model sentence: Allergy symptoms are a result of mast cells releasing histamines.

Histamines have a variety of effects. Some of those effects are useful when a pathogen has infected the body. For example, small arteries and capillaries dilate when exposed to histamines. This brings more blood to the site of infection.

Histamine release is triggered from some people in response to antigens that do not cause disease. The resulting condition is called an allergy. One of the more common things that trigger histamine release is pollen. Antigens on pollen trigger mast cells to release histamines. Histamines lead to the uncomfortable allergy symptoms such as sneezing and itching.

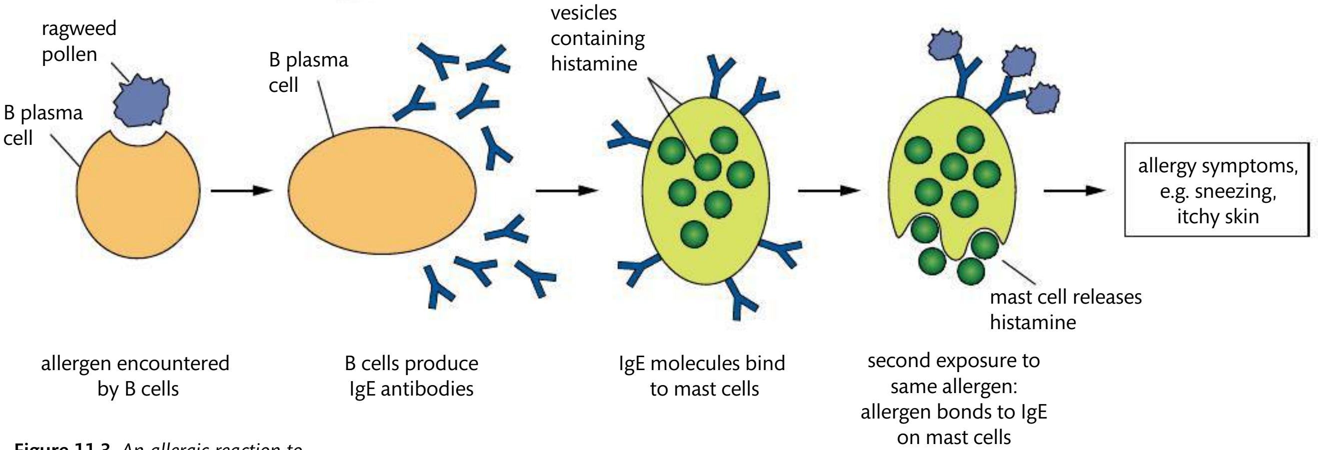


Figure 11.3 *An allergic reaction to an allergen*

General vocabulary

itching a feeling on the skin that makes you want to scratch

Subject vocabulary

immunity having a protection due to previous exposure

primary immune response immune response upon first infection

secondary immune response immune response from any infection of the same pathogen that is not the first infection

Synonyms

B cells............ B lymphocytes

Understanding: Immunity depends upon the continued existence of memory cells.

Model sentence: Memory cells from a previous infection give immunity from further infections of the same type.

The first time a person is exposed to a pathogen it results in a response called the primary immune response. There is a fairly long time period where:

- The pathogen is identified by T cells.
- Various cells including specific B cells undergo cloning.
- B cells produce large numbers of antibodies for that pathogen.

A person is likely to experience symptoms of the disease while completing the primary immune response.

The primary immune response leaves behind long-lived cells called memory cells. Memory B cells can be called into action to produce antibodies in a relatively short period of time. Thus, memory cells give the immune system a ‘head start’ if an infection occurs a second time. Often the second response is so rapid that symptoms of the disease do not have time to appear. Anytime we respond to the same infection after the first time it is called a secondary immune response. As you can see from the graph below, the production of antibodies occurs much quicker and produces many more antibodies as compared to the primary response.

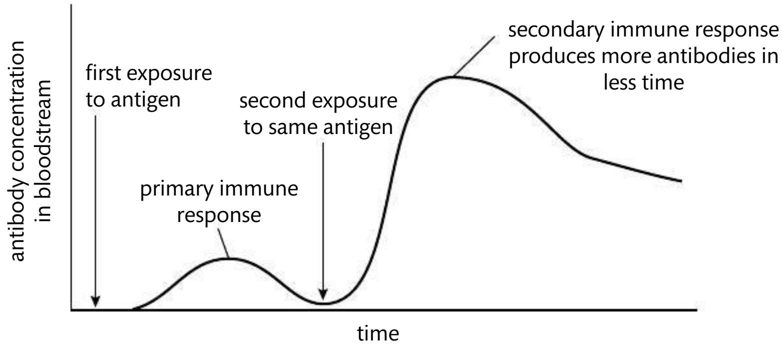


Figure 11.4 *Graph showing antibody production in a primary and secondary immune response. The secondary immune response may occur soon after the primary response, or occur months or years after it*

Understanding: Vaccines contain antigens that trigger immunity but do not cause the disease.

Model sentence: Immunity can be achieved by using a vaccine that contains antigens but does not result in the disease.

To understand how a vaccine results in immunity you will need to understand the difference between a pathogen and an antigen:

- A pathogen is a term used for the disease-causing agent. For example, a virus is a pathogen.
- An antigen is a molecule that makes up the pathogen. Most antigens are proteins. A virus typically has several different proteins making up its outer coating (called a capsid).

A vaccine is created by damaging the disease-causing agents of the pathogen so that it is just the non-pathogenic molecular parts. The antigens are still there but they are no longer in a form that can cause the disease. Our immune system recognizes the antigens as if they were still a part of the intact pathogen. A primary immune response will still occur. Memory cells will still be created. All of the benefits occur without the person having to suffer the symptoms of the disease. If the real pathogen ever infects the body, it will have a secondary immune response. If you remember, that response is quicker than a primary response and produces many more antibodies.

Application: Smallpox was the first infectious disease of humans to have been eradicated by vaccination.

In 1967, the World Health Organization began a campaign to 'vaccinate the world' against the deadly disease smallpox. The last reported case of smallpox was in 1977. The vaccination programme was so successful that people no longer need to be vaccinated.

Subject vocabulary

vaccine an injection prepared from the non-pathogenic antigens of a pathogen

capsid outer coating of a virus

vaccination a shot (inoculation) of an inactive pathogen that leads to a primary immune response

Synonyms

eradicated ..... eliminated/removed

Subject vocabulary

fusion two cells that join together as one

tumour cell a cell that has a very long cellular life-span and divides rapidly

hybridoma cell a cell created by fusing a tumour cell with an antibody-producing plasma cell (B cell)

hybrid something that has the properties of two things

cell culture a container with liquid medium for growing cells outside of the body

monoclonal antibodies antibodies created by a single type of hybridoma cell

mitotic clones identical cells created by mitosis

HCG hormone produced by an early embryo which signals the ovary to secrete progesterone

Understanding: Fusion of a tumour cell with an antibody-producing plasma cell creates a hybridoma cell.

Model sentence: Hybridoma cells are created by fusing a cancer cell with an antibody-producing B cell.

Hybridoma cells are truly a **hybrid** between two types of body cells. The two types of body cells are made to fuse together in a **cell culture.** The resulting cell (the hybridoma) has properties of each of the two cells used to create it. The two cells that fuse together are:

1. A cancerous (tumour) cell.
   - This gives the hybridoma a very long cellular life.
   - The hybridoma will divide by mitosis many times.
2. An antibody-producing B cell.
   - A specific B cell is chosen for the type of antibody it produces.
   - The antibody can be purified from the cell culture.

The hybridoma cells can be grown in cell cultures. The cell culture can be kept healthy for a very long period of time.

Understanding: Monoclonal antibodies are produced by hybridoma cells.

Model sentence: Each hybridoma cell creates a single type of antibody called a monoclonal antibody.

Each hybridoma cell is created by using one antibody-producing plasma cell. This cell will only produce one type of antibody. A cell culture is created starting from a single hybridoma cell. All of the other cells in that cell culture will be **mitotic clones** of the original. They all produce only one type of antibody. All of the antibodies from one culture are called monoclonal antibodies.

Antibodies produced during an immune response are mixed into the blood with many other kinds of antibodies. Monoclonal antibodies are created in a laboratory and have specialized uses in medicine and research.

Application: Monoclonal antibodies to HCG are used in pregnancy test kits

HCG is a hormone that is produced only by a very young embryo. The hormone passes across to the mother's bloodstream. Monoclonal antibodies that recognize HCG as their antigen are used for pregnancy testing. If the monoclonal antibodies find HCG, a reaction occurs leading to a colour change that indicates that the female is pregnant.

11.2 Movement

Understanding: Bones and **exoskeletons** provide **anchorage** for muscles and act as **levers.**

Model sentence: The internal or external skeleton of an animal provides anchor points for muscles allowing parts of it to act as levers.

The type of skeleton most people think of is an internal skeleton (**endoskeleton**) made of bones. Some animals have another kind of skeleton. Their skeleton is located on the outside of the body and is called an exoskeleton.

Both types of skeletons provide support for the body and also:

- anchor muscles at both ends of the muscle
- act as levers in order to provide movement efficiency.

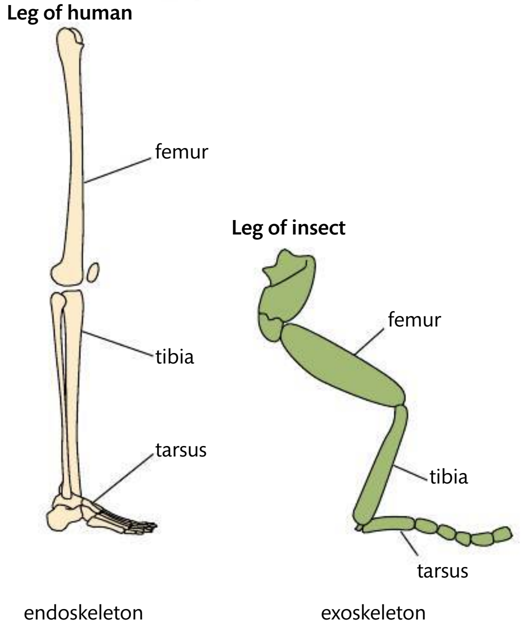


Figure 11.5 *The bones of the endoskeleton of a human and the segments of the exoskeleton of an insect are similar enough to be given many of the same anatomical names*

Understanding: **Synovial joints** allow certain movements but not others.

Model sentence: Bone to bone joints in the body, called synovial joints, permit only certain movements of the bones.

A joint is where one bone connects to another bone. These connections require structures called **ligaments**. If the joint allows movement there may be a fluid that helps **lubricate** the area. If so, the joint is called a synovial joint. Here are two examples of synovial joints and the movements they permit:

- Elbow joint – the elbow joint works like a **hinge**. The elbow allows your forearm to move up and down but it does not permit **rotation**. Your knee is similar to the elbow in its structure and in the movement allowed.
- Shoulder joint – the joint that connects each of your arms into your shoulders is called a ball-and-socket joint. This joint allows all kind of movements including rotation. Your hip joint is similar in structure and movements.

Subject vocabulary

exoskeleton a skeleton of some material that is found on the outside of an animal

endoskeleton a skeleton made of bones found on the inside of an animal

synovial joint a bone to bone connection where there is a chamber filled with a fluid that lubricates movement of the bones

ligaments structures in the body that help join bones together at a joint

General vocabulary

anchorage acting as an attachment point for something

lever a bar-shaped object used to transmit force efficiently

lubricate the use of a substance to reduce friction

hinge an adaptation that allows only a side-to-side or up-and-down movement

rotation movement in a circular motion

Skill: Annotation of a diagram of the human elbow

If given a figure showing a sectioned view of the human elbow, you should be able to label the parts and give their functions.

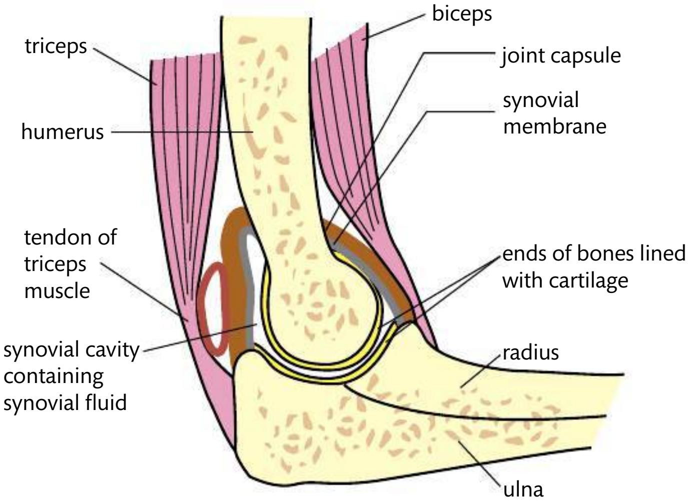


Figure 11.6 *The human elbow in section*

Joint part	Function
cartilage	reduces friction and absorbs compression
synovial fluid	lubricates to reduce friction and provides nutrients to the cells of the cartilage
joint capsule	surrounds the joint, encloses the synovial cavity, and unites the connecting bones
tendons	attach muscle to bone
ligaments	connect bone to bone
biceps muscle	contracts to bring about flexion (bending) of the arm
triceps muscle	contracts to cause extension (straightening) of the arm
humerus	acts as a lever that allows anchorage of the muscles of the elbow
radius	acts as a lever for the biceps muscle
ulna	acts as a lever for the triceps muscle

Understanding: Movement of the body requires muscles to work in antagonistic pairs.

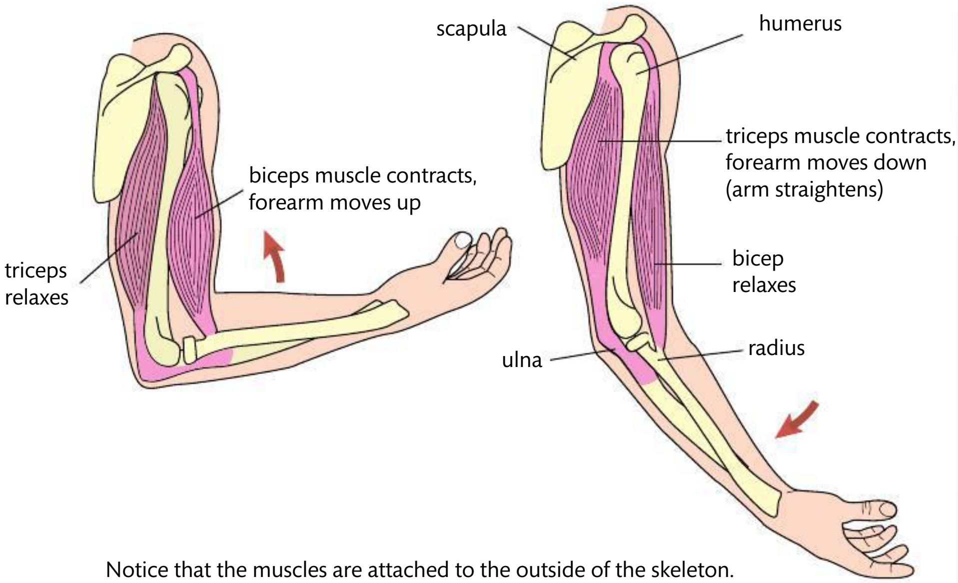
Model sentence: Muscles provide movement by working in antagonistic pairs.

Every time a bone of your body moves into a new position at least one muscle contracts to cause that movement. Now, in order for that same bone to move back to where it started another muscle must be used. The muscles that work in pairs like that are called antagonistic muscle pairs.

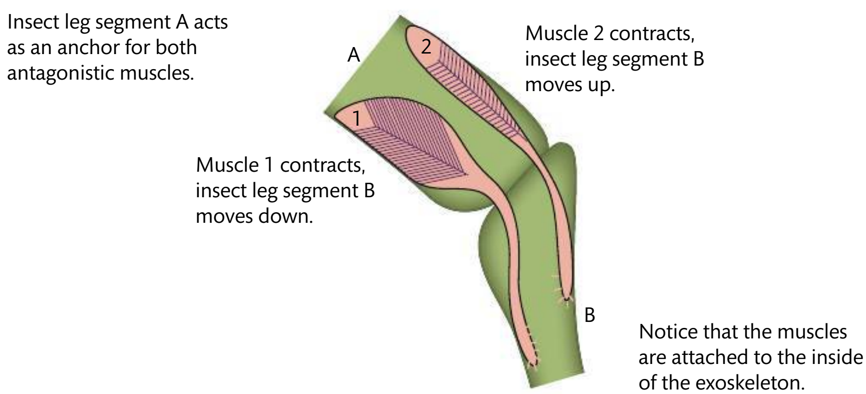
Subject vocabulary

antagonistic muscles muscles that work in pairs to cause opposite movements

A good example of antagonistic muscle pairs is shown by the way your forearm **flexes** and straightens at the elbow. In order for your forearm to flex, you must contract a muscle called your **biceps**. Then, in order to straighten again you must contract a muscle called the **triceps**.



Application: Antagonistic pairs of muscles in an insect leg



Understanding: **Skeletal muscle** fibres are **multinucleate** and contain specialized **endoplasmic reticulum**.

Model sentence: Each cell of a skeletal muscle, called a muscle fibre, has many nuclei and contains specialized endoplasmic reticulum.

Skeletal muscle is muscle that moves your bones. All muscle tissue is made of living cells. The cells are very thin and long. Thus, these cells are called muscle fibres. Unlike most cells, each muscle fibre has many nuclei within the cytoplasm. Muscle fibres are described as being multinucleate.

The endoplasmic reticulum of skeletal muscle cells is different from that in other cells. It is highly branched and has many folds. This specialized endoplasmic reticulum is called the **sarcoplasmic reticulum**.

Synonyms

flex .... bend

Subject vocabulary

biceps muscle that causes the forearm to flex

triceps muscle that causes the forearm to straighten

skeletal muscle muscle that is used to move bones

multinucleate containing many nuclei

endoplasmic reticulum organelle involved in transport within the cell

muscle fibre term used for a muscle cell

sarcoplasmic reticulum the specialized ER in muscle cells

Figure 11.7 *The forearm of a human is moved up and down by the action of the triceps and biceps*

Figure 11.8 *The segments of an insect's leg are moved up and down by the action of antagonistic muscle pairs*

Understanding: Muscle fibres contain many myofibrils.

Model sentence: The interior of muscle cells (fibres) contains many contracting proteins organized into long strands called myofibrils.

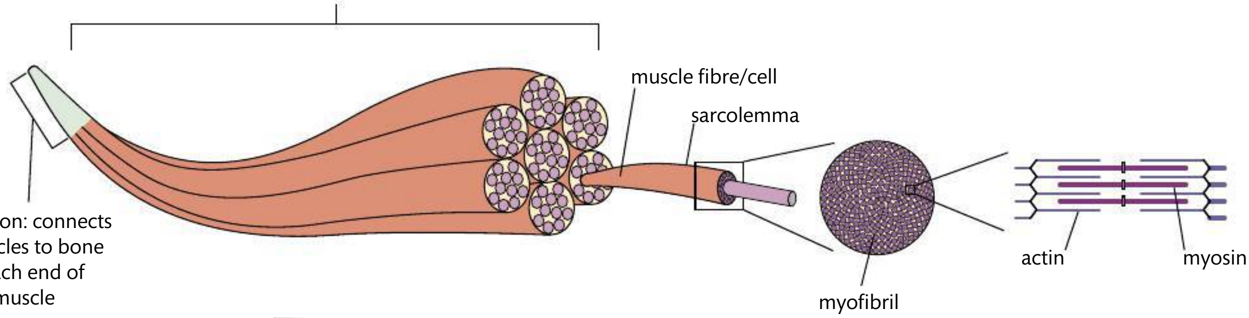


Figure 11.9 *Each muscle fibre is a muscle cell. The entire muscle is composed of many muscle fibres all running in the same direction and thus all able to contract in unison when necessary*

Subject vocabulary

myofibrils the filaments made up of actin and myosin inside muscle fibres

contractile sarcomeres the contracting sections of a myofibril

actin the protein in a sarcomere that slides during a contraction

myosin the protein in a sarcomere that does not move during a contraction

Z-lines the outside boundary of actin within a single sarcomere; each sacromere has a Z-line on each side

General vocabulary

alternating occuring one after the other in a repeated pattern

Understanding: Each myofibril is made up of contractile sarcomeres.

Model sentence: The length of an individual myofibril is made up of many contractile sarcomeres.

A muscle gets shorter when it contracts. The shortening that occurs is because many thousands of individual sections all get shorter at the same time. Those sections are called contractile sarcomeres. The sarcomeres are all connected to each other.

Understanding: The contraction of skeletal muscle is achieved by the sliding of actin and myosin filaments.

Model sentence: The shortening of skeletal muscle occurs because the protein actin slides over another protein called myosin.

Skill: Drawing labelled diagrams of the structure of a sarcomere

Sarcomere

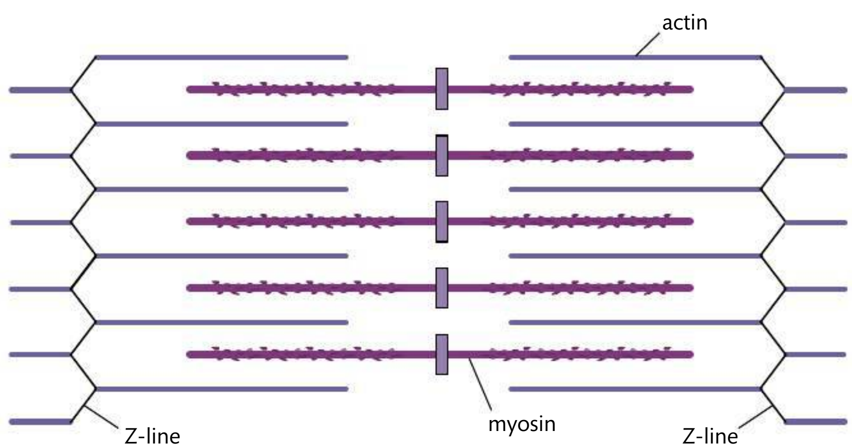


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Figure 11.10 *This figure shows a single sarcomere. Notice that a sarcomere is composed of* ***alternating*** *actin and myosin proteins. The myosin is a set length and cannot move. The actin is able to slide over the top of the myosin. In this figure, imagine the two lines called the* ***Z-lines*** *both moving closer to each other as the actin slides. The entire sarcomere becomes shorter*

Understanding: **ATP hydrolysis** and **cross bridge** formation are necessary for the filaments to slide.

Model sentence: The sliding of actin over myosin requires myosin to form a bridge to actin and energy from ATP.

The myosin within a sarcomere has many protein extensions called 'heads'. The **myosin heads** make connections with or connect with actin. This is called cross bridge formation. An ATP molecule is required each time a myosin head forms a cross bridge with an actin. Notice in the figure below that the two Z-lines move closer to each other when a muscle contracts.

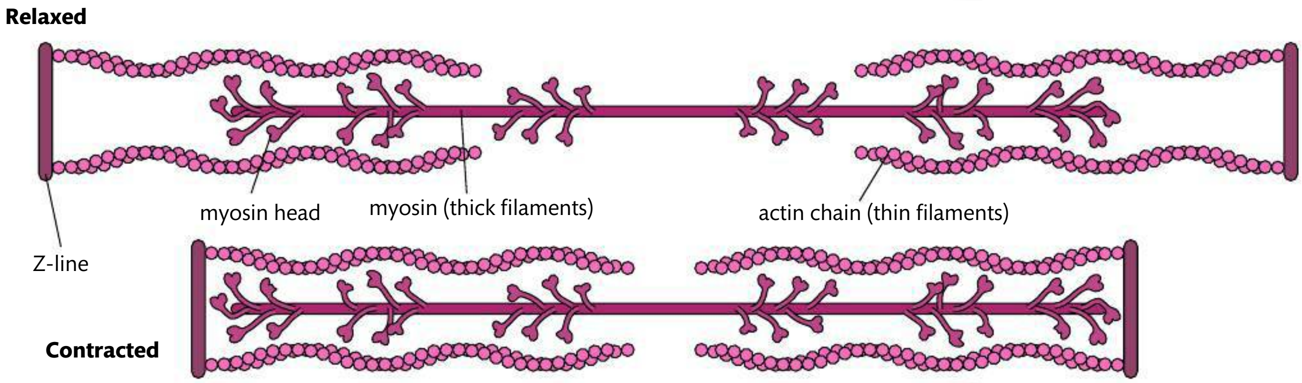


Figure 11.11 *Position of actin and myosin in a relaxed muscle and a contracted muscle. With the energy of ATP the myosin heads have moved the actin fibres toward the centre of the sarcomere*

Skill: Analysis of electron micrographs to find the state of contraction of muscle fibres

Ask your instructor to show you photographs taken using an **electron microscope** that show:

- one or more sarcomeres in a relaxed position
- one or more sarcomeres in a contracted position.

Use your knowledge of how a sarcomere contracts in order to explain what you are seeing in the photographs.

Understanding: **Calcium ions** and the proteins **tropomyosin** and **troponin** control muscle contractions.

Model sentence: A muscle is signalled to contract by the interaction of calcium ions and the proteins tropomyosin and troponin.

When a muscle is relaxed the actin fibres prevent myosin cross bridging. The cross bridging is prevented by binding sites on the actin being covered up. Two proteins, called tropomyosin and troponin are used to cover the actin-binding sites.

Skeletal muscle only contracts when your brain sends an impulse to the muscle. The impulse triggers calcium ions to enter all of the sarcomeres. The calcium ions result in tropomyosin and troponin moving and uncovering the binding sites on actin. The myosin heads automatically bind to actin and cause actin to move toward the centre of the sarcomere. The result is a muscle contraction.

Subject vocabulary

ATP a molecule used for a source of chemical energy

hydrolysis a chemical reaction in which a larger molecule is split into two smaller molecules

cross bridge connections between myosin heads and actin

myosin heads the protein extensions of myosin that connect to actin

electron microscope a microscope capable of very high magnification

calcium ions positively charged ions that enter sarcomeres when a nervous system impulse is received by muscle

tropomyosin one of two proteins that blocks binding sites on actin to control muscle contractions

troponin one of two proteins that blocks binding sites on actin to control muscle contractions

11.3 The kidney and osmoregulation

Understanding: Animals are either osmoregulators or osmoconformers.

Model sentence: Animals stay in osmotic balance in their environment by being either an osmoregulator or an osmoconformer.

Animals achieve water balance with their environments in two main ways:

1. Most animals are osmoregulators. These animals use mechanisms to make sure that they remain in water balance with their environment. They may expel or gain solutes (like salt ions) in order to remain in balance. They also may expel more or less water to their environment in differing situations. Osmoregulators respond to their environment in order to remain in water balance. You are an example of an osmoregulator.

2. Osmoconformers live in a water environment that is already in balance with the cells in their bodies. They neither gain nor lose water because they are already in osmotic balance. Osmoconformers are restricted to living in water environments that match their own tissues. A scallop is an example of an osmoconformer.

Understanding: The Malpighian tubule system in insects and the kidney carry out osmoregulation and removal of nitrogenous waste.

Model sentence: Water balance and removal of nitrogenous waste is done by the Malpighian tubules of insects and the kidneys in many other animals.

Nitrogenous wastes are nitrogen-containing molecules that are waste products traced back to proteins. Each organism must expel these wastes from their body before the waste becomes toxic.

Insects have numerous small tubes called Malpighian tubules within their body cavities. The Malpighian tubules are bathed and surrounded in the insect's blood within their body cavities. The tubules absorb the nitrogenous wastes from the blood. The waste is then taken to the animal's gut to be released with the faeces. Water can also be absorbed into the tubules if excess water needs to be excreted.

Mammals have kidneys that remove nitrogenous wastes from the blood. Blood is taken to the kidneys by large blood vessels. The blood is filtered in the kidney and nitrogenous waste and excess water is removed. These waste products become urine. Urine is stored in a bladder before it is released from the body.

Subject vocabulary

osmoregulator an animal that modifies its own tissues to stay in osmotic balance

osmoconformer an animal that lives in an environment where it is already in osmotic balance

osmotic balance two fluids that have equal solute and water concentrations

solute(s) molecules dissolved in a solvent (water)

Malpighian tubules small tubes located in the body cavities of insects that absorb nitrogenous waste to be taken to the gut

kidney the organ in some animals that filters blood to remove nitrogenous wastes and excess water

nitrogenous waste molecules that contain nitrogen that must be removed from an organism before they become toxic

faeces solid waste from our gut

excrete pass from the body

urine the liquid waste of an animal that has kidneys

bladder a storage sac for urine until it is excreted

Synonyms

expel .... force out/push out

cavity .... space (within)

gut .... alimentary canal

Subject vocabulary

renal artery large blood vessel taking blood into a kidney

renal vein large blood vessel taking blood out of a kidney

renal cortex the outer layer of tissue in a kidney

renal medulla the layer of tissue under the cortex in a kidney

renal pelvis collection chamber for urine in a kidney

ureter tube that takes urine from the kidney to the bladder

Understanding: The composition of blood in the **renal artery** is different from that in the **renal vein**.

Model sentence: Blood entering the kidney in the renal artery has a different chemical composition compared to the blood leaving the kidney in the renal vein.

Humans have two kidneys. Each kidney has a large blood vessel that takes blood into the kidney. That blood vessel is called the renal artery. The kidney then filters the blood to remove nitrogenous waste and excess water. The blood then leaves the kidney through a large vein called the renal vein.

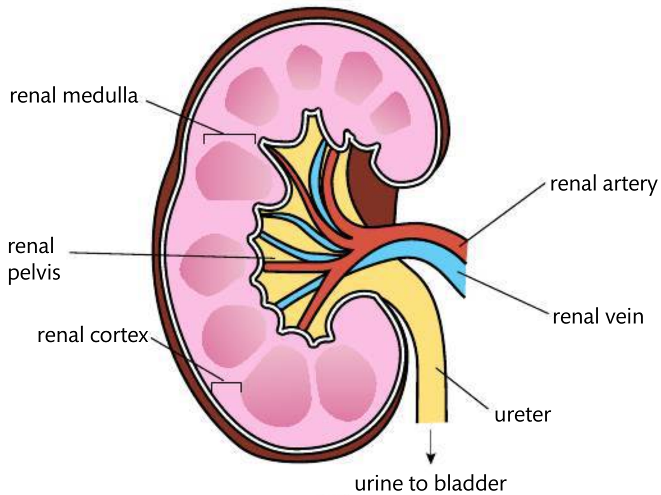


Figure 11.12 *Sectioned view of the human kidney*

Skill: Drawing and labelling a diagram of the human kidney

Practise drawing and labelling the human kidney, as shown in the figure.

Notice that a kidney has an outer layer called the **renal cortex**. The layer under the cortex is called the **renal medulla**. Under that is a collection chamber for urine called the **renal pelvis**. The tube that drains urine out of the pelvis is called the **ureter**.

Hints for success: In an examination, data may be presented to you showing the chemical make-up of molecules in the blood. The difference between the composition of blood in the renal vein as compared to the renal artery shows the chemical change made by the kidney. The molecules removed from the blood will be found in urine.

Subject vocabulary

ultrastructure detailed structure of a cell not visible with a light microscope

glomerulus (plural: glomeruli) the capillary bed inside of Bowman's capsule

Bowman's capsule surrounds the glomerulus capillary

ultrafiltration filtration under pressure

nephron a small filtering 'unit' of a kidney

General vocabulary

facilitate make easier

Understanding: The **ultrastructure** of the **glomerulus** and **Bowman's capsule facilitate ultrafiltration**.

Model sentence: The structural features of the glomerulus and Bowman's capsule are adapted for efficient filtration of the blood.

Each kidney is made up of about 1.25 million filtering units called **nephrons**. Each nephron filters a very small amount of the blood entering the kidney through the renal artery. The filtration process is under high blood pressure and is called ultrafiltration. Each nephron begins with a swollen area called Bowman's capsule. Inside Bowman's capsule is a capillary bed called the glomerulus. Ultrafiltration occurs through the glomerulus capillary bed.

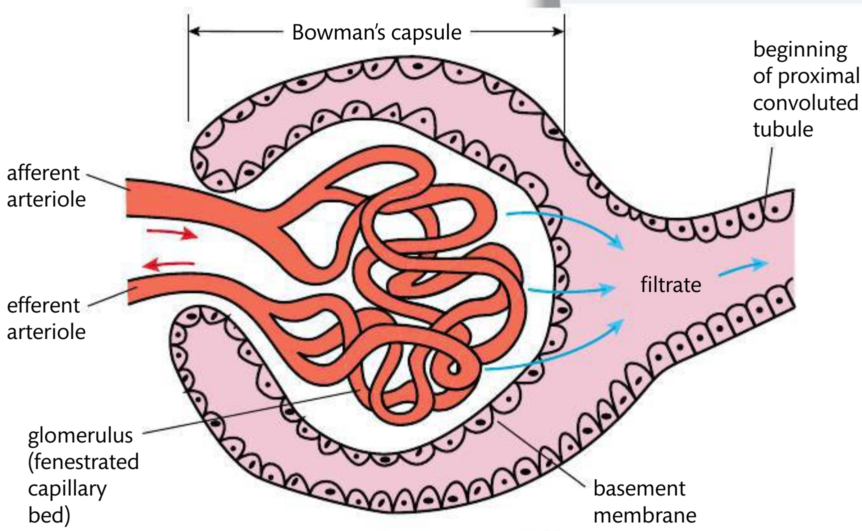


Figure 11.13 *Bowman's capsule is the site of the process called ultrafiltration*

General vocabulary

slits long, narrow openings

selectively some but not all of something

transplant to move from one person to another person

Subject vocabulary

filtrate the fluid that is being filtered out of the glomerulus

proximal convoluted tubule the portion of the nephron just after Bowman's capsule

active transport cellular transport requiring energy (ATP) from the cell

haemodialysis removal and cleansing of blood

loop of Henle portion of the nephron tubule that extends down into the medulla of the kidney

The glomerulus capillary bed contains very small **slits** called fenestrations. These slits open as blood moves through. The fenestrations are only big enough to let some molecules through but not others. Blood cells are much too large to fit through the slits, as are most protein molecules. This **filtrate** must next pass through a membranous structure called the basement membrane. The fluid that does pass through the fenestrations and the basement membrane is called the filtrate. The filtrate then enters a part of the nephron called the **proximal convoluted tubule**.

Application: Blood cells, glucose, proteins, and drugs are detected in urinary tests

Urine is often tested for the presence of substances that should not be there in a healthy person. The presence of blood cells and many proteins is a sign that the kidney is not functioning as it should. The presence of glucose in urine is often a sign that the level of glucose in the blood is too high.

Understanding: The proximal convoluted tubule **selectively** reabsorbs useful substances by **active transport**.

Model sentence: Active transport is used to recover useful substances from the filtrate through the walls of the proximal convoluted tubule.

The filtrate that is formed in Bowman's capsule has many substances that the body cannot afford to lose. A good example of this is glucose. Glucose is small enough to become a part of the filtrate. If this glucose were not recovered it would be lost from the body as part of urine.

Each nephron is capable of actively transporting useful molecules out of the proximal convoluted tubule to be recovered back into the bloodstream. This process is so efficient that no glucose is typically found in a healthy person's urine.

Application: Treatment of kidney failure by haemodialysis or kidney transplant

There are two options available when a patient has failing kidneys. One option is to filter the blood by the use of a machine. This procedure is called haemodialysis. The patient's blood is passed through a device containing a membrane and a fluid. Urea diffuses out of the blood and through the membrane into the fluid. The blood returned to the body has a lower content of urea. This procedure needs to be repeated every few days.

The second option is to receive a transplanted kidney by surgery. The kidney that is received must be 'matched' between the donor and receiving patient.

Understanding: The **loop of Henle** maintains hypertonic conditions in the medulla.

Model sentence: The medulla area of the kidney is hypertonic due to actions of the loop of Henle.

Skill: Annotation of diagrams of the nephron

If shown a diagram of a nephron similar to the one opposite, you should be able to label the parts and describe their function.

As the filtrate moves through the proximal convoluted tubule down and then back up through the loop of Henle further changes occur to the filtrate. One of those changes is that many ions are reabsorbed out of the filtrate. These ions remain for a period of time in the surrounding fluid. This makes that fluid hypertonic to most other fluids in the area.

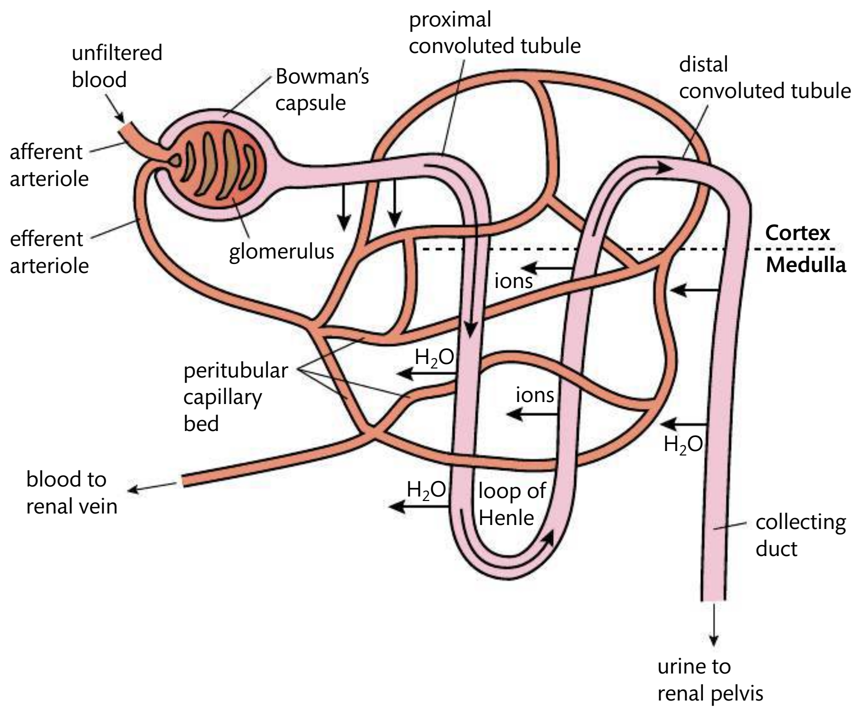


Figure 11.14 *A single nephron of the mammalian kidney. Notice the dotted line showing the portion of each nephron in the renal cortex of the kidney and the portion of each that extends down into the renal medulla*

Subject vocabulary

ADH the hormone that affects the collecting duct to make it permeable to water

reabsorption the return of molecules to the blood that were a part of the filtrate

collecting duct a duct that takes urine to the pelvis of a kidney

hypotonic a fluid that has a high water content compared to another fluid

osmosis movement of water through a membrane along a concentration gradient

General vocabulary

dilute make less concentrated

permeable allows one or more substances to pass through

Understanding: ADH controls reabsorption of water in the collecting duct.

Model sentence: The presence or absence of the hormone ADH determines whether water is reabsorbed out of the collecting duct.

As you can see from the figure above, the filtrate moves up the loop of Henle and into the distal convoluted tubule. From there it passes into a tube called a collecting duct. The filtrate by this time has been modified so that many of the molecules that were originally filtered have now been returned to the blood (reabsorbed).

The filtrate that enters the collecting duct is quite dilute. This means that its water content is quite high. This also means that the fluid in the collecting duct is hypotonic to the highly hypertonic fluid of the medulla of the kidney. If the collecting duct becomes permeable to water, that water will leave the collecting duct by osmosis. Any water that leaves the collecting duct is reabsorbed back into the blood.

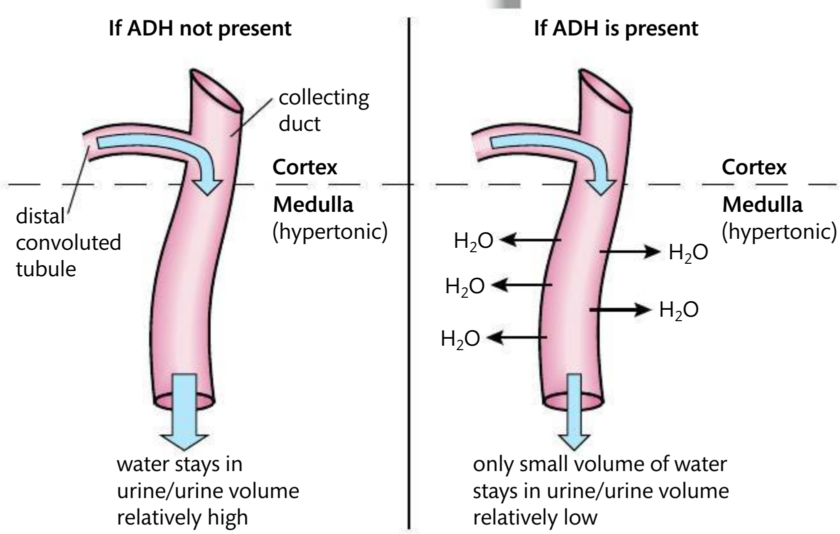


Figure 11.15 *Control of water reabsorption in the kidney by ADH*

The collecting duct is sometimes permeable to water and sometimes it is not permeable. The permeability of the collecting duct is controlled by the hormone, ADH. If ADH is present, the collecting duct allows water to leave by osmosis. If ADH is not present, the collecting duct remains **impermeable** to water. In that case, water stays in the collecting duct and will be lost as part of the urine.

Your body produces ADH when you need to **conserve** water. Your body stops producing ADH when more water needs to be eliminated in urine. This is an example of negative feedback control.

General vocabulary

impermeable does not allow substances to pass through

Synonyms

conserve .... save/retain

Subject vocabulary

positive correlation two factors that both increase together or decrease together

desert an environment where little to no water is available

Understanding: The length of the loop of Henle is positively correlated with the need for water conservation in animals.

Model sentence: Animals that have the greatest need to conserve water tend to have the longest loop of Henle of those animals that have kidneys.

The loop of Henle is the part of the nephron that creates a hypertonic fluid. This fluid surrounds the collecting duct. The longer the loop of Henle the more water can be drawn out of the collecting duct. This water is returned to the animal's blood and is not lost in the urine. Here are two examples to show this correlation:

1. Grass frog – the grass frog has virtually no loop of Henle. The urine of this animal is always very dilute. Grass frogs live in areas where there is high availability of water. Conserving water is not necessary.
2. Kangaroo rat – the kangaroo rat has a very long loop of Henle. There is very little water in the urine of this animal. Kangaroo rats live in **desert** areas. Almost all their water intake is from the food they eat.

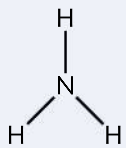
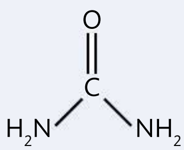
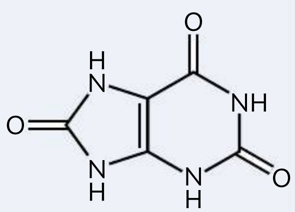
Application: Consequences of dehydration and overhydration

Dehydration is an insufficient intake of water to keep up with water lost by the body. Overhydration is a result of an excess of water intake as compared to water lost. The symptoms of each are shown by this chart.

Dehydration	Overhydration
sleepiness	change in behaviour/confusion
constipation	blurred vision
dry mouth and skin	muscle cramps
dizziness and headache	nausea and vomiting

Understanding: The type of nitrogenous waste in animals is correlated with evolutionary history and habitat.

Model sentence: Evolutionary history and habitat largely determine the type of nitrogenous waste an animal produces.

Structure of nitrogenous waste	Example organism	Advantages	Disadvantages
ammonia 	fish	requires very little energy to produce	very toxic in blood and tissues; must be diluted and removed from the body quickly by using a great deal of water
urea 	mammals	requires less energy to produce compared with uric acid; toxic in blood and tissues but only at physiologically abnormal levels	requires more energy to produce compared with ammonia; requires some water for dilution and removal from the body
uric acid 	birds	relatively insoluble in aqueous solutions such as blood and cytoplasm; can be stored within specialized structures within some animal's eggs; requires little to no water for dilution and removal from the body	its complex structure requires a great deal of energy to produce

Subject vocabulary

spermatogenesis process of creating sperm cells

oogenesis process of creating egg cells

meiosis cell division where one diploid cell becomes four haploid cells

cell differentiation the development of specialized structures within a cell

diploid a cell which has chromosomes in homologous pairs

haploid a cell that has only one chromosome of each homologous pair

flagellum (plural: flagella) whip-like structure which allows movement of cells

organelles non-cellular structures within a cell which carry out organ-like processes

Synonyms

ovum (plural: ova) ... egg

Understanding: Spermatogenesis and oogenesis both involve mitosis, cell growth, two divisions of meiosis, and differentiation.

Model sentence: Production of both sperm and egg requires mitosis, cell growth, meiosis, and cell differentiation.

- Sperm production is called spermtatogenesis.
- Egg (or ova) production is called oogenesis.

Both of these types of reproductive cells require the following:

Process	Purpose
mitosis	Mitosis creates more cells that can become reproductive cells.
cell growth	Cell growth is necessary because the beginning cell will undergo two cell divisions to form four cells.
meiosis	Meiosis converts a single $2n$ (diploid) cell into four $1n$ (haploid) cells.
cell differentiation	Sperm cells are very small and develop a flagellum. Egg cells are very large and have numerous organelles.

Skill: Annotation of diagrams of a seminiferous tubule and ovary to show the stages of gametogenesis

The seminiferous tubules are the small tubes in the testes where sperm are produced by meiosis. The ovary is the structure where eggs are produced by meiosis in females. Using the two figures below, practise labelling and make sure that you understand the events being shown.

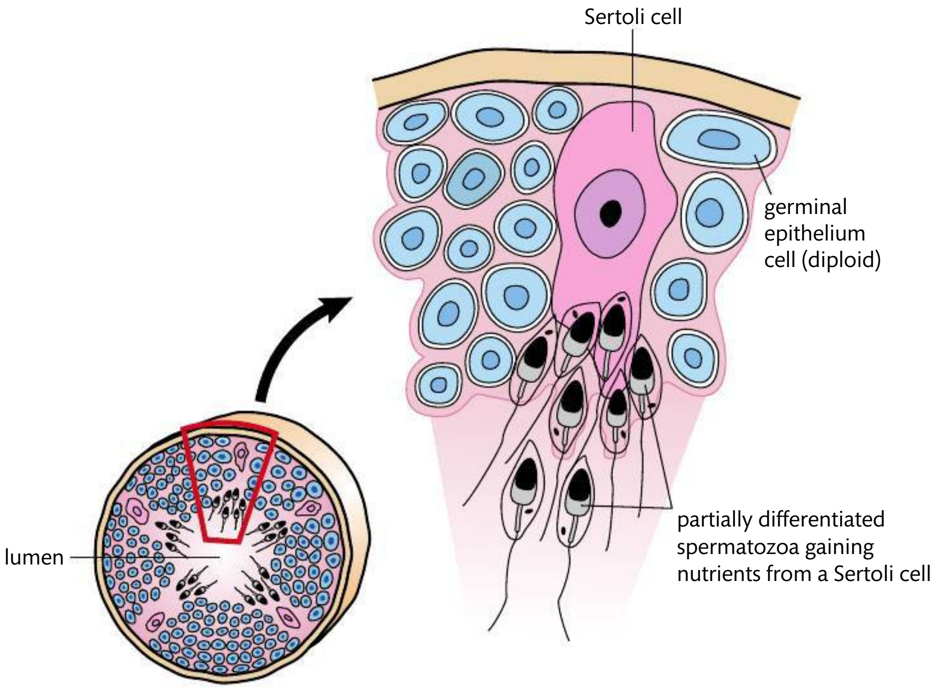


Figure 11.16 *A section view through a seminiferous tubule*

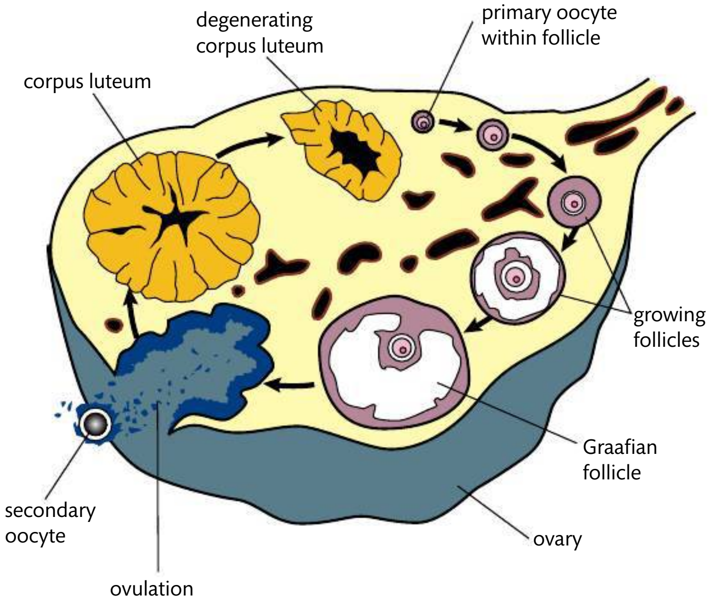


Figure 11.17 *An ovary showing the stages in the production of a human Graafian follicle, leading to ovulation and the formation and degeneration of the corpus luteum. This diagram is like a time-lapse photograph of the ovarian events during a single menstrual cycle, as not all of these stages would be occurring at the same time*

Understanding: Processes in spermatogenesis and oogenesis result in different numbers of **gametes** with different amounts of **cytoplasm**.

Model sentence: The production of sperm and eggs differs greatly in the number of cells created and the size of the cells.

Sperm cell production in a male's **testes** begins when a male reaches **puberty.** Millions of sperm cells are then produced each day. This continues for the rest of a male's life. In contrast, the number of ova produced in a female's **ovaries** is relatively small. Within a female's ovaries there are approximately half a million total cells that can become an ovum. These cells form during a female's **embryonic** development and will be more than enough to last her entire life.

Sperm cells are some of the smallest cells in the body. They have very little cytoplasm and very few organelles. In contrast, an ovum is the largest cell in the body. An ovum has a huge amount of cytoplasm along with many organelles and stored nutrients.

Skill: Annotation of diagrams of mature sperm and egg to indicate functions

Use the figure below to practise labelling and make sure that you understand the function of the structures being shown.

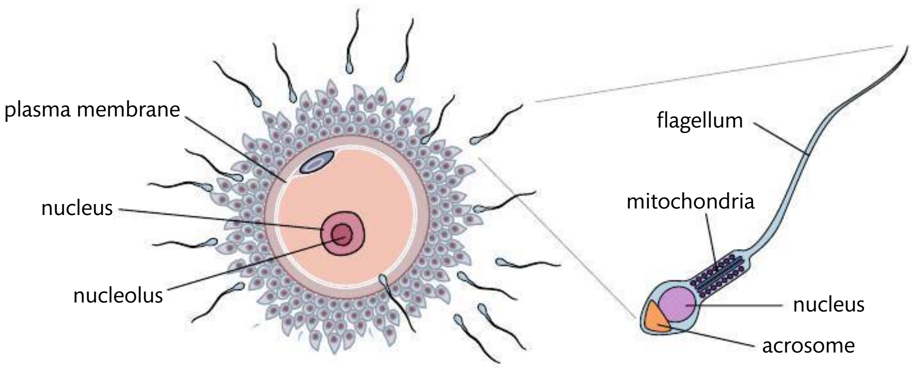


Figure 11.18 *Figure showing an ovum and sperm. Notice how small the sperm are in comparison to the ovum. One sperm is shown enlarged for clarity*

Subject vocabulary

gamete a sex cell, either a sperm cell or an egg cell

cytoplasm region of the cell within the plasma membrane in which the cell organelles exist

testes male organs where spermatogenesis occurs

puberty age in males and females where reproduction is first possible

ovary female organ where oogenesis occurs

embryonic early development after fertilization

Understanding: Fertilization in animals can be internal or external.

Model sentence: Animals use two reproductive strategies, external fertilization and internal fertilization.

Female animals of species that use external fertilization lay unfertilized eggs outside of their body. The male of the species then releases a fluid that contains sperm cells. Typically, only a small percentage of the eggs actually get fertilized. Out of the eggs that do get fertilized only a small percentage of those survive.

A more efficient reproductive strategy is used by species that use internal fertilization. The male and female engage in an act called intercourse. Sperm are deposited inside the female. Fertilization and at least some development also occur inside of the female. This strategy leads to a higher percentage of eggs fertilized.

Understanding: Fertilization involves mechanisms that prevent polyspermy.

Model sentence: There are mechanisms in place to make sure that more than one sperm does not fertilize the same ovum.

An ovum needs to be fertilized by one and only one sperm. Fertilization by more than one sperm is a condition called polyspermy. This condition will not result in a healthy embryo.

Inside of an ovum there are many small organelles called cortical granules. The contents of these cortical granules are released when the first sperm cell enters the membrane of the ovum. The release of the contents of these granules leads to a chemical change to the area just outside of the ovum's membrane called the zona pellucida. The end result is that no more sperm will be able to penetrate to the ovum membrane.

Understanding: HCG stimulates the ovary to secrete progesterone during early pregnancy.

Model sentence: Ovaries are stimulated to continue progesterone secretion under influence of the hormone, HCG.

A human egg is released from an ovary and becomes fertilized in a Fallopian tube. The new embryo does not wait long to begin development. As the embryo moves through the Fallopian tube it is also dividing by mitosis. It takes 7–10 days for an embryo to move into the cavity of the uterus.

During the time that the embryo is dividing and moving down the Fallopian tube, it is also producing a hormone. That hormone is HCG. The effect of HCG is to stimulate the ovaries to continue secreting progesterone. In turn, the continued secretion of progesterone keeps the endometrium of the uterus prepared to receive the embryo. The production of HCG by the embryo is a chemical signal to the mother's tissues that she is pregnant and to be ready to receive the embryo into the uterus.

Subject vocabulary

external fertilization fertilization outside of the female's body

internal fertilization fertilization inside of the female's body

intercourse a reproductive act in which the male deposits sperm inside of a female

polyspermy an abnormal situation where more than one sperm fertilizes an ovum

cortical granules small organelles inside of an ovum that release a substance when the first sperm reaches the egg cell membrane

zona pellucida layer just outside of an ovum's plasma membrane

progesterone hormone produced initially by ovaries; signals endometrium of uterus to remain ready to receive an embryo

Fallopian tubes tubes that carry the ovum or embryo from the ovary to the uterus

endometrium inner portion of the uterus that has many small blood vessels

Synonyms

penetrate....... go through

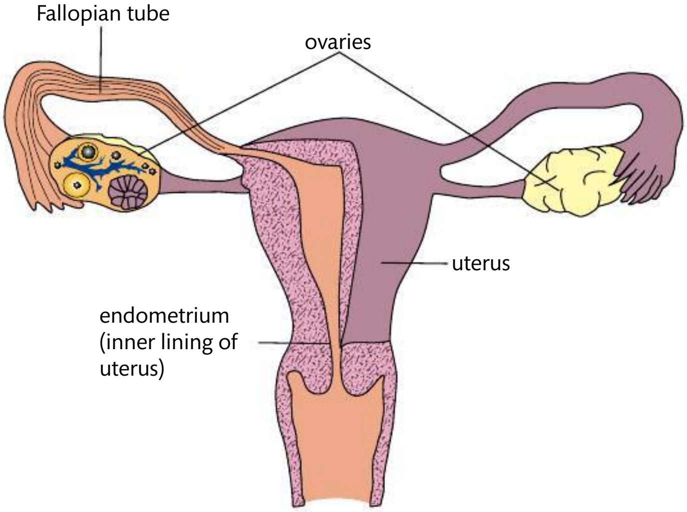


Figure 11.19 *Section view of female reproductive system*

Understanding: **Implantation** of the **blastocyst** in the endometrium is essential for the continuation of pregnancy.

Model sentence: A young human embryo must implant itself into the inner wall of the mother's uterus for pregnancy to be successful.

An ovum contains stored nutrients. This material is called yolk. The stored yolk provides enough nutrition for about the first 10 days of life after fertilization. In order to gain further nutrition an embryo must implant itself into the inner wall of the mother's uterus. This inner wall has many small blood vessels and is called the endometrium.

An embryo begins cell divisions soon after fertilization. It begins to form a hollow ball of cells. After about 10 days this ball of cells is called a blastocyst. The blastocyst enters into the uterus and settles into a location on the endometrium.

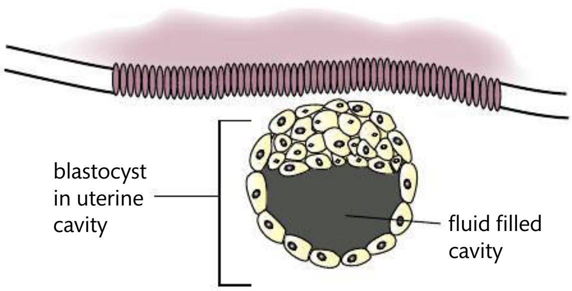


Figure 11.20 *A human blastocyst shown in section. This blastocyst has reached the endometrium of the uterus and is going to implant itself through the cell layers shown in colour*

When the embryo implants into the endometrium a structure called a placenta forms. The **placenta** will allow the mother's bloodstream to provide nutrients to the embryo.

Subject vocabulary

implantation process where a young embryo sinks into the endometrium

blastocyst stage of a human embryo about 10 days after fertilization

uterus muscular organ of females where the embryo develops

placenta a structure found in the uterus that allows exchanges of gases, nutrients, and waste products between mother and foetus

General vocabulary

facilitate make easier

Subject vocabulary

foetus term for an embryo once it forms recognizable features

concentration gradient change in a chemical concentration between two areas

Understanding: The placenta **facilitates** the exchange of materials between the mother and **foetus.**

Model sentence: Nutrients and waste products are exchanged between the mother and the foetus by way of the placenta.

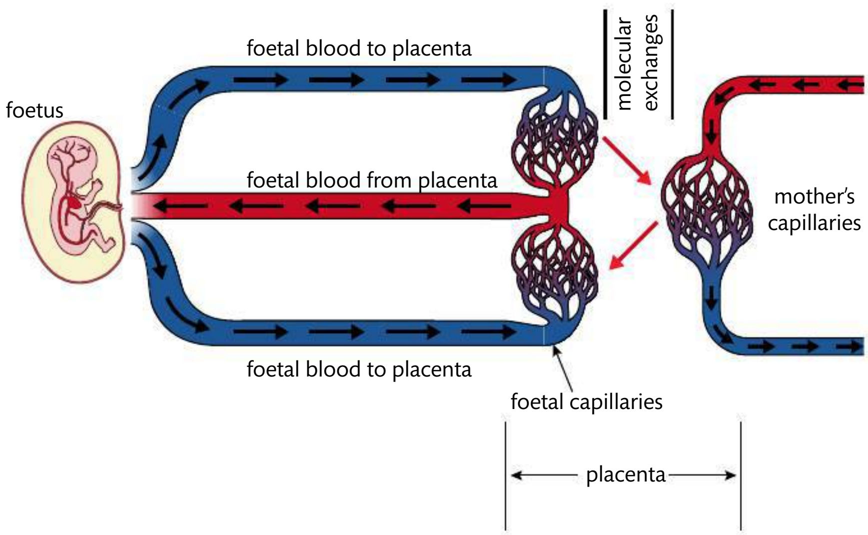


Figure 11.21 *A schematic showing the blood flow pattern of the placenta. No blood is ever exchanged between the mother and foetus*

The placenta is a structure where the capillaries of the mother and the capillaries of the foetus can exchange molecules. Blood does not get exchanged between mother and child. The exchanges that occur are molecules. The direction of the molecular exchange largely depends on the concentration gradient of each type of molecule. The direction of each molecule's diffusion is always from high concentration to low concentration. The table below shows some of the important molecules:

Molecule	Process that explains why and where the molecule becomes concentrated	Direction of diffusion across the placenta
oxygen	Only the mother is breathing. Oxygen concentration is higher in her blood.	Oxygen diffuses from mother's capillaries to foetal capillaries.
carbon dioxide	Both mother and foetus are using cell respiration. The foetus cannot breathe to expel carbon dioxide.	Carbon dioxide diffuses from foetal capillaries to mother's capillaries.
nutrients	Only the mother is eating and digesting. Nutrient concentrations are higher in her blood.	Nutrients, like glucose, diffuse from mother's capillaries to foetal capillaries.
urea	Urea is produced by both mother and foetus as a waste product. The foetus has no way to produce and eliminate urine. Urea is higher in foetal blood.	Urea diffuses from foetal capillaries to mother's capillaries.

Understanding: Oestrogen and progesterone are secreted by the placenta once it has formed.

Model sentence: Once formed, the placenta begins to secrete the two hormones oestrogen and progesterone.

The table below outlines some of the functions of progesterone and oestrogen during pregnancy.

Progesterone	Oestrogen
helps maintain large number of small blood vessels in the endometrium of uterus	encourages muscle growth and expansion of uterus as pregnancy continues
suppresses uterine contractions (until birth)	stimulates mammary gland development late in pregnancy (along with progesterone)

Understanding: Birth is mediated by positive feedback involving oestrogen and oxytocin.

Model sentence: Oestrogen and oxytocin are the two hormones that control the events of birth by way of a positive feedback mechanism.

The secretion of the hormone oestrogen begins at approximately a third of the way through pregnancy. Oestrogen secretion continues to regularly increase. Over time, uterine muscle begins to develop protein receptors for another hormone due to the influence of oestrogen. This second hormone is called oxytocin.

Very late in pregnancy the pituitary gland secretes a small amount of oxytocin. This hormone binds to the newly formed oxytocin receptors in the uterus muscle. The result is a light contraction of the uterus. This is the first labour contraction.

The stretching caused by the first contraction results in the pituitary gland releasing even more oxytocin. This causes a second more intense labour contraction. Once again this causes even more oxytocin to be released. As time goes on during labour, the uterine contractions become more and more intense as well as more frequent. Only birth will stop the positive feedback mechanism that these actions demonstrate.

General vocabulary

suppresses prevents something from growing or developing

Subject vocabulary

mammary gland milk-producing glands in a female's breasts

positive feedback a series of events controlled by one or more hormones that leads to a continuously increasing effect, e.g. contractions of the uterus

oestrogen one of two hormones produced by the ovaries of a female

oxytocin a hormone secreted from the pituitary

labour the series of events in mammals that lead to birth

A.1 Neural development

Main idea

Modification of **neurones** starts in the earliest stages of embryogenesis and continues to the final years of life.

Nature of science: **Use models as representations of the real world – developmental neuroscience uses a variety of animal models.**

Model sentence: **Nerve cells start growing and specializing very early in the developing embryo and can continue to be modified throughout a person's life.**

Subject vocabulary

neurones cells of the nervous system that transmit electrical impulses

chordates organisms that possess a notochord and (usually) a spinal column

embryogenesis process by which undifferentiated cells specialize to become the embryo

neural tube area in the embryo that develops into the central nervous system

ectoderm the outermost layer of cells of an embryo

endoderm the inner layer of cells in an embryo

mesoderm the middle layer of cells in the developing embryo

notochord a long thin part of the back of an organism developed from the mesoderm of the embryo which usually matures into the spine

General vocabulary

elongation to grow longer

sphere shaped like a ball

Understanding: The neural tube of embryonic chordates is formed by infolding of ectoderm followed by elongation of the tube.

Chordates begin their development as an embryo, a **sphere** of hundreds of undifferentiated cells. As the cells divide, they begin to specialize in a process called **embryogenesis**. This section will examine the cells that will specialize to become the nervous system.

Because experimentation on human embryos raises ethical and technical concerns, much of what we know about these early stages of development has come from the study of other chordates. In effect, we use animal models such as clawed frogs of the genus *Xenopus* to learn about embryogenesis. These frogs produce strong and healthy embryos that survive well during experimental manipulation and observation.

A key step in specialization towards a brain and neurones is the formation of the **neural tube**. This forms from the outermost layer of cells in the embryo called the **ectoderm**. There are two other main layers of cells found in the embryo: the **endoderm**, found in the centre, and the **mesoderm** in the middle.

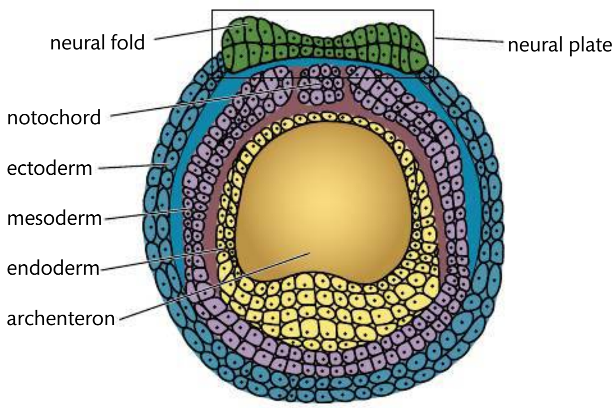


Figure 12.1 *Embryonic tissues in* Xenopus

One part of the mesoderm is called the **notochord**. All chordates have this zone of cells at one point in their development and it is where the phylum Chordata gets its name. In humans, the notochord leads to the formation of the vertebral discs of the spine.

In a process called **induction**, part of the ectoderm forms the **neural plate**, a flattened elongated disc of cells. As this block of cells grows, it develops a fold down the centre. The fold deepens and the sides grow up and around it forming a tube. This is the neural tube. This is where nerve cells will start to form.

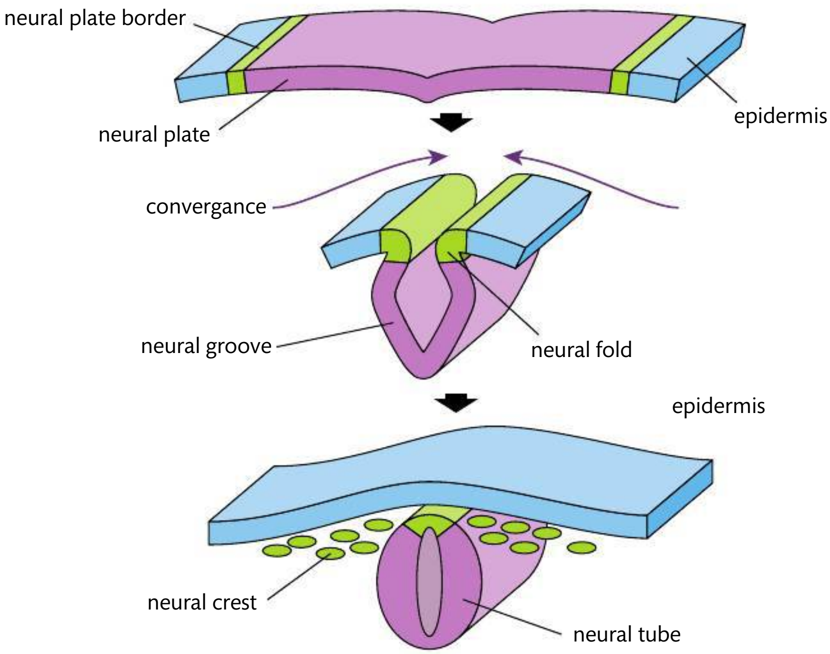


Figure 12.2 *Formation of the neural tube*

Application: Incomplete closure of the embryonic neural tube can cause spina bifida

It is important that the neural tube closes completely. If it does not, there is a risk that some nerve tissue would grow outside the protection of the spine. In humans, the spine forms around the spinal cord and so nerve cells growing outside of it would not be protected by its bony structure.

This can occur in children with a birth defect called spina bifida. The lower part of the neural tube, which forms the base of the spinal cord, does not close correctly. As a result, a little pocket of flesh can be seen at the base of the child's back. Consequences for the child can include learning disorders and difficulty walking.

Understanding: Neurones are initially produced by differentiation in the neural tube.

- The process of forming specialized neurones is called **neurogenesis**.
- **Neuroblasts**, immature nerve cells, are formed in the neural tube. These will mature into two types of cells: neurones and glial cells.
- Neurones carry nerve impulses, whereas **glial cells** are responsible for giving physical support and nutrition to the neurones. Glial cells represent 90% of all cells in your brain. They do not carry nerve impulses.

Subject vocabulary

induction process that forms the neural plate

neural plate a flattened disc of cells that develops into the nervous system

spina bifida a condition where the embryonic neural tube does not close properly

neurogenesis formation of specialized neurones

neuroblasts immature nerve cells

glial cells cells which provided support and nutrition to neurones

Synonyms

migrate.......... travel

Subject vocabulary

glial fibres elongated structures along which nerve cells can travel to their destination

axon long extension of a neurone that carries an impulse away from cell body

growth cone structure at the tip of an axon which directs its growth

chemotrophic factors molecules that affect the growth of an axon

chemoattractive factors molecules that cause the growth cone of the axon to grow towards them

chemorepellant factors molecules that cause the growth cone of the axon to grow away from them

synapse an area where one neurone comes close to another cell in order to send a chemical message

synaptic cleft the gap between two synapses across which neurotransmitters must pass

cell adhesion molecules (CAMs) molecules that signal to the growth cone to form a synapse

peripheral nervous system the part of the nervous system outside of the brain and spinal cord

central nervous system (CNS) brain and spinal cord

sciatic nerve a long nerve cell that controls leg and foot movements; longest neurone in the body

General vocabulary

activated made active

facilitate make easier

Understanding: Immature neurones migrate to a final location.

One way glial cells physically help neurones is by providing a structure along which the neurones can migrate. In effect, neurones need to get from where they are formed to where they are useful.

The immature neurones attach to **glial fibres** and move to their final destination by moving along the fibres.

Understanding: An axon grows from each immature neurone in response to chemical stimuli.

Once the neurone has reached its final location, it is ready for the next step: the production of its axon. From the cell body of the nerve cell, an axon pushes forward, led by a **growth cone**. The growth cone will advance as long as it encounters favourable conditions. If it bumps into a surface that is not favourable to the passage of a nerve impulse, it will pull back and try a new direction.

Molecules called **chemotrophic factors** can influence the direction of the growth cone. **Chemoattractive factors** will pull the axon towards them, whereas **chemorepellant factors** will push the axon away.

When the axon has reached a target cell that is its final destination, it must make a connection with that cell. A **synapse** must be formed. The synapse is used to convert the nerve impulse into a chemical signal using neurotransmitters across the **synaptic cleft**.

One way to form the synapse is to have the target cell send out a chemical message indicating that it is available to link with other nerve endings. **Cell adhesion molecules** (**CAM**s) are used to inform the growth cone on the axon that this is a good location on the target cell for a synapse to form.

CAM-specific receptors on the growth cone are **activated** and enzymes **facilitate** the elongation of the axon.

Understanding: Some axons extend beyond the neural tube to reach other parts of the body.

Model sentence: Nerve cells that stay within the neural tube form the CNS, whereas nerve cells that extend beyond the neural tube will form the peripheral nervous system including sensory cells all over the body.

The neural tube is only going to form the **central nervous system** or **CNS** (the brain and spinal cord). The human body has many other nerve cells such as sensory neurones (for things such as sight, smell, or touch) or motor neurones (to tell the muscles to walk, pump blood, or blink).

To get out of the neural tube and into the other parts of the body, the growth cone of the axon leaves the neural tube and seeks out target cells that are more distant than the ones that will form the brain and spinal cord.

The longest neurone in the human body is the **sciatic nerve** which goes from the spinal cord all the way down to the big toe.

Understanding: A developing neurone forms multiple synapses.

A young neurone starts out with no synapses. It proceeds by pushing its axon forward looking for possible connections. Along the way, it will be attracted and repulsed by chemotrophic factors and eventually it will be encouraged to form a synapse with a cell. Many cells will surround the end of the axon and therefore many connections with many target cells can possibly be made at the end of one axon.

Just because a synapse forms, however, does not mean it will be useful. The axon will try to transmit signals to or from the target cells.

Understanding: Synapses that are not used do not persist.

Model sentence: Nerve cells that are used frequently for transmitting messages will maintain a strong connection with each other, whereas those that go unused will lose their connections.

If synapses are used frequently, they will be maintained. If they are not used, they will not be maintained.

In the cases where the signal is not passed from the axon to the target cell, the synapse weakens until any possible connection is lost. Only the most useful and efficient connections are maintained and the weaker or less used connections are eliminated.

Understanding: Neural pruning involves the loss of unused neurones. The plasticity of the nervous system allows it to change with experience.

'Use it or lose it' is a phrase commonly used to describe neurones in a developing brain.

Neural pruning or synaptic pruning refers to the process of elimination of synapses and axons that are not used.

For example, the neurones found in the part of the brain used for interpreting smell (the olfactory bulb) do not need to send axons out to the muscles. As a result, during neural pruning, any axons randomly extending from the olfactory bulb into muscle will not be useful and will be eliminated.

Likewise, any axons from the neurones in the part of the brain used for muscle contraction (such as the primary motor cortex – see Section A.2) that send axons to the nose to pick up odours would be useless. As a result, they are pruned.

Although this process is especially active during the growth of the brain until adolescence, it continues even in adulthood. The ability of the brain to modify connections based on experiences is referred to as the plasticity of the brain. This means that the brain can re-wire itself depending on the needs of the user.

Although there are limits to the plasticity of the brain, neuroscientists are often impressed with how the brain can adapt to new situations. For example, a person who has suffered brain damage due to an accident can often re-learn skills that were lost. Undamaged parts of the brain can sometimes take over from damaged parts to accomplish tasks such as speech.

Subject vocabulary

neural or **synaptic pruning** process of removing synapses and axons that are not used

motor cortex area of the brain that plans and carries out movement

plasticity the ability of the brain to form new connections to learn new skills or re-learn lost skills

General vocabulary

adolescence the time when a young person is becoming an adult (12–18 years old)

For example, former US Senator Gabrielle Giffords survived an assassination attempt in 2011 but was left with severe brain damage caused when she was shot in the head. Thanks to her inspiring willpower and hard work, as well as the plasticity of the human brain, she has been able to learn to walk and speak again.

Application: Events such as strokes may promote reorganization of brain function

One event that might require the rearranging of neural connections is a stroke. A stroke is caused in the brain when a blood vessel is blocked and blood circulation is cut off from a particular region of the brain. When blood can no longer flow, neurones and glial cells do not get oxygen or nutrients. Such cells can die and consequently a part of the brain is destroyed.

If the part of the brain that is affected by the stroke happens to be the zone in charge of speech, the person might have difficulty speaking. In some cases, other parts of the brain can take over for this damaged zone and the person can learn to speak again.

Model sentence: Model organisms are species such as mice that are studied in detail because of their availability and how easy they are to breed and keep in a laboratory – things learned about the biological processes in model organisms are extrapolated to human biological processes.

Subject vocabulary

neurulation development of the neural tube in embryos

Synonyms

fuse............... merge

Skill: Annotation of a diagram of embryonic tissues in *Xenopus*, used as an animal model, during neurulation

Match the labels on the diagram below with the following:[1]

1. Neural folds. An indentation, called the neural groove, occurs along the neural plate between the neural folds
2. Neural crest. Many of the cells that were once along the folds fuse together to close off the neural tube, other cells detach from the top of the tube to form the neural crest which will later form the peripheral nervous system.
3. Neural plate. Part of the ectoderm above the notochord forms the neural plate
4. Neural tube. This closes all the way along its full length from the cranial end (head) to the caudal end (tail) and will form the central nervous system.
5. Neural groove. This forms as the neural folds push cells downwards.

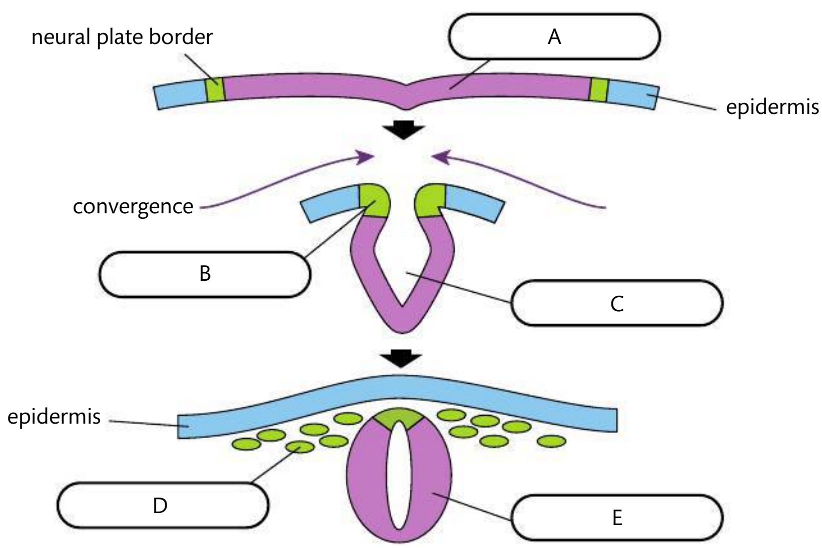


Figure 12.3 *Neurulation in* Xenopus

[1] Answers: A3, B1, C5, D2, E1

A.2 The human brain

Main idea

The parts of the brain specialize in different functions.

Nature of science: **Use models as representations of the real world – the sensory homunculus and motor homunculus are models of the relative space human body parts occupy on the somatosensory cortex and the motor cortex.**

Understanding: The anterior part of the neural tube expands to form the brain.

In the previous section, we saw how the neural tube closes and we learned that this collection of cells will become the central nervous system (CNS). The wider anterior (front) part of the neural tube, also referred to as the cranial end, will form the forebrain. The narrower posterior (back) end of the tube, also called the caudal end, will become the spinal cord and other parts of the brain.

For the brain to form, the anterior section of the neural tube expands as cells divide rapidly. By 7 weeks, the two hemispheres (right and left) begin to form.

Understanding: Different parts of the brain have specific roles.

Model sentence: **Each part of the brain is adapted for specific activities from the lobes of each hemisphere (processing sensory impulses and memory) to the hypothalamus (coordinating the nervous and endocrine systems) and cerebellum (which is in charge of unconscious functions).**

- The cerebral hemispheres are in charge of functions such as memory, emotions, and learning. The outer layer of grey matter makes up the cerebral cortex. The hemispheres can be divided into lobes:
  - The parietal lobe, located at the top of the brain, is in charge of processing sensory information such as touch or temperature.
  - The occipital lobe is the visual processing part of the brain. It is located at the back of the brain.
  - The temporal lobe, located on the side of the brain, is in charge of processing sensory input to make sense of the world around us. This includes transforming the sound of someone speaking into meaningful language or transforming shapes and colours into recognizable objects. Certain memories are also created and stored here, notably long-term ones.
  - The frontal lobe is at the front of the brain and is responsible for a wide variety of tasks including short-term memories, behaviour, learning, and motivation.
- The corpus collosum forms a bridge between the left and right hemispheres allowing them to communicate and share information with each other.
- The hypothalamus maintains homeostasis, coordinating the nervous and the endocrine systems. It is located slightly in front of the centre of the brain. It synthesizes hormones which are stored in the posterior pituitary and releases factors regulating the anterior pituitary.

Subject vocabulary

somatosensory cortex area of the brain that processes information about touch

cerebral hemispheres area of brain that deals with complex functions such as memory, learning, and emotions

cerebral cortex layer of grey matter covering the cerebral hemispheres

parietal lobe area at the top of the brain that processes touch

occipital lobe the part of the brain associated with sight

temporal lobe region on the side of the brain mostly concerned with processing speech and language

frontal lobe front of the brain that controls behaviour, learning, and short-term memory

corpus collosum the bridge between the two hemispheres of the brain

hypothalamus a region of the brain that controls pituitary gland secretions and other autonomic functions

homeostasis steady or controlled state

Synonyms

anterior .... front

posterior .... back

Subject vocabulary

cerebellum area of brain that controls unconcious actions such as movement and balance

medulla oblongata portion of the brainstem that controls many involuntary functions; also known as medulla of the brain

pituitary gland area just below the centre of the brain that secretes several types of hormone

spinal cord an elongated collection of nerve cells that run down the spine and form, with the brain, the central nervous system

brainstem medulla oblongata, area of brain that regulates vital body functions, e.g. breathing

central pattern generators a group of neurones that regulate repetitive actions, e.g. breathing

cardioaccelerator region area of the brain that increases heart rate

cardioinhibitory region area of the brain that decreases heart rate

Synonyms

protruding .... sticking out

- The **cerebellum**, found at the back of the brain below the hemispheres, is responsible for unconscious functions, such as balance.
- The **medulla oblongata** controls automatic and homeostatic activities, such as heartbeat, digestion, and breathing. It is found **protruding** out of the skull from the base of the brain down towards the body.
- The **pituitary gland**, found below the centre of the brain, has two lobes, the posterior lobe and the anterior lobe. Both are controlled by the hypothalamus, and both secrete hormones regulating many body functions.
- The **spinal cord** is below the brain extending into the spine and it connects the brain to the rest of the body.

Application: Swallowing, breathing, and heart rate as examples of activities coordinated by the medulla

From early experiments on the medulla oblongata, it became clear that this part of the brain is responsible for some very vital functions of the body. In the early 1800s, Pierre Flourens experimented on animals such as rabbits and pigeons. Removing some parts of the brain such as the cerebellum allowed the animals to live (with notable impairments) but removal of the medulla oblongata caused death.

Why? Because vital functions such as breathing are controlled by the medulla oblongata, otherwise called the **brainstem**. When a task requires a repetitive or rhythmical action, a network of neurones called **central pattern generators** can be used. The central pattern generators for breathing, for example, are found in the brain stem.

This is also true for swallowing, a complex task requiring the coordination of over 24 muscles. You do not have to think about swallowing because your brainstem uses a central pattern generator in the unconscious part of your nervous system to do it.

Another control centre exists in the medulla oblongata to regulate heart rate. This is made up of two cardiovascular centres, the **cardioaccelerator region** and the **cardioinhibitory region**. The first increases heart rate as part of the sympathetic nervous system, and the second decreases heart rate as part of the parasympathetic nervous system, communicating with the heart via the vagus nerve.

Skill: Identification of parts of the brain in a photograph, diagram, or scan of the brain

You should be able to identify the following parts of the brain:[1]

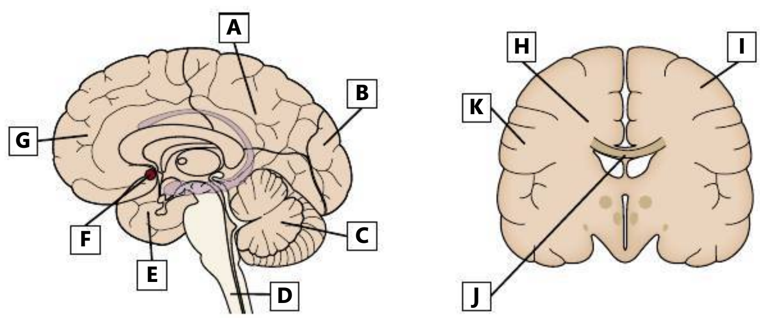


Figure 12.4 *Identifying parts of the brain*

See if you can do the same with a photograph or a scan of the human brain.

[1] Answers: A parietal lobe, B occipital lobe, C cerebellum, D spinal cord, E temporal lobe, F hypothalamus, G frontal lobe, H left cerebral hemisphere, I right cerebral hemisphere, J corpus collosum, K central cortex

Understanding: The autonomic nervous system controls involuntary processes in the body using centres located mainly in the brainstem.

Model sentence: The peripheral nervous system (PNS) is made up of the autonomic nervous system (ANS) and the somatic nervous system (SNS).

The somatic nervous system controls things such as the movement of your arms and legs, and manages the senses you have (touch, smell, hearing, etc.).

The autonomic system is in control of things you are usually not aware of such as heart rate or pupil dilation. The autonomic system is divided into the sympathetic and parasympathetic systems.

There are certain situations in which the brain and body need to function at a higher level of activity. Emergency situations require that your body and brain enter a 'fight or flight' mode. Your heart may beat faster, your brain might process information more quickly, and your breathing rate could increase, depending on the situation. The process of digestion is not a priority in such situations, so blood flows away from the gut and towards other more vital organs. In order to help gather more visual information about your surroundings, your pupils dilate allowing more light to enter the eye.

The part of the peripheral nervous system in charge of 'fight or flight' is the sympathetic system. It is associated with excitatory neurotransmitters such as norepinephrine (or noradrenaline).

There are other situations when your body needs to relax and calm down. Such situations are controlled by the parasympathetic system. The parasympathetic system returns the body to normal. Inhibitory neurotransmitters such as acetylcholine are associated with it.

In a relaxed state, the body can concentrate on things such as digestion, so blood flows back to the gut. Heartbeat and breathing rate return to normal and the pupils constrict back to normal size.

Hints for success: Remember that peripheral is what is outside of the brain and the spinal cord. Somatic has to do with the body, and you know skeletal muscles are voluntary. Autonomic is similar to 'automatic', so you can remember that these functions are not voluntary. Sympathetic is when you are in 'sympathy' with your fear of a lion chasing you. Whereas, with the parasympathetic system, you are like a 'parrot' sitting up in a tree completely relaxed, because the lion is down on the ground. If you can take the complex terms of biology and relate them to something else, you will find it easier to remember them.

Application: Use of the pupil reflex to evaluate brain damage

Since the size of the pupil is controlled by the CNS, it can be used as a tool to test the proper functioning of a person's brain.

In a normally functioning eye, the pupil constricts when exposed to a bright light. Doctors test this during a physical checkup by shining a light into the patient's eye. The light stimulates the photoreceptors which send a signal to the pretectal nucleus of the brainstem. The action potential reaches the Edinger–Westphal nucleus, the axons of which run along ocular motor nerves back to the eye, telling the pupil to contract.

If the pupil does not contract, it could be a sign that the brain is not able to process the information or not able to tell the eyes what to do.

Subject vocabulary

autonomic nervous system that portion of your nervous system that controls unconscious activities

somatic nervous system the network of nerves that control movement and senses

sympathetic system part of the autonomic nervous system concerned with the 'fight or flight' response

parasympathetic system part of the autonomic nervous system responsible for returning the body to 'normal' levels after exertion, e.g. slowing heart rate

norepinephrine (or **noradrenaline**) an excitatory neurotransmitter

pretectal nucleus part of the brain that processes signals from photoreceptor cells

Edinger–Westphal nucleus part of the brain that controls pupil contraction

In modern hospitals, life-support systems can keep a patient breathing and keep their heart beating artificially even after many bodily functions have failed. Is such a person technically 'alive'? One way to determine this is to find out if the brain is still functioning. If there is no sign of brain activity, this suggests that the patient is no longer aware of his or her surroundings and cannot speak, think, or feel. The patient is brain dead.

One way of testing for **brain death** is to perform the **pupil reflex test**. If the pupils do not respond to bright light, this suggests brain death. The body is being kept alive by machines but the brain no longer functions.

Subject vocabulary

brain death abscence of any activity in the brain

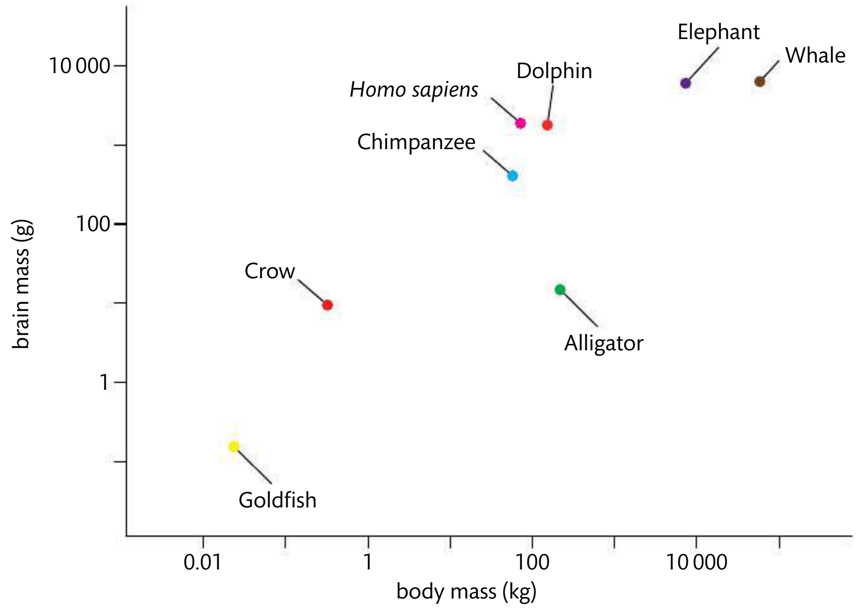
pupil reflex test a check for brain death that looks to see if pupils contract in response to bright light

correlation relationship between two occurrences

grey matter the cerebral cortex

Skill: Analysis of correlations between body size and brain size in different animals

Does a bigger brain mean a more intelligent animal? Analyse the graph below comparing brain mass to body mass. Notice that the scale for body mass is logarithmic: each line on the *x*-axis has a value ten times greater than the line before it.



Source: adapted from Cosmic Evolution website, v7, 2013 © Eric J. Chaisson, Harvard University

Figure 12.5 *A graph plotting brain mass against body mass for various species*

Understanding: The cerebral cortex forms a larger proportion of the brain and is more highly developed in humans than other animals.

Model sentence: The size of an animal's brain is not the only thing that is important for higher order thought processes; the thickness of the cerebral cortex and the number of folds it has also play an important role.

The outermost layer of nerve cells in the two hemispheres of the brain form the cerebral cortex. The cerebral cortex is made up of **grey matter**.

The cerebral cortex is where higher order thought processes happen, such as language, visual processing, reasoning, and complex thought such as problem solving.

Compared to other animals, this part of the brain occupies a high **encephalization quotient** (EQ). It is important to look at such a comparison because although an elephant has a large brain, it is smaller in proportion to its body mass than human brains. See the graph below.

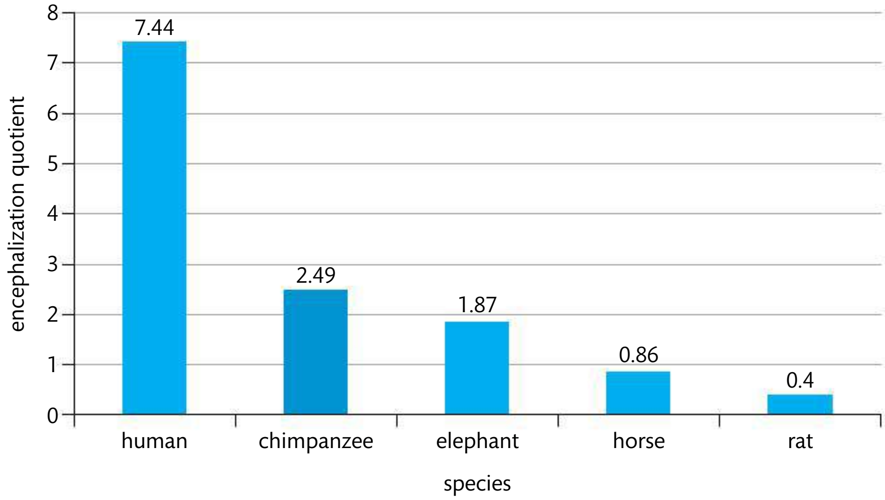


Figure 12.6 *A bar chart of the encephalization quotient of five species*

The EQ takes into consideration the mass of the brain, the mass of the body, an encephalization constant, and an exponential constant to ensure that small animals with comparatively large brains, such as birds, do not appear as outliers.

The EQ of humans is 7.44, that of elephants is 1.87, and rats is 0.40. In general, predators (carnivores) have higher EQs than their prey (herbivores).

We need to be careful about how we interpret graphs like the one above. Does a higher EQ automatically mean that one species is more intelligent that another? Intelligence is difficult to define and therefore difficult to measure and quantify. Intelligence is complex and cannot be reduced to a single number on a scale.

Understanding: The human cerebral cortex has become enlarged principally by an increase in total area with extensive folding to accommodate it within the cranium.

Because the brain is locked inside the skull, it cannot get much bigger. And yet, the total volume of the cerebral cortex has increased during evolution. How? By increasing its surface area thanks to multiple folds.

Examining a mammal brain's hemispheres, one of the most striking features is the complex pattern of indentations caused by folds. The more there are, the greater the surface area of the cerebral cortex. Because the thickness of the grey matter cannot change much, the best way to increase the total volume is to increase the number of folds.

Mice have few folds on the surface of their brains, whereas great apes such as chimpanzees have many.

Subject vocabulary

encephalization quotient the relationship between brain size and body size

Understanding: The cerebral hemispheres are responsible for higher order functions.

Region of the cerebral cortex	Function
prefrontal cortex	organizes thoughts, solves problems, and formats strategies
motor association cortex	coordinates movement
primary motor cortex	plans and executes movements
primary somatosensory cortex	processes information related to touch
sensory association cortex	processes sensory information of perceptions or multisensory information
visual association area	processes visual information
visual cortex	recognizes visual stimuli
Wernicke's area	understands written and spoken language
auditory association area	processes auditory information
auditory cortex	detects sound quality such as loudness or tone
Broca's area	produces speech and language

Application: Visual cortex, Broca's area, nucleus accumbens as areas of the brain with specific functions

In the second half of the 20th century, David Hunter Hubel and Torsten Wiesel did experiments on cats which led to breakthroughs in the understanding of how the visual system in animals works. They inserted electrodes into cats' brains in order to measure neural activity. By projecting black and white shapes in front of the cats, they were able to measure different levels of activity in the visual cortex depending on the images.

In the mid-1800s, Pierre Paul Broca dissected the brains of patients who could not speak and found **lesions** on the temporal lobe which is now called Broca's area. The inability to speak is called **aphasia**. One of his aphasic patients could only say one word: 'tan'.

A remarkable experiment was done in the 1950s with rats. Electrodes were placed in their brains and the rats would have that part of the brain stimulated with an electrical impulse if they walked over to a particular part of their cage. The researchers hypothesized that the electrical stimulation would be unpleasant and that the rats would avoid walking over to the part of the cage with the electricity. On the contrary, the rats seemed to fully enjoy the impulses and kept coming back for more. This part of the brain is called the **nucleus accumbens** or the pleasure centre of the brain. Further investigations allowing rats to push a lever to stimulate the nucleus accumbens had a somewhat disturbing result: rats preferred to push the lever again and again attaching no importance to food or water until they died of **starvation** and **exhaustion**.

Synonyms

lesion .... damage

Subject vocabulary

aphasia inability to speak

nucleus accumbens the part of the brain that detects pleasure

General vocabulary

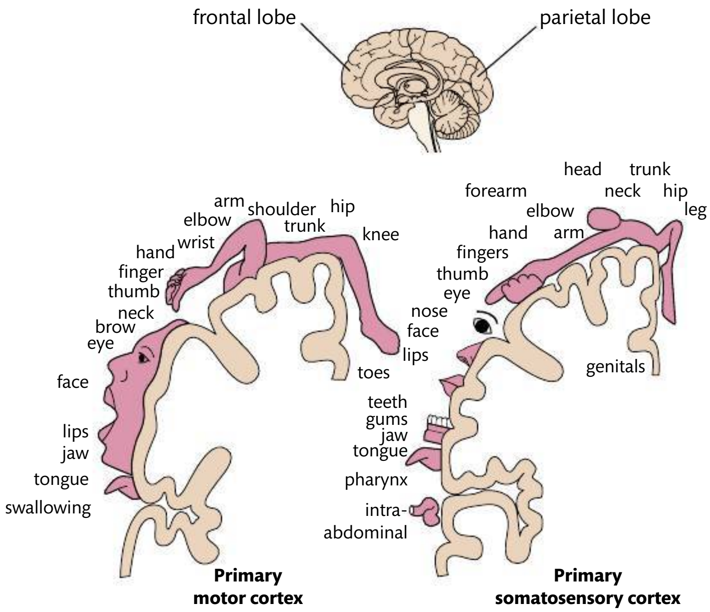
starvation lack of food leading to suffering/death

exhaustion extreme tiredness

One way to help understand the complexity of the functions of the human brain is to represent it with a model.

The drawing below is called a **cortical homunculus**. It is a modified representation of the human body to show where the nerves in the brain are for the somatosensory cortex and the motor cortex.

Notice how the fingers and thumb occupy a disproportionately large area of the brain. This is because there are many more nerve endings in this part of the body.



Subject vocabulary

cortical homunculus a representation that relates areas of the brain to the parts of the body they control

Figure 12.7 *This homunculus cartoon shows the relative importance of areas of the body in the primary motor cortex and the primary somatosensory cortex*

Understanding: The left cerebral hemisphere receives sensory input from sensory receptors in the right side of the body and the right side of the visual field in both eyes and vice versa for the right hemisphere.

The part of the somatosensory cortex found in the left hemisphere of the brain processes information coming from the right-hand side of the body. For example, if you touch a cold drinks glass with your right hand, the sensory neurones send signals to the left hemisphere to process the sensation of cold, the smoothness of the glass, and how heavy it feels.

The opposite is true for the left-hand side of the body. Sensory information picked up from stimuli exciting neurones on the left-hand side of the body send information to the right hemisphere.

As we will see in more detail in section A.3, the left hemisphere also picks up information from the right visual field. This happens in both eyes. It is important to understand that the right eye can see to your right as well as to your left. Consequently, sensory impulses arriving from the right visual field arrives at the left hemisphere and vice versa.

Understanding: The left cerebral hemisphere controls muscle contraction in the right side of the body and vice versa for the right hemisphere.

Model sentence: Senses and actions on the left-hand side of the body are dealt with by the right hemisphere of the brain and senses and actions on the right-hand side of the body are dealt with by the left hemisphere of the brain.

When an athlete swings a tennis racket or a musician presses a key on a piano with their right hand, it is the left side of the brain that is controlling the muscular movements. Likewise, the right side of the brain controls the muscles on the left-hand side of the body.

The part of the brain responsible for movement of muscles is the motor cortex and, like the visual cortex, there is one part on each hemisphere. As with vision, damage to the right hemisphere's motor cortex will possibly paralyse a patient's left side. This can be caused by a stroke and can make **locomotion** very difficult. In severe cases, the damage can be irreversible.

Synonyms

locomotion .... movement

Subject vocabulary

exocytosis active transport in which substances are expelled from the cell

ablation removal by surgery

General vocabulary

autopsy examination of a dead body to find the cause of death

Understanding: Brain metabolism requires large energy inputs.

One of the disadvantages of having a big and highly functional brain is that it demands a large amount of energy.

When the human body is at rest, roughly 20% of the energy being used up is consumed by the brain. Compared to other animals, that is exceptionally high.

Recall that exocytosis requires energy and that neurotransmitters are released by neurones using **exocytosis**. So to keep billions of brain cells sending messages constantly, large amounts of ATP are needed.

Brain cells need glucose in order to get enough ATP. Since neurones cannot store sugar, this glucose must come from the blood, which is why a healthy blood flow to the brain is so important and why a stroke is so dangerous.

Application: Use of animal experiments, autopsy, lesions, and fMRI to identify the role of different brain parts

How do we know what each part of the brain does? There are several techniques, all of which raise ethical issues.

1 Researchers experiment with or dissect animals. Vertebrates such as reptiles and mammals share similarly structured brains; so studying one can help understand the others. It is technically and logistically more practical to find animal subjects for tests and dissections than to find human subjects. By stimulating parts of the brain with electrical signals, for example, researchers can generate certain reactions such as muscle contractions in the body of the animal. **Ablation** (removal) of part of the brain while the animal is still alive can reveal what that part's function is because the animal will no longer be able to perform a certain task such as keeping balance or processing visual stimuli.

2 An **autopsy** on a person who has suffered from a problem can reveal what part of the brain was damaged. This is how Broca's area was found, for example.

3 During brain surgery, doctors can look for lesions (damaged tissue) of the brain that might explain certain problems. Also, stimulating zones of the brain can generate reactions. Although the patient is under anaesthesia, an electrical

stimulation of a certain part of the brain can make the patient laugh. The stimulation of other parts of the brain can make muscles contract.

4 **MRI (magnetic resonance imagery)** has shown itself to be very effective at obtaining images of soft tissue such as the brain. fMRI (the f is for functional) has the additional feature of being able to scan for blood flow in the brain in real time. It is thought that increased blood flow to an area of the brain means that part of the brain is being used for the task at hand.

A.3 Perception of stimuli

Main idea

Living organisms are able to detect changes in the environment.

Nature of science: **Understanding of the underlying science is the basis for technological developments – the discovery that electrical stimulation in the auditory system can create a perception of sound resulted in the development of electrical hearing aids and ultimately cochlear implants.**

Model sentence: **The brain is locked in a dark and silent skull but it can learn about its surroundings by receiving and interpreting nerve impulses from the sensory neurones that pick up stimuli such as light, pressure, chemicals, or temperature.**

Understanding: Receptors detect changes in the environment.

Your brain can only perceive what is around it by receiving electrical impulses. Such impulses are generated by your **sensory neurones** and the brain is in charge of processing and interpreting them so that you are able to observe the sights, sounds, and smells of the world around you.

Sensory neurones can be divided into several categories:

- **Mechanoreceptors** convert pressure or mechanical force into nerve impulses. When you write with a pen, important information about how hard you are pushing the pen (and in what direction) gives your brain the information it needs to decide where to go next in order to write the next word.
- **Chemoreceptors** generate nerve impulses when stimulated by certain molecules. Your ability to taste and smell are made possible by chemoreceptors in your mouth and nose.
- **Thermoreceptors** convert heat energy into nerve impulses. When you dive into cold ocean water at the beach, your skin's thermoreceptors feed signals to your brain allowing it to evaluate the sensation of cold.
- **Photoreceptors** convert light energy into nerve impulses. The retina at the back of your eye has specialized cells that respond to different coloured light. The brain interprets the signals sent by these cells to produce an image in your head of what is in front of you.

Application: **Detection of chemicals in the air by the many different olfactory receptors**

Sometimes when walking down the street, we are distracted by the smell of a coffee shop or bakery. In order for the smell to be recognized by your brain, it has to enter your nose first.

Subject vocabulary

MRI (magnetic resonance imagery) an imaging technology that uses electromagnetic fields interpreted by computers in order to see both hard bones and soft tissue inside a person's body

sensory neurones cells that detect senses such as tastes or smells

mechanoreceptors nervous system receptor cells that are sensitive to pressure or mechanical force

chemoreceptors nervous system receptor cells that are sensitive to one or more chemicals

thermoreceptors nervous system receptor cells that are sensitive to temperature

photoreceptors receptors in the eye that respond to light by beginning a nerve impulse

Subject vocabulary

olfactory receptor cells cells in the nose that detect certain volatile molecules associated with smells

glomerulus (plural: glomeruli) a capillary bed

olfactory bulb the part of the brain associated with smelling

retina the part of the eye containing rod and cone cells that detects light

rod cells cells in the eye that detect light intensity

cone cells cells in the retina that detect bright light and colours

How does this work? Volatile chemicals diffuse into the air and can be picked up by **olfactory receptor cells** in your nose. They send an impulse to the **glomeruli** in the **olfactory bulb**, which is a part of the brain located just above the nasal passages.

The impulses are now ready to be sent to the brain for processing and interpretation. It is the brain that recognizes the smell of coffee, not the nose. The nose prepares the nerve signal for the brain to interpret .

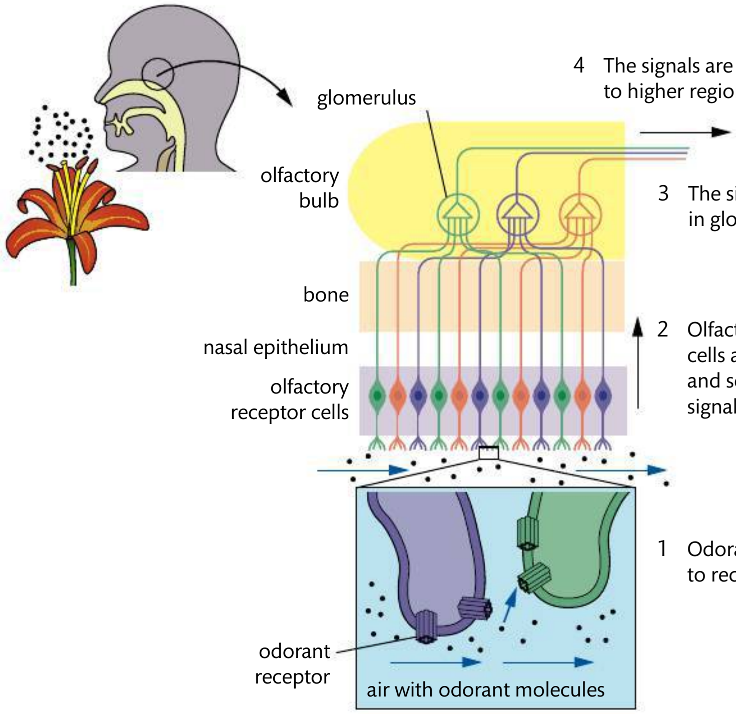


Figure 12.8 *How receptors function in the olfactory system*

Exactly how the olfactory receptors are able to pick up so many different smells is not fully understood. One thing is clear: humans have a much poorer sense of smell than many other mammals, notably dogs.

Understanding: Rods and cones are photoreceptors located in the retina.

Model sentence: Rod cells are well adapted for low light situations but are low resolution and cannot distinguish between colours, whereas cone cells are well adapted for bright light situations and allow for full colour and high resolution.

The part of the eye that senses light is the **retina**, found at the back of the eye. The retina has two categories of photoreceptors in it: rod cells and cone cells.

- **Rod cells** are adapted for low light vision and send signals to the brain about light and dark. They have a very limited range of wavelengths they can detect which peak at 498 nm.
- **Cone cells** are adapted for bright light and can send signals to the brain about a much wider range of wavelengths from just under 400 nm to about 750 nm. We perceive the different wavelengths as different colours.

Skill: Labelling a diagram of the structure of the human eye

You should be able to label the parts of the human eye shown below. Trace the outline and replace the names with letters or numbers. Once you have memorized them, use the letters or numbers to test yourself.

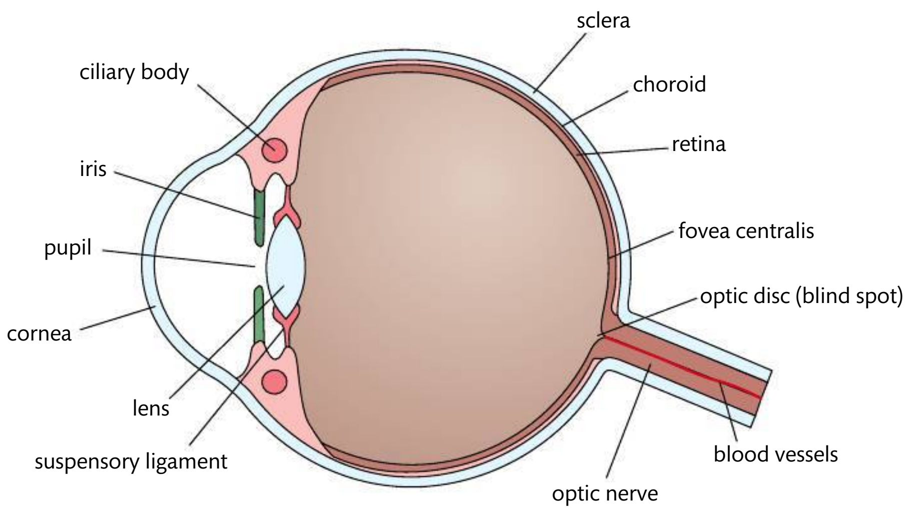


Figure 12.9 *Structure of the human eye*

Skill: Annotation of a diagram of the retina to show the cell types and the direction in which light moves

The diagram below is a close-up of one portion of the retina. You should be able to annotate a figure like this one. Just like for the eye diagram, practise testing yourself using a redrawn diagram with letters or numbers replacing the names.

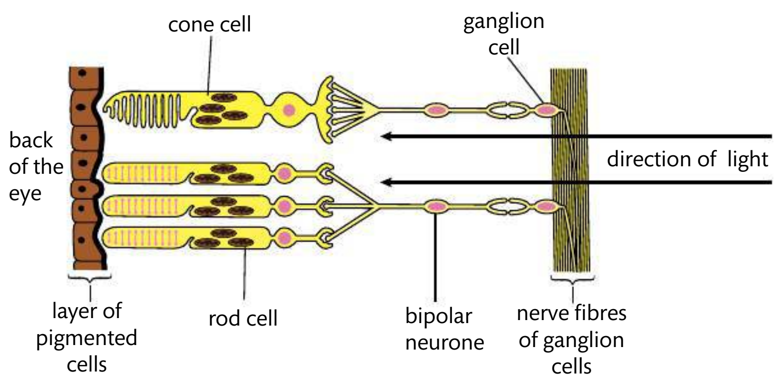


Figure 12.10 *Structure and function of the retina*

- Possible labels:
  - Rod cells receive the stimulus of light, even very dim light, and synapse with a **bipolar neurone**.
  - Cone cells are activated by bright light and synapse with a bipolar neurone.
  - Bipolar neurones carry impulses from a rod or a cone cell to a **ganglion cell**.
  - Ganglion cells synapse with the bipolar neurones and send the impulses to the brain via the **optic nerve**.

Subject vocabulary

bipolar neurone a type of sensory neurone with two extensions protruding from the cell

ganglion cells cells that receive impulses from the rod and cone cells via the bipolar neurone

optic nerve nerve that carries impulses from the eye to the brain

Understanding: Ganglion cells send messages to the brain via the optic nerve.

Ganglion cells have long axons that make up a network of fibres that line the retina.

The ganglion cells relay the nerve impulses along the optic nerve. The optic nerve sends the impulses to the part of the brain where vision happens.

Where the optic nerve leaves the eye, no rod cells or cone cells are present. In this zone, called the **blind spot**, no light can be converted to nerve impulses.

Application: Red–green colour-blindness as a variant of normal trichromatic vision

When all three types of cone cells function properly, full colour vision is possible. This happens when light hits special pigments inside the photoreceptors called **photopigments** and changes their shape. This modification signals to the photoreceptor that light has hit the cell.

Some people have **dichromatic vision**, where one category of cone cell does not function. For example, if the red cells do not work or are not present, the person cannot perceive the colour red. The same is true for green cone cells.

Red–green colour blindness is the most common form of colour perception **deficiency**. As we saw in Chapter 3, it is hereditary and is sex-linked.

What is wrong with the photoreceptors? It could be that there is no functional photopigment **synthesized** in the cone cells but in red–green colour blindness it can be because a **hybrid** pigment is synthesized that cannot discriminate between red or green objects. The photopigment would cause the same signal to be sent whether it was hit with red light or green light.

Subject vocabulary

blind spot area of retina with no rod or cone cells so light cannot be sensed

photopigments molecules that react to specific wavelengths of light

dichromatic vision having only two functioning types of cone cell

synthesized chemically created

hybrid something that has the properties of two things

left visual field area which can be seen to your left when you are looking at a central point

right visual field area which can be seen to your right when you are looking at a central point

Synonyms

deficiency ...... shortage/absence

Understanding: The information from the right field of vision from both eyes is sent to the left part of the visual cortex and vice versa.

Model sentence: Contralateral processing happens when light entering from the left visual field of each eye is processed in the right visual cortex of the brain and vice versa.

Vision is a complex function of the brain. Here we will examine one aspect of vision: how the brain processes right and left visual fields. In reality, vision is more complex than this, but let us simplify the idea down to only right and left and ignore up / down as well as how three-dimensional vision works by mixing right and left visual fields.

In the figure below notice that the retina in each eye has a zone on which light from your **left visual field** enters. In other words, your left eye receives light from your left visual field and your right eye also receives light from your left visual field. Both eyes also have a zone where light from the **right visual field** enters. If you close your right eye, you can still see things both to the right and to the left.

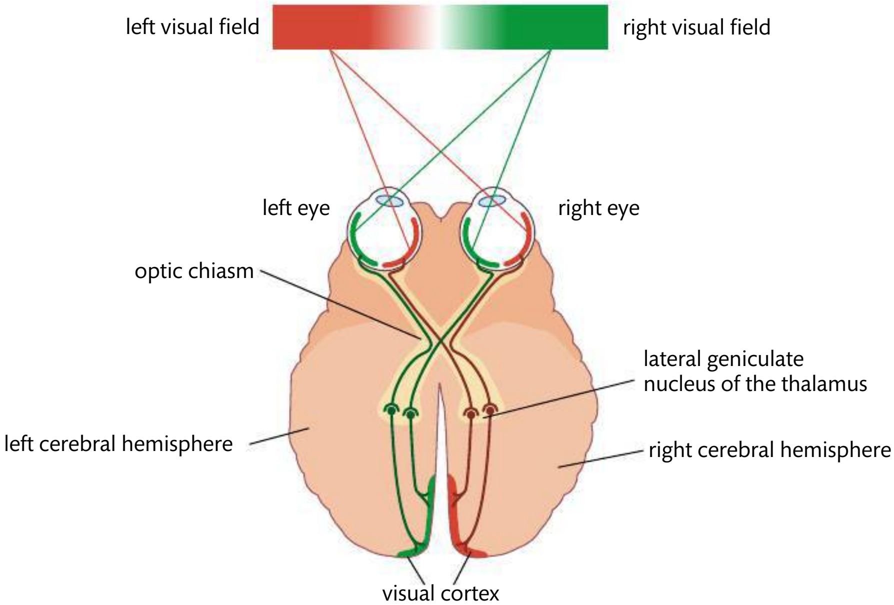


Figure 12.11 *How contralateral processing works to produce an image based on what your two retinas pick up*

Notice also that in each eye, the light from each visual field hits the opposite side of the retina. So light entering the eye from the left visual field touches the right side of the retina in both the right and left eyes.

Follow the green and red lines inside the brain on the diagram. They show the path taken by nerve impulses from the optical nerve to the back of the brain where vision is processed by the visual cortex in the occipital lobe. Along the paths, the optic nerves relay the impulses to other nerves at a zone called the **lateral geniculate nucleus** (LGN). Note: the red and green colours in the diagram have nothing to do with red/green cone cells.

Red represents signals from stimuli that are present in the left visual cortex. Green is for information about the right visual field. The visual cortex has a zone in the right hemisphere of the brain (shown in red), which processes information from the left visual field. Can you see what is happening for the left hemisphere?

As seen in the diagram, each eye sends some signals to the same side of the brain and some to the opposite hemisphere of the brain. The point where the nerves sending impulses to opposite sides of the brain cross is called the **optic chiasm**. The idea of sharing and interpreting information across the two hemispheres is called **contralateral processing**. The brain is remarkably skilled at **fusing** the two fields together to make a smooth and **seamless** image in the brain.

Hints for success: Practise drawing diagrams of the neural pathway for vision until you understand it thoroughly.

Subject vocabulary

lateral geniculate nucleus an area of the brain that relays nerve impulses from the optic nerves to other nerves

optic chiasm point where nerves cross between the two hemispheres of the brain

contralateral processing the sharing and processing of information by both hemispheres of the brain

Synonyms

fusing............ merging

seamless........ smooth/unbroken

Understanding: Rods and cones differ in their sensitivities to light intensities and wavelengths.

The reason why rod cells are well adapted for dim light is that they are more sensitive to light than cone cells. In other words, they will produce a nerve impulse even in low light situations. But since there is only one type of rod cell, they do not generate any signals about colour. This is why night vision is not colour vision.

The cone cells, however, come in three types. One is specialized to respond to wavelengths in the red part of the spectrum, a second responds to green, and

Subject vocabulary

trichromatic vision normal colour vision involving three types of cone cells that detect blue, green, and red light

refraction the act of bending a ray of light as it passes through a liquid or a lens

auditory canal part of the outer ear through which sound waves enter

tympanic membrane or **eardrum** part of the ear that transmits sound waves to the bones of the middle ear

incus anvil; one of three bones that transmit vibrations through the middle ear

malleus hammer; one of three bones that transmit vibrations through the middle ear

stapes stirrup; one of three bones that transmit vibrations through the middle ear

oval window a part of the ear that vibrates when struck by the stapes

cochlea the part of the ear that detects sound waves

General vocabulary

blurry difficult to see clearly

amplify make louder/stronger or increase in number

Synonyms

relay .... pass on

a third to blue. This is referred to as **trichromatic vision**. If a cell specialized in detecting blue light receives a red wavelength, it will not produce a nerve impulse. Among the three types of cone cells, only the red ones will send information to the brain when red light enters the eye. This is how the brain recognizes colours. By mixing even slightly different combinations of these three signals, the brain can interpret intermediate colours between red, green, and blue.

Understanding: Bipolar cells send the impulses from rods and cones to ganglion cells.

Once the rod or cone cells are stimulated, they send their nerve impulses to bipolar neurones. They are called bipolar because of the two extensions protruding from the cell.

Look back at Figure 12.10, notice that cone cells have their own dedicated bipolar cell. This is to ensure that the brain receives information about the correct colour that the cone cell is detecting. It also ensures high-resolution vision.

On the other hand, multiple rod cells are connected to the same bipolar cell. This makes low-light vision a bit **blurry** since only one bipolar cell **relays** the information of three rod cells. In addition to this, the density of rods in the fovea is very low and the **refraction** of the light that rod cells detect is not so well focused as those of the cone cells.

The bipolar cells send their nerve impulses to the ganglion cells.

Understanding: Structures in the middle ear transmit and **amplify** sound.

Model sentence: The ear plays two roles in the sensory system: (1) it converts sound vibrations into nerve impulses for the sense of hearing and (2) it converts motion of the head into nerve impulses for the sense of balance.

In order to transmit nerve impulses to the brain about the sounds around you, the sound vibrations must be transformed into mechanical movement for mechanoreceptors deep inside your ear.

First, sound waves enter the outer ear through the **auditory canal** and cause the **eardrum** (or **tympanic membrane**) to vibrate. See the figure opposite.

Three small bones behind the eardrum work as levers to increase the vibrational movement by a factor of 20. This has the effect of amplifying the sound. The names of the bones, which are found in the middle ear and which are the smallest ones in your body, are the **incus**, **malleus**, and **stapes**.

The stapes transmits the amplified vibrations to the **oval window**, which is not a window at all, but another flexible membrane similar to the eardrum.

Now the amplified vibrations can enter the **cochlea**, which is the part of the ear that contains the mechanoreceptors.

Skill: Labelling a diagram of the structure of the human ear

Below are the parts of the ear referred to in this section. You should be able to label a blank version of this diagram. Why not practise right now?

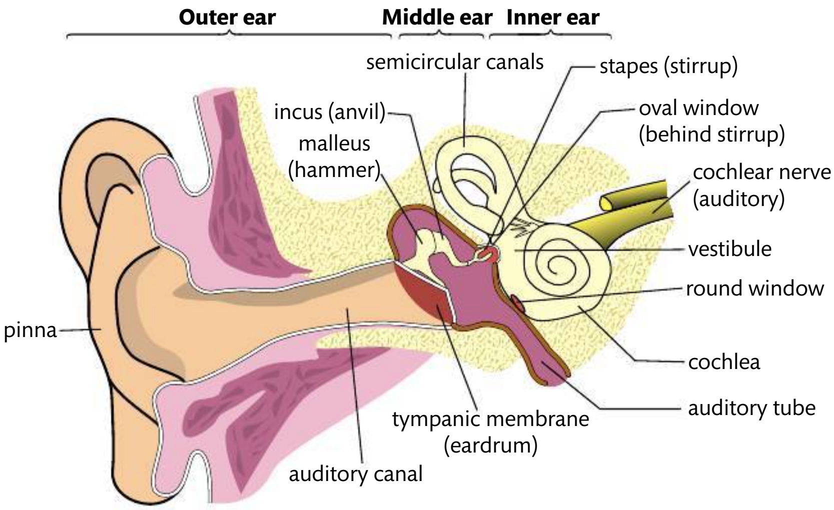


Figure 12.12 *Anatomy of the human ear*

Understanding: Sensory hairs of the cochlea detect sounds of specific wavelengths.

The cochlea, found in the inner ear, is filled with fluid through which vibrations travel.

Small **hair cells** that line the cochlea have hair-like **projections** called stereocilia that are pushed back and forth by the vibrations in the fluid. These hair cells are the mechanoreceptor cells that can convert the movement into nerve impulses.

Different cells are sensitive to different vibrations. **Frequency** refers to how rapid a vibration is and it is measured in **hertz**. One hertz (Hz) is one vibration per second. The human ear can hear sounds of low frequency vibrations (lowest notes on a bass musical instrument, 30 Hz), medium frequency (human voice, 200 Hz), or high frequency (high notes on a flute, 20 000 Hz).

Understanding: Impulses caused by sound perception are transmitted to the brain via the auditory nerve.

The nerve impulses leave the ear and are sent to the brain via the **cochlear nerve** (also called **auditory nerve**). At this point, we are not dealing with sound anymore, only electrical impulses generated by the hair cells.

The brain receives the nerve impulses and processes them to be able to recognize sounds. You hear with your brain, not with your ears.

Subject vocabulary

hair cells cells that detect vibrations in the ear and convert them to nerve impulses

frequency how often an event happens in a fixed time

auditory or **cochlear nerve** the nerve that carries impulses from the ear to the brain

General vocabulary

projections something that protrudes or projects outwards

hertz a unit of the frequency of a vibration defined as one cycle per second

General vocabulary

dissipate become less or weaker

profound complete

Subject vocabulary

round window part of the ear that helps to regulate sound intensity

cochlear implant a device that aids hearing by stimulating the auditory nerves

vestibular system the part of the nervous system that controls balance

semicircular canals part of the ear that detects movement

vestibular nerve the nerve that carries impulses from hair cells in the ear to the brain

Synonyms

oriented .... located/positioned

Back in the cochlea, the vibrations **dissipate** through the **round window**. This structure is also useful if sounds are too loud, because it can lessen the pressure in the fluid if necessary.

Application: Use of cochlear implants in deaf patients

If a person has mild to moderate hearing loss, a hearing aid can be used to improve their perception of sound. These are external devices that have a miniaturized microphone, battery, amplifier, and earphone to increase the volume of sounds.

If a person has severe to **profound** hearing loss, hearing aids will not be sufficient. If the eardrum is not functioning or there is damage to the middle ear, the vibrations cannot get to the cochlea. Fortunately, there is another way of getting nerve impulses to the brain: a **cochlear implant**.

This is an electronic device with two parts: one external and one internal. The internal part is an implant that must be surgically placed inside a person's skull that stimulates the cochlear nerves. The external part contains a microphone, processor, and battery.

The microphone picks up the sound vibrations, the processor converts the vibrations into electrical impulses and the implant transmits the impulses through electrodes to the cochlear nerve cells. These in turn generate their own impulses that are sent to the auditory nerve. The brain receives the signals and the person can hear. There are some inspiring videos online of people hearing for the first time thanks to this technology.

Because it requires delicate surgery and is an expensive solution, it is not available for all people with hearing loss.

Understanding: Hair cells in the semicircular canals detect movement of the head.

Your ears are also in charge of something else that has nothing to do with hearing: sensing balance. The part of the nervous system in charge of balance is called the **vestibular system**.

If you look back at the figure, you will notice in the middle ear three **semicircular canals**. These tubes are **oriented** in different directions so that various movements can be detected: up/down, side to side.

They are filled with liquid and, like the cochlea, they also have hair cells that act as mechanoreceptors. Only this time, instead of detecting vibrations from sound, they detect movements of the head.

When the head moves, the liquid tends to want to stay in one place, the way that sliding a glass of water across a table makes it splash out of the glass. The hair cells have cilia protruding into the liquid. The liquid being pushed against one extreme or the other of the semicircular canals pushes the cilia around the same way that ice cubes in the glass of water would be pushed around when it is moved.

The hair cells generate a nerve impulse which is sent to the **vestibular nerve**. The brain interprets these signals constantly to make sure we do not lose balance.

A.4 Innate and learned behaviour

Main idea

Behavioural patterns can be inherited or learned.

Nature of science: **Looking for patterns, trends, and discrepancies – laboratory experiments and field investigations helped in the understanding of different types of behaviour and learning.**

Model sentence: **Behaviour can be divided into two categories: (1) innate behaviour, which is determined by genetics and is inborn, and (2) learned or acquired behaviour, which must be learned.**

Understanding: Innate behaviour is inherited from parents and so develops independently of the environment.

Some animal behaviour is **innate**. This means that it is encoded in the animal's DNA. It is a mistake to think of DNA as being only for physical attributes. Some behaviour is determined by genetics.

When given a sour-tasting food, babies will instinctively make a face that communicates disgust. They did not learn this from others; it happens without having to **imitate** parents or siblings.

One way of measuring the effects of innate behaviour is to measure the movements of animals in different environments. The idea is that if they move towards something, it means they are attracted to it but if they move away they are repulsed by it. Likewise, they might increase their movement or they might change direction frequently. The types of movement are:

- **Taxis** – a directional response to a stimulus. Positive taxis is when the animal moves towards the stimulus and negative is when it moves away. There are several types of taxes:
  - **phototaxis** – movement towards or away from light
  - **gravitaxis** – movement towards or away from Earth's gravitational pull
  - **rheotaxis** – movement towards or away from water current
  - **thigmotaxis** – movement towards or away from touch
  - **chemotaxis** – movement towards or away from certain molecules.
- **Kinesis** – a non-directional response to a stimulus. The animal moves but not necessarily towards or away from the source of stimulus. Rather than depending on the direction it is coming from, the response of the animal depends on the intensity of the stimulus. Organisms slow down or turn less in favourable environments (so stay longer) and speed up and turn more frequently in less favourable environments to leave that zone more quickly. Stimuli can include things such as concentrations of gases in the surrounding atmosphere, humidity levels, and light intensity (but not direction). Examples of kineses:
  - **orthokinesis** – when an animal changes the speed at which it moves around (fast or slow) depending on the stimulus
  - **klinokinesis** – how often the organism changes direction in response to a stimulus.

Synonyms

discrepancies . differences/ inconsistencies

imitate .... copy

Subject vocabulary

innate genetically determined, controlled by DNA

taxis directional movement in response to a stimulus

phototaxis movement in response to light

gravitaxis movement in response to gravity

rheotaxis movement in response to water current

thigmotaxis movement in response to touch

chemotaxis movement in response to particular molecules

kinesis movement in response to a stimulus

orthokinesis change of speed in response to a stimulus

klinokinesis change of direction in response to a stimulus

Skill: Analysis of data from invertebrate behaviour experiments in terms of the effect on chances of survival and reproduction

One way of gathering data about how animals learn is to give them a task to do, such as putting them in a maze, and see if they improve how well they do the task. If the time it takes the animal to perform the task gets shorter and shorter or if the number of successful trials increases, it suggests that the animal is learning the best way to do the task. Although such experiments are often done with mice, they can also be done with marine invertebrates such as the cuttlefish, *Sepia officianalis*.

A study published in 2003 by a team lead by Miranda Karson showed that cuttlefish could learn how to escape from an unfavourable environment in a tank.

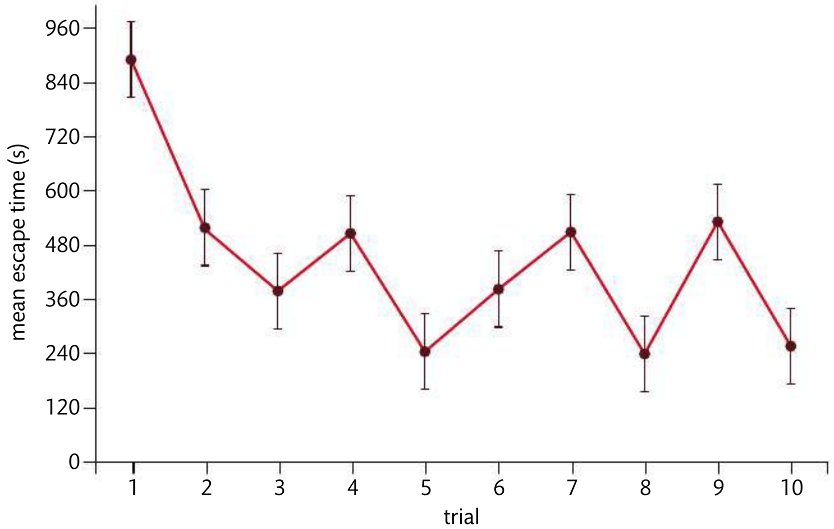
- The researchers built a tank that was separated by a vertical **opaque** wall with two 20 cm holes in it, one 10 cm from the bottom and the other 60 cm from the bottom.
- The side of the tank the cuttlefish were placed in was unfavourable to the cuttlefish because it had no horizontal surface to rest on. Cuttlefish are benthic invertebrates, meaning that they live on the ocean floor.
- The other part of the tank had more favourable conditions such as horizontal surfaces to rest on and artificial sea grass to **mimic** the animal's natural habitat.
- Ten trials were done and exit times were measured in seconds. If the cuttlefish did not escape, a maximum time of 1000 s was recorded. The results can be seen in the graph below.

General vocabulary

opaque difficult to see through

Synonyms

mimic............ copy



Source: adapted from American Psychological Association (APA)

Figure 12.13 *Mean escape times for cuttlefish over 10 trials. The error bars represent standard errors*

- Trial 1 has the highest mean time due to the fact that very few cuttlefish (3 out of 18) managed to escape and the rest were assigned the maximum escape times.
- The overall trend showing a reduction in mean escape times is, in fact, more of a result of increased success in completing the task rather than completing the task faster and faster.
- An animal that can improve performance at a skill such as escaping from an unfavourable environment will increase its chances of survival.

Understanding: Autonomic and involuntary responses are referred to as reflexes.

During a visit to the doctor, a swift tap on the knee with a reflex hammer should generate a kicking response that happens without you thinking about it. This is your **patellar reflex**. It is a surprising feeling because you have the impression that you did not make the decision to kick. This is because your spinal cord made the **kneejerk** decision for you.

In some circumstances, the brain is not needed to make a decision and take action. When there is a sudden loud noise, you are startled and various muscles flex suddenly to make you jump in surprise and your eyes blink. Like with the knee jerk reaction, this is an **involuntary response**. You did not make the conscious decision to tell your muscles to move or your eyes to blink.

Application: Withdrawal reflex of the hand from a painful stimulus

Have you ever touched a hot stove by accident? Pain receptors in your hand detect painful stimuli which, when painful enough, can cause a **withdrawal reflex**. This is when the hand is pulled away from danger without you thinking about it.

Anything that is innate is hereditary. Hereditary traits follow the laws of natural selection, so if we have this reflex today it is because it most likely gave our ancestors a survival advantage.

Reflexes are controlled by the autonomic nervous system, the part of the CNS found in the medulla oblongata and the spinal cord. In other words, the brain has no say.

Subject vocabulary

patellar reflex the automatic jerking of the leg when the knee is tapped

kneejerk automatic kicking reflex that does not require a conscious decision

involuntary response automatic reaction

withdrawal reflex the automatic reaction that causes an animal to quickly move away from a pain stimulus

relay neurone cell that passes impulses from sensory neurones to motor neurones

effector the organ that performs a response when stimulated by a motor neurone

reflex arc the chain of events from stimulus to spinal cord to response, involving a receptor cell, a sensory neurone, a relay neurone, and a motor neurone

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Understanding: Reflex arcs comprise the neurones that mediate reflexes.

Model sentence: When a stimulus goes to the spinal cord and a reflex reaction is generated immediately without going to the brain, it is said to follow the path of a reflex arc.

Here is how the withdrawal reflex works:

- Pain receptors in the hand convert the pressure (or extreme heat) into nerve impulses
- The sensory neurone carries the signal up the arm and into the spinal cord.
- The signal is passed on to a **relay neurone** inside the spinal cord. This is where the 'decision' is made to move the hand away from danger. If the signal is weak, there will be no reflex. If it is strong, the reflex will pull the hand away.
- To move the hand, the relay neurone passes the signal to the motor neurone.
- The motor neurone signals to the **effector** (the muscle) it synapses with to contract and move the hand away from danger. This is the response to the original stimulus.
- The path of the message follows an almost complete loop. This shape – from the hand to the spinal cord back to the arm – is called the **reflex arc**.
- Note that the arc does not go through the brain. Other neurones send impulses to the brain where they can be recognized as pain. The sensation of pain comes from these impulses that reach the brain. This happens after the reflex response so you feel the pain after your hand has been pulled away.

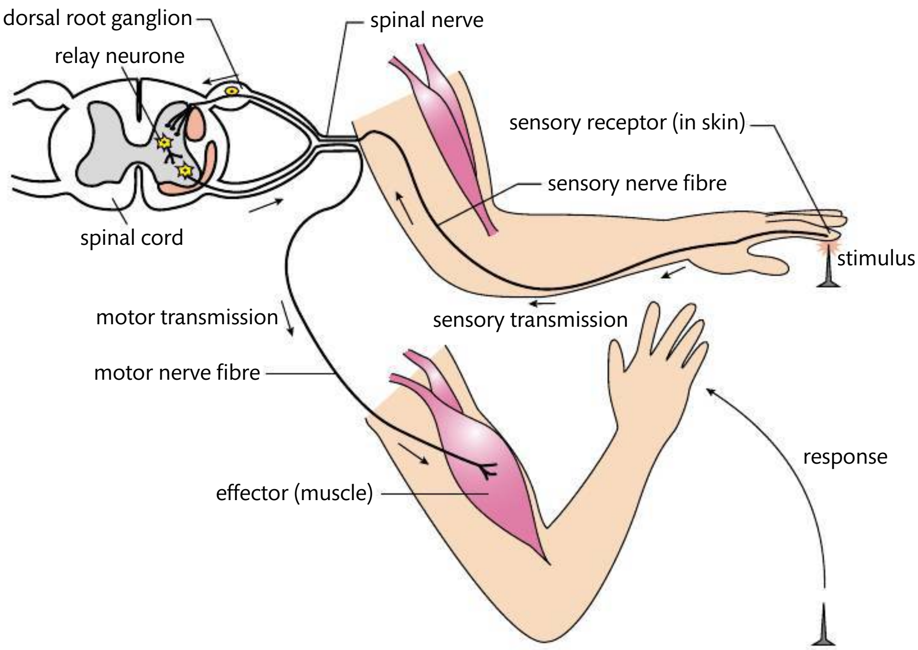


Figure 12.14 *A reflex arc showing the path of a spinal reflex*

Skill: Drawing and labelling a diagram of a reflex arc for a pain withdrawal reflex

You are expected to be able to draw the diagram above. After studying it, close your book, take out a blank sheet of paper and try drawing and labelling it. You should have the following five labels: receptor cell, sensory neurone, relay neurone, motor neurone, and effector.

Understanding: Reflex conditioning involves forming new associations.

Model sentence: Reflex conditioning, also known as classical conditioning, happens when an animal is trained to associate a once neutral stimulus with an unconditioned stimulus to generate a conditioned reflex that did not exist before the training.

Generally speaking, a reflex only happens with a specific stimulus. The withdrawal reflex should only happen in case of sudden pain. The sharp object or the hot surface is considered the **unconditioned stimulus**. No training or learning is necessary to cause the reflex.

Through special training, however, it is sometimes possible to produce a reflex response using a different stimulus. Before training, this stimulus, a **neutral stimulus**, does not produce a response.

During training, exposure to the neutral stimulus at the same time as the unconditioned stimulus can cause the nervous system to associate the neutral stimulus with the reflex. This pairing of the two stimuli during training is called **reflex conditioning** or **classical conditioning**.

After training is complete, the neutral stimulus will now produce the reflex response even without the unconditioned stimulus. Since it produces a response, it is referred to as the **conditioned stimulus**. The new response is the result of a **conditioned reflex** instead of an innate reflex.

Subject vocabulary

unconditioned stimulus a specific sensation or action which produces an automatic response

neutral stimulus an action that does not produce a response

reflex conditioning training an animal to respond to a neutral stimulus

classical conditioning association of a neutral stimulus with a reflex

conditioned stimulus a neutral action or sensation which, through training, produces a response

conditioned reflex a trained response

Such experimentation with animals and later with humans is one of the founding principles of the field of **behaviourism**. Conditioning was well illustrated in Pavlov's experiments with dogs.

Application: Pavlov's experiments into reflex conditioning in dogs

In 1903, Russian scientist Ivan Pavlov published his work experimenting with dogs.

First, he observed that hungry dogs had a natural reaction to the stimuli of the sight and smell of food: they salivated and the volume of saliva was proportional to the response. This was an easy response to measure because he could collect the saliva in tubes. The unconditioned stimulus was the food and the innate reflex was the production of saliva.

Next, he tested some neutral stimuli. The sound of a **metronome** and the ringing of a bell did not produce a response. No saliva was produced when the dogs heard these sounds.

Now the training began: Pavlov paired the sound of a metronome with the presentation of food. The food would be hidden from the dog until the sound was produced, at which point the food was presented to the dog. Repeating this systematically over time allowed the dogs to associate the sound with food. He repeated the method using other neutral stimuli, including the sound of a bell ringing.

Final result: when the conditioned stimulus (the sound) was produced, the conditioned response occurred (the dogs salivated), even when the unconditioned stimulus (the food) was completely absent. The volume of saliva that was produced with the conditioned stimulus was the same as that from the unconditioned stimulus.

Understanding: Learned behaviour develops as a result of experience.

The opposite of innate behaviour is **learned behaviour**. If an organism makes the same mistakes over and over, its chances for survival will be reduced.

Learned behaviour is not passed on genetically through DNA. It must be acquired through experience with the organism's surrounding environment. Chimpanzees like to eat termites but this kind of food is hard to get because termites live inside the tunnels of their mound. Chimpanzees can make tools for fishing out termites. They find a twig that is just the right length and diameter and, by passing the twig through their clenched teeth, the fibres separate to make a brush. When put into a termite tunnel, the twig is attacked by soldier termites which bite it. The chimp pulls the twig out and eats the nutritious termites. This tool-making behaviour is learned and takes time to perfect.

The table below summarizes the differences between innate and learned behaviour.

Innate behaviour	Learned behaviour
develops independently of the environmental context	is dependent on the environmental context of the animal for development
controlled by genes	not controlled by genes
inherited from parents	not inherited from parents
developed by natural selection	develops as a result of experience
increases the chance of survival and reproduction	may or may not increase chance of survival and reproduction

Subject vocabulary

behaviourism a branch of psychology based on individual behaviour

learned behaviour behaviour that is acquired rather than innate

General vocabulary

metronome an instrument which makes a repeated sound similar to a clock

Be aware of the fact that the ability to learn is genetic. Whether or not an organism is capable of learning things (such as language acquisition) is a genetic trait. However the behaviours that are learned are not genetic. The ability to speak Spanish, for example, is learned, not innate.

Application: The role of inheritance and learning in the development of birdsong

Certain behaviours are a mix of innate plus learned behaviours. For example, some types of birds have an innate birdsong that is the same for all the members of their species. However, they can add to this song and **improvise** new melodies by inventing songs to add or by imitation.

Since birdsong is a key stage in the courtship process, it is important for the male birds to have a song that will attract a female. He will start out with a crude **template song**, which is the basic melody of his species. Birds hatched in captivity with no exposure to the sound of their species' birdsong still sing this template. This demonstrates that it is innate.

When exposed to other birds singing its species' song, a bird can listen and perfect the template. This is called the **memorization phase** and it lasts about 100 days.

Once he is sexually mature, he can add to the song during the **motor phase**. Here, he can improvise and add his personal touch.

General vocabulary

improvise do something without preparation

Subject vocabulary

template song a sample song that is copied

memorization phase the time during which a male bird listens to and perfects the template song of his species

motor phase the time during which a male bird can improve upon the template song and add his own improvisations

ethology study of behaviour

imprinting learning at a particular age that is independent of the consequences of behaviour

operant conditioning chamber or **Skinner box** apparatus used to train an animal to perform particular actions

Understanding: Imprinting is learning occurring at a particular life stage and is independent of the consequences of behaviour.

Model sentence: Imprinting is an example of an innate behaviour that requires an external stimulus to generate a behaviour.

The study of behaviour is called **ethology**. Ethologist Konrad Lorenz did some interesting experiments with graylag geese. He noticed that the baby geese (goslings) would follow their mother out of the nest and go wherever she went. He decided to have some goslings hatch in an incubator far from the mother and see what happened when they saw him. He found that they followed him around instead.

This is an illustration of **imprinting**. This is when one animal looks upon another animal as a parent figure or a figure of trust. It is a form of learning that must happen at a particular developmental stage. For graylag goslings, Lorenz discovered that it was 13 to 16 hours after hatching.

Understanding: Operant conditioning is a form of learning that consists of trial and error experiences.

Model sentence: A Skinner box, developed by behaviourist B.F. Skinner, can be used for operant conditioning, the process by which positive and/or negative reinforcement is used to shape behaviour.

Another behaviourist was B.F. Skinner, who did experiments in the 1930s with pigeons and rats. One of his most influential contributions to science was the invention of the **Skinner Box** or **operant conditioning chamber**. This is a small box into which an animal is placed. The box has one or more buttons or levers that the animal can activate. The box also contains a way of rewarding the animal, such as a system for delivering a treat.

Skinner observed that as the animal explores its cage, it eventually activates the lever. The act of unintentionally pushing the lever is an example of **operant behaviour**. The animal is simply acting by trial and error, not responding to a stimulus yet. If this action delivers a food treat, the animal quickly learns how to feed itself. Variations of this kind of experiment might include lights flashing in a certain sequence before the animal can reward itself, or the sound of a buzzer.

To make things more complex, multiple levers can be introduced. Some might produce a negative stimulus such as an electric shock. Again, the animal learns very quickly which lever does what. This is what Skinner called **shaping** of behaviour. For this to work, the process of **reinforcement** is key. Positively reinforced behaviour is favoured and negatively reinforced behaviour is avoided.

This was a breakthrough in behavioural science. Instead of merely talking about stimulus–response, Skinner saw a third important factor: stimulus–response–reinforcement. Skinner had pioneered the idea of **operant conditioning**. This comprised of multiple steps:

- an animal exploring its environment by trial and error
- its behaviour being shaped by positive and negative reinforcement
- a new behaviour is learned.

Understanding: Learning is the acquisition of skill or knowledge.

Learning is complex. Learning involves using your experiences in life to acquire knowledge or be able to perform skills.

Learning is measured by performance. If a student does well on a test, it suggests that she learned the material and had acquired the skills necessary to obtain a good grade.

In order to be able to perform, the knowledge and skills have to enter your memory, preferably your long-term memory. Then they have to stay there until you need them, and finally, they need to be available for recall when you want to use them.

Understanding: Memory is the process of encoding, storing, and accessing information.

Encoding is the process of placing ideas and skills into your memory. There are many ways of accomplishing this – think of the ways people study for a test:

- Sometimes you can use **visual encoding** to memorize images and keep a mental picture of something.
- Some students prefer to hear sounds such as a melody or the sound of a phrase. Making up a song about the subject or hearing definitions read out loud can help with **acoustic encoding**.
- Sometimes it helps to connect a new idea with an old idea that is already present in your memory. Analogies such as saying that enzymes and substrates are like a lock and key help this kind of memorization called **elaborative encoding**.
- **Sensation encoding** is memorizing the way things feel, smell, or taste. Performing a heart dissection might help a student learn about the chambers and blood vessels – being able to touch them and feel the different thicknesses of tissues in the heart helps encode the memory of the experience.

Subject vocabulary

operant behaviour in behavioural psychology, a type of behaviour encouraged by the consequences it produces

shaping in behavioural studies, the modification of behaviour of a test subject animal by positive or negative reinforcement

reinforcement a technique used in behavioural psychology that strengthens or encourages a desired behaviour

operant conditioning in behavioural psychology, a technique for generating desired behaviour by giving rewards; in contrast with classical conditioning

encoding processing of information to be remembered

visual encoding a way of remembering things by associating them with a picture or image

acoustic encoding using sound as an aid to remembering something

elaborative encoding adding new knowledge to memories that are already stored

sensation encoding remembering the smell, taste or feel of something

Subject vocabulary

storage the way memories are kept

short-term memory type of memory that can remember small amounts of information for short periods of time

long-term memory type of memory that can remember large amounts of information for long periods of time

accessing reaching or retrieving

recognition identify

recall remember

excitatory neurotransmitters chemicals that cause the postsynaptic neurone to produce an action potential

inhibitory neurotransmitters chemicals that prevent the postsynaptic neurone from producing an action potential

dopamine a neurotransmitter often associated with reward pathways in the brain

Storage of memories works by maintaining synapses.

- There are two types of memory: short term and long term.
  - Short-term memory is well adapted for small amounts of information for a few minutes, hours, or days.
  - Long-term memory is well adapted for larger amounts of information for months, years, or even a lifetime.
- The brain is good at remembering things but it is even better at forgetting. Your brain is constantly getting rid of information that is unimportant. How? Recall from earlier in this chapter that when a connection is weak and not used, it is not maintained.

Accessing memory: ideas you have put in your memory are useless if they are not accessible. There are two ways of accessing memory: recognition and recall.

- Recognition is the ability to connect an object or event with something you have already experienced and know. Examples include hearing a familiar melody, seeing a familiar face, or identifying the smell of apple pie in the oven.
- Recall is bringing to mind a fact, object, or event that is not currently present. Recall questions on exams are the ones that ask for definitions or the name of a famous scientist.

A.5 Neuropharmacology

Main idea

Communications between neurones can be altered through the manipulation of the release and reception of chemical messengers.

Nature of science: **Assessing risks associated with scientific research – patient advocates will often press for the speeding up of drug approval processes, encouraging more tolerance of risk.**

Understanding: Some neurotransmitters excite nerve impulses in postsynaptic neurones and others inhibit them.

In this section, keep in mind that the presynaptic neurone is the one that is attempting to pass on its message and the postsynaptic neurone is the one that needs to be ‘convinced’ to pass on the message.

There are two types of neurotransmitter: excitatory and inhibitory.

- Excitatory neurotransmitters are chemicals present in the synaptic cleft that encourage the postsynaptic neurone to produce an action potential.
- Inhibitory neurotransmitters are chemicals present in the synaptic cleft that attempt to block the postsynaptic neurone from producing an action potential.

The nature of the neurotransmitter does not determine if it is excitatory or inhibitory. Rather, it is the receptor it binds to and the resulting action which determine this. For example, the neurotransmitter dopamine can have an excitatory effect or an inhibitory effect depending on which receptors it binds to in different situations.

Understanding: Nerve impulses are initiated or inhibited in postsynaptic neurones as a result of summation of all excitatory and inhibitory neurotransmitters received from presynaptic neurones.

Model sentence: Summation is the process by which postsynaptic neurones receive a combination of excitatory and inhibitory neurotransmitters – if the excitatory neurotransmitters succeed in raising the positive charge above a certain threshold without being cancelled out by the inhibitory neurotransmitters, the cell will produce an action potential.

Just because neurotransmitters arrive at the postsynaptic neurone does not mean that the message will be relayed. A sort of 'voting' process determines whether or not the postsynaptic neurone will pass on the signal. If there is not a strong enough signal, it does not produce an action potential and the message stops being relayed from neurone to neurone.

The 'voting' process works by adding up the 'for' votes (excitatory neurotransmitters) and subtracting any 'against' votes (inhibitory neurotransmitters). The term used for this is **summation**. If the signals from excitatory neurotransmitters are stronger than the signals from all the inhibitory neurotransmitters, the postsynaptic nerve is depolarized and generates an action potential to keep transmitting the message. Otherwise, no signal is transmitted; the postsynaptic neurone does not produce an action potential.

When an action potential is produced:

- The receptors are like gates that allow ions to enter or leave when the neurotransmitter binds to them.
- Excitatory neurotransmitters increase the **permeability** of the postsynaptic membrane to positive ions. This is done by opening the **gated ion channels** that are **embedded** in the membrane.
- Positive sodium ions (Na^+) that are in the synaptic cleft **diffuse** into the postsynaptic neurone through the open channels.
- **Depolarization** occurs, meaning that the total net charge inside the neurone becomes more positive compared to the outside of the cell.
- As more and more excitatory neurotransmitter depolarize the cell, the positive charge increases, a bit like charging up a battery. In order for an action potential to be produced, a certain **threshold** must be reached. Once the charge arrives at the threshold, the action potential is generated and sent down the axon. The excitatory neurones have succeeded in getting the postsynaptic neurone to send the message. In the voting analogy, the 'for' vote has won.

In the case where an action potential is blocked, here is what happens:

- When the receptors receive inhibitory neurotransmitters, the inside of the cell becomes more negative than the outside. Negatively charged chloride ions (Cl^-) are pulled into the cell and positively charged potassium ions (K^+) are pushed out of the cell.
- This process, called **hyperpolarization**, has the effect of cancelling out some or all of the positive charges that the excitatory neurotransmitters are building up.
- The result is that it becomes very difficult or impossible to reach the threshold. The message is blocked.

Subject vocabulary

summation a combination of excitatory and inhibitory neurotransmitters that together either cancel each other out or trigger the further transmission of an action potential

gated ion channels transmembrane proteins that can be activated to let ions in or out of a cell

diffuse movement of a substance from an area of high concentration to an area of low concentration

depolarization sodium ions diffusing from outside to inside the neurone membrane

threshold some significant level which brings about some sort of change or shift in response

hyperpolarization process where the inside of the neurone becomes more negative

General vocabulary

permeability ability to allow one or more substances to pass through

embedded positioned firmly and deeply

A single postsynaptic neurone receives both excitatory and inhibitory neurotransmitters from thousands of presynaptic neurones. Billions of connections are happening every millisecond of every day of your life. The figure below summarizes the process of synaptic transmission.

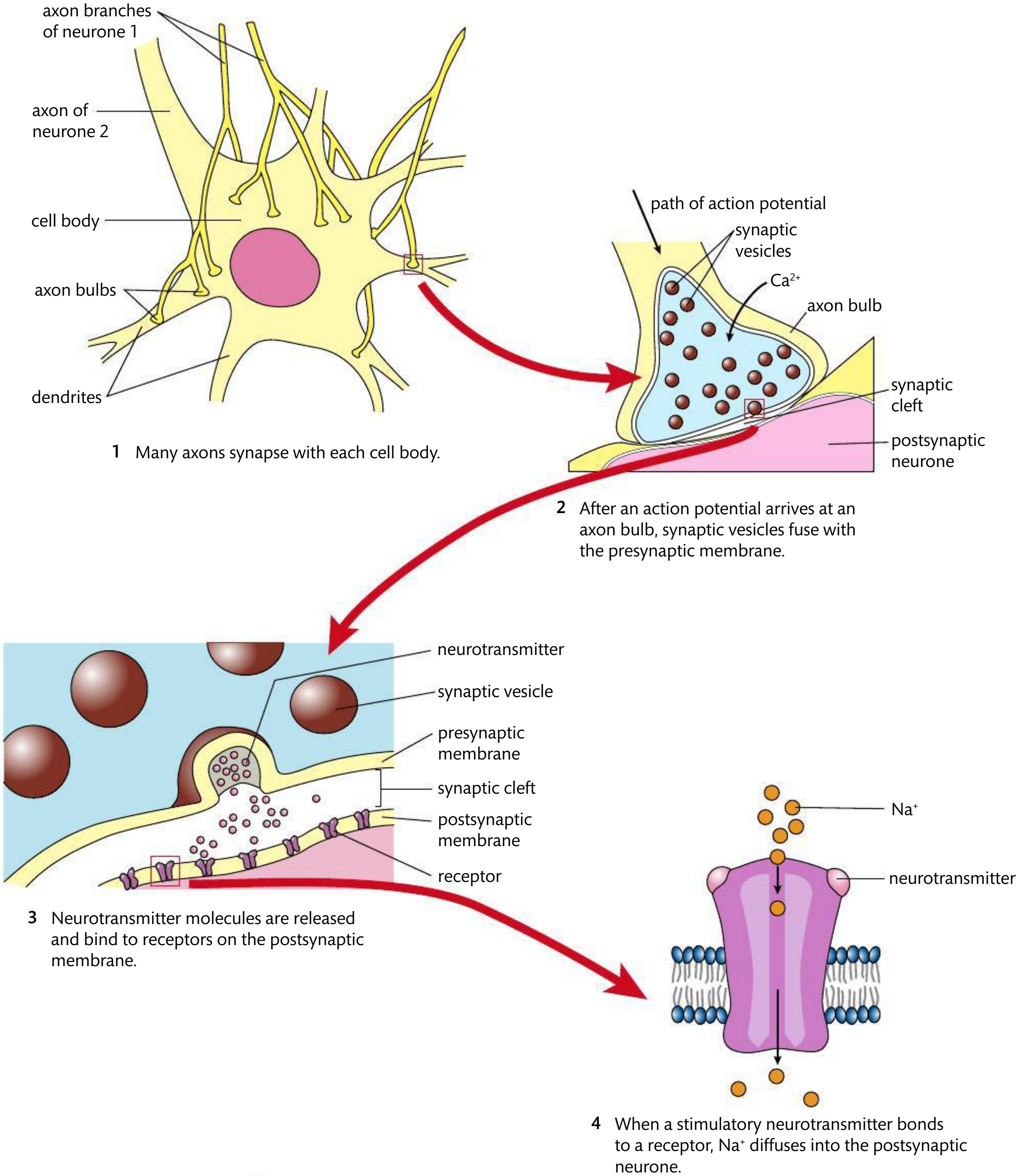


Figure 12.15 *Synaptic transmission*

Understanding: Many different slow-acting neurotransmitters modulate fast synaptic transmission in the brain.

Some neurotransmitters have a faster effect than others:

- **Fast-acting neurotransmitters** have an effect on the target cell within 1 millisecond of binding to a receptor.
- **Slow-acting neurotransmitter** have an effect on the target cell in hundreds of milliseconds or can take up to a minute.

As seen in the figure to the right, fast-acting neurotransmitters can open the gated ion channel directly without the help of other molecules. This is why they can act so quickly.

Slow-acting neurotransmitters, on the other hand, cannot open gated ion channels themselves. Instead, they bind to a receptor which in turn sends a second chemical messenger to open the gate. This slows down the process considerably. Examples of slow acting neurotransmitters include:

- dopamine
- serotonin
- acetylcholine.

Slow-acting neurotransmitters can have a **modulating effect** on the transmission of signals. This means they can change the rate at which the transmissions happen, a bit like traffic lights regulating the flow of cars. One way they do this is to regulate the efficiency of neurotransmitter release from the presynaptic neurone (the sender). Slow-acting neurotransmitters can also regulate the efficiency of the postsynaptic neurone (the receiver). Because of this ability, these types of neurotransmitters are called **neuromodulators**.

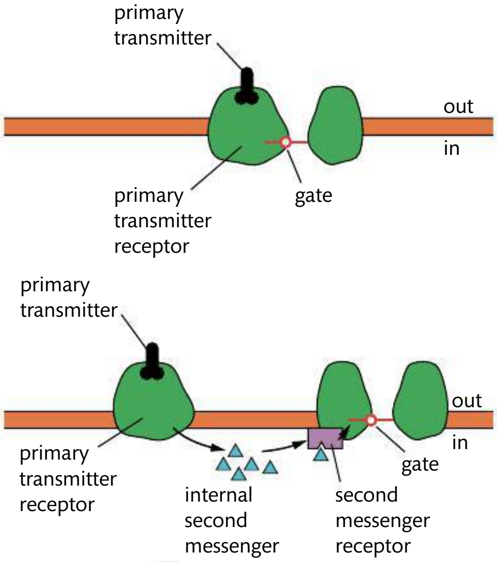


Figure 12.16 *Fast and slow transmission at the postsynaptic membrane. Adapted from Hille 2001*

Subject vocabulary

fast-acting neurotransmitters neurotransmitters that produce an effect within 1 ms of binding to a receptor

slow-acting neurotransmitters neurotransmitters that produce a delayed effect up to 1 minute after binding to a receptor

modulating effect controlling the speed of a process or the degree to which it occurs

neuromodulators a type of neurotransmitter that regulates postsynaptic neurones

Synonyms

phenomena.... events/ happenings

Understanding: Memory and learning involve changes in neurones caused by slow-acting neurotransmitters.

Memory and learning at the level of neurones are **phenomena** that are not fully understood. One thing that appears to be clear is that when a new idea or skill is learned and encoded in memory, plastic changes occur in synaptic connections in the brain. These can be biophysical changes (involving the physical structure of the connections, or 'wiring') and/or biochemical changes (involving neurotransmitters and other molecules such as messenger molecules).

Since slow-acting neurotransmitters such as serotonin act as neuromodulators, they are good candidates for helping in the process of increasing neural transmission rates. In experiments, dopamine has been found to play a role in memory in the prefrontal cortex. Recall the 'use it or lose it' rule for synaptic connections. If a connection is used frequently (and slow-acting neurotransmitters can modulate this), then it is maintained. Hence, a connection that is encouraged by neurotransmitters to continue passing will be reinforced. The idea or skill that this connection is helping to encode is retained thanks to the reinforced connection.

Short-term memory tends to be more of a biochemical change in synaptic connections, whereas long-term memory also involves biophysical changes. In order for long-term memory to work, new axons are grown which makes necessary the switching on of the transcription of certain genes inside the neurone's nucleus.

These genes control the production of proteins such as the ones needed for axon growth, synaptic vesicle formation, and neurotransmitter receptor formation.

Understanding: Psychoactive drugs affect the brain by either increasing or decreasing postsynaptic transmission.

Model sentence: Psychoactive drugs can affect the process of summation, disturbing the natural system of determining whether or not a message will be sent by the postsynaptic neurone.

Certain drugs can have an effect on synaptic transmission:

- **Stimulants** are **psychoactive drugs** that increase alertness and wakefulness. They are sometimes referred to as 'uppers' for their ability to improve peoples' moods, increase heart rate, or sharpen mental focus. They can do this by:
  - promoting activity at excitatory receptors
  - inhibiting activity at inhibitory receptors.
- **Depressants** are psychoactive drugs that reduce stimulation of brain activity and calm down a person's mood. They are sometimes referred to as 'downers' for their ability to calm people by numbing the senses and slowing transmission of signals. They can do this by:
  - promoting activity at inhibitory receptors
  - inhibiting activity at excitatory receptors.

Because of these properties, psychoactive drugs can significantly affect the brain and produce changes in emotion, perception, or personality. Examples below include ones prescribed by doctors as medicine as well as drugs that are not, but are either illegal or controlled by the law.

Stimulants		Sedatives / Depressants	
Pharmaceutical	**Non-pharmaceutical**	**Pharmaceutical**	**Non-pharmaceutical**
analgesics/ painkillers (such as paracetamol)	nicotine (notably in cigarettes)	benzodiazepines (as sedatives or anti-anxiety treatments)	alcohol
adderall (for attention deficit hyperactivity disorder (ADHD) management)	caffeine	antihistamines (against allergies)	cannabis
	ecstasy	morphine	heroin
	khat, a plant from East Africa		

Application: Endorphins can act as painkillers

Your brain produces natural analgesics (painkillers) called **endorphins**. These are small neuropeptides that bind to opiate receptors in the brain. **Opiates** occur naturally and can be found in plants such as the opium poppy plant, *Papaver somniferum*. It is from this plant that drugs such as opium, morphine, and heroin are made.

Endorphins can be released when the body does intense exercise such as running long distances. Athletes can get pain relief as well as a feeling of **euphoria** known as

Subject vocabulary

stimulants drugs that increase neural activity

psychoactive drugs drugs that affect postsynaptic transmission altering perception or mood

depressants drugs that reduce neural activity in the brain and produce a calming effect

endorphins chemicals produced by the body that act as painkillers

opiates naturally occurring painkillers found in the opium poppy plant

General vocabulary

euphoria feeling extremely happy/excited for a short time 'runner's high'. These neuropeptides can also be released in high-stress situations or in case of serious injury.

Endorphins are released by the pituitary gland and they work by blocking transmission of impulses relating to pain. When they bind to the opiate receptors, they prevent the pain-related neurotransmitters from delivering their message.

Understanding: Anaesthetics act by interfering with neural transmission between areas of sensory perception and the CNS.

Before surgery, doctors remove a patient's ability to feel pain by giving the patient **anaesthetics**. These molecules prevent any signals being produced by the sensory neurones from arriving at the central nervous system (CNS). They produce a numbing effect where the part of the body affected cannot feel heat, touch, or pain. Examples of drugs used as an anaesthetic are **lidocaine** or nitrous oxide (also known as laughing gas).

One way of blocking pain is to introduce molecules that will target the receptors on the surface of neurones in the CNS that interpret pain signals. The anaesthetic molecules can either block the receptors on the neurones or modify them so that the neurotransmitters that are supposed to bind there cannot do so.

Since the receptors are in charge of opening ion gated channels, the blocked channels stay shut and therefore the depolarization cannot happen. The action potential is not produced and the message of pain is blocked. Even though the sensory neurones are doing their job to relay pain signals to the brain, the person does not feel the pain because the message is blocked.

Another way anaesthetics can work is to occupy the ion channels so that Na^+ ions cannot get through.

Application: The effect of anaesthetics on awareness

There are two categories of anaesthetics:

- **General anaesthetics** – when the entire body is anaesthetized and the person is unconscious. This is for major surgery.
- **Local anaesthetics** – when only a part of the body is anaesthetized and the person remains awake. This is for minor surgery such as dental work or it can also be used during childbirth since the mother needs to be awake to help with the birthing process.

One characteristic of anaesthetic treatments is that they are reversible. When the drugs wear off, the person can feel again. After surgery, the patient will start to feel pain, at which point an analgesic (painkiller) is given.

Subject vocabulary

anaesthetic a drug which prevents the signals from sensory neurones reaching the central nervous system, producing a numbing effect

lidocaine a drug used as an anaesthetic

general anaesthetic medication given to a patient before surgery to provoke unconsciousness and take away reflexes and pain

local anaesthetics drugs that cause numbness of a small part of the body

Understanding: Stimulant drugs mimic the stimulation provided by the sympathetic nervous system.

Stimulant drugs can mimic neurotransmitters found operating in the sympathetic nervous system. Nicotine, for example, mimics the neurotransmitter called acetylcholine. Acetylcholine can act as an excitatory neurotransmitter when dealing with muscles in charge of running or fighting. After acetylcholine delivers its message to the receptors, it is broken down by acetylcholinesterase. This enzyme cannot break down nicotine molecules that bind to the same receptors. This excites the postsynaptic neurone and it begins to release the neurotransmitter dopamine.

Subject vocabulary

dopamine a neurotransmitter often associated with reward pathways in the brain

reward pathways chemical reactions in the brain that give a feeling of satisfaction, encouraging the animal to repeat the action

cocaine a drug that acts as a stimulant

amphetamines a class of drugs that act as stimulants

diazapam a sedative

benzodiazepine a type of sedative

γ-aminobutyric acid or **GABA** a neurotransmitter that reduces the activity of neurones

opioids medications such as morphine that mimic the painkilling effects of opiates such as opium

μ-opiate receptors specific receptors that bind to opioids

General vocabulary

insomnia inability to sleep

amplify make louder/stronger

Dopamine plays an important role in the **reward pathways** of the brain. When a person is very hungry and then eats a meal, dopamine plays a role in producing the sensation of satisfaction. It is the brain's way of saying, 'Yes, that feels good. Keep going.' Reward pathways can be thought of as the opposite of pain.

Stimulant drugs can mimic this feeling of pleasure and satisfaction. But there are costs and disadvantages to the brain and body, which we will see later when we look at addiction.

Application: Effects on the nervous system of two stimulants and two sedatives

Stimulants:

- Illegal drugs such as **cocaine** stimulate alertness and can produce temporary feelings of euphoria. The feeling produced by cocaine comes from the fact that dopamine uptake receptors are blocked and dopamine neurotransmitters cannot be removed from the synaptic cleft as they usually are. Under normal conditions, the dopamine uptake receptors clean out the synaptic cleft by pulling back into the presynaptic neurone any dopamine neurotransmitters that have finished delivering their message. Because cocaine has blocked their passage, they stay and are able to repeatedly bind with the postsynaptic receptors to keep sending a reward pathway message: 'Yes, that feels good. Keep going.' Drug users fool their brains into thinking it feels good.
- Another class of drug, amphetamines, has a similar stimulating effect but for a different reason. **Amphetamines** mimic neurotransmitters such as dopamine or noradrenaline, a neurotransmitter that can increase heart rate or release more glucose to the muscles. Amphetamines enter the presynaptic neurone and are incorporated into vesicles just like the natural neurotransmitters. When they are released, they send the same message as the natural neurotransmitters. What is different is that unlike the natural neurotransmitters, which are attacked by enzymes and broken down after delivering their message, amphetamines are not broken down. The enzyme's active site does not fit. As a result, the amphetamines can continue to deliver their message and mimic the reward pathway. The person feels awake, alert, and euphoric until the drug eventually wears off.

Sedatives:

- **Diazapam**, a type of **benzodiazepine**, which can be found under the trade name Valium, is a prescription medication used to treat **insomnia** and anxiety. To understand how it works, you need to know about the neurotransmitter **GABA**. This neurotransmitter's full name is **γ-aminobutyric acid**. It plays an important role in reducing neurone activity by being able to control chloride ion (Cl^-) or potassium ion (K^+) channels. When a drug such as Valium is taken, the effect is that it **amplifies** the signal of the GABA neurotransmitter. More Cl^- ions are pumped into the postsynaptic neurone. The hyperpolarization effect will reduce the chances of the threshold being reached and the cell will be less likely to pass on the message. A patient suffering from anxiety will feel relaxed and relieved because the neural activity is reduced. They may also feel sleepy.
- **Opioids** such as opium, morphine, or heroin act upon the nervous system by binding to specific receptors called **μ-opiate receptors**. These receptors are only found in neurones in certain parts of the body and brain. Opioids contain opiate molecules, which bind to the opiate receptors. Inhibitory neurotransmitters that would normally stop the release of dopamine are blocked when the opiate receptors are activated. Dopamine can now be released in large quantities. The user feels the pain go away; they are sedated and can get a feeling of artificially induced euphoria. Undesirable effects of the use of opioids can include nausea, constipation, constricted pupils, or death.

Skill: Evaluation of data showing the impact of MDMA (ecstasy) on serotonin and dopamine metabolism in the brain

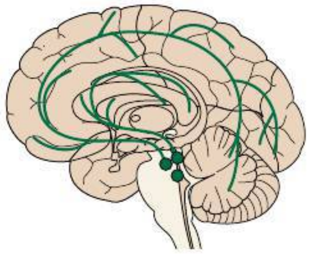
Serotonin is an important neurotransmitter related to many things including appetite, reproduction, well-being, and happiness. Imbalances can lead to symptoms such as digestive problems and depression.

The recreational drug **MDMA**, also known as **ecstasy**, has an effect on NTs such as serotonin and dopamine.

MDMA causes the release of extra serotonin by presynaptic neurones. The postsynaptic serotonin neurone's receptors are activated. A **serotonin transporter** vesicle, or **SERT** receptor, in the presynaptic neurone will remove excess serotonin from the synaptic cleft once the message has been delivered. The continued exposure to MDMA will cause more and more serotonin to be released. The user gets an artificial high as the brain is fooled by an artificially induced feeling of well-being. Eventually, all the cell's serotonin will be used up.

When the serotonin is used up, the SERT receptors are empty. Dopamine now enters the SERT receptors in place of serotonin. This is not supposed to happen. The nerve cells destroy the dopamine. The problem is that the products of the breakdown of dopamine are toxic to the nerve cell. This can damage or kill nerve cells, causing irreversible damage to the brain.

You should be able to analyse data about MDMA levels in laboratory tests. The data below are from an experiment with rats that were given ecstasy. A molecule labelled MIL was injected to label active serotonin receptors in the brains of the animals.



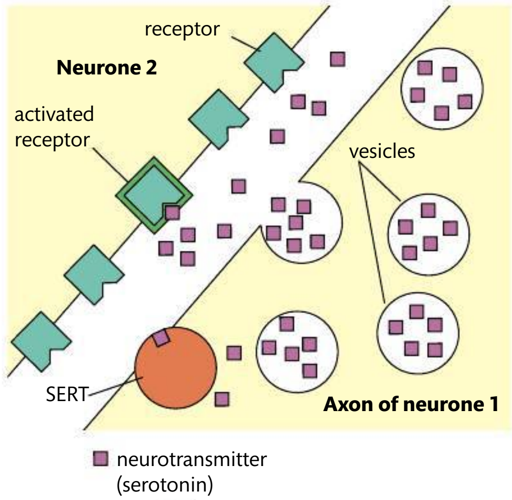


Figure 12.17 *Serotonin neurones in the brain and in the synapse*

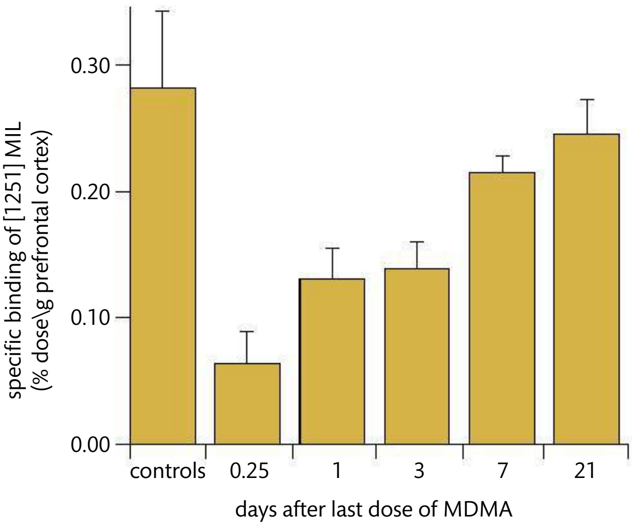


Figure 12.18 *The effect of MDMA on the number of available serotonin receptors in the brains of a group of rats. MIL is a molecule used to label active serotonin receptors.*

Subject vocabulary

serotonin a slow-acting neurotransmitter associated with happiness, appetite, and reproduction

ecstasy or **MDMA** a psychoactive excitatory drug that is illegal in most countries

serotonin transporter (SERT) a vesicle that removes excess serotonin from the synaptic cleft once the message has been delivered

Understanding: Addiction can be affected by genetic predisposition, social environment, and dopamine secretion.

Model sentence: Addiction to a drug happens when a person is so dependent on a substance that they cannot stop taking it; stopping consumption would lead to physical and/or mental suffering.

Addiction is a difficult concept to define because of how complex it is. For psychoactive drugs, it refers to a state of such chemical dependency that if the user stopped consuming the drug, there would be symptoms of withdrawal. **Withdrawal** is a negative reaction to stopping a drug and can include anxiety, depression, or cravings. In extreme cases, there can be seizures or severe shaking. In the worst cases, withdrawal can be fatal.

Addiction is a serious problem in itself but the long-term consumption of drugs can lead to serious health problems:

- Cigarettes are linked to respiratory diseases including lung cancer.
- Alcohol is associated with car accidents and liver disease.
- Overconsumption of **psychotropic** drugs can lead to **psychosis**.
- Purchasing illegal drugs contributes to killings in drug trafficking circles.
- Consuming intravenous drugs can sometimes lead to needle sharing which is an effective way to spread HIV, the virus responsible for AIDS.

The causes of addiction are multiple and complex. It is difficult to say with certainty why any one user becomes addicted to the drug they are using. Here are some causes to possibly consider:

- Genetic predisposition. Some people are born with brains that are more sensitive to psychoactive drugs than others. There is a component of alcoholism that is genetic, for example. This does not mean, however, that someone born with a genetic predisposition to be addicted to alcohol will become an alcoholic. They can still choose whether or not to consume alcohol.
- Social factors. If a child grows up in a family or community surrounded by consumers of a particular drug, they have a higher chance of consuming that drug than a child never exposed to it. Peer pressure can play a role. In places where the cultural norm is not to consume alcohol, such as the state of Gujarat in India, alcoholism is not a social phenomenon the way it is in so many other parts of the world.
- Dopamine secretion. When the brain gets exposed to a drug over long periods of time, it develops a **tolerance** to the drug. This means that the drug no longer works at the current dose. In order to get the same sensation, more of the drug is needed. This neuroadaptive change is called **desensitization**, another term for tolerance to a drug. Increasing the dose to get the same sensation can lead to addiction.

Subject vocabulary

addiction extreme desire/need for something

withdrawal the negative effects often felt when regular drug use is stopped suddenly

psychotropic drugs that affect perception

psychosis a mental disorder involving a loss of connection to reality

tolerance being used to a drug and so needing more of that drug to produce an effect

desensitization development of tolerance to a drug that results in the drug having a reduced effect

A.6 Ethology

Main idea

Natural selection favours specific types of behaviour.

Nature of science: **Testing a hypothesis – experiments to test hypotheses on the migratory behaviour of blackcaps have been carried out.**

Understanding: Ethology is the study of animal behaviour in natural conditions.

Ethology is the study of animal behaviour in natural conditions. Ethologists go out into the field and observe the way animals behave in their habitat. Sometimes experiments are set up in labs to recreate a natural habitat if possible, but ideally the observations are in the field.

Jane Goodall went to the forests of Tanzania in the 1960s to observe chimpanzees and subsequently became the world's leading authority on chimpanzee behaviour.

Understanding: Natural selection can change the frequency of observed animal behaviour.

Scientists studying animal behaviour have observed that some populations of animals have changed the frequency of their behaviour. As is true for physical genetic traits, if the frequency of a behaviour changes in a population, there is evidence of evolution by natural selection. As we will see in this section, some birds may migrate earlier, some salmon may mature quicker, and some birds may develop more extreme courtship patterns.

Understanding: Behaviour that increases the chances of survival and reproduction will become more **prevalent** in a population.

Model sentence: Because of natural selection, if an innate behaviour helps a population survive better or produce more offspring, its frequency in the population will increase.

Whether or not it is innate or learned, behaviour that improves survival chances will be seen more frequently in a population.

For example, male emperor penguins (*Aptenodytes forsteri*) that need to keep warm in Antarctica do so during the cold winter by using a behaviour called huddling. They stand in large groups with their bodies pressed up against one another. Part of this behaviour includes a rotation system so that individuals take turns being on the outside of the formation.

Imagine if one penguin has the innate behaviour of standing on his own, away from the group. He will freeze to death. When he dies, the chances of passing on his free-standing genes to the next generation drop to zero. This is a behaviour that is not selected for – there is a selective pressure against it.

Synonyms

prevalent....... common

Understanding: Learned behaviour can spread through a population or be lost from it more rapidly than innate behaviour.

Because innate behaviour is passed on from generation to generation by genes, it does not change quickly. Learned behaviour, on the other hand, can be modified more rapidly.

Learned behaviour is acquired by observing and repeating what another individual does. This can happen between members of the same generation as well as from offspring to parents, or it can even miss a generation. The same is not true for innate behaviour, which must go from parents to offspring.

Unlike innate behaviour, which is built into the organism's DNA, learned behaviour can be lost in a population if it is no longer being observed and repeated.

Application: Feeding on cream from milk bottles in blue tits as an example of the development and loss of learned behaviour

The Eurasian blue tit (*Cyanistes caeruleus*) is a bird species common to Europe and Western Asia. For much of the 20th century, especially before the home refrigerator was introduced, it was common in Britain to have milk delivered to the door early in the morning. The glass bottles had foil caps on them to keep germs out and the foil was painted different colours depending on the type of milk in the bottle. At the time, milk was not homogenized the way it is today so the cream would float to the top.

Blue tits somehow figured out that the foil was thin enough to pierce with their beaks and be peeled away. Then they could drink the nutritious cream off the top. Birds see colours in a similar way to humans and they quickly recognized that some milk containers had higher fat content than others. They learned to peel open only the tops with the richest, thickest layer of cream and ignore the low-fat milk.

Other birds in the population watched the well-nourished birds and learned the behaviour. This bird's social communication allowed the learned technique to be spread all over the country.

Because bottles are not delivered to homes anymore, the learning in this population has been lost. If bottles were delivered to doorsteps again, the populations alive today would have to learn the technique all over again. It did not get passed down genetically, so it is gone from the population.

Application: Migratory behaviour in blackcaps as an example of the genetic basis of behaviour and its change by natural selection

Model sentence: Sometimes learned human behaviour can have an impact on innate animal behaviour – the case of migration patterns in the European blackcap is one example.

The European blackcap (*Sylvia atricapilla*) is a bird that usually migrates from Germany to Spain in the winter to escape the cold temperatures and lack of available food.

There are many bird watchers and bird lovers in the UK and it is a common practice to leave out bird feeders in the winter for birds that are having trouble finding food. Since the 1950s, it has been observed that some blackcaps do not go down to Spain in the winter but go to the UK instead, where they find enough food in feeders to survive the winter.

This offshoot population of birds returns to Germany 10 days earlier than the ones that go to Spain. This gives them an advantage of finding the best nesting spots and there is less competition for food. In addition, the journey is not as difficult.

Experiments have been done where eggs from each population were removed from nests and hatched away from the parents. The chicks that hatched could not observe other birds' migration patterns. When they grew up and were ready to migrate, the birds from the original population went southwest towards Spain and the ones from the UK-migrating population went northwest. This is evidence that it is innate rather than learned behaviour.

Application: Blood sharing in vampire bats as an example of the development of altruistic behaviour by natural selection

Vampire bats, notably the species *Desmodus rotundus*, demonstrate an uncommon behaviour among animals – they regularly share their food with other individuals close to them. This is an example of **reciprocal altruism**, the idea that 'if you help me now, I will help you later'. This is in contrast to **altruism**, in general, which is a way of helping another individual with a cost to oneself and without expectation of repayment.

As their name indicates, vampire bats are **sanguivorous** – they feed on blood from live animals including birds, pigs, goats, and cows.

To make flight efficient, they maintain low body masses by not storing large amounts of fat. As a result, they must eat a blood meal every 2 days to stay alive. They only hunt at night and each night about 30% of the bats come back to the group without success. The bats who have found blood will **regurgitate** some to the bats who ask for it. The following night, the situation might be the other way around.

It would be tempting to think that this is a good example of **kin selection** (helping individuals who are genetically related), but in fact, many groups of bats who help each other are not related.

Application: Foraging behaviour in shore crabs as an example of increasing chances of survival by optimal prey choice

Successful shore crabs (*Carcinus maenas*) have been naturally selected to invest their time and energy looking (**foraging**) for a type of food that will give them the most benefit. They eat mussels by breaking the shells with their claws. Although a bigger mussel will have more food inside it, the energy needed to crack the shell and the risk of damage to the crab's claws represents a high cost. So it is better to eat two medium-sized mussels than to try to break open and eat one large mussel.

Saving the claws has a reproductive advantage: when males fight to mate with the females, those with fully functioning claws will have an advantage. Crabs who have damaged their claws trying to break an oversized mussel shell will probably be less successful in competing for a female. Notice the role that natural selection has played in determining the preference of mussel size.

Application: Breeding strategies in coho salmon populations as an example of behaviour affecting chances of survival and reproduction

Model sentence: Innate behaviours are the result of natural selection so if an animal has a behaviour that seems atypical such as a fish swimming long distance against the current of a river, there must be a selective pressure that gives that animal a better chance of survival.

Coho salmon (*Oncorhynchus kisutch*) spend their adult lives in the Pacific Ocean but they are **spawned** in freshwater rivers and return to mate in the same river.

Subject vocabulary

reciprocal altruism performing a good act in the expectation that it will be repaid

altruism behaviour that benefits the receiver without reward to the giver

sanguivorous blood eating

kin selection helping closely related individuals in preference to unrelated individuals

foraging searching for food

General vocabulary

regurgitate bring back into the mouth food already swallowed

spawned large amounts of eggs produced at the same time

Subject vocabulary

redds a nest

courtship display a demonstration to attract a mate

Females lay their eggs in shallow, fast running zones of freshwater rivers. They build multiple nests, called **redds**, and lay thousands of eggs in each one.

Male coho salmon will fertilize the eggs by releasing sperm cells over the eggs. They then keep watch over the eggs and attack potential predators if they get too close. Most return after 3 years but some males, called jacks, return to the river at the age of 2 years.

Males go through some physical changes when they are in reproductive mode: their colour changes, they develop a hooked nose and jaw and their backs develop an arch. When they have completed their role, they do not return to the ocean; instead, they die.

Can you see how the behaviour of these fish increases the chances of survival of this species?

- First of all, spawning (laying eggs) in the river instead of the ocean reduces the chances that potential predators will eat the eggs. Shallow water will prevent larger fish from accessing the eggs. Fast-moving water will dissuade hungry predators that cannot fight the current.
- Fast-moving water is often well-oxygenated water and the fragile eggs will need a good supply of dissolved oxygen.
- Constructing redds instead of simply laying eggs directly on the riverbed keeps the eggs and sperm from being pulled away by the current.
- Laying thousands of eggs instead of just a few greatly enhances the chances of some surviving.
- Spreading the eggs out over several nests also increases the chances that some will not be found by predators.
- The fact that the males remain present to protect the nests also greatly enhances survival rates. The development of the hooked nose and jaw allows a male to have defensive behaviours such as ramming into predators, hitting them hard, or grabbing their tails.
- Even though they usually only represent a small percentage of the male population, the jacks show a behaviour (returning early) that is a sustainable one and therefore must have been selected for by natural selection.
- The change in colour can have multiple possible messages including signalling to females that they are ready to fertilize eggs or signalling to rivals or predators that they are ready to defend themselves and their offspring. The arching of the back could have similar meaning and could also help in making sure the fish do not wander into water that is so shallow it will not be favourable for spawning.
- The death of the male at the end of the spawning season suggests that this species, like many salmon, have adapted in such a way that they invest all their energy in ensuring that the next generation is off to a good start.

Application: Courtship in birds of paradise as an example of mate selection.

Why would a male blue bird of paradise (*Paradisaea rudolphi*) hang upside down? In addition to seeming to be useless, it would put the bird at a disadvantage in many ways including making it open to predators.

Why would another bird of paradise dance around in circles or sway its head back and forth in rhythm like a fan at a rock concert? Or hop backwards up a branch?

The answer to all of these is that each one is a **courtship display**. The male is trying to impress a female with such rituals. Male birds that do the most elaborate displays have a better chance of impressing a female. Displaying feathers by stretching them out demonstrates that the bird has undamaged wings and would make a good partner. Birds are often the victims of attacks by parasites and showing off his wings is a way of demonstrating that he is not infested. Swaying the head back and forth without getting dizzy and falling off the branch suggests strength, good health, and reliability. If the female is impressed (or hypnotized) she will be more willing to mate. Notice the steps of this process in which natural selection is acting and the importance of the role of sexual selection.

Application: Synchronized oestrus in female lions in a pride as an example of innate behaviour that increases the chances of survival and reproduction of offspring

Lions (*Panthera leo*) are social animals that live in groups called prides. The females raise the young together: all females can give milk to all the cubs and all females watch over all the cubs. The females within a pride are related – they are either sisters, aunts, or cousins.

When male lions take over a pride, they tend to kill all the cubs they find.

After the death of her cubs, a lioness will move into **oestrus** within 2 weeks. This means that her body will prepare her to have new cubs. She produces a scent that signals to the male lion when she is ready to mate.

Since all the females had their cubs killed at the same time, they are all synchronized in oestrus. This means that all the cubs in the next generation will be the same age.

This has some advantages for survival including less competition or bullying between the cubs and a shorter time during which the cubs are too young to be left on their own.

If they have increased chances of survival, they will have a much better chance of passing on the genes of that pride. Once again, natural selection has made it possible to favour adaptations that are the most successful.

Subject vocabulary

oestrus period of time when a female is fertile

B.1 Microbiology: organisms in industry

Main idea

Microorganisms have been modified for use in industrial processes.

Synonyms

diverse .... different/varied

Subject vocabulary

metabolic pathway a chemical pathway in which a series of enzymes produces intermediate compounds on the way to producing a final product needed by the organism

microorganism any relatively small organism which requires a microscope to observe

autotrophs organisms capable of producing their own food

chemoautotrophs organisms which produce their own food by using energy from the oxidation from an inorganic source and carbon dioxide

photoautotrophs organisms which produce their own food using energy from the Sun, water, and carbon dioxide

nutrient chemical material a cell or organism needs

producer a photosynthetic organism that starts a food chain

heterotrophs organisms not capable of producing their own food, requiring preformed organic compounds from other sources

saprotrophs organisms which use detritus as their energy and nutrient source

detritus dead organic matter

binary fission simplified form of cell division in bacteria

General vocabulary

optimal the best or most suitable

Understanding: Microorganisms are metabolically **diverse**.

Model sentence: Different species of microorganisms show great variation in their metabolic pathways.

The term **microorganism** refers to any small organism which can only be seen with a microscope. Microorganisms may include bacteria, fungi, protozoans, and algae. These small organisms are very diverse in structure, ecological role, and in the metabolic pathways they possess. Microorganisms may occupy various roles in the ecosystems they are a part of. These possible roles include:

- **Autotrophs** – these microorganisms act as **chemoautotrophs** or as **photoautotrophs** and are able to produce the **nutrients** they need for survival from inorganic sources. Photoautotrophs use the energy from the Sun, water, and carbon dioxide to produce the organic nutrients they need. Chemoautotrophs use the energy from the oxidation of an inorganic source and carbon dioxide to produce the organic nutrients they need. Autotrophs are often referred to as **producers**.
- **Heterotrophs** – these microorganisms require preformed organic compounds as their nutrient source. A group of heterotrophic microorganisms known as **saprotrophs** uses **detritus** as their energy and nutrient source. Detritus is dead organic matter. The actions of saprotrophs free the nutrients in dead organic matter for use within the ecosystem. Another group of heterotrophic microorganisms called yeast is able to carry out anaerobic respiration of simple sugars to derive their energy and nutrients.

The diversity of microorganism metabolism provides many products that are very useful to us. These products include food, biofuels, industrial solvents, food additives, pharmaceuticals such as antibiotics, and valuable biochemicals such as enzymes and proteins.

Understanding: Microorganisms are used in industry because they are small and have a fast growth rate.

Model sentence: Small sizes and rapid growth rates are two characteristics of microorganisms which make them valuable for industrial use.

The small size of microorganisms is a great advantage for using them in industrial roles. They take up little space. Due to their size, it is easier to control their surroundings. They can also be cultured or grown in huge numbers allowing for more production of desired products. They have very fast growth rates as well. Many bacteria reproduce by **binary fission** every 30 minutes if their environment is **optimal**.

Understanding: **Pathway engineering** optimizes genetic and regulatory processes within microorganisms.

Model sentence: Genetic engineering has been carried out to make the metabolic pathways of many microorganisms more beneficial to us.

Pathway or metabolic engineering is the practice of optimizing genetic and regulatory processes within microorganisms for our use. **Genetic engineering**, also known as **genetic modification**, is used to bring about this optimizing process. To achieve this optimization two things are necessary:

- a thorough knowledge of existing metabolic pathways in the microorganism of interest
- changes made at key points in the microorganism **genome** to bring about more efficient pathways to produce the desired product or products.

Genetic engineering may also be carried out to allow the use of more common **substrates** in a particular metabolic pathway. Sometimes, the pathways are altered so a group of products may be produced by a pathway rather than just one product.

Understanding: Pathway engineering is used industrially to produce **metabolites** of interest.

Model sentence: Industry uses genetic modification of metabolic pathways in microorganisms to produce desired products.

A bacterium called *Escherichia coli* has a natural metabolic pathway which allows it to produce a 2-carbon alcohol. Longer chain alcohols are important to us because they yield more energy especially when they are present in gasolines and jet fuels. Scientists introduced new genes into *E. coli* to modify the naturally existing metabolic pathway which produced a 2-carbon alcohol. The result of the genetic modification is that this bacterium can now produce industrial quantities of a 5-carbon alcohol. This 5-carbon alcohol is very important in increasing the efficiency of our gasolines and jet fuels and is the metabolite of interest in this case.

Understanding: Fermenters allow large-scale production of metabolites by microorganisms.

Model sentence: Scientists and industry have produced very efficient fermenters which allow microorganisms to produce large quantities of desired metabolites.

Structures referred to as fermenters have been developed by scientists and industry for large-scale production of a desired metabolite by specific microorganisms.

Subject vocabulary

pathway engineering modifying the chain of reactions in a metabolic process (usually within a microorganism) to produce a substance or perform an action that is useful to us

genetic engineering process of artificially altering the normal genome of an organism

genetic modification genetic engineering, process of artificially altering the normal genome of an organism

genome the complete DNA sequence of an organism

substrate substance which begins a chemical reaction or process

metabolite product of metabolism

fermenters structures in which fermentation occurs

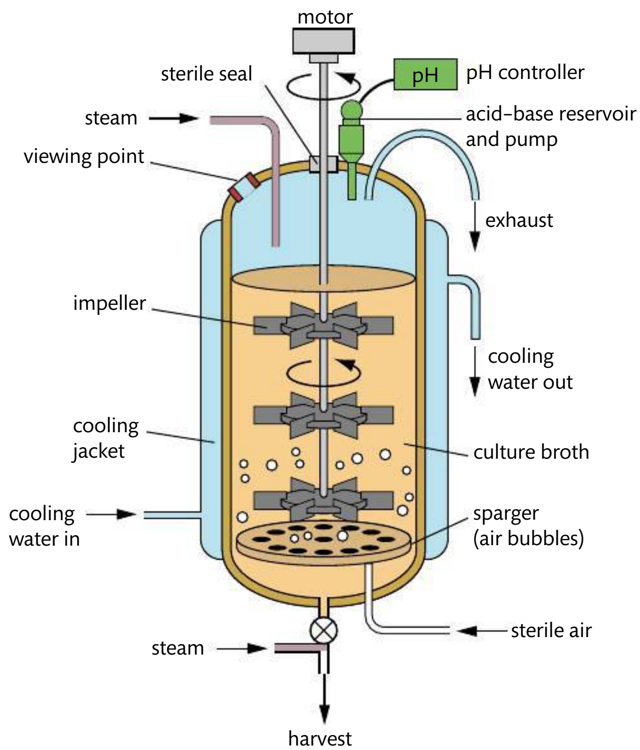


Figure 13.1 *An industrial fermenter*

Subject vocabulary

contamination process of being made unfit for further growth or development

toxic level concentration at which serious harm and death may occur to involved organisms

archaeans members of the prokaryotic domain Archaea

biogas gas produced by the anaerobic breakdown of organic matter which may be used for cooking, heating, or running engines

methane a biogas composed of carbon and hydrogen

methanogens bacteria group capable of producing methane

General vocabulary

broth nutrient mixture

agitation mixing

Fermenters, like the one above, allow effective control of the conditions surrounding and within the culture **broth**. The culture broth contains the microorganism which provides the desired metabolite. The maintenance of optimum growth conditions for the microorganism allows the recovery of large quantities of the product. One major feature of fermenters involves a design that prevents **contamination**. Contamination may occur as a result of the introduction to the fermenter of other microorganisms. The chance of this happening is decreased with the use of a stainless steel growth chamber which has closely monitored input and exit points. Contamination may also occur with the build-up of waste products. Many fermenters are designed with exit points. The exit points allow waste products to be removed so that their levels never reach a **toxic level**.

Most fermenters include some sort of device which allows mechanical agitation. This **agitation** helps maintain proper conditions throughout the culture.

Application: Biogas is produced by bacteria and archaeans from organic matter in fermenters

Fermenters containing cultures of bacteria and **archaeans** are being used to produce **biogas**. Biogas is the gas produced from the anaerobic breakdown of organic matter which may be used for cooking, heating, and running engines. Scientists apply the normal metabolic activities of bacteria and archaeans to bring about the production of methane from organic matter. **Methane** is the desired metabolite. The sequence of steps in the production of biogas in fermenters is:

- the splitting of long-chain organic compounds by bacteria to produce a liquid product
- the production of short-chain acetate, hydrogen, and carbon dioxide by bacteria
- the production of methane and carbon dioxide by archaeans or bacteria known as **methanogens**.

Skill: Production of biogas in a small-scale fermenter

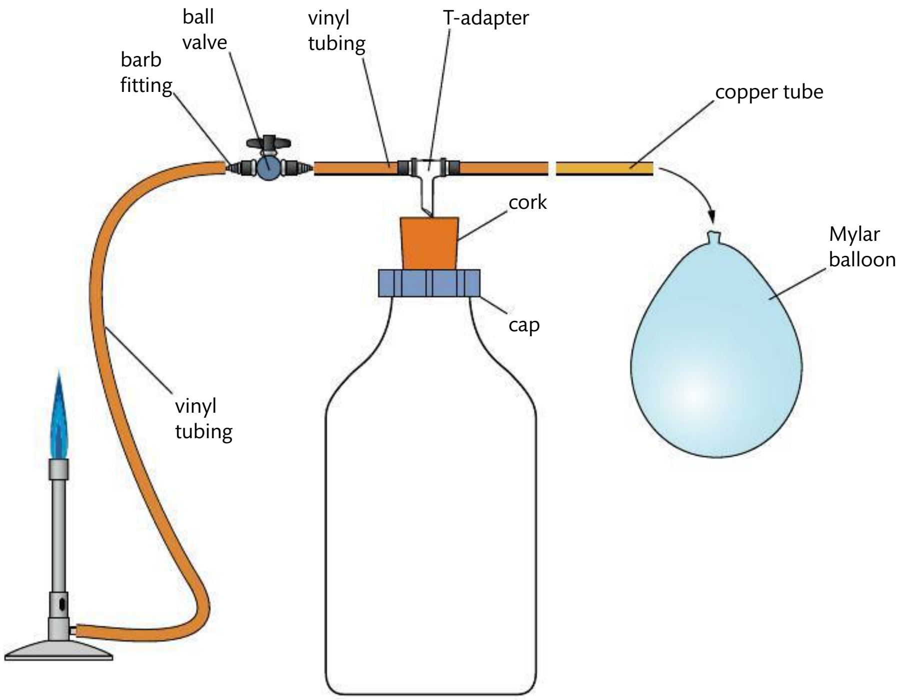


Figure 13.2 *Small-scale lab fermenter*

Understanding: Fermentation is carried out by batch or continuous culture.

Model sentence: Industry uses batch culture and continuous culture fermentation techniques.

Batch culture techniques in fermentation utilize a one-time introduction of a microorganism into the fermenter. The fermenter has all the nutrients necessary for the successful culturing of the microorganism. The microorganism is then allowed to reproduce to its maximum density level possible in the fermenter. The desired metabolite is removed from the fermenter once the carrying capacity for the microorganism in the culture broth has been reached.

Continuous culture techniques in fermentation utilize a continuous addition of nutrients and required substrates to the fermenter. This allows the desired metabolite to be continuously produced and recovered from the nutrient broth. This process can be maintained over a long period of time.

Hints for success: Batch culture techniques involve fermentation product extraction only when the concentration of the product is high. Continuous culture techniques allow a continuous extraction of the fermentation product over an extended period of time.

Subject vocabulary

batch culture technique way of fermenting microorganisms which involves a one-time introduction of the microorganism

carrying capacity an environment's ability to support an organism's population based on resource availability and other factors

continuous culture technique way of fermenting microorganisms which involves continuous addition of nutrients and required substrates

General vocabulary

utilize make use of

Application: Deep-tank batch fermentation in the mass production of penicillin

Science and industry have applied the principles of batch culture techniques to mass produce penicillin. Modifications of the usual batch culture techniques were necessary to produce large amounts of penicillin from a bacterium of the genus *Penicillium*. Some of the modifications include:

- Deep tank fermenters are used to allow increased yields compared to the usual shallow tanks.
- Bacteria of the genus *Penicillium* grow best when oxygen levels are relatively high. Oxygen is bubbled into the deep tanks and a stirring device is used to provide optimum conditions throughout the culture broth for penicillin production.
- *Penicillium* is most efficient at producing penicillin when glucose levels are low. This knowledge led to a reduction of glucose in the nutrients which are placed in the fermenter to begin the culture.
- pH and temperature are maintained at the optimum levels for *Penicillium* reproduction.

Penicillin is a **secondary metabolite** in this batch culture technique. Secondary metabolites are only produced in an organism if certain conditions occur. Large quantities of penicillin are only produced when the bacterium is stressed. Scientists have applied the natural ways the *Penicillium* is stressed to obtain the maximum amounts of penicillin possible.

Subject vocabulary

secondary metabolite products of metabolism produced in organisms only under specific conditions

homeostatic system environment in which all conditions are steadily maintained

Application: Production of citric acid in a continuous fermenter by *Aspergillus niger* and its use as a preservative and flavouring

Citric acid is a common food additive for flavour enhancing and preservation used by industry. Citric acid may be successfully produced by continuous culture techniques and the microorganism *Aspergillus niger*. Conditions under which this bacterium grows optimally have been applied in the continuous culture technique. pH, temperature, and nutrient levels kept at ideal levels allow large amounts of citric acid to be obtained over extended periods of time. There is a continuous input of nutrients and environmental conditions are continuously monitored to maintain the *Aspergillus* at its ideal growth conditions. The continued removal of the citric acid occurs during this culturing process. This culture occurs over an extended period because a **homeostatic system** is maintained.

Understanding: Microorganisms in fermenters become limited by their own waste products.

Model sentence: The build-up of microorganism waste products in fermenters is a limiting factor in microorganism growth and survival.

Common waste products of microorganisms which must be controlled in fermenters include:

- Heat – this is a by-product of metabolism and it may increase the temperature of the medium within the fermenter.
- Carbon dioxide – this a common product of metabolism and, in higher amounts, may alter the optimum pH within the fermenter.
- Various gases may be released in large enough quantities so that pressure within the fermenter may be raised to a harmful level.
- Alcohol may be one of the products of microorganism metabolism in the fermenter. Alcohol becomes toxic to the microorganism when it reaches certain concentrations.

- Oxygen levels may be affected by the metabolic actions of the microorganism.
- Secondary metabolites may reach toxic levels. Secondary metabolites are metabolites produced by a microorganism that are not used for energy.

These waste products must all be considered and controlled in the culturing of microorganisms in fermenters.

Understanding: Probes are used to monitor conditions within fermenters.

Model sentence: Conditions within a fermenter are monitored through the use of probes.

Many conditions within a fermenter must be monitored when continuous culture techniques are being used. Probes within the fermenter allow constant monitoring of these conditions so changes may be made to obtain maximum desired products. These probes are designed and located to prevent contamination of the culture broth. Usually, these probes are connected to computers to allow easier monitoring by technicians.

Subject vocabulary

probe a device used in a laboratory for data logging a specific measurement, e.g. temperature

Understanding: Conditions are maintained at optimal levels for the growth of the microorganisms being cultured.

Model sentence: Optimal conditions must be maintained to bring about the desired growth of microorganisms in industrial fermenters.

The maintenance of optimal conditions for a microorganism in a fermenter is especially important when using continuous culture techniques. Conditions to monitor and maintain at optimal levels in continuous cultures include:

- temperature
- pH
- oxygen and carbon dioxide levels
- pressure
- water concentrations of the culture broth
- foam or bubble amounts of the culture broth
- correct nutrient levels for the microorganism
- waste product concentration
- microorganism density.

Batch culture techniques do not require all these conditions to be monitored and maintained. This is because the desired product will only be extracted when the carrying capacity for the microorganism in the fermenter has been reached. Once the maximum number of microorganisms possible is achieved, they are removed. If more microorganisms are then necessary, a complete new setup would be produced and the process repeated. Batch culture techniques involve limited periods of time.

Skill: Experiments showing zone of inhibition of bacterial growth by bactericides in sterile bacterial cultures

Bacterial cultures showing **zones of inhibition** using **bactericides** are easily produced in the classroom. Suggested materials for this skill development include:

- a safe, non-**pathogenic** strain of bacteria
- petri dishes
- proper nutrient **agar** for the bacterium being used
- a potential bactericide, such as a market disinfectant
- small, disc-shaped sections of a sterile absorbent filter paper dipped in **disinfectant**
- bacterial **incubator**.

Place the paper discs soaked with the bactericide being used on the agar to which the safe bacterium has been introduced. Incubate for sufficient time to allow visual bacterial growth. Do not remove the tops of the Petri dishes in your final observations. Zones of inhibition are areas of no bacterial growth where the disc is placed and a varying distance outward from the disc. The larger the zone of inhibition, the more effective the bactericide.

Skill: Gram staining of Gram-positive and Gram-negative bacteria

Gram staining should be done in the classroom to understand this important technique in bacteria identification. Bacteria with cell walls which accept the Gram stain are said to be Gram-positive and appear blue or violet in colour. Bacteria with cell walls which do not accept the Gram stain are said to be Gram-negative and will appear pink in colour. The Gram-staining process includes crystal violet, Gram's iodine, 95% alcohol, safranin stain, and water.

Subject vocabulary

zone of inhibition area of no bacterial growth in an area to which a bactericide has been introduced

bactericide chemical which kills bacteria

agar gelatin-like substance used to support growth of a bacterium or specific cell

Gram staining type of staining done with bacteria to determine their general grouping in classification

biotechnology science which uses knowledge to artificially alter organisms so they may be more useful

proteome the unique collection of proteins within a cell, tissue type, organ, or organism

transgenic having one or more genes from a different plant/animal

General vocabulary

pathogenic something that causes disease

disinfectant a chemical that destroys bacteria

incubator a container that maintains a specific temperature

B.2 Biotechnology in agriculture

Main idea

Biotechnology in agriculture is being used to modify crops to increase crop yield and even the products harvested from crops.

Understanding: **Transgenic** organisms produce proteins that were not previously part of their species' proteome.

Model sentence: A genetically modified organism will produce proteins it did not produce before the modification.

A **proteome** is the set of proteins an organism can produce due to its genome. The genome of an organism is its complete DNA sequence. A genetically modified organism (GMO) is one in which a new gene or group of genes has been added to its genome. These genetically modified organisms are called transgenic organisms. The result of the changed genome could be the production of a protein or proteins that were not being produced before the modification occurred. Another result of the changed genome is that a protein or proteins which may have been produced naturally are no longer produced.

Understanding: Genetic modification can be used to overcome environmental resistance to increase crop yields.

Model sentence: Limiting factors in the environment for higher crop yields may be overcome by genetically modifying existing organisms.

Environmental resistance refers to limiting factors in the environment which limit an organism from reaching its growth and production potential. Environmental factors which may limit crop yields include both **biotic** and **abiotic** factors. Genetic modification is being used to overcome these limiting factors in many crops.

Possible abiotic limiting factors of the environment include **drought**, **frost**, high salinity soils, and low-nitrogen-containing soils. Rice has been genetically modified to produce a variety which is able to produce a higher yield and to survive extended dry spells. A gene known as *Arabidopsis HARDY* has been added to rice to produce a variety which has an increased photosynthesis rate and decreased water loss by transpiration. Another gene known as *DRO1* has recently been added to this transgenic rice which increases the root depth of the plant, making it more drought tolerant.

Possible biotic limiting factors of the environment include insects, viruses, and weeds. An example of overcoming a biotic environmental limiting factor is the introduction of a gene which brings about **glyphosate** resistance in soybean crops.

Application: Use of tumour-inducing (Ti) plasmid of *Agrobacterium tumefaciens* to introduce glyphosate resistance into soybean crops.

Scientists have applied genetic modification to produce a variety of soybeans which is resistant to a chemical used to control weed growth called glyphosate. Weeds create environmental resistance by taking water and nutrients away from desired crops. These weeds must be controlled. A bacterium normally pathogenic to plants called *Agrobacterium tumefaciens* contains a **plasmid** known as a Ti plasmid (tumour-inducing plasmid). This Ti plasmid can be genetically modified to carry a gene which brings about glyphosate resistance. *A. tumefaciens* with this modified plasmid will 'infect' soybean cells. The result is the growth and development of soybean plants with glyphosate resistance. Fields of these genetically modified soybean plants are then sprayed with glyphosate allowing control of weeds without damage to the soybean plants.

Skill: Evaluation of data on the environmental impact of glyphosate-tolerant soybeans

You should develop your ability to evaluate data to determine the environmental impact of adding glyphosate-tolerant genes to soybeans. In your evaluation, note the **gene flow** of the glyphosate-tolerant gene from the soybean plants to the wild plants (weeds) in the surrounding area. A high gene flow from the soybean plants to the weeds would indicate a risk involved with this example of genetic modification. On the other hand, data showing low gene flow between the soybean plants and weeds would indicate high benefits and low risks to this genetic modification.

Subject vocabulary

environmental resistance limiting factors in the environment which prevent an organism from reaching its full growth and production potential

biotic pertains to living

abiotic pertains to non-living

glyphosate chemical used to control weeds

plasmid small ring of DNA separate from the bacterial chromosome often used in genetic modification

gene flow movement of a gene from one population to another involving transfer by gametes

General vocabulary

drought shortage of water due to dry weather

frost very cold weather that causes water to freeze

Understanding: Genetically modified crop plants can be used to produce novel products.

Subject vocabulary

phenotype visible result of an organism's genotype

transgenic plants plants of one species which contain genes from plants of different species

pharmaceuticals medicines

hepatitis B antigen protein which is produced in organisms with hepatitis B

antibodies protective proteins produced in an organism in response to exposure to disease-causing antigens

amylopectin type of starch produced by plants that has adhesive and paper uses

amylose type of starch that is the most common storage form of carbohydrates in plants

bioinformatics branch of biology which uses computers in an effort to understand biological processes

General vocabulary

adhesive the ability to stick to/attach to another substance

Model sentence: New proteins or phenotypes may be produced in plants when they are genetically modified.

Genetic modification has led to the development of transgenic plants capable of producing very unique products. Some of these novel or unique products include vitamins, pharmaceuticals, enzymes, and even vaccines.

Application: Genetic modification of tobacco mosaic virus to allow bulk production of hepatitis B vaccine in tobacco plants

Scientists have genetically modified tobacco mosaic viruses to carry a gene which codes for the production of hepatitis B antigen. When these modified viruses are allowed to contact tobacco plants, the gene carrying the code for the production of the hepatitis B antigen is transferred to the tobacco plant. The tobacco plant then produces the hepatitis B antigen. This transgenic tobacco plant is then fed to an animal such as a mouse, which has an immune system which will respond to the hepatitis B antigen. The desired response of the animal is the production of antibodies. These antibodies may then be used to bring about passive immunity in organisms receiving them. Future plans are to modify the hepatitis B antigen into a non-pathogenic form which could be given to individuals in a vaccine to bring about active immunity.

Application: Production of Amflora potato (*Solanum tuberosum*) for paper and adhesive industries

Scientists at the company BASF have produced a variety of potato called the Amflora potato by genetic modification. This potato only produces starch of one type called amylopectin. Normally, 20% of the starch potatoes produce is amylose. In Amflora potatoes the gene to produce amylose has been modified so no amylose is produced. The 100% production of amylopectin by this modified potato allows more efficient paper and adhesive properties than non-modified potatoes. Another benefit of this modified potato is it allows conservation of energy and water in the production of paper.

Understanding: Bioinformatics plays a role in identifying target genes.

Model sentence: The use of computers in bioinformatics allows the identification of specific genes called target genes.

Bioinformatics uses computers in an effort to understand biological processes. Bioinformatics has been especially valuable in the sequencing of DNA so that particular genes of interest or target genes may be identified and located in an organism's genome. It has also been essential in the sequencing of whole organism genomes.

Understanding: The target gene is linked to other sequences that control its expression.

Model sentence: Specialized DNA sequences are necessary for the expression of a target gene in genetic modification.

A target gene must include more than just the DNA sequence necessary to produce a particular protein if it is to be expressed when placed into an organism's genome. The target gene is also called the transgene. DNA sequences that must be added to the target gene include:

- A promoter DNA sequence must be present to initiate transcription and the gene expression process.
- A termination DNA sequence is necessary to signal the end of the target gene sequence.

Often, a marker or a gene known as a recognition sequence is included. This recognition sequence allows scientists to see that the target gene has been taken up by the host DNA. All the parts for a functional target gene in genetic modification are called a construct and it often takes the form shown in the figure below.

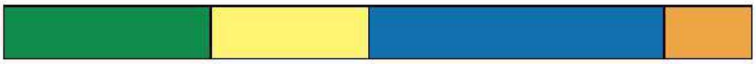


Figure 13.3 *General example of a functional target gene*

Understanding: An open reading frame is a significant length of DNA from a start codon to a stop codon.

Model sentence: The DNA base sequence from a start codon to a stop codon which codes for a polypeptide is called an open reading frame.

An open reading frame (ORF) is the DNA base sequence which codes for a particular gene. Once an organism's genome has been sequenced, the location of genes may then be determined from the database. Some key points about ORFs are:

- The DNA code occurs in base triplets.
- There are 64 possible base triplets. 61 of these base triplets code for an amino acid. There are three base triplets (TAG, TGA, and TAA) which signal the end of a gene or ORF. These three triplets are called stop codes. One base triplet (ATG) signals the start of a gene or ORF. The base triplet which signals the beginning of an ORF also codes for an amino acid and is called a start code.
- Most ORFs in DNA are over 100 base triplets and code for proteins which have at least 100 amino acids.

To find ORFs, scientists look for sequences of DNA base triplets which do not contain a stop code. The sequence of DNA base triplets would occur after a start code (ATG).

Skill: Identification of an open reading frame (ORF)

Develop your skill to recognize ORFs from a long DNA sequence. There is a public website presented by the National Center for Biotechnology Information (NCBI) which lists DNA sequences from various organisms. Visit the site, select a DNA segment of bases and find an ORF. Remember to look for a start code (ATG) in the

Subject vocabulary

target gene also called the transgene, the gene and all the sequences necessary to control its expression in genetic engineering

promoter DNA sequence section of DNA which initiates transcription of a gene

termination DNA sequence section of DNA which signals the end of a target gene sequence

construct all the parts for a functional target gene in genetic modification

open reading frame (ORF) DNA sequence which codes for a particular gene

Synonyms

initiate........... start/begin

DNA segment. Then look for a longer sequence of DNA base triplets without one of the stop sequences mentioned above. It is typical to find roughly 300 DNA bases separating the start code and the stop code.

Understanding: Marker genes are used to indicate successful uptake.

Model sentence: Marker genes are used in genetic modification to indicate the target gene has been taken up.

Marker genes are important to scientists since they confirm that a target gene or construct in a genetic modification attempt has been successfully incorporated into the desired host's genome. Some marker genes allow visual confirmation of the uptake. An example of this is the attachment of a marker gene which codes for the production of a green fluorescent protein. Other marker genes are called selectable markers. Selectable markers allow some sort of natural selection property. An example of this is a marker gene which brings about resistance to an antibiotic in a bacterium. A bacterium which has taken up a construct with this type of marker gene will not be affected if grown on agar which contains the antibiotic.

Subject vocabulary

marker gene a gene which when present has an accompanying identification factor, such as a fluorescent colour

selectable marker genes a gene used for recognition by allowing some sort of natural selection property

recombinant DNA DNA which contains sequences of bases from two or more sources

vector carrier

Understanding: Recombinant DNA must be inserted into the plant cell and taken up by its chromosome or chloroplast DNA.

Model sentence: The production of a transgenic plant requires that recombinant DNA be inserted into one of the plant's chromosomes in the nucleus or into the DNA of the plant's chloroplasts.

Recombinant DNA contains sequences of bases from two or more sources. Organisms with recombinant DNA are known as transgenic organisms. The first step in producing a transgenic plant is the introduction of the recombinant DNA into a plant cell. There are two general ways recombinant DNA may be introduced into a plant cell. These are:

- The recombinant DNA may be taken up into a plant cell's chromosomes, which occur in the nucleus of the cell.
- The recombinant DNA may be taken up by the DNA of the chloroplasts of the plant cell. Recombinant DNA taken up in this way will not be transferred in pollination. This method is often used when it is not desirable to spread the genetic modification to other plants.

The introduction of recombinant DNA into plant cells often utilizes a vector or carrier of some type.

Understanding: Recombinant DNA can be introduced into whole plants, leaf discs, or protoplasts.

Model sentence: Once introduced into a plant's cells, recombinant DNA can then be taken up by sections of that plant's leaves, protoplasts from the plant, and finally, the whole plant.

Protoplasts refer to the living parts of a plant cell including the cell membrane. They do not have cell walls. Vectors carrying recombinant DNA may be used to infect protoplasts from specific plants with desired traits. A common vector used is the bacterium *Agrobacterium*. The Ti plasmid of this bacterial genus may be genetically modified to carry the desired trait into the genome of the protoplasts.

Sections of plant leaves may also be incubated with the genetically modified *Agrobacterium* to allow introduction of a desired gene into a particular plant species. A selectable marker is used with this technique to confirm the uptake of the desired gene into the leaf cells. The selectable marker usually is a gene which gives resistance to a particular type of antibiotic.

Once the recombinant DNA is introduced into the protoplast or the leaf section, a whole plant may result in which all the cells have the desired trait or traits.

Understanding: Recombinant DNA can be introduced by direct physical and chemical methods or indirectly by vectors.

Model sentence: Both direct and indirect methods may be used to introduce recombinant DNA into an organism.

Direct physical methods of introducing recombinant DNA into plants include:

- Electroporation – a high voltage electrical field is produced by electrical pulses at the plant cell membrane. The resulting electrical field forms pores in the plant cell membranes to allow recombinant DNA to enter the cell and nucleus.
- Biolistics – tiny metal particles such as gold or tungsten are covered with the gene to be introduced into the plant. The coated particles are then propelled into the plant by a particle gun.
- Microinjection – a micro-needle is used to inject the desired gene into a cell. This usually includes the use of a micropipette to hold the target cell while the injection occurs.

Direct chemical methods of introducing recombinant DNA into plants include:

- Liposomes – liposomes are artificially prepared lipid sacs with an aqueous interior. The DNA to be introduced into a plant is placed into the aqueous solution of the liposome interior. The liposome with the desired DNA may then fuse with the plant cell membrane allowing the DNA to be transferred into the cell's nuclear DNA.
- Calcium chloride – the plant cells to be genetically modified are placed in a cold solution of calcium chloride containing the desired DNA for uptake. Addition of heat to the cell and calcium chloride solution allows the active transport of the desired DNA in the solution by endocytosis into the cell.

Subject vocabulary

protoplasts living parts of a plant cell including the cell membrane but not the cell wall

electroporation process by which a high voltage electrical field is produced by electrical pulses at the cell membrane

biolistics particles coated with a gene are propelled into a cell to bring about recombinant DNA

microinjection process by which a desired gene is actually injected into a cell

liposomes artificially created lipid sacs used to deliver a substance in a biological system

calcium chloride chemical used to increase the uptake of recombinant DNA into a cell

endocytosis active transport in which substances are brought into the cell

Synonyms

pore.............. hole/opening

General vocabulary

coated covered with a thin layer of something else

Vectors are biological agents used to carry recombinant DNA into cells. Vectors are viruses, plasmids such as the Ti plasmid, and other biological agents. Specific examples of commonly used vectors include:

- *Agrobacterium tumefaciens* – this bacterium includes a Ti plasmid commonly used as a vector.
- Tobacco mosaic virus – used to carry the hepatitis B gene into tobacco plants allowing the expression of hepatitis B antigens. These antigens may then be used with certain animals to produce a hepatitis B vaccine.

B.3 Environmental protection

Main idea

Potentially toxic wastes in our environment may be decreased or eliminated by the use of biotechnology.

Understanding: Responses to pollution incidents can involve bioremediation combined with physical and chemical procedures.

Model sentence: Bioremediation along with physical and chemical procedures may be used in the response to pollution incidents.

Pollutants are factors in the environment which affect the lives and health of living things in a negative way.

Bioremediation is the process where the normal metabolic processes of organisms are used to breakdown pollutants. Microorganisms are commonly used in the bioremediation process.

Phytoremediation is the use of plants in the removal of environmental contaminants. Bioremediation along with chemical and physical methods are utilized to treat areas where pollution occurs.

Chemical methods often used in treating environmental pollutants include:

- **Gelling agents**, which react with pollutants such as oil to form solids. The solids are then recovered and thrown away.
- **Oxidizing agents**, which may be injected into soil or added to water to accelerate the breakdown of organic pollutants.

Physical methods often used in treating environmental pollutants include:

- Removal of chemically contaminated soils followed by crushing, filtering, and mixing with water. If the pollutant is water soluble it will go into the solution with water. The water may then be **purified**.
- Detergents may be added to polluted areas to bring about quick **dispersal** of the pollutant.
- **Skimmers** may be used to remove pollutants which occur on the top of water.

Subject vocabulary

pollutants substances released into an ecosystem that have the potential to do harm

bioremediation process where the normal metabolic processes of organisms are used to breakdown pollutants

phytoremediation use of plants in the bioremediation process

gelling agents substances that react with certain pollutants to produce solids which can be disposed of

oxidizing agents agents used to accelerate the breakdown of organic materials

skimmers physical method used to remove pollutants from the top of bodies of water

Synonyms

purified .... cleansed/cleaned

General vocabulary

dispersal spreading out

Understanding: Microorganisms are used in bioremediation.

Model sentence: Microorganisms are often very effective in the breakdown of pollutants.

Many microorganisms are quite effective in bioremediation due to the enzymes they possess allowing them to break down long hydrocarbon chains present in organic pollutants. These microorganisms include prokaryotes such as bacteria and archaeans. These prokaryotes work well for several reasons:

- They have rapid reproductive rates.
- They possess quite variable metabolic pathways. The prokaryotes have metabolic pathways to break down many pollutants since they are such a diversified group.

Understanding: Some pollutants are metabolized by microorganisms.

Model sentence: Certain microorganisms may remove some pollutants from the environment by actually using the pollutant in their normal metabolic pathways.

Application: Degradation of benzene by halophilic bacteria such as *Marinobacter*

Scientists use an archaean of the genus named *Marinobacter* to remove a **carcinogenic** pollutant called benzene. Benzene occurs in the highly saline wastewater produced by drilling for oil in marine environments. This archaean is known as a **halophilic** bacterium due to its ability to survive in high saline environments. *Marinobacter* possesses the enzymes in a metabolic pathway which will break benzene down completely into carbon dioxide.

Application: Degradation of oil by *Pseudomonas*

Scientists found a species of bacterium within the genus *Pseudomonas* which naturally occurs on the bottom of ocean environments. This bacterium was observed to break down petroleum which seeped upward into the ocean water through cracks in the ocean floor. Scientists have now applied the naturally occurring metabolic pathways of this bacterium to break down oil pollutants in salt water. Chemicals such as rhamnolipid, glycerol, urea, and potassium are often added to the oil spill area to increase the growth and effectiveness of this bacteria in eliminating the oil pollutant.

Application: Conversion by *Pseudomonas* of methyl mercury into elemental mercury

Scientists have applied another bacteria from the genus *Pseudomonas* to remove methyl mercury from garbage dumps. Mercury is a component of some paints and is found in some types of light bulbs. A bacterium known as *Desulfovibrio desulfuricans* adds a methyl group to the mercury in rubbish. The result is methyl mercury which is potentially quite dangerous to many organisms due to **biomagnification** near the top of food chains. When the *Pseudomonas* bacterium is added to the garbage dumps with methyl mercury, it changes this dangerous chemical into insoluble elemental mercury. This insoluble elemental mercury sinks to the bottom of the garbage dump and does not become part of any food chain.

Subject vocabulary

carcinogenic having cancer-causing properties

halophilic organisms able to survive in high saline environments

biomagnification increasing concentration of a pollutant as the pollutant moves up through the trophic levels of a food chain

Understanding: Cooperative aggregates of microorganisms can form biofilms.

Model sentence: Biofilms are composed of large numbers of microorganisms working as a team to cover the surface of objects.

Biofilm key points:

- Biofilms are large groups or **aggregates** of microorganisms working together to cover a surface.
- Biofilms may include many different types of microorganisms including fungi, bacteria, and algae.
- Biofilms hold together by secreting **extracellular polymer-like substances (EPS).** These EPS also allow the aggregate to **adhere** to a surface.
- Biofilms can develop in a short time, even in hours.

Examples of biofilms include the **plaque** which occurs on teeth, the layers of microorganisms which may contaminate the surfaces of materials used in food production, and the very thick layers of microorganisms which may lead to the blocking and **corrosion** of pipes.

Application: Use of biofilms in trickle filter beds for sewage treatment

Scientists have applied the properties of biofilms in a positive way to bring about the efficient treatment of sewage. Biofilms are used with **trickle filter beds** in treating sewage. An aerobic bacteria is used to produce biofilms on rocks or artificial particles which exist as a bed in a filter tank. Sewage water is sprayed onto the rock or particle bed with the biofilm. The spraying adds oxygen to the sewage. The biofilm of aerobic bacteria on the rocks or particles in the bed breaks down the sewage into carbon dioxide, which escapes into the atmosphere. The treated water is collected through a drainage system at the bottom of the tank.

Understanding: Biofilms possess emergent properties.

Model sentence: The properties of the biofilm community are greater than the properties of the individual components.

The self-organization of individual members of a biofilm into a complex structure or architecture is an **emergent property**. The complex structure or architecture which a biofilm may form is often referred to as a matrix. Common emergent properties of the biofilm include:

- complex matrix formation
- **quorum sensing**
- resistance to antimicrobial agents.

Hints for success: Emergent properties are common in biology. We see them when all the individual parts of a cell work together to form a structure which has properties greater than the sum of the properties of the individual parts. The same is true of biofilms. The 'team' formed in the development of biofilms possesses many more properties than the sum of the properties of the individual members.

Subject vocabulary

biofilm large groups of microorganisms working together that cover a surface

extracellular polymer-like substances (EPS) substances which hold the microorganisms of a biofilm together and add in the adherence to a surface

plaque build-up of cholesterol and other substances on the inner wall of arteries or biofilm on the surface of teeth

trickle filter bed a bed of rock or other particles which allows fluid to pass through bringing about the removal of some substance, usually a pollutant

emergent property a property which is greater than the sum of the parts

quorum sensing process of communication when the population of a microorganism in a biofilm reaches a population level which brings about some change in response

General vocabulary

aggregates clumps

corrosion slow destruction

Synonyms

adhere........... stick

Understanding: Microorganisms growing in a biofilm are highly resistant to antimicrobial agents.

Model sentence: Antimicrobial agents have very little effect on the microorganisms which exist within a biofilm.

Many biofilms are resistant to antimicrobial agents such as antibiotics. Examples of problems due to this emergent property are:

- Biofilms are often found in hospitals and may cause secondary infections in patients during their stay.
- Biofilms often occur in the lungs of cystic fibrosis patients in which the bacterium *Pseudomonas aeruginosa* forms a biofilm which is very difficult to control.
- Biofilms may develop in the medical catheters or on implants of patients requiring their replacement. This replacement results in significant cost and trauma to the patient.

Causes of this resistant antimicrobial emergent property are being researched at present. One possible cause is the EPS produced by the individual members of the biofilm. Another possible cause is the fact that individual microorganisms of a biofilm have a much lower rate of cell division than when they occur alone. This presents a problem controlling biofilms because most antimicrobial agents act by controlling or inhibiting cell division.

Skill: Evaluation of data or media reports on environmental problems caused by biofilms

It is important for you to study data provided by studies in order to evaluate the environmental problems caused by biofilms. There are many studies available concerning biofilms. One study addresses the effects of biofilms which occur in ship ballast water. It has been shown these biofilms may become aquatic invasive species when released into the ocean. Read media reports of the effects in the environment of biofilms. Many media reports are available concerning the role of biofilms in quite varied instances of food poisoning. Certainly, this activity should bring about some concern about biofilms in the environment. However, many reports show their potential benefits to our environment.

Understanding: Microorganisms in biofilms cooperate through quorum sensing.

Model sentence: Quorum sensing allows the microorganisms of biofilms to work together.

Quorum sensing is an emergent property which occurs when the population of microorganisms in a biofilm reaches a certain (threshold) population level. Bacteria in biofilms will express different genes as their population changes. There appears to be signalling or communicating molecules and receptor-like molecules involved in quorum sensing. When population levels are higher more signalling molecules are present. These signalling molecules are detected by receptor molecules on the involved cells. Very often the result of this signalling and reception is the production of more EPS by the microorganisms involved. The EPS allows the further development of the biofilm.

Subject vocabulary

antimicrobial an agent which harms or kills microscopic organisms

secondary infections infections developed during treatment for some other disease

species a group of organisms which are structurally similar and able to pass their genetic traits onto their offspring

threshold some significant level which brings about some sort of change or shift in response

Hints for success: Quorum sensing brings about greater communication and increased chances of success for the organisms involved. It only occurs when a particular level of population is achieved which is known as the threshold population. A threshold in biology is generally the level of some factor at which specific actions begin to occur.

Understanding: Bacteriophages are used in the disinfection of water systems.

Model sentence: Bacteriophages may be used to control biofilm-forming bacteria which occur on the equipment of water systems.

A **bacteriophage** is a virus which has the ability to attack and destroy a specific type of bacteria. There are many different types of bacteriophages. Each type of bacteriophage attacks a particular bacteria type.

Biofilms may cause serious damage to water systems. Uncontrolled biofilms may corrode or block the pipes of the system.

Treatment with a number of different bacteriophages has been shown to successfully reduce the biofilm which may develop in pipes of our water systems. The success of the bacteriophage treatment is increased when the addition of chlorine follows the addition of the bacteriophage mixture. The bacteriophage success is largely due to the ability of the virus to **penetrate** all the layers of the existing biofilm. Disinfectants are not as effective in treating water system biofilms because they are only effective on the outer most layer of the biofilm.

Subject vocabulary

bacteriophage a type of virus which infects bacteria

pathogens disease-causing agents such as viruses and bacteria

antigen substance which stimulates the production of antibodies in vertebrates

polymerase chain reaction (PCR) process which increases the amount of DNA of a specific type

enzyme-linked immunosorbent assay (ELISA) test for specific antigens or antibodies

DNA microarrays tests for the presence of particular sequences of DNA by using mRNA

Synonyms

penetrate....... go through

B.4 Medicine

Main idea

Biotechnology is allowing greater efficiency at finding, identifying, and treating disease.

Understanding: Infection by a **pathogen** can be detected by the presence of its genetic material or by its **antigens**.

Model sentence: Tests for a pathogen's genetic material or for the antigens it produces allows its detection in an infection.

Disease can be treated more effectively when the pathogen which is causing it is accurately and quickly identified. Identification of the pathogen involves an analysis of its genetic material or the observation of an antigen it produces. Present biotechnology tests commonly used in this pathogen identification process are:

- **PCR (polymerase chain reaction)** – tests for the actual genetic material of a pathogen
- **enzyme-linked immunosorbent assay (ELISA)** – tests for the antigens a pathogen directly produces or tests for the antibodies an organism produces in response to a disease (both antigens and antibodies are proteins)
- **DNA microarrays** – tests for the presence of particular sequences of DNA by using mRNA.

Skill: Interpretation of the results of an ELISA diagnostic test

ELISA stands for enzyme-linked immunosorbent assay. It was the first test used to successfully screen for the HIV antibody in blood. The presence of the HIV antibody indicated the potential presence in the system of the human immunodeficiency virus. In the ELISA test for HIV antibody, a sample of blood from the individual to be tested is **centrifuged** and placed in a small well. The well contains the HIV protein which will provide a positive result for the antibody in question. The **serum** is allowed to incubate in the well with the protein. The serum is removed after the incubation period. A series of buffer washes then occur. The final step is the addition of an enzyme substrate. The well will now show colour if the serum antibodies match the protein placed in the well for identification purposes. Follow these steps to interpret the results of an ELISA test:

- If colour is present in the well, the serum antibodies match the identification protein placed in the well for identification purposes.
- The amount or intensity of the colour of the well is directly proportional to the amount of serum antibody initially bound to the protein on the well bottom.

Application: Use of PCR to detect different strains of influenza virus

Scientists use polymerase chain reaction (PCR) to detect various types of influenza virus. PCR involves the production of multiple copies of DNA. Influenza virus is a **retrovirus**, which means it contains RNA but not DNA. The influenza RNA is purified from an infected patient. An enzyme called **reverse transcriptase** is then added to the RNA. The enzyme allows **cDNA** to be produced. Complementary DNA (cDNA) is DNA produced from mRNA by base pairing. Primer sequences for the influenza virus being tested are then added. More cDNA produced after the primer addition indicates this particular influenza virus is present.

Understanding: **Predisposition** to a genetic disease can be detected through the presence of markers.

Model sentence: The presence of specific genetic markers indicates a predisposition to a genetic disease.

Genetic markers are DNA sequences which are associated with a tendency to develop a particular genetic disease. A genetic marker may be of varying lengths of DNA sequences.

Single nucleotide polymorphisms (SNPs) often called 'snips' are DNA sequences that involve single nucleotides. SNPs serve as markers indicating a predisposition to certain genetic diseases.

Segments of DNA composed of repeats of particular sequences of DNA nucleotides called **tandem repeats** are also valuable as markers.

The most valuable markers are found close to the gene that is thought to be the cause of the genetic disease. Markers are also useful when they are associated with a single gene which is the cause of the genetic disease. Markers are less useful when multiple genes are the cause of a genetic disease. Markers also show less value when associated with genetic diseases strongly influenced by the environment.

Examples of genetic markers and the genetic disease they cause predisposition toward are:

- *melanocortin 1 receptor* (*MC1R*) – predisposition to melanoma skin cancers
- *BRCA 1* – predisposition to breast or ovarian cancer
- *BRCA 2* – predisposition to breast or ovarian cancer.

Subject vocabulary

centrifuged process of separating solids from a liquid by spinning the liquid at high speed

serum component of blood minus blood cells and clotting factors

retrovirus virus which contains RNA as its nucleic acid within a capsid

reverse transcriptase enzyme which allows the production of cDNA from mRNA

cDNA complementary DNA produced from mRNA by base pairing, single stranded

genetic marker DNA sequences which are associated with a tendency to develop a particular genetic disease

single nucleotide polymorphisms (SNPs) DNA sequences which involve changes in single nucleotides

tandem repeats segments of DNA composed of particular sequences of DNA nucleotides

General vocabulary

predisposition tendency to suffer from a certain illness

Understanding: DNA microarrays can be used to test for genetic predisposition or to diagnose the disease.

Model sentence: Markers and genetic diseases are capable of being identified by using DNA microarrays.

A DNA microarray is a collection of DNA probes attached to a solid surface which can be used to identify a genetic marker or disease. The steps in using a DNA microarray to identify specific genetic sequences are:

- Isolate mRNA from the patient in question.
- Carry out **reverse transcription** to produce complementary DNA (cDNA) which is single stranded.
- Label the cDNA with a type of florescent dye.
- Expose the cDNA to the microarray which contains DNA probes of the marker gene or the **defective** gene causing the disease.
- Rinse excess cDNA from the microarray.
- Base pairing of the cDNA and the microarray DNA probes which is called **hybridization** results in a recognizable colour.

Many microarray tests involve the use of green and red fluorescent dyes. Green dyes are added to normal or non-cancer control cell cDNA. Red dyes are added to cDNA of cancerous cells. Analysis using these two dyes and the colours observed on the microarray would be based on the following:

- green colour – high hybridization for normal cells or cDNA
- red colour – high hybridization for cancer cells or cDNA
- yellow colour – equal hybridization for both cell (cDNA) types.

The yellow colour indicates the gene is not involved in the cancer. A red colour indicates the gene is involved with the cancer. A green colour indicates the gene may be involved with prevention of the cancer.

Subject vocabulary

reverse transcription process in which cDNA is produced from mRNA

hybridization in molecular genetics, the complementary base pairing between two segments of DNA such as between a strand of cDNA and microarray probes

metabolite product of metabolism

biomarkers a substance not normally produced by the body but produced by the metabolic pathway of a particular disease that can be used to indicate the patient has that disease

Synonyms

defective........ faulty

Understanding: Metabolites that indicate disease can be detected in blood and urine.

Model sentence: Certain diseases produce products of unique metabolic pathways which are detectable in blood and urine.

Many genetic diseases include unique metabolic pathways often due to DNA which affects the enzymes controlling a normal pathway. The result of the defective pathway is a **metabolite** which is unique and detectable. These metabolites may be referred to as **biomarkers** due to their occurrence with specific diseases. Biotechnology is allowing detection of these metabolites so that early detection and treatment may occur. Several diseases produce these detectable metabolites in blood and urine.

- Prostate cancer is usually associated with high levels of the metabolite prostate-specific antigen (PSA).
- A significant number of breast cancer patients have a high level of a protein in their blood known as HER2 (human epidermal growth factor receptor 2).
- Lesch–Nyhan syndrome results in a large concentration of uric acid in the urine.

Understanding: Tracking experiments are used to gain information about the localization and interaction of a desired protein.

Model sentence: Proteins of interest may be modified to allow tracking within an organism.

Another type of biomarker is a protein to which a radioactive probe is attached allowing tracking of the protein's circulation and distribution within an organism. Some proteins can be tracked after attaching a green fluorescent protein (GFP) to them. Equipment recognizing radioactivity or fluorescent colouring is then used to study the actions of the protein.

Application: Tracking tumour cells using transferrin linked to luminescent probes

Scientists now **routinely** use fluorescent proteins also known as luminescent probes to track tumour cells. Transferrin is the fluorescent protein often used. Transferrin will seek out and attach to unique receptors which occur on cancer tumour cells. This allows detection of the cancer. It also represents a future means of attacking tumour cells by attaching anticancer drugs to the transferrin protein.

Understanding: Biopharming uses genetically modified animals and plants to produce proteins for **therapeutic** use.

Model sentence: Genetically modified plants and animals have been developed to produce proteins for the treatment of diseases.

The genetic modification of plants and animals has been developed to allow these plants and animals to produce therapeutic proteins which may be used in the treatment of diseases. This process is called **biopharming**. Genetically modified bacteria are used to produce human insulin and growth hormone which are simple proteins. However, bacteria are not able to produce the complexity of protein structure needed to form most therapeutic proteins. This complexity issue is why plants and animals with eukaryotic cells are now being developed for biopharming.

Application: Biopharming of antithrombin

Scientists are using goats and biopharming techniques to produce a protein called **antithrombin**, which decreases the occurrence of blood clots in surgery and in birthing. Excess **clotting** occurs in people with a hereditary antithrombin deficiency. Clotting is especially a problem in these people when they are having surgery or when they are birthing. Goats have been genetically modified to produce antithrombin in their mammary **glands**. The gene which is necessary for the production of antithrombin must be inserted into the goat's genome along with the proper **promoter** and signal sequences. The proper **signal sequence** is essential so that the antithrombin is produced by ribosomes attached to the ER. Ribosomes attached to the ER of the goat's mammary cells will produce antithrombin which is carried outside the cells and will become a part of the milk. Ribosomes free in the cytoplasm would still produce antithrombin. However, this antithrombin would remain in the cells and would not be able to be recovered. Goats were chosen because they have a high milk production rate. They also have a short generational time of 18 months. Antithrombin can be successfully retrieved from the milk of these genetically modified goats. This isolated and purified antithrombin may then be given to antithrombin-deficient patients to minimize the excess clotting problem.

General vocabulary

routinely done as a normal part of a process or job

clotting becoming thicker and more solid

gland an organ of the body which produces a substance

Subject vocabulary

therapeutic relating to the treatment of disease

biopharming genetic modification of plants and animals in order to produce therapeutic proteins or medicines

antithrombin protein which decreases the action of thrombin in blood clotting

promoter region of a target gene which initiates transcription and the gene expression process

signal sequence group of amino acids coded by mRNA which controls whether a ribosome is attached to the endoplasmic reticulum or not

Understanding: Viral vectors can be used in gene therapy.

Model sentence: Viruses may be used to deliver new genetic material into organisms in which gene therapy may be helpful.

Subject vocabulary

somatic therapy use of viruses to insert beneficial genes into body cells, not reproductive cells, in gene therapy

adenosine deaminase (ADA) enzyme which breaks down the metabolite deoxyadensine which adversely affects the immune system

deoxyadenosine metabolite which is toxic to B and T lymphocytes

lymphocytes white blood cells capable of producing antibodies, often referred to as B lymphocytes or B cells

The use of viruses to insert beneficial genes in gene therapy is usually called **somatic therapy**. This name comes from the fact that body or somatic cells are being altered, not reproductive cells. It is essential that the viruses used in gene therapy delivery cases are disabled in some way so they will only infect the cells that need to be modified.

Cystic fibrosis is a very serious genetic disease which is presently being treated with great promise by gene therapy. SCID is also being treated successfully in many cases with gene therapy. The steps of SCID gene therapy are explained in the application below.

Application: Use of viral vectors in the treatment of Severe Combined Immunodeficiency (SCID)

Scientists are using viruses as vectors to insert into cells a gene missing from patients with a disease known as Severe Combined Immunodeficiency (SCID). People with SCID do not have a gene which produces an enzyme known as **adenosine deaminase (ADA)**. The lack of ADA results in the build-up of a metabolite known as **deoxyadenosine**. This metabolite is toxic to the immune system's T and B **lymphocytes**. Loss of T and B lymphocytes results in a non-functional immune system. Any infection becomes a very serious problem to these people. A treatment involving genetic modification is now being used to treat many of these SCID patients. Steps in this treatment are:

- Remove ADA-deficient lymphocytes from a SCID patient.
- Culture these lymphocytes in the laboratory (*in vitro*).
- Infect the cultured lymphocytes with a genetically modified retrovirus which is carrying the normal ADA gene and the necessary promoter sequence. The retrovirus is disabled before being modified so it only affects target tissues which produce lymphocytes.
- Transfuse the modified lymphocytes back into the SCID patient.

Scientists have achieved beneficial effects with this procedure that have lasted 4 years.

B.5 Bioinformatics

Main idea

The use of computer-stored databases and other computer information sources to analyse biological research is known as bioinformatics.

Understanding: Databases allow scientists easy access to information.

Model sentence: Access to biological information has been made much easier due to structured collections of data on computers known as databases.

Databases have made the access to scientific information much easier. Databases need the following characteristics to be successful:

- an accessible, identifying code or name
- the name of the scientists contributing to the database
- indication of the time the data were entered
- literature information providing additional sources about the information being presented
- real data which were actually generated.

A few major biology databases in use today are:

- GenBank – lists a collection of DNA sequences of many, many sources
- OMIM (On-Line Mendelian Inheritance in Man) – lists the phenotypes for a series of disease-causing SNPs (single nucleotide polymorphisms)
- Swiss-Prot – lists a huge set of protein sequences from many sources
- Ensembl – provides complete genomes of humans and many other vertebrates.

Scientists may use databases to:

- extract information for a particular question or for further research
- add new data found by personal research.

Skill: Explore chromosome 21 in databases

You should develop your skill in using a biotechnology database by examining chromosome 21 of the human genome. The database known as Ensembl can be used for this. Chromosome 21 is suggested because it is the shortest of the human chromosomes. Its genetic sequence is also well known due to numerous studies associated with research involving Down syndrome, also known as trisomy 21. An Ensembl search involving this chromosome will show the genes present, their location on the chromosome, the proteins they express, and even centromere location relative to the genes present.

Understanding: The body of data stored in databases is increasing exponentially.

Model sentence: The amount of data available in databases is increasing at an exponential rate.

Biotechnology has added greatly to the data which are being added to databases. Every day more scientists are becoming even more involved with the generation of data using biotechnology and other modes of research. Increased access to these databases has also added to their size and value.

Subject vocabulary

database collection of data maintained on computers

General vocabulary

exponential getting faster as more is added

Understanding: BLAST searches can identify similar sequences in different organisms.

Model sentence: BLAST is a computer program which allows comparison of nucleotide and protein sequencing in different organisms.

BLAST is an acronym for Basic Local Alignment Search Tool. Similar protein amino acid and DNA nucleotide sequences exist in different organisms. BLAST is a computer program which can demonstrate these similarities by comparing nucleotide or protein sequences to sequence databases. Comparing sequences may lead to greater understanding of evolutionary and functional relationships amongst organisms. BLAST actually consists of a family of programs which allow specific queries to be made. Of all the BLAST programs, BLASTn and BLASTp are most used. The reason they are most used is that they allow direct comparisons between sequences.

Some other uses of BLAST are to aid in the identification of species, assist in the DNA mapping of an organism, and to identify common genes in different organisms.

Subject vocabulary

BLAST computer program which utilizes databases to compare biological sequences

model organisms organisms studied to understand biological phenomena

knockout technology technology in which a non-functional gene is substituted for a functional gene to determine the actions of the functional gene

General vocabulary

acronym a word made up from the first letters of the name of something

Synonyms

ethical .... moral

Understanding: Gene function can be studied using model organisms with similar sequences.

Model sentence: Model organisms may be used to study gene functions in organisms with similar nucleotide sequences.

Model organisms are extensively studied to understand biological phenomena. The goal is that the studies will provide a better understanding of the functions within other organisms. Humans are not used as model organisms to avoid possible ethical issues and other difficulties in the studies.

There is great variety in model organisms. Several viruses have even been selected for detailed study. Some other organisms studied extensively as model organisms are the bacterium *Escherichia coli*, a green single-cell alga called *Chlamydomonas*, the fruit fly *Drosophila melanogaster*, the plant *Arabidopsis thaliana*, and the mouse *Mus musculus*. Most model organisms have had their entire genome sequenced allowing sequence sharing with other organisms.

Application: Use of knockout technology in mice to determine gene function

Scientists often use a process called knockout technology to determine gene function. This technology involves the substitution of functional gene sequence with a non-functional sequence. It is carried out using stem cells and embryos until an organism, for example, a mouse, is obtained which is pure for the non-functional gene sequence. The purebred 'knockout' organism may then be observed to see what phenotype or phenotypes are not expressed as a result of the change. A gene which expresses the hormone known as leptin in mice has been studied by knockout technology. Findings indicate leptin is essential in controlling energy metabolism and fat deposition.

Understanding: **Sequence alignment** software allows comparison of sequences from different organisms.

Model sentence: Sequence alignment software allows a way to identify similar regions between organisms involving DNA and protein sequences.

Short or similar sequences may be **aligned** manually. Most organism comparisons involve very long sequences. These long sequences require sequence alignment software. Sequence alignment software can compare sequences of DNA, RNA, and protein. Alignment may refer to the open reading frames (ORFs) of DNA being compared. Alignment may also refer to the translated protein of ORFs being compared. Alignment can involve the comparison of mRNA from ORFs as well. This software usually presents the aligned sequences of various organisms as rows within a matrix. The rows of similar sequences may then be compared to determine such things as evolutionary and structural similarity. If similar sequences from different organisms have few substitutions, then the region probably is involved with structural or functional importance to the organism.

There are many sequence visualization software programs available. These various programs allow queries of many different types to be addressed when looking at sequences from different organisms.

Skill: Use of software to align two proteins

You must be able to compare two proteins by using appropriate sequence alignment software. BLASTp or FASTA are databases that are often used to compare the amino acid sequences of two proteins produced by similar open reading frames. Selection of a protein common to two different organisms is the first step in this process. The beta haemoglobin chain in humans and rats can be compared using either of the two programs mentioned above. The algorithms of both programs will allow the sequence alignment of this protein in these two organisms.

Subject vocabulary

sequence alignment matching strings of nucleotides in different samples of DNA or amino acids in proteins to identify how similar organisms are

Synonyms

align.............. line up

Understanding: BLASTn allows nucleotide sequence alignment while BLASTp allows protein alignment.

Model sentence: BLASTn allows comparison of similar nucleotide sequences from different organisms. BLASTp allows comparison of similar protein amino acid sequences from different organisms.

BLASTn is a program into which a researcher may enter a particular DNA nucleotide sequence. The particular DNA nucleotide sequence entered most often represents an ORF. Once the sequence has been entered, the researcher then specifies which database the program should use to find any similar DNA sequences. Hopefully, the similar DNA sequences will allow the researcher to satisfy any queries they may have.

BLASTp is a program that works in the same way as BLASTn. However, BLASTp is used for protein amino acid sequences.

There are many other BLAST programs. Here are some:

- BLASTx – allows identification of potential protein products from a nucleotide query
- tBLASTx – allows location of a nucleotide sequence in an organism that produces a particular protein.

Understanding: Databases can be searched to compare newly identified sequences with sequences of known function in other organisms.

Model sentence: Databases are valuable in the comparison of DNA and protein sequences between organisms.

The various BLAST programs may be used to find comparable sequences or products from sequences in different organisms. These database searches are valuable in attempting to find comparable sequences in DNA, mRNA, or protein amino acids. These types of searches may also compare the products produced in different organisms from similar DNA sequences.

Understanding: Multiple sequence alignment is used in the study of phylogenetics.

Model sentence: Multiple sequence alignment is used to find out evolutionary relationships between or amongst different organisms.

Subject vocabulary

phylogenetics study of the evolutionary history of an organism or group of organisms

homologous structures structures which have similar genetic and structural origin that now show obvious differences

analogous structures structures which have common functions but different origins genetically and structurally

cladogram branching diagram showing relationships among a group of organisms

phylogram branching diagram showing relationships among a group of organisms in which the branches represent proportional amounts of change or differences

Phylogenetics is the study of the evolutionary history of an organism or group of organisms. When carrying out multiple sequence alignment involving several different organisms, it is important to note similarities may occur due to structures which are homologous or analogous.

Homologous structures are more likely to have similar mutations or base substitutions at similar positions in the DNA sequence examined. Homologous structures in evolution have similar genetic and structural origin but may have over time developed different functions. This results in similar sequences and a possible common evolutionary history.

Analogous structures are structures with similar function at the present time. However, analogous structures may have had very different origins in both structure and genetics. The reason you may see similar sequences with analogous structures is that the DNA sequence may have significantly changed over time to produce common products.

ORFs are most often examined in these types of studies.

Skill: Use of software to construct simple cladograms and phylograms of related organisms using DNA sequences

It is important that you develop the ability to construct a simple cladogram and phylogram from related organisms using DNA or protein sequences. Both cladograms and phylograms show probable evolutionary relationships of a group of organisms. A phylogram has lengths of branches which indicate relative amounts of change. A cladogram does not have lengths of branches which indicate relative amounts of change. Use the database Swiss-Prot to compare the haemoglobin beta chains of the following eight organisms: domestic duck, Canada goose, rat, mouse, alligator, Nile crocodile, human, and rhesus monkey. This database will provide you with the differences among these organisms' haemoglobin beta chains. Organisms with the greatest differences in sequences are the farthest apart on the cladogram or phylogram. Programs are available to produce cladograms and phylograms of the differences in the sequences of the haemoglobin beta chains in these eight organisms using Swiss-Prot.

Understanding: EST is an expressed sequence tag that can be used to identify potential genes.

Model sentence: An EST may be used to identify and locate an organism's potential gene from a database.

There is an EST database involving over 1000 organisms which is known as **dbEST**. An EST is a short segment of complementary DNA (**cDNA**) that is single stranded. The cDNA is produced using reverse transcriptase from messenger (mRNA). This cDNA does not have any **introns** since it comes from the mature mRNA which is translated to produce a protein at the ribosome. These ESTs are generally between 300 to 500 nucleotides long. A BLAST search involving the dbEST may then be done to see if there is a known gene for the protein the EST produces. The database may even provide the location of the gene in an organism's genome.

Application: Discovery of genes by EST data mining

Scientists use a technique known as EST data mining to match DNA sequences with the dbEST database. This allows them to determine if the EST in question matches a known gene and to find the gene's function.

Subject vocabulary

EST short segment of cDNA that is single-stranded used to see if there is a known gene for the protein the EST produces

dbEST database of short sequences of single-stranded cDNA

cDNA complementary DNA produced from mRNA by base pairing, single stranded

introns non-coding regions of DNA which are transcribed onto the mRNA molecules, they are removed before leaving the nucleus

C.1 Species and communities

Understanding: The distribution of species is affected by limiting factors.

Model sentence: Species live in certain areas because of both non-living and living factors that affect their survival.

All species have certain requirements to stay healthy and alive. Those factors might be as simple as available water and sunlight. It is also possible that there is a wide range of factors including such things as food availability, **predators** in the area, maximum or minimum temperature, and many other possibilities. The factor or factors that determine whether a species can **inhabit** an area is called a limiting factor. Limiting factors can be subdivided into two main groups as shown by the following table.

Abiotic – limiting factors that are not created by something that is alive	**Biotic – limiting factors due to one or more other living species**
sunlight availability	**abundance** of a prey animal
water availability	abundance of a predator
soil type	abundance of a **competitor** for a resource
air or water temperatures	abundance of a **parasite**

Application: Distribution of one animal and one plant species to illustrate limits of tolerance and zones of stress

Example 1: animal species

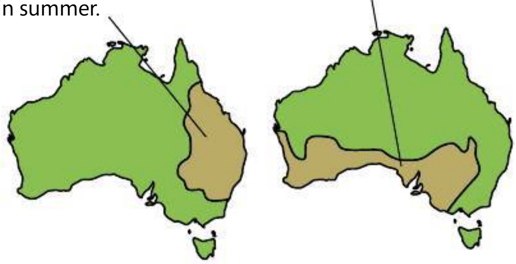


Figure 14.1 *These three maps show the habitat of three species of kangaroos in Australia. Southern Australia is cooler than northern Australia. The interior of Australia receives less rainfall than the coasts. These three maps illustrate the limits of tolerance that each species has for water availability and temperature. When the distribution area nears the green area that area is called a zone of stress. The animals can live in that area but water availability or temperature has begun to be a problem for that species in that area*

Subject vocabulary

limiting factors environmental factors that determine the maximum size of a population or the maximum rate of a process

predator an organism that hunts and eats other organisms

abiotic pertains to non-living

biotic pertains to living

competitor two organisms that compete for the same resource

parasite organism that uses another organism for resources and harms that organism

limits of tolerance the edges of the range for any one environmental limiting factor, e.g. if a species of fish can live in water temperatures between 18–26 °C, then 18 °C and 26 °C would be its limits of tolerance

zone of stress an area of a habitat where a species is nearing the limits of tolerance for any one limiting factor

Synonyms

inhabit .... live in/occupy

General vocabulary

abundance large quantity of something

Example 2: plant species

E. californica is confined to a narrow zone along the coast of California and Baja California, which is cool and moist in the north and cool and dry in the south.

E. actoni lives farther inland, where conditions are drier and warmer than the areas inhabited by *E. californica*.

E. farinosa and *E. frutescens* live still farther inland in areas that are much hotter. The geographic distributions of these two species overlap a great deal.

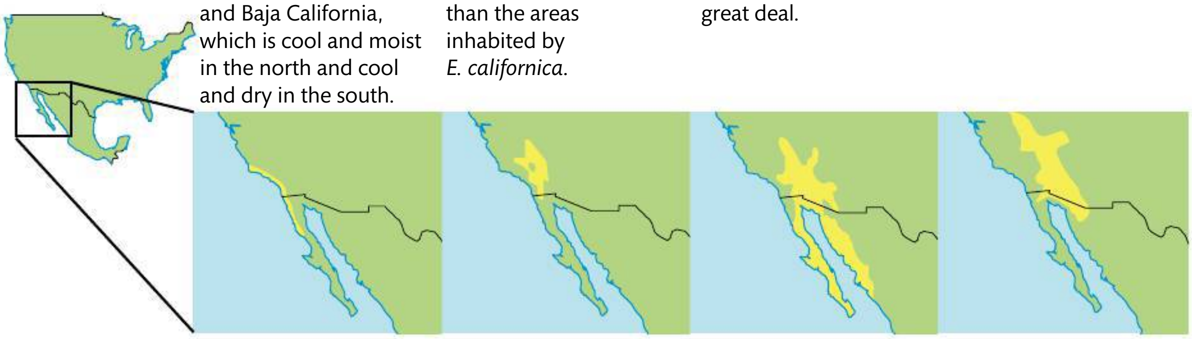


Figure 14.2 *Plants of the genus* Encelia *are in the daisy family. Four different species of this genus live in different habitats in California and Baja California of North America. Each species has a habitat based on water availability and temperature. Each has different* ***adaptations*** *that allow it to survive according to their own limits of tolerance. Once again, when the distribution area nears the green area, that area is called a zone of stress. The animals can live in that area but water availability or temperature has begun to be a problem for that species in that area*

Understanding: Community structure can be strongly affected by **keystone species**.

Model sentence: The health of a biological community is negatively affected if a keystone species is removed.

A keystone species in a biological community is one that is particularly important to the health of that community. Whether a species is a keystone species is not dependent on how many individuals of that species are present.

The test to determine whether a species is a keystone species is to remove that species from an area for a period of time. After removal, if the health of the community is not severely affected, then the species is not a keystone species.

Understanding: Each species plays a unique role within a community because of the unique combination of its **spatial habitat** and interactions with other species.

Model sentence: Where a species lives and the interactions it has with other species are important to the role the species plays within its community.

A species' spatial habitat is simply the location that it lives in. Within that spatial habitat each species is likely to have many types of interactions with other species who share that spatial habitat.

No matter where a species lives it is likely to have many interactions with other species. Sometimes that interaction is very direct. An example would be one species eating another as a food source. Other times the interaction may be much less direct. An example would be a species of bacterium that provides **nutrients** that can be taken up by a species of plant.

General vocabulary

adaptation change which makes something more suitable for a situation

Subject vocabulary

keystone species a species that has an unusually large impact on a community if that species is no longer present

spatial habitat the location where a species exists

nutrient chemical material a cell or organism needs

Subject vocabulary

symbiotic a relationship between two species in which both benefit from their relationship with each other

mutualism a type of symbiotic relationship where two different species benefit from a relationship they have with each other

resource a factor within an ecosystem that is useful to one or more species

host the species that a parasite lives within or on

General vocabulary

dispersal spreading out

Application: The symbiotic relationship between zooxanthellae and reef-building coral reef species

One type of symbiotic relationship between species is called **mutualism**. This interaction is one in which both species benefit from the relationship. Coral reefs would not be possible without a mutualistic relationship between species. Zooxanthellae are single-celled algae that live inside coral tissues. The zooxanthellae photosynthesize and provide nutrients for the coral. The coral provides a home and various compounds needed by the algae. Each relies on the other for a mutual benefit.

Understanding: Interactions between species in a community can be classified according to their effect.

Model sentence: It is possible to classify species to species interactions based on the effect the interaction has.

This table summarizes some of those types of species to species interactions.

Category of interaction	Brief description	Example
competition	Two species competing for the same **resource.**	Two species of birds who both feed on the same species of insects.
predator / prey	One species that is a prey animal for another.	Apple snails are the only prey of a bird called the Everglades kite.
parasitism	One species acts as a **host** to another (the parasite). Parasite damages the host.	Leeches are parasites to many mammals. The leech gains blood as food and the host loses blood.
mutualism	Both species benefit from the interaction between species.	Some flowering plants are pollinated by insects. The insect gains nectar and/or pollen to eat. Plant gains **dispersal** of its sex cells.
commensalism	One species benefits and the other is relatively unaffected by the relationship.	Many 'air plants' (epiphytes) like Spanish moss in the southern United States simply use various trees as places to grow. The tree is not harmed or benefited in any way.

Application: Local examples to illustrate the range of ways in which species can interact within a community

Look at the examples given of species to species interactions in the table above. See if you can come up with one or more examples of each category of interaction for species in your area of the world.

Understanding: Two species cannot survive indefinitely in the same habitat if their niches are identical.

Model sentence: One of two species that share an identical niche will eventually be forced out of the same habitat.

A well-studied principle in ecology is known as the **competitive exclusion principle**. This principle states that if two species share the same ecological niche, one of the two species will outcompete the other. The end result will be that one species will be excluded from the habitat by the other. This doesn't mean the excluded species will go extinct. The species that gets outcompeted in this habitat might **flourish** in another spatial habitat.

So, what is the niche of a species? A simple way to think of a niche is that it is the species' special role or function within its ecosystem. Frequently, an important component of a species' niche includes what it eats. Thus, if two species share a limited food source, the species that outcompetes the other is the one that will not be excluded.

Sometimes an organism's niche becomes modified over time. These modifications often occur because of human activities. Fundamental niche is the term used for a niche without any limitation from other organisms. A realized niche is the term used for a niche in reality. A realized niche takes into account the interactions of other organisms including humans.

For example, beaches have been in existence long before people started using them for leisure. Seagulls that live near a beach area used to make use of the natural food sources that the shoreline provides. Those natural food sources are an important part of their fundamental niche. Today, people often offer food to seagulls. This food is typically not healthy for the birds. The birds now spend their time 'begging' food from people. This unhealthy food is now a part of the realized niche of seagulls.

Skill: Use of a transect to correlate the distribution of plant or animal species with an abiotic variable

A transect is a method of sampling a type of organism along a straight line. The length of the line should vary in an environmental factor expected to be important to the organism sampled.

Subject vocabulary

niche a function within an ecosystem (an insectivore is an example)

competitive exclusion (principle) the ecological principle that states that two species who share an identical niche cannot both survive in the same spatial habitat

transect straight line along which measurements are made at regular intervals during an ecological study

General vocabulary

flourish survive and grow well

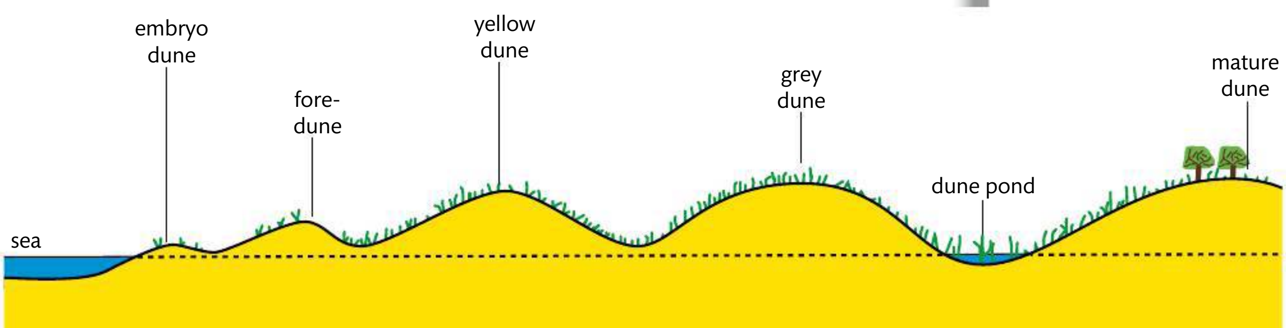


Figure 14.3 *The figure shown shows a possible transect line (dotted line) that starts at a shoreline and runs on top of the various dune types that eventually lead to a mature dune. One of the factors expected to vary amongst the various dune types is pH of the soil. In order to do this study, a researcher would choose length intervals along the transect line and then collect two pieces of data at each interval. One would be the pH of the soil at that location and the other would be a count of the number of a particular organism. A plant species would be an appropriate type of organism to study by this technique. Alternatively, a line of traps could be used to study the distribution of animal species along the transect*

C.2 Communities and ecosystems

Understanding: Most species occupy different **trophic levels** in multiple **food chains**.

Model sentence: Most species have a diet that includes many types of food and thus they fit into multiple food chains at different trophic levels.

A food chain shows a possible transfer of food (energy) along a single set of organisms. The following is an example food chain:

grass ⟶ rabbit ⟶ rattlesnake ⟶ eagle

The arrows within the food chain show the transfer of energy from one step of the food chain to the next. In this food chain each organism can be given a trophic (feeding) level. A photosynthetic organism (grass) is always **trophic level 1**. This level can also be called the **producer** for the food chain. The rabbit in this food chain is **trophic level 2** or primary consumer. The snake is **trophic level 3** or secondary consumer. Finally, the eagle is **trophic level 4** or tertiary consumer.

Each food chain only represents one possible set of events. For example, the eagle may directly eat the rabbit. In that shorter food chain, the eagle would be on trophic level 3 and would be a secondary consumer. This shows that real life is much more complicated than shown by a single food chain.

Subject vocabulary

trophic levels the position of an organism in a food chain

food chain one possible set of feeding relationships starting with a producer

producer a photosynthetic organism that starts a food chain

food web a figure showing all of the feeding relationships in a community

Synonyms

trophic level 1	producer
trophic level 2	primary consumer
trophic level 3	secondary consumer
trophic level 4	tertiary consumer

Understanding: A **food web** shows all the possible food chains in a community.

Model sentence: A more realistic view of the feeding relationships in a community is by way of interconnecting all possible food chains in a diagram called a food web.

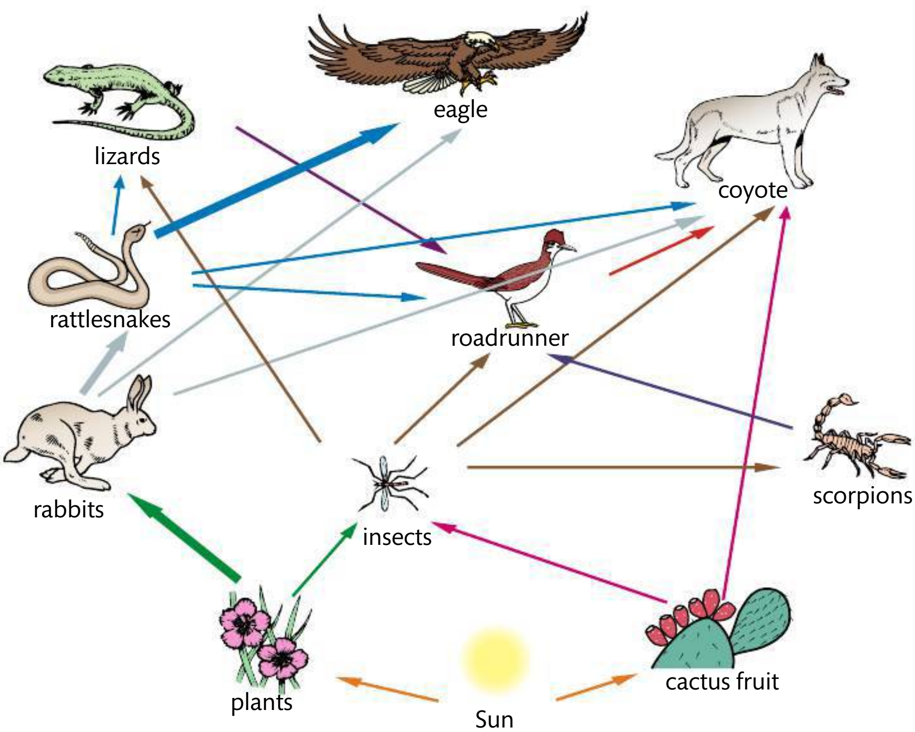


Figure 14.4 *This figure shows a food web for a desert community. Notice that there is more than one food source for many of the organisms. Any one 'food path' that one follows starting at one of the producers will ultimately end at a top predator. The top predators shown in this food web are the eagle and the coyote. Notice that producers have no arrows leading to them (except energy from the Sun) and top predators have no arrows leading away from them*

Understanding: The percentage of ingested energy converted to biomass is dependent on the respiration rate.

Model sentence: In living organisms, the amount of food that gets converted to biomass depends on how much energy is lost by cell respiration.

Food provides energy to animals. Animals use that energy for body movements and many physiological processes in their bodies. The specific process that provides energy for things like body movements is cell respiration.

Food chains always begin with a producer. The producer uses photosynthesis to store energy in the form of carbohydrates. Plants respire to produce energy for processes inside of their cells. Thus, for a plant we can use this simple formula to calculate their energy totals:

$$\text{energy from gross production} - \text{energy used for respiration} = \text{net energy production}$$

Where:

gross production is the energy that plants create from photosynthesis

A similar idea is valid for animals when they eat food. The amount of energy used by cell respiration is subtracted from the energy from the food they eat. The difference can be used to add to the biomass of the organisms.

Each step of a food chain is not very efficient for transferring energy. Much of the food that is eaten is lost as energy or waste. A typical number used to estimate energy transfer from one step of a food chain to the next is 10%. In other words, 10% of the energy from food goes into increasing the biomass of the next step of a food chain. This idea is often represented by a pyramid of energy as shown below.

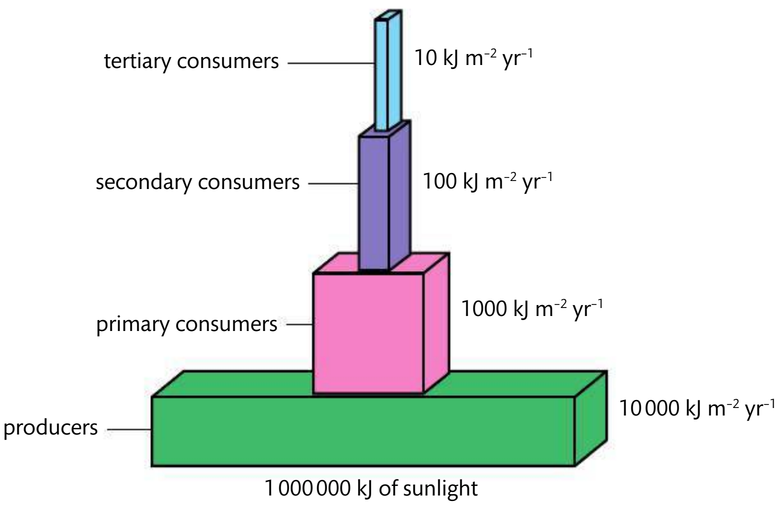


Figure 14.5 *A pyramid of energy (not drawn to scale)*

Skill: Comparison of pyramids of energy from different ecosystems

When comparing two or more pyramids of energy, look for the efficiency of the transfer of energy at each step. As mentioned earlier, an estimate that can be used is a 10% energy transfer at each step. That estimate can vary based on the type of ecosystem and the trophic level that is being compared.

Application: Conversion ratio in sustainable food production practices

A feed conversion ratio is a mathematical calculation of how efficiently an animal converts food into body mass. This is especially important for farm animals that are raised for food. The lower the feed conversion ratio (FCR), the more efficient the animal is in converting its food into body mass.

Subject vocabulary

ingested food/substances taken into the body

biomass the mass of all organisms of a particular category of organisms, e.g. the mass of all producers for a food chain

respiration rate a measurement of cell respiration per unit mass per unit time

gross production the total energy plants produce by photosynthesis

pyramid of energy a graphic representation of the energy flow through a food chain

feed conversion ratio a calculation of how efficient an animal is in converting food into body mass

Understanding: The type of stable ecosystem that will emerge in an area is predictable based on climate.

Model sentence: Stable ecosystems called biomes form based on climate differences in various parts of the Earth.

The major biomes on Earth

Biome	Type of climate
desert	high temperatures low rainfall
grassland	low elevations seasonal low and high temperatures varying rainfall
coniferous forest	slightly warmer than tundra low rainfall
temperate forest	seasonal low and high temperatures high rainfall
tropical forest	high temperatures high rainfall
tundra	high elevations low temperatures low rainfall

Skill: Analysis of a climograph showing the relationship between the temperature, rainfall, and the type of ecosystem.

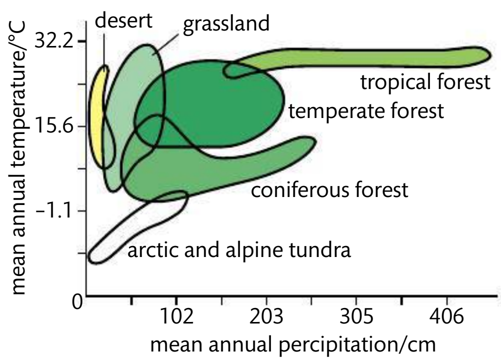


Figure 14.6 *This graph is called a climograph. You can use it to predict the type of biome that will exist in an area based on **mean** annual temperature and mean annual **precipitation***

Subject vocabulary

biome an ecosystem that forms due to a combination of temperature and rainfall in that area

climograph a graph that plots annual precipitation versus annual temperature and shows the predictable biomes that exist based on those two factors

General vocabulary

coniferous having leaves like needles and producing seed-containing cones

temperate never very hot or very cold

Synonyms

mean............. average

precipitation .. rain, snow, dew

matter........... material

Understanding: In closed ecosystems energy but not matter is exchanged with the surroundings.

Model sentence: Ecosystems that are closed off to the outside world require an outside source of energy but do not exchange matter with their surroundings.

No natural ecosystem on Earth is completely closed off to the outside world. There are some that come close, as is the case with small islands, for example.

In a closed ecosystem there is still a need for an input of energy. This energy typically comes from light. The light energy is used for photosynthesis. This allows food chains in the closed system to have one or more producers.

Application: Consideration of one example of how humans interfere with nutrient cycling

One might consider the entire Earth to be a closed system. In fact, we refer to the parts of Earth where living organisms can live as the **biosphere**. Within this huge closed system, a variety of substances are constantly being recycled. One of those substances is carbon. Remember that carbon is the basis of all organic molecules and therefore is of great importance to living things.

Humans are currently causing serious problems for the cycling of carbon. Much of the harm caused is a result of mining carbon-based fuels and then burning them. This is resulting in a slow, but ever increasing amount of carbon dioxide in our atmosphere. The implications of this increase in carbon dioxide in the atmosphere are just beginning as Earth's global temperature rises as a result.

Skill: Construction of Gersmehl diagrams to show the inter-relationships between nutrient stores and flows within and between biomes

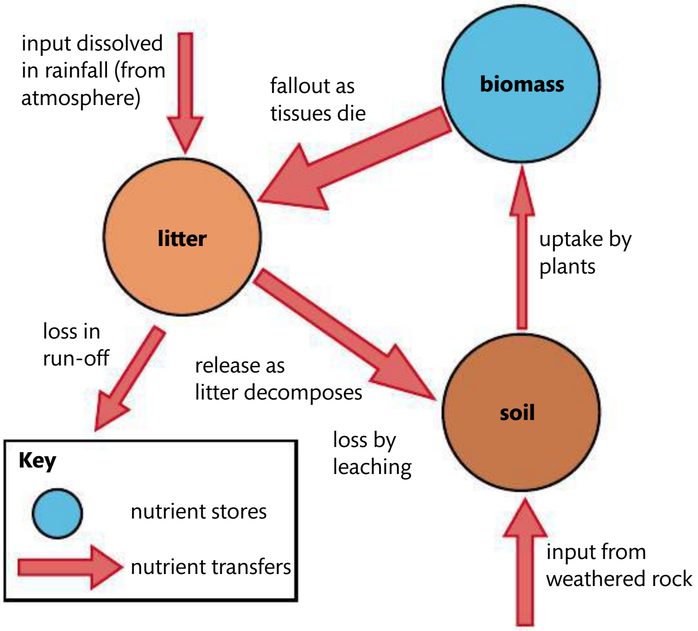


Figure 14.7 *This is a Gersmehl diagram showing mineral nutrient cycling of an ecosystem. The circles show the main storage of a nutrient that is being studied. The size of the circle shows how much of the nutrient is being stored in that form. The arrows show transfer or loss of the nutrients. The width of the arrow shows how much of the nutrient is being transferred or lost*

Understanding: Disturbances influence the structure and rate of change within ecosystems.

Model sentence: When an ecosystem is disturbed, the disturbance changes the structure and rate of change of the ecosystem.

An ecosystem that has been in existence and reasonably stable for a very long period of time is called a **mature ecosystem**. A mature forested ecosystem will typically be dominated by a certain species of tree. The entire forest may be very similar because this tree species is dominating the available light and soil resources.

Occasionally, a mature ecosystem experiences a major disturbance such as a forest fire. If this is a major fire, all of the dominant trees may be burned off in a large area. Without those trees to dominate the available light and soil resources other species of plants begin to **colonize** the area.

Subject vocabulary

biosphere all areas on and in Earth where living organisms exist

Gersmehl diagram diagram showing nutrient stores and cycling within or between ecosystems

mature ecosystem an ecosystem that has been in place for a very long period of time and is no longer undergoing major changes

Synonyms

disturbance.... interruption

General vocabulary

colonize organisms that first come to live in an area

Subject vocabulary

succession a series of changes that occur within an ecosystem as it progresses towards becoming a mature ecosystem

primary succession succession beginning with new land

lava rock in hot liquid form that emerges from volcanoes

secondary succession succession that occurs when an existing ecosystem is disrupted by a major disturbance and soil is already present

alien species a species that is introduced into an ecosystem

competitive exclusion (principle) the ecological principle that states that two species who share an identical niche cannot both survive in the same spatial habitat

Synonyms

diversity .... wide range

endemic species .... native species

The description above is called **succession**. Succession leads to a series of changes that eventually will give rise to the same mature ecosystem each time. There are two main categories of succession:

- **Primary succession** is the series of changes that occur when new land is formed. An example of this is when a volcano makes an island larger by flowing **lava** into the sea. This new land has no soil and will take a very long period of time to establish a **diversity** of life.
- **Secondary succession** is the series of changes that occur after a major disruption to an existing ecosystem. The situation described above with an area burned by a forest fire is an example. Because there is already soil and perhaps some remaining living things, this type of succession is much more rapid than primary succession.

C.3 Impact of humans on ecosystems

Understanding: Introduced **alien species** can escape into local ecosystems and become invasive.

Model sentence: Plants and animals that are not native to an area are sometimes introduced and result in a permanent breeding population.

There are numerous examples of species that have been brought to an area and have established a breeding population in that area of the world. Sometimes the introduction is done by accident and sometimes on purpose. For example, pet owners have released their pet python snakes in the Florida Everglades in recent times. It is thought that the pythons became too large to keep as pets. These pythons have formed breeding populations in the Everglades and thus have become an invasive species. They compete with the alligators and other top predators of the area for prey.

Hints for success: You may be asked to describe a local example of an invasive species. Be sure to research a species of plant or animal that has been released in your area and has established itself.

Understanding: **Competitive exclusion** and the absence of predators can lead to reduction in the numbers of **endemic species** when alien species become invasive.

Model sentence: Invasive species can reduce the numbers of endemic species due to competition and absence of predators.

The pythons that are now breeding in the Florida Everglades have no natural predators. Ecological principles state that other top predators, such as the Florida alligator, will be in competition for food.

The description above is a classic example of the competitive exclusion principle. This principle states that two species that share a common niche cannot survive in the same ecosystem. One of the two will be eliminated from the ecosystem due to 'losing' the competition for a common resource.

Understanding: Pollutants become concentrated in the tissues of organisms at higher trophic levels by biomagnification.

Model sentence: Biomagnification explains how pollutants become more concentrated in the tissues of organisms at the top of food chains.

Most pollutants that are released into an ecosystem are in very low concentrations. One example is the insecticide DDT. DDT use is primarily to kill mosquitoes, but at one time DDT was used to spray on crops to kill a wide variety of insects. Run-off from rainwater made its way into many rivers, lakes, and saltwater estuaries. DDT in the environment is very long lasting as it is not biodegradable.

The smallest living organisms in a food chain are often microscopic. In an estuary, these very small organisms are collectively called plankton. The water that the plankton were in only contained a very small amount of DDT. This was taken into the cells of the plankton. Larger plankton organisms eat smaller plankton organisms. This helped to concentrate the DDT in the larger plankton. Very small fish often eat the larger plankton organisms. When they do eat plankton, they eat many. This concentrates the DDT even more in the small fish. Larger fish eat many smaller fish, once again increasing the concentration. Finally, top predators, such as osprey, pelicans, and eagles eat many of the larger fish. These top predators receive the highest concentration of DDT.

Unfortunately for each of these birds, the effect was to damage their calcium metabolism. This resulted in thinner than normal eggs. These thin eggs often were crushed when the birds tried to incubate them. The ultimate effect was a severe population decline of these birds as very few young birds were hatched (born). It was not until many areas banned the use of DDT that these bird populations recovered.

This example shows how a pollutant makes its way through the trophic levels of a food chain. At each step, the pollutant becomes more concentrated. This effect of becoming more concentrated is called biomagnification.

Application: Discussion of the trade-off between control of the malarial parasite and DDT pollution

The parasite that results in the disease called malaria is spread from person to person by mosquitoes. The best way to prevent malaria is to control mosquito populations. Malaria kills over 1 million people each year worldwide.

Mosquito populations are most effectively controlled by the use of DDT. In areas of the world such as parts of Africa and Indonesia, there is on-going debate over the use of DDT to help control cases of malaria. There is no easy answer to this problem. If DDT is used, biomagnification will result in severe ecological damage. If DDT is not used, people will continue to die of malaria.

Hints for success: You may be asked to discuss a topic such as use of DDT to control malaria. When doing so, be sure to give points that support both possible sides of an issue. If you only give your opinion you will not receive full marks.

Subject vocabulary

pollutants substances released into an ecosystem that have the potential to do harm

biomagnification increasing concentration of a pollutant as the pollutant moves up through the trophic levels of a food chain

DDT a non-biodegradable insecticide that has created problems in areas of the world in which it has been utilized

plankton small organisms at or near the bottom of marine food chains

calcium a mineral necessary for healthy bird eggs

General vocabulary

run-off water that makes its way into rivers, lakes, and other bodies of water

biodegradable able to be broken down by bacteria or in other natural ways

estuary a marine environment where a river also adds fresh water

incubate keep eggs warm until the young are born

Synonyms

trade-off........ balance

Subject vocabulary

macroplastics plastic items larger than 5 mm

microplastics plastic items smaller than 5 mm

ingesting taking food/substances into the body

indicator species an organism that is very sensitive to one or more changes in its ecosystem

Synonyms

debris............ rubbish/waste

accumulated .. built up

contaminate... pollute

General vocabulary

degrade break down into a simpler form

Understanding: Macroplastic and microplastic debris has accumulated in marine environments.

Model sentence: Large and small plastic items have accumulated in saltwater environments.

Any item that is made of plastic will not degrade in the environment for a very long period of time. It is estimated that a plastic bottle that is carelessly disposed of in an ecosystem will still be in one piece more than 400 years later. Ecologists classify plastic pollutants into two categories based on their size:

- Macroplastics are relatively large items made of plastic. This includes anything larger than 5 mm. Bottles, toys, dinnerware, etc., made of plastic are all considered a macroplastic item.
- Microplastics are plastic items smaller than 5 mm. Some of these are broken off from macroplastic items and some were originally created in a small form. Microplastics created in a small form are frequently from facial cleaning products.

Both macroplastics and microplastics are damaging to living organisms in marine environments.

Example 1: Laysan albatross

Adult birds often look for available food on the water surface. Sometimes they mistake floating plastic objects as food. In addition, the adult bird often returns to the nest and provides the plastics as food to the young birds on a nest. Both adult and young birds can die from ingesting items made of plastics.

Example 2: sea turtles

Sea turtles often eat jellyfish as a food source. When a sea turtle encounters a plastic bag floating in the water, they easily confuse it for a jellyfish. After swallowing the plastic bag the digestive system of the animal becomes blocked and death often occurs.

C.4 Conservation of biodiversity

Understanding: An indicator species is an organism used to assess a specific environmental condition.

Model sentence: An environmental problem is often first noticed when there is a decline in the population of an organism called an indicator species.

Many different types of organisms can act as indicator species. What all indicator species have in common is that they are all very sensitive to one or more changes in their ecosystem. When an environmental problem begins these organisms are some of the first to be affected by the change. Here are two examples:

Example 1: frogs

Frogs have many ways of taking chemicals into their bodies. They breathe air with possible pollutants. They eat prey animals that may already contain a pollutant. They drink water that may be contaminated. Additionally, they take chemicals directly through their moist skin. Biologists have learned to monitor frog populations for possible environmental problems associated with freshwater ecosystems.

Example 2: lichen

A lichen is a mutualistic relationship between an algae and a fungus. Lichens grow best in areas with good air quality. It is very rare to see lichen growth in large cities with air pollution problems. For this reason, lichens are good indicator organisms for air quality problems.

Understanding: Relative numbers of indicator species can be used to calculate the value of a biotic index.

Model sentence: A biotic index is a number that can be calculated by using relative numbers of indicator species in one area.

One ecosystem may contain many indicator species. Each indicator species may be sensitive to one or several environmental problems. Each species may also have its own sensitivity to an environmental problem.

A good example is a freshwater stream. In some freshwater streams, these three organisms can be used to calculate a biotic index:

- mayfly larvae – very sensitive to water quality problems
- dragonfly larvae – reasonably sensitive to water quality problems
- blackfly larvae – not very sensitive to water quality problems.

To create a biotic index, one would first count the number of each of these organisms in an area. Each type of organism would be given a number based on its sensitivity to water quality. The mayfly larvae would receive the highest number because they are the most sensitive to water pollution. Dragonfly larvae would receive the second highest number and blackfly larvae the lowest number. The count of each organism is then multiplied by its sensitivity number. A sum of all the resulting numbers is then made.

The sum is a type of biotic index. The higher the biotic index, the better the water quality. The biotic index has two ways of becoming high:

- having larger numbers of organisms counted
- having larger numbers of the sensitive organisms counted.

Understanding: *In situ* conservation may require active management of nature reserves or national parks.

Model sentence: Maintaining natural populations in nature reserves or national parks is called *in situ* conservation and sometimes requires human intervention.

There are large and small nature reserves and national parks all over the world. Most of these are areas of land set aside for plants and animals to live a life with minimal human intervention. A few reserves and national parks have been set up in marine environments.

Plants and animals cannot live as nature intended if humans are building roads, homes, and businesses. The type of conservation that sets aside natural areas for plants and animals to live is called *in situ* conservation. In most instances these areas are not large and independent enough to remain completely untouched from humans. For that reason, they require human intervention at times.

Subject vocabulary

lichen a growth that is composed of a fungus with algae growing within

mutualistic relationship relationship between two organisms in which both are helped

biotic index a calculation based on numbers of environmentally sensitive organisms in an ecosystem

***in situ* conservation** maintaining populations of plants and animals in their natural setting with minimal human intervention

Subject vocabulary

***ex situ* conservation** preservation of a species outside of its natural environment

captive breeding animals bred while being kept in a zoo or other wildlife facility

seed banks facilities designed for long-term storage of seeds

biogeographic term indicating both location (geography) and living (bio) organisms

species diversity a measurement of the number of different species

General vocabulary

elevation height above sea level

mid-range at or near a half-way point

Understanding: *Ex situ* conservation is the preservation of species outside their natural habitats.

Model sentence: Where species are kept alive outside of their natural habitats this is called *ex situ* conservation.

There are situations where it is not possible to maintain a species in its natural environment. The following situations often lead to *ex situ* conservation:

- habitat destruction may have already occurred to the point where a species cannot survive in its natural environment
- a population may be so small that breeding is either unlikely or genetic diversity cannot be maintained
- protection of the species can best occur in an environment outside the natural environment of that species.

The following are examples of *ex situ* conservation methods:

- captive breeding of some species of animals
- growing of plant species in botanic gardens
- long-term storage of seeds in seed banks.

Application: Case study of the captive breeding and reintroduction of an endangered animal species.

The California condor (*Gymnogyps californianus*) is a very large species of vulture that is native to the southwestern area of the United States. California condor numbers dramatically declined in the early 1900s due to habitat destruction, hunting, and chemical poisoning. By 1987 the population had declined to a total of 22 birds. All 22 birds were captured and added to birds held at two zoos in California where captive breeding programmes were underway. Thus, in 1987, California condors became extinct in the wild.

The captive breeding programme proved successful and by 1991 condors were being reintroduced back into wild habitats.

Understanding: Biogeographic factors affect species diversity.

Model sentence: The number of species and the relative abundance of each is affected by both biological and geographic factors.

The following geographic factors have an influence on species diversity:

- Distance from equator: land areas near the equator tend to have the highest species diversity. This simply means that there will be a greater number of species in areas near the equator. As you move north or south of the equator species diversity tends to decrease.
- Elevation: the greatest number of species tends to be at a mid-range of elevation. Species diversity increases until a midpoint in elevation is reached and then it declines after that.
- Size of habitat: larger habitats can support more organisms and they can also support greater species diversity. Some habitats are true islands and others can sometimes be thought of as islands. If a habitat is physically separated from other habitats (like lakes and ponds) then the ecosystems they support work like a true island. Since larger habitats have greater biodiversity, larger 'islands' also tend to have greater biodiversity.

- Edge effect: the edge effect is due to areas where two different kinds of habitat border each other. A classic example is where a forest borders a grassland area. Some species specialize in using this 'edge area' as habitat or as a source of food. The edge effect tends to increase biodiversity as it increases the number of species in an area.

In summary, the greatest species diversity would be found in a relatively large area, near the equator, and at a midpoint in elevation within that area.

Understanding: Richness and evenness are components of biodiversity.

Model sentence: Biodiversity is a combination of how many species live in an area and the relative abundance of each species.

There are two components of biological diversity:

1. **Richness** – this is the number of different species that live in an area.
2. **Evenness** – this is the relative abundance of each species in an area.

The table below compares the number of species of larvae at two ponds.

Larva species	Number of individuals in sample 1*	Number of individuals in sample 2*
caddisfly larvae	200	20
dragonfly larvae	425	55
mosquito larvae	375	925
total	1000	1000

*Sample 1 and sample 2 are larvae counts taken at two different ponds.

Notice that both ponds have three species of larvae. Thus, the two ponds would have the same richness of larvae. Also notice that the two counts are identical in total number of larvae. Note that the sample taken from pond 2 is dominated by mosquito larvae. This shows that pond 2 has very low evenness. A community is not considered diverse if it is dominated by one species.

Skill: Analysis of the biodiversity of two local communities using Simpson's reciprocal index of diversity

The biodiversity of an ecosystem can be calculated through a formula called the Simpson's reciprocal index of diversity. The formula takes into account both the richness and evenness of species. The formula is:

$$D = \frac{\text{sum of } n(n - 1)}{N(N - 1)}$$

Where:

D = Simpson reciprocal index of diversity

N = total number of organisms in the ecosystem

n = number of individuals of each species

Subject vocabulary

richness a measurement of the number of different species living in an area

evenness a measurement of the relative abundance of each species in an area

larva (plural: larvae) an immature form of an insect species

Simpson reciprocal index of diversity a calculation that indicates biodiversity of an ecosystem taking into account both richness and evenness

C.5 Population ecology

Subject vocabulary

sampling technique counting a sample of a total number of organisms in order to calculate an estimate of a total population

quadrat an area of land marked off in order to count or study the organisms within

density number of organisms per area

random number generator a mathematical tool that will pick random numbers from a set

sample part of a whole

Synonyms

stationary ...... non-moving/ sendentary

General vocabulary

disperse spread out

humane showing compassion or consideration

Understanding: Sampling techniques are used to estimate population size.

Model sentence: Populations of organisms that are too large or difficult to directly count can be estimated by sampling techniques

Two common types of sampling technique are:

- quadrat counting
- capture–mark–release–recapture.

Quadrat counting works well for stationary organisms such as plants. The organism chosen should show a fairly equal density throughout the area to be counted. The entire area to be counted is marked off and subdivided into many equal sized parts. These equal sized parts are called quadrats. A reasonable number of quadrats is decided upon in order to count the number of organisms within. A random number generator is used in order to decide the identity of the quadrats to count. After the sample quadrats are counted, the mean number of organisms per quadrat is calculated. The mean number of organisms per quadrat is then multiplied by the total number of quadrats. The resulting number is an estimate of the total population in the area.

Example: quadrat counting

A landowner wants to estimate how many black cherry trees are found on his very large forested property. The trees are reasonably equally dispersed and quite plentiful. The property is a rectangle measuring 12 km long and 10 km wide. Using GPS co-ordinates, the property is divided into 120 equal sized quadrats. The landowner decides to count the number of trees in 8 of the 120 quadrats. A random number generator is used to identify the 8 quadrats and they are counted. The total number of trees in those 8 quadrats turns out to be 176 black cherry trees.

Mean of 22 trees per quadrat × 120 total quadrats = 2640 estimated trees

Application: Use of the capture–mark–release–recapture method to estimate the population size of an animal species

This capture–mark–release–recapture method of estimating the size of a population works well for some animals. The technique involves capturing a sample of the animal population to be estimated. The animals are temporarily marked in a humane way in order to be identified later. The animals marked are released back into their habitat. Time is given for the animals to disperse. After that period of time, a second sample of animals is captured. It is expected that some, but not all, of this second capture will be marked. The following formula is then used:

$$N = \frac{n_1 \times n_2}{n_3}$$

Where:

N = estimated population size

n_1 = number marked in the first capture

n_2 = number caught in the second capture

n_3 = number marked in the second capture

Example: capture–mark–release–recapture method

An estimate is needed for the number of soft-shell turtles in a pond. A researcher uses a net to capture 10 turtles. Each of the turtles is marked with a small amount of fingernail polish on their shell. The turtles are all released back into the pond. A day later, the researcher nets 15 turtles. Of those 15 turtles, 4 of them have marked shells. The estimate would be:

$$\text{Estimate of turtles} = \frac{(10 \times 15)}{4}$$

= 38 turtles (rounded to nearest whole number)

Understanding: The **exponential growth** pattern occurs in an ideal, unlimited environment

Model sentence: An organism introduced into a suitable environment will show an exponential growth pattern if an environment is ideal with unlimited resources.

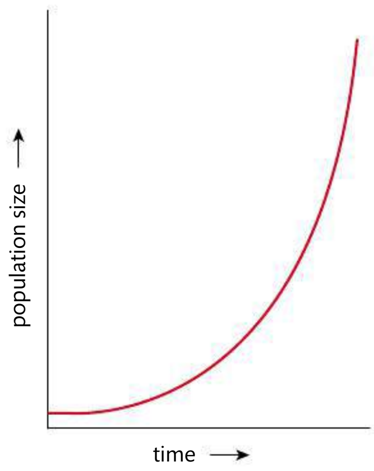


Figure 14.8 *This graph shows a population of organisms that is experiencing exponential growth. The population was introduced into a new environment at time = 0. No slowing of the rate of growth is evident*

The exponential growth pattern is only shown in nature under a rare set of conditions. First, this must be an organism introduced into a new and ideal environment. The environment must have plenty of resources for the organism. Resources may include food, sunlight, locations to live, and many other possibilities. The resources must be so plentiful that the organism itself is not competing for any of the needed resources.

This ideal situation is not sustainable forever. Some organisms may show exponential growth for a long period of time, but eventually one or more limiting factors will begin to slow the rate of growth. You will explore what happens when limiting factors do influence the growth rate in the following section.

Subject vocabulary

exponential growth growth of a population in which the number of individuals being added is proportional to the number already present

Subject vocabulary

carrying capacity an environment's ability to support an organism's population based on resource availability and other factors

sigmoid having a shape like the letter 'S'

logistic growth a pattern of population growth that follows a sigmoid shape due to increasing density of the population

Synonyms

scarce............ limited

General vocabulary

fluctuates a value that rises above and falls below a set value

Understanding: Population growth slows as a population reaches the carrying capacity of the environment.

Model sentence: Rate of growth of a population will begin to slow as conditions begin to approach the carrying capacity of the environment.

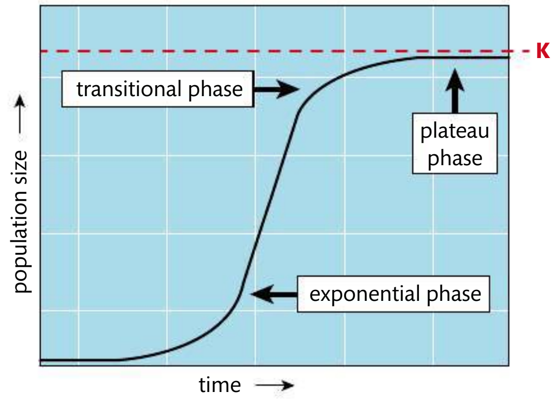


Figure 14.9 *Graph showing the overall pattern and phases of logistic growth. Imagine an organism introduced into an ideal environment at time = 0. Notice that the overall pattern has the shape of the letter 'S'. This graph shape is called sigmoid. The three phases and the line shown at 'K' will be explained in following sections*

The logistic growth curve has three phases:

- Exponential phase: the first phase of logistic growth is called the exponential phase. This phase begins when an organism first enters a new and suitable environment. The conditions and circumstances for this phase were described in the previous section of this text. Population rate of growth is very high due to ideal conditions.
- Transitional phase: one or more resources is beginning to become scarce as the population increases. One or more predators may be slowing the population rate of growth. Population density is becoming high enough that spread of disease may have become a problem. Notice that growth is continuing, but the rate of growth has slowed during this phase.
- Plateau phase: competition for resources and possibly other limiting factors have led to a zero growth rate. Notice that the number of organisms is as high as ever, but the rate of growth is zero. This does not mean that no new individuals are being produced. The graph simply shows that the total number of individuals in this environment is stable.

When a population is within their plateau phase of logistic growth, it is said that they have reached the carrying capacity of that environment. The carrying capacity is shown by the dotted line in the figure above labelled as 'K'. There are enough resources to support that number of individuals, but no more. In reality, a population that has reached the carrying capacity of an environment fluctuates a little above or below the carrying capacity as time progresses.

Skill: Modelling the growth curve using a simple organism such as yeast or species of *Lemna*

Start a population of yeast growing in a suitable culture medium. Alternatively, you could start with a small sample of duckweed (*Lemna*) in a container of water under light. Either approach should show population numbers characteristic of logistic growth over a suitable period of time.

Understanding: The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration, and emigration.

Model sentence: Relative rates of natality, mortality, immigration, and emigration explain the various phases of the logistic growth curve.

As described in the previous section, logistic growth has three phases:

- exponential – very high growth rate in population
- transitional – growth rate beginning to slow
- plateau – growth rate has slowed to zero (population has peaked).

The rate of growth in each of these phases is ultimately determined by the rate of these four factors:

- natality – the birth/hatching rate
- mortality – the death rate
- immigration – the rate of organisms moving into an area
- emigration – the rate of organisms moving out of an area.

Application: Discussion of the effect of natality, mortality, immigration, and emigration on population size

Natality and mortality have an opposite effect on a population's growth rate. Immigration and emigration also have an opposite effect on a population's growth rate. One way a population can reach its plateau phase is for natality and mortality to be equal and immigration and emigration to also be equal. Your class might want to have a discussion on what happens to a population when one or more of these factors increase or decrease.

Population growth rate = (natality – mortality) + (immigration – emigration)

Understanding: Limiting factors can be top down or bottom up.

Model sentence: Limiting factors determine the carrying capacity of an environment and can be top down or bottom up.

Consider a population of organisms that shows a population growth curve as shown below.

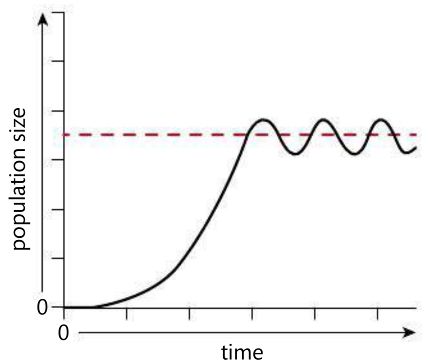


Figure 14.10 *Population showing logistic growth. Notice that when the population begins its plateau phase the population size begins to **fluctuate** a little above and below the carrying capacity*

General Vocab

fluctuate move back and forth

This population shows logistic growth. Notice that once the population has reached the plateau phase (carrying capacity of that environment), the population size does not typically follow a perfect straight line for number of individuals. A pattern begins where sometimes the population is slightly above the carrying capacity and sometimes below. The reason is the top-down and bottom-up limiting factors that are influencing the population size at any given time.

Top-down limiting factors affect food chains by determining mortality rates due to predation and disease. For example, if a population of mice was to exceed the carrying capacity, this would attract more predators of mice. In addition, disease spread among the mice would be more likely.

Bottom-up limiting factors are due to limitations placed on resources when populations begin to exceed the carrying capacity. These resources may be food or habitat availability.

Application: Bottom-up control of algal blooms by shortage of nutrients and top-down control by herbivory

In some locations, grass fertilizers containing nitrogen and phosphate run off into lakes and ponds. This often begins what is called an algal bloom. An algal bloom is when the growth of algae in a body of water becomes very rapid. This leads to an unhealthy body of water for the other organisms. The control of algal blooms can be achieved in two ways:

1. Limit the amount and timing of fertilizers applied to lawns and shrubs. For example, some locations ban the sale and use of fertilizers during their 'rainy seasons' in order to limit the fertilizer run-off.
2. Stock the body of water with fish species that eat algae. This will help keep the algae under control through herbivory.

Application: Evaluating the methods used to estimate the size of commercial stock of marine resources

Marine resources are all of those foods and other useful items that humans take from our oceans. This includes many species of fish and also other marine organisms that we eat and use for a variety of purposes. These resources are not unlimited. There are many species of marine organisms that humans have already had an impact on *n* a negative way. One approach is to determine a **maximum sustainable yield** (MSY) for each species that is harvested. The MSY is the maximum number of each population that can be removed without impacting on the population size for the future.

Because the oceans are so massive, a variety of methods are used to estimate the current size of each organism at any given time. These estimation methods include:

- asking fishermen to collect data on their catch
- direct observation by government agents on fishing vessels
- monitoring fish populations by **sonar devices**
- **tagging** fish for capture–mark–release–recapture data
- studies on ages of fish that are caught:
  - too few young fish may mean problems with **spawning**
  - too few old fish may mean overfishing is occurring.

Each of these techniques gives nothing more than an estimate of the current state of a population's size.

Subject vocabulary

yield maximum number of each (fish) population that can be removed without affecting the yield for the future

tagging applying a tag (sometimes electronic) that allows an animal to be identified at a later time

General vocabulary

sonar device a device that works by way of a sound echo

spawning producing large amounts of eggs at the same time

C.6 Nitrogen and phosphorus cycles

Understanding: Nitrogen-fixing bacteria convert atmospheric nitrogen to ammonia.

Model sentence: Some bacterial species convert nitrogen from the atmosphere into ammonia.

Like many other substances, the element nitrogen is cycled through ecosystems. At any given time most nitrogen on our planet is found in the atmosphere. This form of nitrogen is N_2, also known as **diatomic** nitrogen gas. The forms of nitrogen that are useful to plants are ammonia (NH_3) and nitrates (NO_3^- compounds). The conversion of N_2 into compounds such as ammonia and nitrates is called nitrogen fixation.

Many of the conversions of one form of nitrogen substance to another is achieved by specific types of bacteria most often found in soil. The first step in converting N_2 in the atmosphere into another form is accomplished by nitrogen-fixing soil bacteria and results in the formation of ammonia. Some plants can take in ammonia and further metabolize it to make useful nitrogen-containing organic compounds.

Other bacteria can convert ammonia into compounds known as nitrites. Still other soil bacteria can then convert the nitrites into nitrates. This process of converting ammonia into nitrites and nitrates is called nitrification. The process of **nitrification** requires oxygen and occurs best in soils that are well **aerated**. Often, it is these nitrates that plants use as their source of nitrogen in order to synthesize amino acids, nucleotides, and other nitrogen-containing compounds.

Subject vocabulary

diatomic molecule consisting of two atoms of the same element

nitrification bacterial process of converting ammonia into nitrites and nitrates

Rhizobium type of nitrogen-fixing bacteria that forms a mutualistic relationship with legumes

mutualistic relationship relationship between two organisms in which both are helped

legumes a plant grouping that includes beans, peas, and clover

nodules growths on the roots of legumes where *Rhizobium* bacteria live

General vocabulary

aerated containing air

associates forms a relationship with

Synonyms

decomposes… decays

Understanding: *Rhizobium* associates with roots in a mutualistic relationship.

Model sentence: In some plants, the bacterium *Rhizobium* forms a mutualistic relationship with the plant.

Some plants form a mutualistic relationship with a bacterium known as *Rhizobium*.

One group of plants known to form this relationship are the **legumes** that include beans, peas, and clover. The *Rhizobium* bacteria live in outgrowths on the roots of the plant. These outgrowths are called **nodules**.

Rhizobium are nitrogen-fixing bacteria and provide nitrates to the plant. In turn, the plant provides carbohydrates and a suitable environment for the bacteria to grow. Thus, both species benefit. Other plants also benefit as the nitrates often remain in the soil when the legume dies and **decomposes** into the soil.

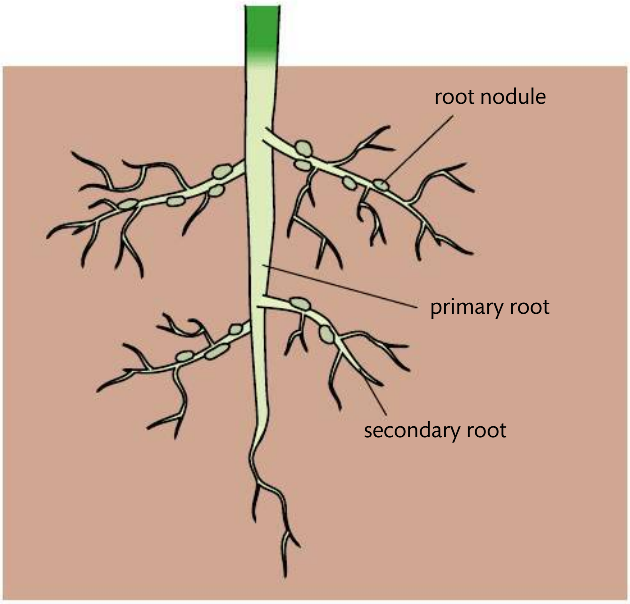


Figure 14.11 *The root of a legume showing the enlargements known as nodules. It is within these nodules that* Rhizobium *lives*

Subject vocabulary

denitrifying bacteria bacteria that reduce nitrates back into atmospheric nitrogen under low oxygen conditions

aerobic an environment with good oxygen availability

anaerobic an environment with poor (or no) oxygen availability

denitrification the process of converting nitrates into nitrites and atmospheric nitrogen

waterlogged soil soil where all of the air spaces are filled with water

General vocabulary

insectivorous insect eating

adaptation(s) change(s) which make(s) something more suitable for a situation

Understanding: In the absence of oxygen, **denitrifying bacteria** reduce nitrate in the soil.

Model sentence: If there is no or little oxygen present, denitrifying bacteria convert nitrates in the soil to nitrites and atmospheric nitrogen.

Hints for success: Be able to draw and label a flowchart showing the major events of the nitrogen cycle as shown in the figure below.

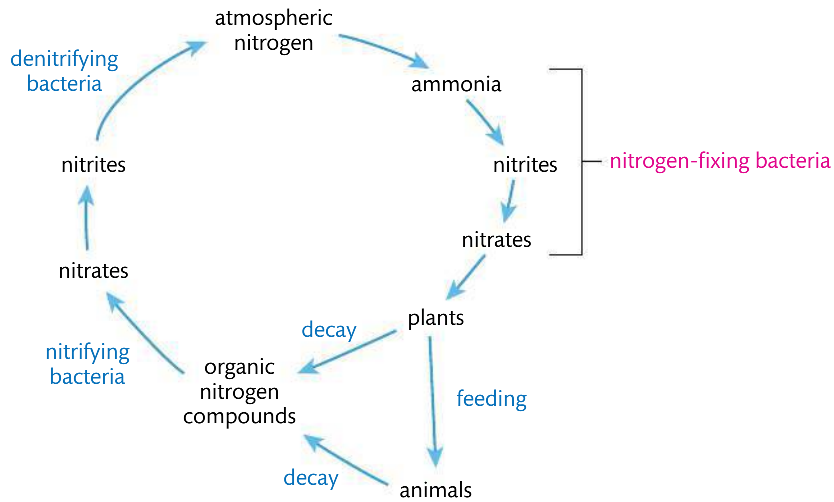


Figure 14.12 *Flow chart showing the nitrogen cycle. Notice that nitrogen truly does follow a cycle. The majority of nitrogen at any given time is within the atmosphere. Any nitrogen that becomes 'fixed' into nitrogen compounds useful for living organisms will eventually be returned to the atmosphere*

Plants use nitrates as a source of nitrogen for a variety of molecules including amino acids and nucleic acids. These nitrogen-containing molecules then either become a part of a food chain if an animal eats the plant (or an animal eats an animal that ate the plant) or the plant dies and decays into the soil. Eventually, the animals in the food chain will also die and decay. Either way, this returns the nitrogen compounds back into the soil.

If the soil has good oxygen availability (**aerobic** conditions), nitrifying bacteria will produce nitrates from the organic nitrogen compounds released from decay. If the soil is low in oxygen (**anaerobic** conditions), another group of bacteria will act on the nitrates in a process called **denitrification**. The process of denitrification will convert nitrates to nitrites and finally return the nitrogen back to the atmosphere.

Application: The impact of waterlogging on the nitrogen cycle

When soil becomes too wet and stays that way for an extended period of time, the level of oxygen in the soil becomes very low. As you have seen, anaerobic conditions favour denitrification of the nitrogen cycle. This means the low oxygen conditions will favour the production of atmospheric nitrogen from nitrates and nitrites in the soil. As a result **waterlogged soils** tend to have very low useful nitrogen levels.

Application: Insectivorous plants as an adaptation for low nitrogen availability in waterlogged soils

You may have heard of a plant called the Venus flytrap. This plant was named because of its ability to trap insects. The plant uses the insects as a source of nitrogen as the plant often grows in nitrogen and phosphorus poor soils. The Venus flytrap is a plant and photosynthesizes like any other plant. The trapping of insects is simply an **adaptation** for life in a soil that cannot support most plant species.

Understanding: Phosphorus can be added to the phosphorous cycle by application of fertilizer or removed by the harvesting of agricultural crops.

Model sentence: Fertilizers containing phosphorus are frequently made from phosphorus removed from ground deposits, and when agricultural crops are harvested that phosphorus is effectively removed from future use.

Although phosphorus does cycle through ecosystems, the cycle is extremely slow. Almost all reserves of phosphorus are contained within **marine sediments**. There are only a few places on Earth where these sediments can be economically mined from ground deposits.

The most common use for mined phosphorus is to make fertilizers for agricultural use around the world. The phosphorus is removed from the soil by plants in order to make phosphorus containing organic molecules such as DNA, RNA, ATP, and phospholipids. When the plants are harvested the phosphorus is removed as molecular parts of the plant. A farmer has no choice but to add additional phosphorus fertilizer in order to grow a new crop.

Subject vocabulary

marine sediments the slow deposit of a variety of substances on the ocean floor

United States Geological Survey (USGS) a science organization that provides impartial information on the health of Earth's ecosystems and environment

General vocabulary

turnover the continuous process of loss and replacement of something

reserves a location where something is kept for future use

Understanding: The rate of **turnover** in the phosphorous cycle is much lower than the nitrogen cycle.

Model sentence: The phosphorus cycle is a much more time consuming cycle as compared to the nitrogen cycle.

As mentioned in the previous section, most phosphorus is contained within marine sediments. These sediments become buried under further sediments for incredibly long periods of time. The only economical way that large quantities of phosphorus can be mined is when a previous ocean floor area becomes uplifted to become dry land.

The nitrogen cycle in comparison can be a relatively fast cycle. The change from atmospheric nitrogen to the various forms of nitrogen produced by nitrogen-fixing bacteria is a wide-scale and ongoing process.

Understanding: Availability of phosphorous may become limiting to agriculture in the future.

Model sentence: Growing of agricultural crops relies on availability of limited phosphorus and this may become more of a problem in the future.

Because so much of Earth's phosphorus is contained within hard to access marine sediments, the availability of phosphorus is a limited resource at any given time. The **United States Geological Survey (USGS)** currently estimates that we will run out of phosphorus available in currently known **reserves** in about 80 years.

Subject vocabulary

leaching removal of mineral nutrients such as phosphorus and nitrogen compounds from soils by dissolving in rainwater and run-off

eutrophication term used to describe a body of water that has experienced an algal bloom due to fertilizer run-off and the resulting oxygen depletion

algal bloom very rapid increase in the algae population of a body of water

biological oxygen demand the oxygen required by aerobic organisms in a body of water, for metabolism

Understanding: **Leaching** of mineral nutrients from agricultural land into rivers causes **eutrophication** and leads to increased biochemical oxygen demand.

Model sentence: Rainwater run-off dissolves mineral nutrients from agricultural land leading to eutrophication and increased biochemical oxygen demand in rivers and other bodies of water.

Farmers need rain to provide water for their crops. One of the negative consequences of rain is the leaching of mineral nutrients from the soil. Leaching is where phosphate and nitrogen compounds become dissolved in the rainwater. This rainwater does not always stay in the soil, sometimes it runs off into nearby bodies of water. The phosphate and nitrogen compounds are taken with the water run-off. This not only lessens the mineral nutrients in the soil, but it also may greatly increase the mineral nutrient content of the river, lake, or sea, negatively affecting water quality.

This is what happens when phosphate and/or nitrogen mineral nutrients leach into a body of water:

- High nitrates and phosphates fertilize the algae in the body of water.
- There is a rapid increase in growth of algae (called an **algal bloom**).
- This rapid increase is not sustainable for long.
- Aerobic bacteria begin to decompose the overgrowth of algae using up much of the available oxygen in the water (this is called a high **biological oxygen demand** or high BOD).
- The body of water becomes very low in oxygen and organisms such as fish die as a result.

The term used to describe this effect of fertilizer run-off on bodies of water is eutrophication.

D.1 Human nutrition

Understanding: Essential nutrients cannot be synthesized by the body, therefore they have to be included in the diet.

Model sentence: **Those nutrients that cannot be synthesized by the body are called essential nutrients and must be part of our diet.**

The term essential is often used for something that is important. When it comes to our diet, the term 'essential' has a very specific meaning. Something essential in our diet must be a part of our diet or a health problem will eventually result. Your body has a metabolism that allows it to make (or synthesize) some nutrients from other nutrients when needed. That is not true for all nutrients, however. Those that cannot be synthesized and must be within the foods that we eat are called essential nutrients.

Understanding: Dietary minerals are essential chemical elements.

Model sentence: **Minerals in the diet are chemical elements that are essential.**

Perhaps you have read on a food product **nutrition label** the percentage of daily iron, calcium, or magnesium contained in a serving of that food. These three are examples of the **essential minerals** we must include in our diet. Each essential mineral is used for specific biochemical purposes. The body is very good at **recycling** minerals, but that recycling is not perfect. Therefore, we always need to include small amounts of essential minerals in the foods that we eat.

Some common minerals and some of their uses within the body:

- calcium – bone growth and repair
- magnesium – activation of many enzyme reactions
- iron – important component of **haemoglobin**.

Understanding: Vitamins are chemically diverse carbon compounds that cannot be synthesized by the body.

Model sentence: **Vitamins are a diverse group of organic molecules that are essential in our diet.**

Unlike minerals, vitamins are organic compounds. Like minerals, we only need very small quantities of vitamins on a daily basis. There are many different types of vitamins and each is used for one or more specific purposes. A well-balanced diet should include all of the vitamins necessary for good health. Vitamins are synthesized by living organisms and a diet with numerous fruits and vegetables should provide all one needs.

Subject vocabulary

essential nutrient nutrient that must be included in our diet

nutrition label a packaging label found on many food products listing amounts of a variety of ingredients

essential mineral elemental substance needed in our diet

haemoglobin a protein found in red blood cells used to carry oxygen in the blood

vitamins organic compounds needed in small amounts in our diet

General vocabulary

recycling make use of something more than once

diverse showing a great deal of variety

Application: Production of ascorbic acid by some mammals, but not others that need a dietary supply

Ascorbic acid is also known as vitamin C. Many animals can produce their own vitamin C as part of their metabolism. This is not true for humans and just a few other animal species. Thus, ascorbic acid is an essential vitamin for humans. It is not an essential vitamin for those animals that can synthesize it. Humans who do not consume any source of vitamin C for a long period of time develop a serious disease caused scurvy. At one time, scurvy was a common disease among sailors who went on **voyages** for many months and did not carry foods containing ascorbic acid.

Understanding: Some fatty acids and some amino acids are essential.

Model sentence: There are some fatty acids and some amino acids that cannot be synthesized by the body.

In Chapter 2, you learned that there are a variety of types of fatty acids within **triglycerides** and **phospholipids**. Two fatty acids are essential in our diets. Remember that the term essential does not imply importance; essential means that our body cannot synthesize the molecule from another molecule. The two that are essential are called **omega-3** and **omega-6 fatty acids.**

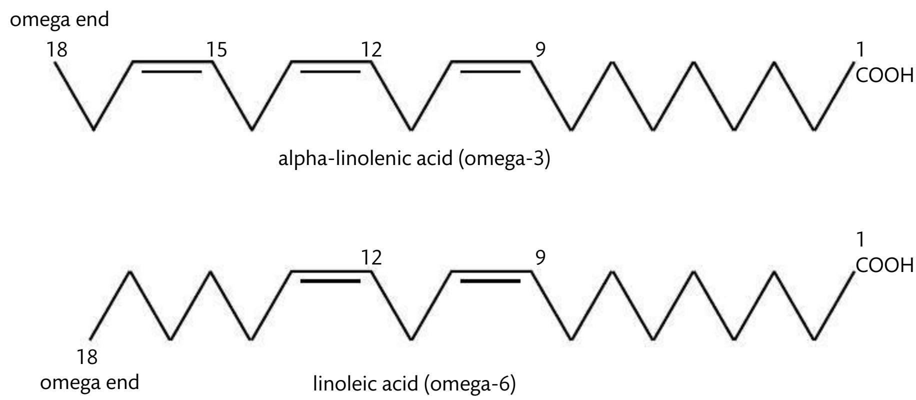


Figure 15.1 *The two essential fatty acids shown in abbreviated form. Carbon number 1 is the carbon of the carboxyl group. Each angle change after that represents a carbon atom. Carbon atoms with double bonds are shown, and the first is numbered. Each carbon in the chain would have an appropriate number of hydrogens to make four bonds around each. The carbon on the far left of each structure is called the omega carbon. Counting from the omega carbon, you can easily see why these fatty acids are called omega-3 and omega-6, respectively. There is no reason to memorize these structures*

Application: Cholesterol in blood as an indicator of the risk of coronary heart disease

Cholesterol is a lipid substance needed in the body for a variety of reasons. Unfortunately, many people have cholesterol levels circulating in their blood stream that are too high. This can create long-term health problems within their blood vessels.

Over time, many people develop deposits on the inside of their arteries called **plaque**. One of the components of plaque is cholesterol. As these deposits begin to get larger, the inside of the blood vessel has less room to carry blood. One of the locations in the body where this can occur is in the arteries that carry oxygenated blood directly into heart muscle. These arteries are called coronary arteries. Build-up of plaque deposits in coronary arteries is called coronary heart disease or CHD. When one or more of the coronary arteries can no longer carry a sufficient amount of blood into the heart muscle a heart attack results. People are encouraged to monitor their cholesterol levels in their blood as high cholesterol levels are an indicator for possible coronary heart disease.

General vocabulary

voyage long journey by ship

Subject vocabulary

triglycerides fats or oils formed from three fatty acids and a glycerol molecule

phospholipid a type of lipid molecule that occurs in a bilayer to make up cell membranes

omega-3 fatty acid a fatty acid that has a double bond starting at the third carbon from the omega end of the molecule

omega-6 fatty acid a fatty acid that has a double bond starting at the sixth carbon from the omega end of the molecule

plaque build-up of cholesterol and other substances on the inner wall of arteries or biofilm on the surface of teeth

As you may remember, there are 20 different amino acids within proteins. We need all 20, but we are capable of synthesizing only 11 of the 20. That means that 9 amino acids are essential in our diets. Obtaining these 9 essential amino acids is typically not a problem for someone who eats a variety of protein sources.

Understanding: Lack of essential amino acids affects the production of proteins.

Model sentence: Protein synthesis is affected if one or more essential amino acids is not included in the diet.

There are 20 types of amino acids. As you learned earlier, 9 of the 20 must be included in the diet. Anyone that regularly eats a variety of foods that contain protein will be getting all 20 different types. When their own cells are synthesizing proteins, there should be enough of each type of amino acid available.

In some areas of the world, people sometimes use a single crop as their primary protein source. One example is corn or maize. Maize is lacking in two essential amino acids, lysine and tryptophan. Researchers are working on new breeds of corn that have increased levels of lysine and tryptophan.

Understanding: Malnutrition may be caused by a deficiency, imbalance, or excess of nutrients in the diet.

Model sentence: Deficiencies, imbalances, or excesses of one or more nutrients in the diet can result in malnutrition.

Nutrition problems are collectively called malnutrition. There are three situations in which malnutrition can occur. Here are examples of all three:

1. Deficiency of one or more essential nutrient(s): it is obvious that as a person grows, their skeleton must grow as well. Most of the growth occurs at the ends of bones in areas called bone plates. When either vitamin D or the mineral calcium is not available, this growth does not occur in a normal way. Instead the ends of the bones become irregularly shaped and unusually thick. In children, this is a condition called rickets. The legs of children with rickets grow to become highly bowed inward or outward. They will never achieve their full potential height. Adults who do not consume enough vitamin D or calcium develop a condition called osteomalacia. Their bones become soft, and bowing and fracturing are more likely.

2. Imbalance of one or more essential nutrient(s): as mentioned above, some people live in areas of the world where food variety is a problem. Their source of protein may be primarily from a single type of crop. In this situation, one or more of the essential amino acids may be lacking.

3. Excesses of nutrient(s): obesity is a major health concern in many countries. There are many health conditions that are correlated with obesity. What is considered excess for one person may not be an excess for another. An example is shown in the following application.

Subject vocabulary

malnutrition an unhealthy condition due to insufficient, excessive, or unbalanced consumption of nutrients

rickets abnormal bone growth in children due to a deficiency of vitamin D or calcium or both

osteomalacia a condition leading to bone softening in adults due to a deficiency of vitamin D or calcium or both

Synonyms

deficiency ...... shortage/absence

bowed .... curved/bent

Subject vocabulary

phenylketonuria (PKU) a genetic disease leading to the inability to metabolize a single amino acid (phenylalanine)

appetite the desire to eat

hypothalamus a region of the brain that controls pituitary gland secretions and other autonomic functions

autonomic functions involuntary or unconscious functions

leptin hormone produced by body fat that lowers the appetite

anorexia an eating disorder where people eat very little in order to achieve what they perceive as an 'ideal' (too thin) body image

hypertension high blood pressure

type II diabetes a form of diabetes where one develops a resistance to the normal function of insulin

Application: Cause and treatment of phenylketonuria (PKU)

Some children are born with the inherited disease known as phenylketonuria or PKU. These children are unable to metabolize the amino acid phenylalanine because they lack the enzyme to do so. If left untreated phenylalanine will build up in their bloodstream and cells. This creates a toxic situation leading to mental deficiencies, behavioural problems, and seizures. In areas of the world where good medical care is available, it is common for all children to be tested for PKU right after birth. If the test is positive, the child is given protein sources that are low in phenylalanine. A diet that contains proteins known to be relatively low in phenylalanine is the only known treatment for PKU.

Understanding: Appetite is controlled by a centre in the hypothalamus.

Model sentence: An area of the brain called the hypothalamus contains a control centre for one's appetite.

The hypothalamus is in an area of your brain called your brainstem. Your brainstem, including the hypothalamus, controls activities that we call autonomic. These are activities that are controlled at the unconscious level.

After you eat a meal, there a variety of signals that provide your hypothalamus with information. For example:

- The swollen condition of your stomach full of food results in nervous system impulses being sent to the hypothalamus.
- The intestines and pancreas produce hormones that provide information to the hypothalamus.
- Adipose (fat) tissue produces a hormone called leptin that provides information to the hypothalamus.

The hypothalamus uses this information to reduce your appetite. All of this is occurring without your conscious knowledge and that is typical of brainstem actions.

Application: Breakdown of heart muscle due to anorexia

Anorexia is an eating disorder characterized by having an 'ideal' body image that is far too thin. The body image desired by someone with anorexia is too thin for proper health. Sometimes the greatly restricted diet is accompanied by a desire to exercise excessively. People who suffer from this eating disorder are not receiving the correct amount and type of essential nutrients. Many systems of the body are negatively affected. The heart is no exception. Without an adequate intake of protein for amino acids and other essential substances, the heart begins to get smaller and weaker over time. Successful treatment for the eating disorder can save a life in this instance.

Understanding: Overweight individuals are more likely to suffer hypertension and type II diabetes.

Model sentence: People who are overweight are more likely to develop hypertension and/or type II diabetes.

Hypertension is also called 'high blood pressure'. People with hypertension place a strain on both their heart and arteries as a result of the increased pressure. There are many factors that can contribute to hypertension and some of those are not controllable. Examples are age and genetic background. One factor that is controllable for most people is their body mass index or BMI. Your BMI is a calculation of body mass corrected for height. High BMI values have been positively correlated with hypertension.

Another health problem that has been positively correlated with high BMI is type II diabetes. People are not born with type II diabetes, they develop the disease at some point in their life. People with this disease do not **metabolize** glucose as they should within their cells. This is because their body cells have developed a **resistance** to the hormone insulin. Under normal circumstances, insulin is the hormone that adds plasma membrane channels that allow glucose to enter the cell. When channel proteins no longer respond to insulin properly, glucose is not able to enter cells and stays in the bloodstream.

Understanding: Starvation can lead to breakdown of body tissue.

Model sentence: Body tissues are digested when a person is starving.

Earlier you read about some health conditions that result when a specific nutrient is out of balance in the diet. But what happens when almost no nutrients are available? The answer is that the body begins to make use of its own stored nutrients.

You probably have seen photographs of people who are experiencing starvation conditions. They often appear as is they have very little to no muscle. This is because they have used their own **skeletal muscle** as a source of amino acids to make other proteins. The muscle is still there but has become so thin that it is hardly noticeable.

D.2 Digestion

Understanding: Nervous and hormonal mechanisms control the **secretion** of **digestive juices**.

Model sentence: Digestion of foods requires the secretion of digestive fluids controlled by the nervous and endocrine systems.

Digestion is a chemical process that requires various **glands** to secrete specific substances. These fluids are necessary in order to convert the relatively large molecular nutrients that we **ingest** into smaller molecular forms that can be absorbed into our blood stream. Many of the chemical reactions that occur are hydrolysis reactions that you studied in Chapter 2.

It would be wasteful and possibly harmful to have digestive secretions within the stomach and intestines all of the time. Therefore, there are **mechanisms** that the body uses in order to recognize when various secretions are needed.

Some of these mechanisms are under the control of your **nervous system**. Simply seeing, smelling, or thinking about food may trigger a nervous system response that begins some digestive secretions. Another system of your body that is involved is your **endocrine system.** The endocrine system includes all of your glands that secrete hormones into your bloodstream. You will learn about two of the hormones that help control stomach secretions in a later topic of this unit.

Subject vocabulary

metabolize to perform metabolism

resistance the inability of a tissue to respond normally to a chemical such as a hormone

skeletal muscle muscle that is used to move bones

secretion release of a substance from a cell, tissue, or gland

digestive juices fluid secretions that chemically aid the digestive process

digestion a chemical process whereby large molecules undergo reactions in order to become a molecular size that can be absorbed into the blood

ingest take food/substances into the body

nervous system system of the body that includes your brain, spinal cord and various nerves for communication with body tissues

endocrine system system of the body that includes all those glands that produce hormones secreted into the bloodstream

General vocabulary

gland an organ of the body which produces a substance

Synonyms

mechanism .... way/process

Subject vocabulary

exocrine gland a gland that secretes a substance into a duct for transport

lumen area within surrounding walls or membranes; usually used for the cavity of a tubular structure such as a blood vessel

duct a small tube

endocrine gland a gland that produces a hormone

gastric secretions fluid secreted into the stomach by cells of the stomach

autonomic nervous system that portion of your nervous system that controls unconscious activities

oesophagus tube of the alimentary canal that connects the mouth to the stomach

gastric pit small and numerous exocrine glands located in the inner wall of the stomach

pepsinogen an inactive form of a protein-digesting enzyme secreted into the lumen of the stomach

mucus a protective secretion produced by certain cells of the body including cells of the stomach

Synonyms

gut................ alimentary canal

cavity............ space (within)

General vocabulary

pit-like shaped like a small cave or pit

Understanding: Exocrine glands secrete to the surface of the body or the lumen of the gut.

Model sentence: Exocrine glands secrete substances either to the body surface or the interior of the gut.

Exocrine glands do not secrete into the blood. Instead, they secrete into a small tube called a duct. The duct takes the secretion to a specific location in the body for use. The ducts for some exocrine glands take the secretion to the surface of the body. Other exocrine glands take their secretions to the interior cavity of the gut. This interior cavity is called the lumen. Here are some examples of exocrine glands:

Exocrine gland	Secretion	Duct takes secretion to
lacrimal (tear) glands	tears	outer surface of each eye
sweat glands	sweat	surface of the skin
gastric glands	gastric fluid for digestion	lumen of the stomach
pancreas	pancreatic fluid for digestion	lumen of the small intestine

Note: the pancreas is also an endocrine gland as it produces hormones as well.

Hints for success: The two types of glands mentioned in this section have similar sounding names: exocrine and endocrine. Spend some time matching the names with the type of gland that the name applies to. Remember that exocrine glands secrete into a duct and endocrine glands secrete into the bloodstream.

Understanding: The volume and content of gastric secretions are controlled by nervous and hormonal mechanisms.

Model sentence: The nervous and endocrine systems control the volume and content of secretions into the stomach lumen.

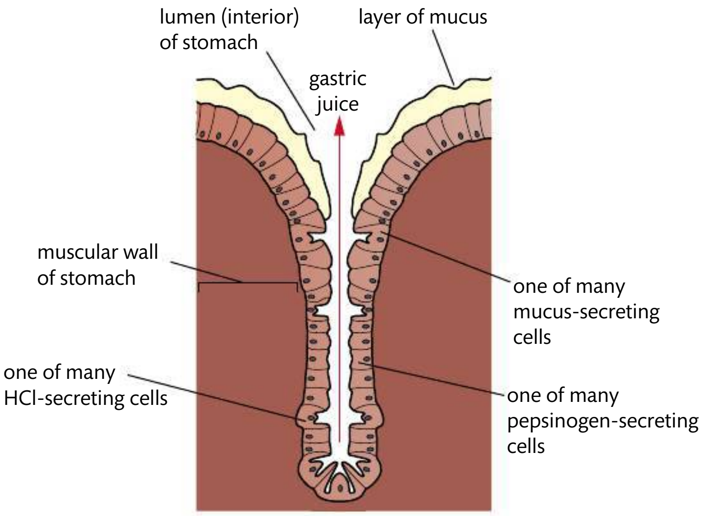


Figure 15.2 *One of the many gastric pits located in the inner lining of the stomach. Each pit is shared by each of the glandular cell types creating and secreting one of the components of gastric juice (hydrochloric acid, pepsinogen, or mucus). Note the thin duct leading to the lumen of the stomach; the presence of this duct qualifies each of these pits as an exocrine gland*

Even before you eat, your nervous system is preparing your gut for food. Even thinking about food may result in your autonomic nervous system sending signals to begin saliva and gastric juice secretions. After being swallowed, food goes through a tube called the oesophagus. The oesophagus takes the food to the stomach where it remains for a period of time.

Within the stomach are numerous very small exocrine glands called gastric pits. Each of these pit-like structures is lined with cells that secrete a substance into the lumen of the stomach. These secretions include hydrochloric acid, a protein digesting enzyme (pepsinogen) and mucus. Collectively, this fluid is called gastric fluid. The food that enters the stomach is mixed with this fluid. Muscle layers of the stomach create a churning motion in order to mix the food with the gastric fluid.

The nervous system impulses mentioned earlier that are being sent to the stomach also result in some stomach cells releasing a hormone. This hormone is called **gastrin**. Gastrin enters the bloodstream and makes its way to the cells in the gastric pits. This results in the production of even more gastric juice. Eating a full meal results in the stomach swelling. This results in a nervous system impulse being sent to the brainstem. The brainstem then sends impulses for even more gastric juice. Thus, the volume of gastric juice depends on the amount of food in the stomach.

Application: *Helicobacter pylori* infection as a cause of stomach ulcers

Stomach ulcers were once thought to be a result of stress. The thinking was that stress caused excess **hydrochloric acid** to be secreted. It was assumed that the excess acid both caused and irritated the ulcer. In the early 1980s, two researchers found a species of bacteria (*Helicobacter pylori*) in the stomach wall of ulcer patients. It surprised researchers, as up to that point everyone assumed no living thing could survive in this highly acidic environment. Ulcer patients who are successfully treated with antibiotics show that it was damage from the bacteria that was the cause of the ulcer.

Understanding: Acid conditions in the stomach favour some hydrolysis reactions and help to control **pathogens** in ingested food.

Model sentence: The hydrochloric acid secreted into the stomach helps prevent food poisoning and provides a favourable chemical environment for some hydrolysis reactions.

As mentioned in the previous section, hydrochloric acid is a component of gastric juice. This creates a very acidic environment within the lumen of the stomach. One benefit to this is that pathogens are often destroyed by stomach acid. We refrigerate many foods to keep bacteria and fungi from multiplying, but the majority of foods that we eat still contain many of these microorganisms.

A second benefit is the chemical environment provided by the acid. In the previous section, you learned that a protein hydrolysing enzyme called pepsinogen was a component of gastric juice. Pepsinogen is secreted as an inactive enzyme. Its structure is slightly modified when it enters an acidic environment and it becomes active. The active form of pepsinogen is called **pepsin**. Laboratory tests show that pepsin is most effective at digesting protein when at a low pH as provided by the stomach.

Application: The reduction of stomach acid secretion by proton pump inhibitor drugs

The highly acidic environment of the stomach can sometimes result in health problems. In a condition referred to as **acid reflux**, highly acidic gastric fluids irritate the inside wall of the oesophagus. An ulcer is a damaged area of the inside wall of the stomach or small intestine. The damage is made worse by the acid. Late in the 20th century, researchers developed a class of drugs called **proton pump inhibitors**. These drugs work by **inhibiting** the production of HCl by cells in the gastric pits. Healing of both acid reflux and ulcers is often possible, aided by the lowered production of acid.

Subject vocabulary

gastrin hormone produced by the stomach that leads to increased production of gastric juice

Helicobacter pylori species of bacteria that has been shown to be the cause of stomach ulcers

ulcer an open sore

pathogens disease-causing agents such as viruses and bacteria

food poisoning an illness that sometimes results when one eats food containing pathogenic organisms

pepsin the active form of a protein-hydrolysing enzyme in the stomach

acid reflux a painful condition caused by stomach acid irritating the lower portion of the oesophagus

proton pump inhibitors a class of drugs that result in gastric pit cells producing less hydrochloric acid

Synonyms

hydrochloric acid............... HCl

inhibiting....... preventing/reducing

Subject vocabulary

epithelium cell layer that often forms a covering or outer cell layer of a structure (formed of epithelial cells)

absorption the passage of molecules through membranes

villus (plural: villi) a small finger-like projection that extends into the lumen of the small intestine

microvillus (plural: microvilli) cell membrane projections that greatly increase plasma membrane surface area

ATP a molecule used for a source of chemical energy

active transport cellular transport requiring energy (ATP) from the cell

General vocabulary

adapted efficient for a particular purpose

projection something that protrudes or projects outwards

Understanding: The structure of cells of the epithelium of the villi is adapted to the absorption of food.

Model sentence: The cells of small projections called villi, found in the small intestine, are adapted for the absorption of digested food.

When partially digested food leaves the stomach it enters the small intestine. Digestion will continue, but another important process begins. That process is absorption. Absorption occurs when the macromolecules within foods have become small enough to be taken through the cells of the intestine and enter the bloodstream.

The interior lumen of the small intestine is not smooth. It is lined with millions of very small finger-like projections called villi. The presence of villi greatly increases the surface area for absorption. Each **villus** (singular) has epithelial cells that are in contact with the fluid in the lumen. Digested molecules must pass through these epithelial cells before entering the interior of a villus. Inside of each villus is a capillary bed for absorption of the nutrients into the bloodstream.

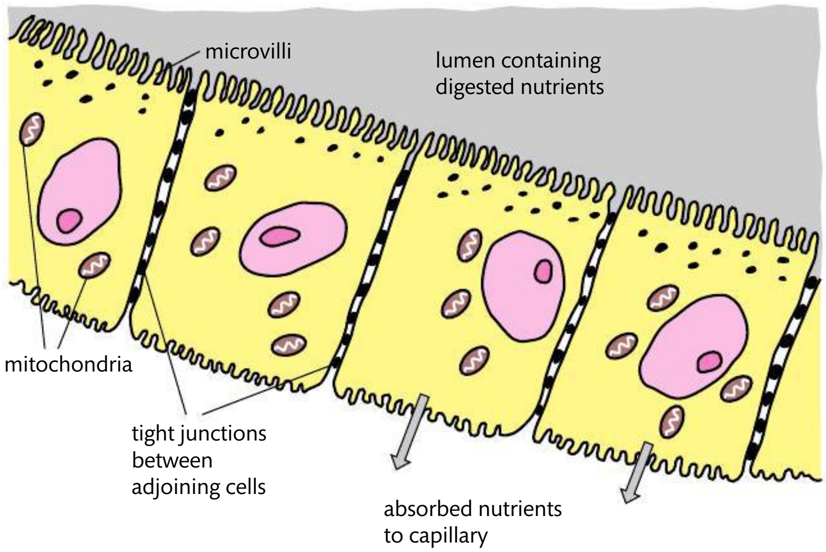


Figure 15.3 *Individual epithelial cells of a villus. Digested molecules must pass through these cells in order to reach a capillary bed*

Summary of villi epithelial cell adaptations for efficient food absorption:

- One side of the cell is in direct contact with digested molecules in the lumen of small intestine.
- Each villus cell has many cell membrane projections (**microvilli**) on that same side. This further increases the surface area for absorption.
- Epithelial cells are held tightly together by shared proteins. This is called a tight junction. This prevents undigested food from entering the villus without passing through a plasma membrane.
- Each villus has numerous mitochondria in order to provide **ATP**. Some molecules will be absorbed using an **active transport** mechanism.
- The inside of the cell is near to a capillary bed for absorption into the bloodstream.

Understanding: The rate of transit of materials through the large intestine is positively correlated with their fibre content.

Model sentence: Undigested foods move through the large intestine more efficiently when they contain a high fibre content.

Some natural foods that you eat have a relatively high fibre content. These foods typically come from a plant. This is because the highest components of fibre are cellulose and lignin. These two types of molecules are the largest components of plant cell walls. Therefore, whenever you eat any vegetable or fruit, you will be eating fibre.

The human digestive system does not produce any enzymes that digest cellulose or lignin. As a result, these two molecules pass through our gut relatively unchanged. Both are much too large to be absorbed through the villi of the small intestine. When each of these two molecules reaches the end of the small intestine they next enter the large intestine. The presence of a relatively high fibre content in the large intestine helps all of the solid waste to keep moving. This is considered to be healthy as solid waste (faeces) will not remain in the large intestine for as long a time period.

Application: Dehydration due to cholera toxin

Cholera is a disease caused by the bacterium *Vibrio cholera*. More specifically, cholera is a result of a toxin released by these bacteria. People typically become infected by drinking contaminated water. Often the water is contaminated with human or animal sewage. The toxin results in severe diarrhea. Prolonged diarrhea can lead to severe dehydration. The infection can be life threatening if not treated.

Understanding: Materials not absorbed are egested.

Model sentence: Solid wastes are egested as faeces.

The large intestine's primary function is to absorb water from the fluids that enter. The water content of the solid waste is much lower at the end of the large intestine as compared to the beginning. In addition, there are multitudes of bacteria that live within our large intestine. These bacteria are able to thrive given the water, warmth, and food material they are being provided. These bacteria provide a normal environment within the interior of our large intestine for us. They also produce vitamin K that we need for blood clotting purposes.

When the bacteria have finished acting on the waste and the water has been absorbed, the leftover material is called faeces. It is eliminated through our rectum in a process called egestion.

Synonyms

transit .... movement

Subject vocabulary

large intestine the final sections of the gut (much of the large intestine is often called the colon)

fibre food material that will not digest and cannot be absorbed

solid waste all of the undigested and unabsorbed substances in the gut

dehydration condition caused by losing more water than you are taking in

cholera a disease caused by a bacterium that results in severe diarrhea

diarrhea frequent loss of faeces in a very liquid form

egestion elimination of solid waste from our gut

vitamin K a vitamin produced by gut bacteria that is important for blood clotting

blood clotting a body response to minimize blood loss from small blood vessels

faeces solid waste from our gut

rectum the last portion of the large intestine

General vocabulary

contaminate to make something impure by the addition of a pollutant such as sewage

prolonged continuing for a long time

thrive grow/multiply well

D.3 Functions of the liver

Understanding: The liver removes toxins from the blood and detoxifies them.

Model sentence: When blood circulates through the liver, toxins are removed and are detoxified.

The human diet often contains many more toxins than most people are aware of. It is not uncommon for trace amounts of **pesticides** and **herbicides** to be included in and on some of the foods that we eat. Many people drink alcohol in beer, wine, and liquors. Each of these substances and many more are filtered out of our bloodstream by liver cells. These cells are called **hepatocytes.**

Hepatocytes also chemically alter toxins after filtering the substance from the blood. The chemical change results in the molecule becoming non-toxic. The resulting molecule is either used for a useful purpose or added back into the blood for eventual elimination by kidney filtration.

Subject vocabulary

toxin a poisonous substance

detoxify to chemically modify a toxin to make it harmless

pesticide poison used to treat pest infestations

herbicide a chemical that kills selected plant life

hepatocytes the most numerous cells making up liver tissue

bone marrow soft tissue which fills the inner, hollow spaces of certain types of bones

haemoglobin a protein found in red blood cells used to carry oxygen in the blood

haem group the non-protein portions of haemoglobin molecules

bilirubin a main component of bile

Understanding: Components of red blood cells are recycled by the liver.

Model sentence: Many of the molecules that make up red blood cells are recycled in the liver.

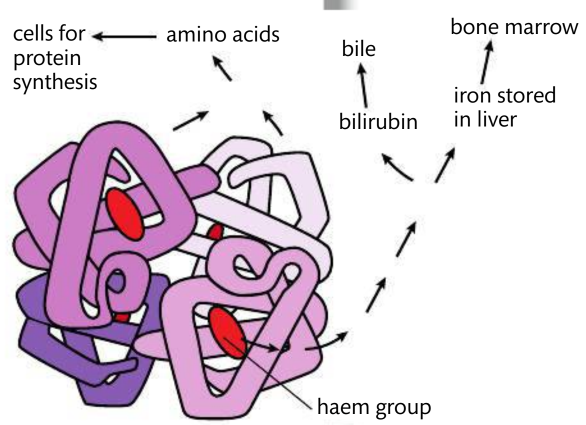


Figure 15.4 *The molecular components of haemoglobin are recycled when erythrocytes die after about 4 months*

Red blood cells are being continuously formed within our **bone marrow.** The reason for this is that red blood cells live for only about 120 days after being formed. Mature red blood cells have no nucleus. This limits their cellular life span. The body has developed chemical processes to ensure that components of these cells are recycled as much as possible. The liver is a key contributor to these processes.

Each red blood cell typically contains about 250 million **haemoglobin** molecules. This is a protein that binds to oxygen in the lungs and carries it to our tissues. When you consider that a human being has many trillions of red blood cells, you can see that recycling components of haemoglobin is very important.

In the figure shown above you can see a single haemoglobin molecule. This molecule is a large protein that is composed of four polypeptides. Each polypeptide contains a non-protein part near its centre called a **haem group.** Near the centre of each haem group is an iron atom. It is this iron atom that temporarily binds to an oxygen molecule in the lungs. The following events are all part of the recycling of haemoglobin within the liver:

- Each of the four polypeptides is hydrolysed into amino acids. The amino acids are returned to the blood for general body use.
- The iron is removed from each haem group and is sent to the bone marrow to be used for making new haemoglobin.
- The haem group is modified to become a molecule called **bilirubin**. Bilirubin is one of the main components of a substance called bile. Bile is produced by hepatocytes in the liver and sent to the small intestine to help in the digestion of lipids.

Understanding: The breakdown of erythrocytes starts with phagocytosis of red blood cells by Kupffer cells.

Model sentence: Kupffer cells within small liver blood vessels called sinusoids remove ageing red blood cells and haemoglobin by phagocytosis.

Very small blood vessels within the liver are lined by a type of white blood cell, called Kupffer cells. These cells specialize in removing red blood cells and haemoglobin from the blood by phagocytosis. Red blood cells are then lysed releasing haemoglobin within the Kupffer cell. Each haemoglobin is then chemically disassembled into its component parts. Some of the component parts are sent to the nearby hepatocytes for further modification and some are returned to the blood.

Understanding: Iron is carried to the bone marrow to produce haemoglobin in new red blood cells.

Model sentence: The iron that is removed from haemoglobin is sent to bone marrow so that new haemoglobin can be produced.

Iron is one of the most important components of haemoglobin to recycle. The iron that is removed from haemoglobin is sent by way of the blood stream to bone marrow. This is the location in the body where new red blood cells are formed. Our diet needs to include some iron each day. This is because the recycling of iron is not 100% efficient. In addition, any blood loss will not allow iron to be recycled and it will need to be replaced.

Figure 15.4 summarizes the recycling of haemoglobin that occurs in the liver. Haemoglobin is a large protein that is composed of four polypeptides. Each polypeptide contains a non-protein part near its centre called a haem group. Near the centre of each haem group is an iron atom. It is this iron atom that temporarily binds to an oxygen molecule in the lungs.

Understanding: Surplus cholesterol is converted to bile salts.

Model sentence: Bile salts are made from surplus cholesterol.

An important function of the liver is the production of a digestive secretion called bile. Bile is produced by hepatocytes in the liver. Bile can be stored in a sac called the gall bladder.

Ingested lipids are not water-soluble. Therefore, lipids tend to combine together to form lipid droplets within the lumen of the stomach and small intestine. The enzyme that digests lipids is called lipase. Lipase can only have access to the lipid molecules on the outside of a coalesced mass. This limits the rate of hydrolysis reactions catalysed by lipase. The function of bile is to emulsify lipids for faster digestion. Emulsification occurs when bile forces itself into a lipid mass and breaks it into smaller droplets. This increases the surface area to volume ratio and thus increases the rate of hydrolysis of lipids by lipase.

Bile has two primary components, bilirubin and bile salts. The formation of bilirubin was discussed in the previous section. The second component, bile salts, are formed in the liver from surplus cholesterol.

Subject vocabulary

Kupffer cell a type of white blood cell within sinusoids of the liver

sinusoids specialized capillaries found in the liver

phagocytosis active transport in which larger particles and substances are brought into the cell

lysed ruptured or broken open

hepatocytes the most numerous cells making up liver tissue

polypeptide polymer of many amino acids combined by peptide bonds

bile salts a component of bile made from cholesterol

gall bladder a storage sac for bile

lipase the enzyme that catalyses the hydrolysis of lipids into glycerol and fatty acids

emulsify to physically break a coalesced mass into smaller masses / droplets

General vocabulary

disassembled taken apart/ broken down

combine to add together to make a whole

droplets small drops

Understanding: Endoplasmic reticulum and Golgi apparatus in hepatocytes produce **plasma proteins**.

Model sentence: Hepatocytes produce some plasma proteins with the help of endoplasmic reticulum and Golgi apparatus within hepatocytes.

The liquid part of blood is called plasma. Plasma proteins are those proteins that circulate within this liquid. There are many types of plasma proteins, but we are going to focus on just two:

1. **Albumin**: this is a plasma protein that is used to help regulate the **osmotic balance** of the blood. In addition, albumin is used as a carrier molecule for bile salts and some other fat-soluble molecules.
2. **Fibrinogen**: this plasma protein is needed for blood clotting. When a blood vessel is damaged, a series of chemical events occurs. These events ultimately lead to fibrinogen being converted into **fibrin**. Fibrin forms mesh-like protein fibres that trap cells and various other substances. This forms a **blood clot**.

Cells that secrete substances typically contain a great deal of endoplasmic reticulum and Golgi apparatus. Each of these **organelles** creates a membrane (a vesicle) around a group of molecules. The vesicle created by the endoplasmic reticulum is transported to the Golgi apparatus. Within the Golgi apparatus, the protein may be modified. The Golgi apparatus then creates another membrane vesicle around the modified plasma proteins. This vesicle is transported to the inner surface of the plasma membrane. A process called exocytosis or secretion then occurs. See Chapter 1 for a more complete description of exocytosis.

Subject vocabulary

plasma proteins protein molecules that circulate within blood plasma

albumin a plasma protein that helps regulate the osmotic balance of the blood

osmotic balance two fluids that have equal solute and water concentrations

fibrinogen the inactive form of the blood-clotting protein called fibrin

fibrin the active form of fibrinogen that forms the mesh of a blood clot

blood clot a protein mesh that traps cells and other substances to help seal a damaged blood vessel

organelles non-cellular structures within a cell which carry out organ-like processes

hepatic portal vein a major vein that brings blood from the small intestine to the liver

hepatic artery a blood vessel that brings oxygenated blood to the liver

Understanding: The liver intercepts blood from the gut to regulate nutrient levels.

Model sentence: Blood from the villi of the small intestine is routed to the liver in order to help regulate nutrient levels.

In an earlier section you learned that inside of each villus of the small intestine there is a capillary bed. This capillary bed absorbs nutrients from digested foods. All of the capillary beds in all of the villi bring blood into a single vein. This vein is called the hepatic portal vein. The nutrient content of the blood in the **hepatic portal vein** varies greatly. This is because we eat different foods and at different times. Thus, nutrient absorption into the capillary beds within the villi varies greatly.

The hepatic portal vein brings this blood to the liver. The liver is then able to remove some of the nutrients from the blood. The blood that leaves the liver has a more stable nutrient level as compared to the blood that enters the liver through the hepatic portal vein.

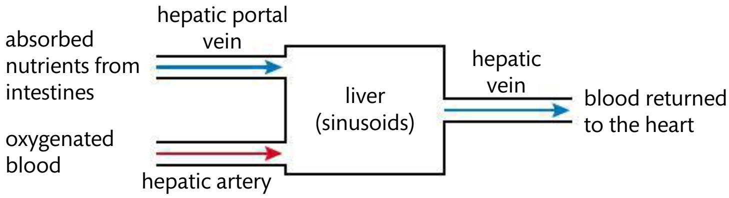


Figure 15.5 *A schematic showing the blood circulation pattern to and from the liver. Notice that the liver receives oxygenated blood from the* ***hepatic artery*** *in addition to the blood from the small intestine by way of the hepatic portal vein. This means that there are two major blood vessels sending blood to the liver but only one that takes blood away from the liver*

Understanding: Some nutrients in excess can be stored in the liver.

Model sentence: The liver stores some surplus nutrients.

One of the nutrients that is regulated by the liver is glucose. The liver is able to remove some of the excess glucose and store it. The liver stores it within hepatocytes. When the glucose enters a hepatocyte, the glucose is converted into a polysaccharide known as **glycogen**. It is common for hepatocytes to contain many vesicles filled with glycogen molecules.

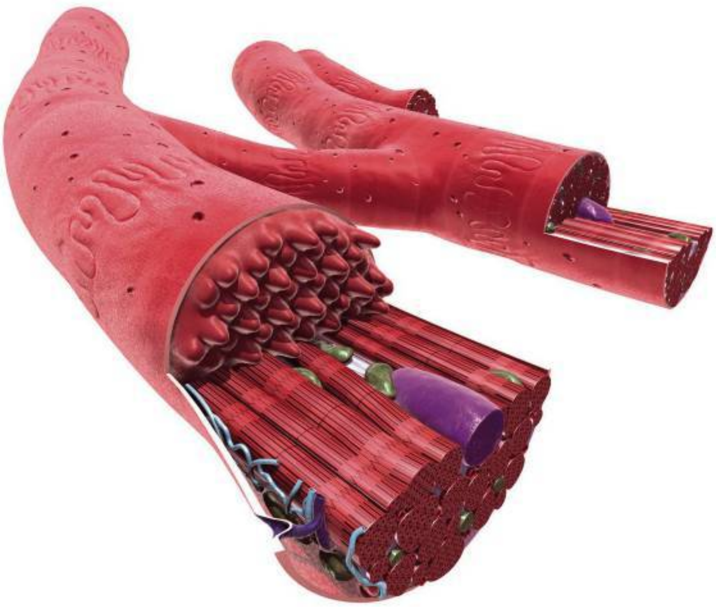
If glucose levels are relatively low in the blood, the stored glycogen can be converted back to glucose. This glucose is then added back into the bloodstream.

D.4 The heart

Understanding: Structure of **cardiac muscle** cells allows **propagation** of stimuli through the heart wall.

Model sentence: Heart muscle cells are highly adapted to allow efficient passage of electrical signals through the heart wall.

The heart is a muscular pump composed of four chambers. The upper two have a thin muscular wall and are called atria. The lower two chambers have very thick muscular walls and are called ventricles. This section describes the muscle cells that make up the heart. This type of muscle is called cardiac muscle.



Source: DK Images / Zygote Media Group

Figure 15.6 *Illustration showing a small portion of cardiac muscle. Notice the branching between one area of muscle cells and another. There are several individual cardiac muscle cells shown, with two shown in section. The sections are shown with a portion of an intercalated disc cut in half. The sections also show sarcomeres and a large central nucleus (purple)*

The illustration above shows several cardiac muscle cells. Look carefully in one of the sectioned areas and you will see sarcomeres. Remember, sarcomeres are the contracting units of muscle. Individual cardiac muscle cells connect to each other by way of **intercalated discs**. The two muscle cells closest to you in the illustration show what the structure of an intercalated disc looks like. The cell that has been cut in a half-section would have had an opposite shape to the one shown. Thus, the two

Subject vocabulary

glycogen a polysaccharide composed of many individual glucose units

cardiac muscle muscle type that makes up the heart

intercalated discs membrane projections that form interlocking units between adjoining cardiac muscle cells

General vocabulary

propagation the process of spreading to another area

Subject vocabulary

intercalate to insert into each other

sinoatrial node a specialized group of cells in the heart that send out spontaneous electrical signals leading to a resting heart rate

atrioventricular (AV) node a specialized group of cells in the heart that receives an impulse from the SA node and then sends an impulse to the ventricles

artificial pacemaker a battery-operated device that regulates heart rate when the SA node fails to do so

systole time period in which a heart chamber is undergoing a contraction

Synonyms

sinoatrial node .... SA node

originating (from)............ starting/coming (from)

General vocabulary

spontaneous something that happens without apparent external cause

would fit together and intercalate. Cytoplasm and electrical signals for contraction can be passed from cell to cell at these intercalated discs. Notice also that cells form branches. This means that cardiac muscle cells can chemically communicate with each other. This chemical communication is in the form of electrical signals that lead to contractions. All of the cardiac cells of both atria work together as a unit when they contract. Soon after, all of the cardiac cells of both ventricles contract together.

Cardiac muscle cells also contain nuclei and many mitochondria.

Understanding: Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles.

Model sentence: The sinoatrial node results in contraction of the atria only as its signal cannot be directly passed to the ventricles.

You learned in Chapter 6 that the sinoatrial (SA) node acts as the natural pacemaker of the heart. The SA node is a grouping of cells located in the right atrium. The impulse originating from the SA node only spreads through the atria. This spread is by way of the intercalated discs and numerous branches as described in the previous section. The intercalated discs and branching do not extend down into the muscle tissue of the ventricles.

The ventricles receive their electrical signals from a second node of cells called the atrioventricular (AV) node. The AV node is also located in the right atrium of the heart. The AV node does not send a spontaneous impulse like the SA node. In other words, the AV node does not act as a natural pacemaker. The AV node waits to receive an impulse from the SA node before sending its own electrical signal.

Application: Use of artificial pacemakers to regulate the heart rate

Some people have a heart condition where the SA node does not send out a signal at an optimum timing. This can lead to a heart rate that is too slow, too fast, or simply irregular. A common treatment is the insertion of a battery-operated device called an artificial pacemaker. The device is implanted under the skin, often in the chest area. The pacemaker will give off a small electrical signal that takes the place of the timing that normally occurs by way of the SA node. Artificial pacemakers have battery lives of about 7 years. At that time, the entire pacemaker is replaced.

Understanding: There is a delay between the arrival and passing on of a stimulus at the atrioventricular node.

Model sentence: The atrioventricular node receives an electrical signal from the sinoatrial node and then delays a short time before sending a signal to the ventricles.

All four chambers of the heart cannot contract at the same time. If this were to happen, the blood would not continue moving in a single useful direction. In order to prevent all four chambers from contracting at the same time, the AV node has a very short delay after receiving a signal from the SA node. This short delay allows both atria to undergo systole. Then when the AV node does send its signal, both ventricles will then undergo systole.

Application: Use of defibrillation to treat life-threatening cardiac conditions

During a heart attack, the heart is no longer beating or is beating in a pattern not consistent with a normal cardiac cycle. Defibrillation is a process carried out using a device that delivers an electric shock to the heart. This resets the electric signals and often the heart will begin normal electric activity. When successful, the heart will begin beating normally on its own once the shock has been delivered.

Small portable defibrillators have become common in places where people normally gather. These devices are called automated external defibrillators or AEDs. These devices can be used by anyone as they have built-in audible instructions and include components that are easy to use.

Understanding: This delay allows time for atrial systole before the **atrioventricular valves** close.

Model sentence: The delay between impulses of the two heart nodes gives enough time for both atria to contract and force blood into the ventricles before the atrioventricular valves close.

Notice the location of the right and left AV valves on the figure to the right. When these two valves are open, blood is able to move from the atria to the ventricles. Atrial systole is the event that completes blood moving into the ventricles for any single heart cycle. Atrial systole is initiated by the SA node and the actual contraction occurs during the short delay by the AV node.

Heart valves open and close based on pressure differences on either side of the valve. After the delay, the contraction of the ventricles raises the blood pressure inside of the ventricles. This increased pressure closes the AV valves to allow the ventricular pressure to increase even more. Eventually, the very high pressure in the ventricles opens the **semilunar valves** and the blood exits the ventricles.

Skill: Mapping of the cardiac cycle to a normal ECG trace

An ECG is the abbreviation for an **electrocardiogram**. An ECG is shown as a graph with electrical activity (voltage) shown on the *y*-axis and time on the *x*-axis. The electrical activity is from the SA and AV nodes.

How to read a normal ECG trace:

- P wave: shows the voltage given off by the SA node
- Point Q: shows the voltage given off by the AV node
- QRS complex: shows the voltage from the AV node spreading down the **conducting fibres** and **Purkinje fibres**
- T wave: the AV node is repolarizing (getting ready to send another impulse).

Subject vocabulary

atrioventricular valves valves located between each atrium and ventricle

semilunar valves valves located where blood exits each ventricle

cardiac cycle all of the events that comprise one heartbeat

trace a line drawn by a recording instrument

electrocardiogram a record of the electrical activity of the heart as measured by a device called an electrocardiograph

conducting fibres nerve fibres within and between the ventricles of the heart

Purkinje fibres branches of the main conducting fibres coming from the AV node in the ventricles of the heart

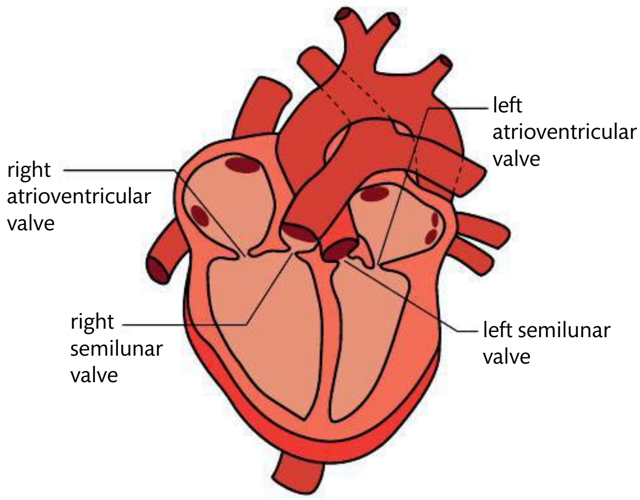


Figure 15.7 *The location of the four heart valves.*

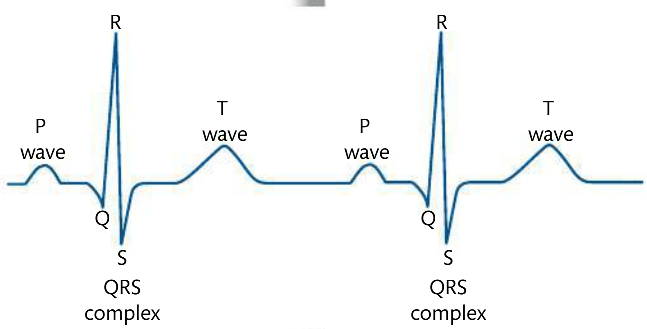
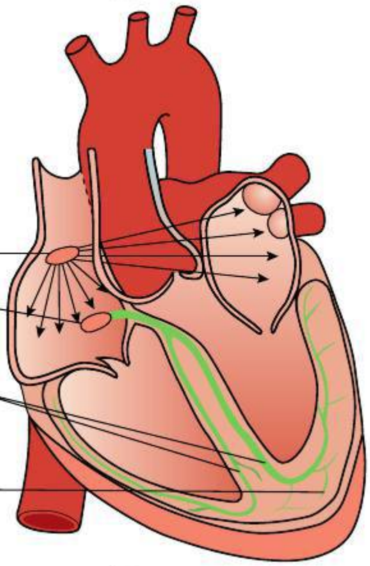


Figure 15.8 *ECG for a normal heart showing two heart cycles*

Understanding: Conducting fibres ensure coordinated contraction of the entire ventricle wall.

Model sentence: All of the muscle cells of the ventricles contract at the same time due to conducting fibres carrying the electrical signal from the atrioventricular node.



The muscular walls of the ventricles are very thick. This means that there are many more cardiac muscle cells making up the ventricles as compared to the atria. When the SA node sends an impulse the highly branched and intercalated cells spread the electrical signal quickly and both atria contract at the same time. There are too many cells making up the ventricles for cell-to-cell communication only to work in a timely manner. The ventricles also rely on conducting nerve fibres to quickly spread the electrical signal from the AV node.

Figure 15.9 *This drawing of the human heart shows the location of the SA node, AV node and the conducting fibres spreading out through the ventricles from the AV node. The black arrows show an electrical signal coming from the SA node. After that there is a time delay before the AV node sends a signal through the conducting fibres to various branches called Purkinje fibres*

Understanding: Normal heart sounds are caused by the atrioventricular valves and semilunar valves closing, causing changes in blood flow.

Model sentence: The normal sounds of the heart as heard through a stethoscope are caused by the closing of two sets of heart valves.

Subject vocabulary

stethoscope a device used to listen to sounds made within the body

The sounds of the heart as heard through a stethoscope are often described as a 'lub' sound, followed by a 'dub' sound and then a silence. This same pattern is then repeated over and over. Each single set of sounds represents one heart cycle.

Heart sounds are created by valves closing. The first heart sound, 'lub', is created by the atrioventricular valves closing. There are two of these valves but they close at the same time. Therefore, there is only one sound. The second heart sound, 'dub', is created when both semilunar valves close. Once again, a single sound.

When valves close, the blood is routed in a direction opposite to the newly closed valve. This keeps the blood moving in a direction that is beneficial to body needs.

Hints for success: Use the heart diagrams in the previous sections to trace the flow of blood. Link blood flow to when heart chambers are contracting, valves are opening and closing, and the sounds of the heart.

Skill: Interpretation of systolic and diastolic blood pressure measurements

A blood pressure in medical terms is actually two pressures. One is called the systolic pressure and the other the diastolic pressure. A typical example might be:

$$\frac{115 \text{ (systolic pressure)}}{68 \text{ (diastolic pressure)}}$$

These values are read as 115 over 68 (both pressure readings are in mm of Hg)

- Systolic pressure is a measurement of the pressure in arteries when the ventricles of the heart contract (undergo systole).
- Diastolic pressure is a measurement of the pressure when the ventricles are resting and refilling with blood.

Application: Causes and consequences of hypertension and thrombosis

Hypertension is a medical condition characterized by having blood pressure that is consistently higher than is considered to be healthy. Hypertension is a condition that typically develops slowly over many years. Loss of **elasticity** in blood vessels is one contributing factor. Another is the build-up of a substance called **plaque**. Plaque is long-term build-up of cholesterol and other substances on the inside wall of arteries. This can greatly decrease the volume of blood that the blood vessel can carry. Arteries blocked with plaque greatly increase the threat of a heart attack or **stroke**.

Thrombosis is a medical condition where a **thrombus** (clot) develops and breaks loose within a blood vessel. Often the origin of a thrombus is an area of plaque build-up. Sometimes a section of plaque breaks away and begins circulating. When this thrombus reaches a blood vessel diameter that it will no longer fit through, it becomes stuck. Two locations where this can become immediately life threatening are:

- in the coronary arteries feeding heart muscle
- in arteries within the lungs.

D.5 Hormones and metabolism

Understanding: **Endocrine glands** secrete **hormones** directly into the bloodstream.

Model sentence: Hormones from endocrine glands travel throughout the body because they are secreted directly into the blood.

The endocrine system is a diverse set of glands in the body. Two things unite this group of glands:

1. All endocrine glands secrete a molecule called a hormone.
2. All hormones are secreted into the bloodstream for delivery to cells of the body.

Cells that are capable of responding to a hormone are called **target cells** (of that hormone). For example in Chapter 11, you learned about **osmoregulation** in the kidneys. Osmoregulation is controlled by a hormone known as antidiuretic hormone (ADH). ADH is a hormone produced by the posterior lobe of the pituitary gland. The pituitary gland is located at the base of the brain. The target tissue of ADH is the collecting ducts of the kidneys. In order for ADH to have an effect on kidney cells it must travel to the kidney by way of the bloodstream. All hormones travel throughout the body by way of the bloodstream.

Subject vocabulary

hypertension high blood pressure

plaque build-up of cholesterol and other substances on the inner wall of arteries

stroke a sudden decrease in blood supply to a portion of the brain

thrombosis a clot that breaks loose and lodges in another smaller blood vessel in the body

thrombus a clot that develops in a blood vessel

endocrine gland a gland that produces a hormone

hormone chemical messenger produced in very small amounts by an endocrine gland

target cell cells that respond to a particular hormone

osmoregulation control mechanism used by an organism to regulate water balance

Synonyms

elasticity........ flexibility

Subject vocabulary

steroid lipid-soluble organic substance, e.g. cholesterol

solubility degree of how readily a substance will dissolve into another substance

transcription the process of creating RNA from DNA

regulatory area a section of DNA that determines whether a particular gene is currently active

Understanding: Steroid hormones bind to receptor proteins in the cytoplasm of the target cell to form a receptor–hormone complex.

Model sentence: Hormones classified as steroids enter the cytoplasm and bind to receptor proteins to become a receptor–hormone complex.

Steroid hormones are lipid molecules. Therefore, steroids have the **solubility** properties of lipids. This means that steroid hormones pass directly through the plasma membranes of a cell. You should remember from Chapter 1 that the plasma membrane is also a lipid structure. Once a steroid hormone enters a cell, it bonds to a receptor protein located in the cytoplasm of the cell. This forms a receptor-hormone complex.

Understanding: The receptor–hormone complex promotes the transcription of specific genes.

Model sentence: Transcription of specific genes is promoted within a target cell by the receptor–hormone complex.

In the simplest scenario, the receptor–hormone complex next passes through the nuclear membrane. Once inside the nucleus the complex binds to a **regulatory area** of a gene. The receptor–hormone complex acts to promote the activity of certain genes. When a particular gene is promoted by the receptor–hormone complex, the process of transcription is initiated for that gene. Thus, the steroid hormone is able to control the production of protein within a target cell. Examples of naturally occurring steroid hormones are oestrogen, progesterone, and testosterone.

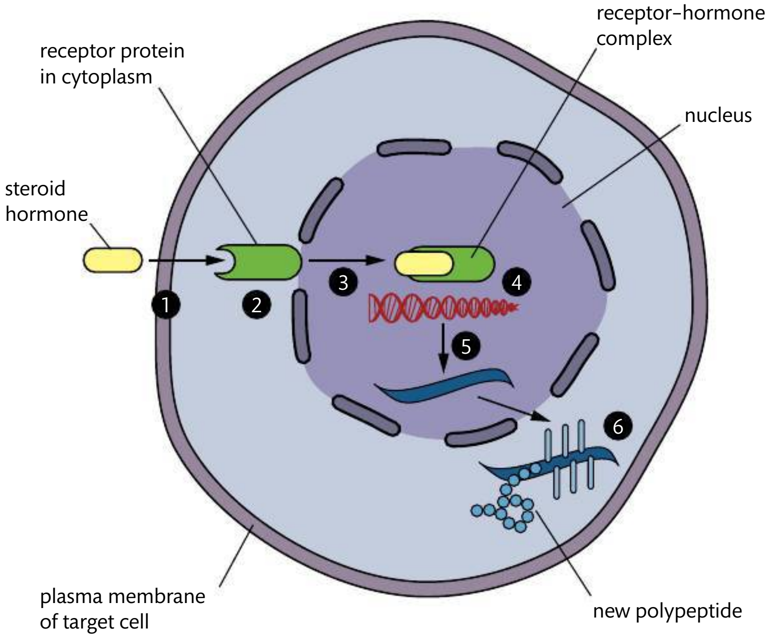


Figure 15.10 *An illustrated version of the general mechanism of a steroid hormone. (1) A non-polar (lipid soluble) steroid hormone enters directly through the biphospholipid layer of the plasma membrane. (2) A steroid hormone binds to a receptor protein in the cytoplasm to make a receptor–hormone complex. (3) The receptor–hormone complex enters the nucleus through a nuclear pore. (4) The receptor–hormone complex binds to a specific gene of DNA and, in this example, promotes transcription for this gene. (5) Messenger (m)RNA molecules are synthesized as a result. (6) Ribosomes on the endoplasmic reticulum translate mRNA into a new polypeptide*

Understanding: **Peptide hormones** bind to receptors in the plasma membrane of the target cell.

Model sentence: Hormones classified as peptide hormones affect target cells by binding to receptors in the plasma membrane.

Peptide hormones are composed of amino acids. A peptide hormone recognizes a target cell by locating a part of a receptor molecule that extends out of the plasma membrane. The peptide hormone must form a 'fit' with this receptor molecule. This 'fit' is very similar to the way an enzyme and its substrate fit together. There must be a matching, but opposite, complementary shape and set of charges between the two molecules.

The receptor molecule extends all the way through the plasma membrane of the target cell. Therefore, a part of the receptor molecule also extends down into the cytoplasm of the cell. This will be important for the action initiated by the hormone that will be described in the next section.

Subject vocabulary

peptide hormone a hormone composed of amino acids

charges positive and negative area of molecules as a result of polar covalent bonding and other intramolecular forces

secondary messenger a molecule located on the inside of a plasma membrane that is activated when a peptide hormone binds to a receptor protein

transcription factor a molecule that affects when a gene is synthesizing RNA

Synonyms

initiated......... started/begun

General vocabulary

cascade a sequence of events, each one causing the next

Understanding: Binding of hormones to membrane receptors activates a **cascade** mediated by a second messenger inside the cell.

Model sentence: When a peptide hormone binds to a membrane receptor it causes a secondary messenger to be activated inside the plasma membrane initiating a cascade of reactions within the cell.

Assume a peptide hormone and a receptor protein fit each other. The peptide hormone will chemically induce the receptor protein to activate a molecule located on the inside of the plasma membrane. The molecule activated is called a secondary messenger. In this way peptide hormones can affect the internal chemistry of the cell without ever entering the cell.

Often the secondary messenger activates one or more other molecules in the cytoplasm. The final messenger molecule will typically do one of two things:

1. Activate an enzyme in the cytoplasm. This promotes one or more reactions that were not occurring before the peptide hormone began this sequence.
2. Activate a transcription factor that either promotes or inhibits production of a particular RNA molecule. Protein synthesis is directly affected.

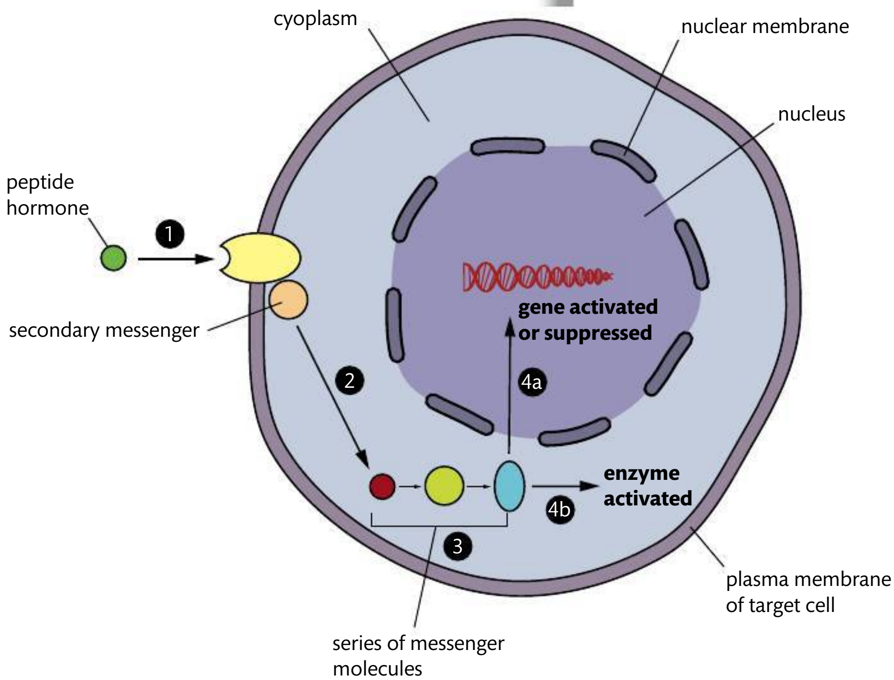


Figure 15.11 *An illustrated version of the general mechanism of a peptide hormone. (1) A peptide hormone fits the complementary shape and charge of a receptor protein within the plasma membrane of a target cell. (2) A receptor protein signals the beginning of a cascade of reactions. (3) A series of second messenger molecules is activated. (4a) One possible consequence is a second messenger molecule that promotes or inhibits a gene, leading to more or less of a polypeptide being synthesized. (4b) A second possibility is that an enzyme is activated and a reaction or reaction sequence begins that is catalysed by that activated enzyme*

Hints for success: When distinguishing between steroid and peptide hormones, take note that steroid hormones enter cells and peptide hormones do not enter cells.

Subject vocabulary

hypothalamus a region of the brain that controls pituitary gland secretions and other autonomic functions

axon long extension of a neurone that carries an impulse away from cell body

terminal buttons the small knob-like structures at the end of axons that release a neurotransmitter in neurones or a hormone for neurosecretory cells

releasing factors molecules produced and secreted from the hypothalamus that control secretion of hormones from the anterior pituitary gland

Understanding: The hypothalamus controls hormone secretion by the anterior and posterior lobes of the pituitary gland.

Model sentence: Hormone secretion by the anterior and posterior lobes of the pituitary gland are controlled by the part of the brain called the hypothalamus.

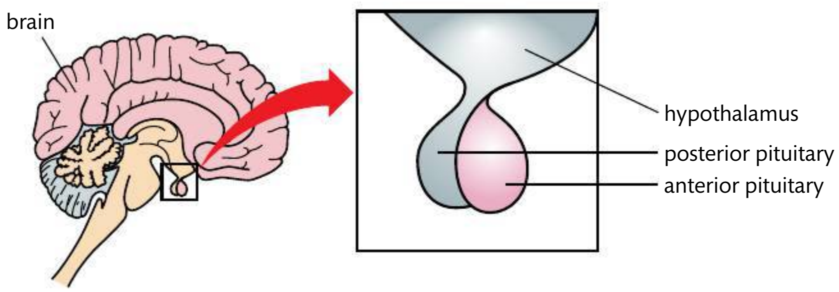


Figure 15.12 *The position of the hypothalamus and pituitary*

The pituitary gland is composed of two lobes. Each lobe secretes a different set of hormones. Each lobe is controlled by the hypothalamus, but in very different ways.

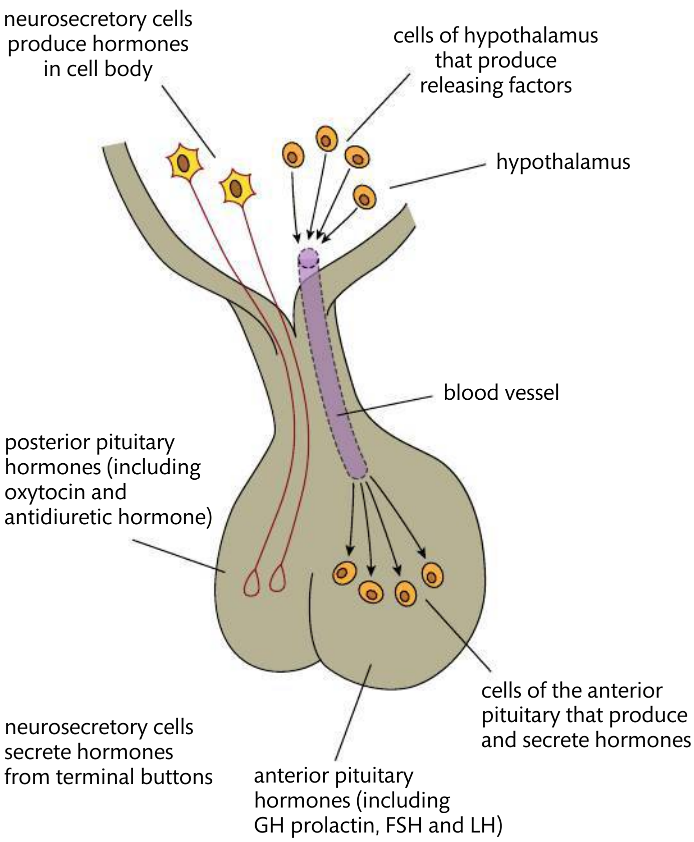


Figure 15.13 *The hypothalamus and pituitary*

The posterior lobe of the pituitary secretes the two hormones, oxytocin and ADH. These two hormones are produced by cells in the hypothalamus. These cells are called neurosecretory cells. They have relatively long **axons** that extend down into the posterior pituitary. When physiological conditions call for secretion of either oxytocin or ADH, they are secreted from the **terminal buttons** into the blood stream at the ends of these long axons.

The anterior pituitary secretes many hormones. These include growth hormone (GH), prolactin, FSH, and LH among others. The hypothalamus controls the secretion of all anterior pituitary hormones by secretion of its own hormones. These hormones are called **releasing factors** or releasing hormones. The releasing factors from the hypothalamus are directly taken to the anterior pituitary by an interconnecting blood vessel. The hypothalamus controls anterior pituitary secretions by controlling which releasing factors are produced.

Hints for success: In an exam, take note whether a question is asking for location of production or location of secretion of a hormone. The hormones secreted from the posterior pituitary are produced in the hypothalamus.

Understanding: Hormones secreted by the pituitary control growth, developmental changes, reproduction, and homeostasis.

Model sentence: A variety of body processes are controlled by pituitary gland hormones, including: growth, developmental changes, reproduction, and homeostasis.

Hormone	Category	Example
growth hormone (GH)	growth	stimulates growth in children and adolescents
FSH and LH	development	these two hormones are necessary for steroid production in both males and females
FSH and LH	reproduction	these two hormones are necessary for oocyte production in females and sperm production in males
ADH	homeostasis	needed for water balance (osmoregulation)

Application: Some athletes take growth hormones to build muscles

Even though there is very little research on the dangers involved, some athletes choose to take or inject growth hormones. Many professional sports organizations have banned the use of these substances. Time will tell whether there will be long-term physiological effects from this practice.

Application: Control of milk secretion by oxytocin and prolactin

Lactation is production and release of milk by a new mother. During pregnancy, the pituitary hormone, prolactin, stimulates development of milk producing cells in the breasts. The naturally high levels of oestrogen characteristic of a pregnancy inhibit the release of milk. At the time of birth, oxytocin, another hormone from the pituitary is secreted. The increase of oxytocin and the decrease of oestrogen (because of the birth) stimulate milk release. The production of both prolactin and oxytocin is further stimulated by stimulation of the breast nipple from the suckling activity of the newborn. This is an example of positive feedback control of a physiological process.

D.6 Transport of respiratory gases

Understanding: Oxygen dissociation curves show the affinity of haemoglobin for oxygen.

Model sentence: Graphs called oxygen dissociation curves show haemoglobin's affinity for oxygen.

Earlier in this chapter you learned that each erythrocyte contains about 250 million haemoglobin molecules. You also learned that a human being has many trillions of erythrocytes circulating in their blood at any given time. Each haemoglobin molecule is composed of four polypeptides, four haem groups with an iron atom at the centre of each haem group. An oxygen molecule can bond to each

General vocabulary

adolescent a person who has undergone puberty but has not reached maturity

Subject vocabulary

oxytocin a hormone secreted from the pituitary

prolactin anterior pituitary hormone that stimulates development of milk-producing cells

lactation production and release of breast milk

oxygen dissociation curve a graph that plots partial pressure of oxygen against percentage of haemoglobin saturation

affinity attraction for

haem group the non-protein portion of haemoglobin molecules

Synonyms

erythrocyte .... red blood cell

iron atom. Thus, each haemoglobin molecule is capable of transporting four **oxygen molecules**.

Synonyms

oxygen molecule........ O_2

Subject vocabulary

saturated all four iron atoms within a single haemoglobin are bonded to an oxygen molecule

sigmoid having a shape like the letter 'S'

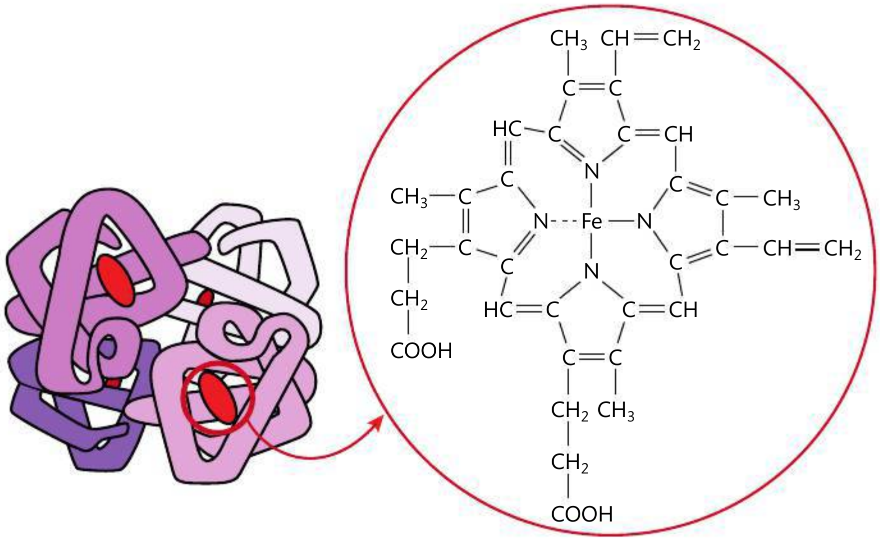


Figure 15.14 *Haemoglobin is a large protein consisting of four polypeptides with a haem group within each. The molecular structure of a haem group is shown on the right. Notice the iron atom at the centre of the molecule*

A graph called an oxygen dissociation curve shows haemoglobin's differing affinities for oxygen. Haemoglobin's affinity for oxygen is dependent on how many oxygen molecules are currently being 'carried'. When an oxygen molecule bonds to haemoglobin, it results in a molecular shape change to the haemoglobin. This change in molecular shape increases the affinity of haemoglobin for oxygen. In other words, haemoglobin that is already carrying three oxygen molecules has the greatest affinity for another oxygen molecule.

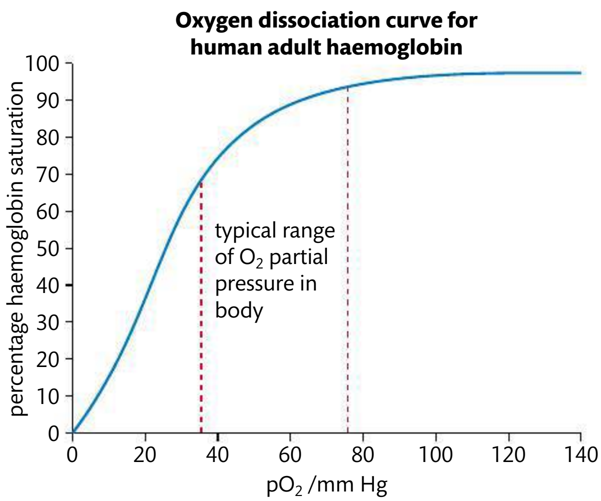


Figure 15.15 *This oxygen dissociation curve shows the range of oxygen partial pressure found in the body*

Notes to help you make sense of this graph:

- The *y*-axis shows percentage of haemoglobin that is **saturated**. This means saturated with oxygen molecules. Haemoglobin is only saturated with oxygen when it is carrying four oxygen molecules.
- The *x*-axis shows partial pressure of oxygen in mm Hg. The partial pressure of a gas (oxygen) is the pressure exerted by a single gas when it is in a mixture of gases. Oxygen is a single gas in the mixture of gases we call air.
- The reason the graph has a **sigmoid shape** ('S' shape) is because of haemoglobin's increase in affinity when already bonded to one or more oxygen molecules.
- The two dotted red lines will help you to better understand when haemoglobin loads oxygen and unloads oxygen. The term used for an oxygen molecule

breaking its bond to haemoglobin is dissociation. This is where these graphs derive their name. The red line on the right shows the partial pressure of oxygen in the lungs. Notice that over 90% of the haemoglobin molecules are saturated with oxygen. The red line on the left shows partial pressure of oxygen typical in body tissues. Notice that some, but not all haemoglobin molecules have given up at least one oxygen molecule to the cells. Saturation of haemoglobin has dropped to slightly less than 70%.

Understanding: Carbon dioxide is transformed in red blood cells into hydrogen carbonate ions.

Model sentence: Within the cytoplasm of red blood cells, carbon dioxide is transformed into hydrogen carbonate ions.

The cytoplasm of red blood cells contains an enzyme called **carbonic anhydrase**. This enzyme catalyses a reaction in which carbon dioxide and water combine to form carbonic acid (H_2CO_3). **Carbonic acid** then separates into a hydrogen carbonate ion and a hydrogen ion.

The hydrogen carbonate ions formed from this reaction exit the red blood cell through specialized protein channels. This is an example of **facilitated diffusion**.

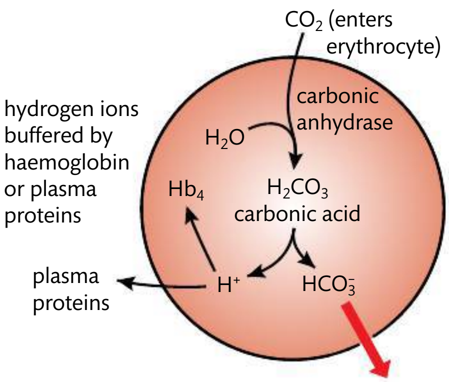


Figure 15.16 *The events occurring when carbon dioxide enters a erythrocyte include the formation of carbonic acid and the resulting buffering by haemoglobin and plasma proteins*

Understanding: Carbon dioxide is carried in **solution** and bound to haemoglobin in the blood.

Model sentence: Carbon dioxide has various ways of being transported in blood, including being dissolved in blood plasma and bound to haemoglobin.

There are three ways that carbon dioxide is transported in the blood:

- The majority of carbon dioxide undergoes the reaction described in the previous section and becomes hydrogen carbonate ions (HCO_3^-). The majority of these ions diffuse out of erythrocytes into the blood plasma. When in the lung tissues, these ions will convert back to carbon dioxide molecules.
- A small percentage (about 5%) of carbon dioxide simply stays as carbon dioxide and dissolves into the solution of blood plasma.
- Some carbon dioxide (about 10%) enters red blood cells and temporarily binds to haemoglobin.

Subject vocabulary

hydrogen carbonate ions a negatively charged ion made of hydrogen, carbon, and three oxygen atoms

carbonic anhydrase the enzyme that catalyses hydrogen carbonate ion formation in red blood cells

facilitated diffusion diffusion of a substance through protein channels in a membrane

solution a solvent with one or more solutes (in the context used above the solution is referring to blood plasma)

Synonyms

carbonic acid.. H_2CO_3

Subject vocabulary

Bohr shift an effect whereby an increase in carbon dioxide in the blood decreases the affinity of haemoglobin for oxygen

respiring actively engaged in cell respiration

chemoreceptors nervous system receptor cells that are sensitive to one or more chemicals

pH a measure of the acidity or alkalinity of a solution

Understanding: The Bohr shift explains the increased release of oxygen by haemoglobin in respiring tissues.

Model sentence: In an effect known as the Bohr shift, haemoglobin increases its release of oxygen in tissues that have increased their rate of cell respiration.

Haemoglobin's affinity for oxygen is reduced in an environment where carbon dioxide levels are high. Where in the body are carbon dioxide levels relatively high? Within body tissues that are most actively using cell respiration. The best example would be muscle tissue in a person who is exercising. Since haemoglobin loses some of its affinity for oxygen in active muscle tissue, the haemoglobin gives up more oxygen than it would have otherwise. This effect is called the Bohr shift.

The Bohr shift can be seen on an oxygen dissociation curve by plotting haemoglobin in a non-exercise situation (blue line on left) and haemoglobin while exercising (green line on right). Notice that haemoglobin in body tissues that are exercising has a lower percentage of haemoglobin saturation. The reason for this is that the haemoglobin has given up more of its oxygen to the muscle tissues that need it.

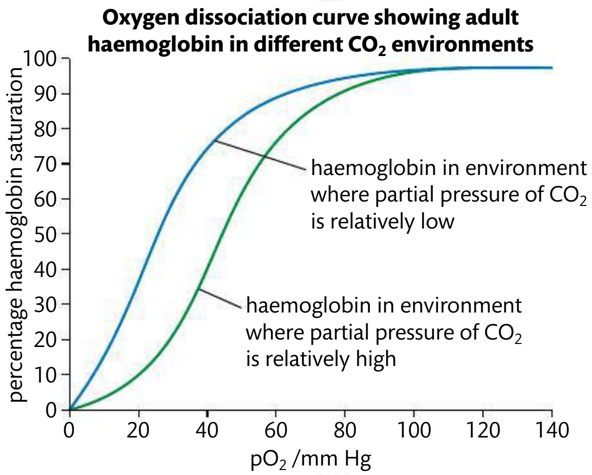
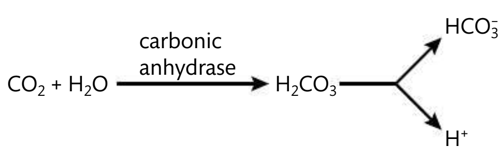


Figure 15.17 *The Bohr shift*

Understanding: Chemoreceptors are sensitive to changes in blood pH.

Model sentence: Nervous system receptors called chemoreceptors monitor changes in blood pH.

Let's revisit the equation for production of hydrogen carbonate ions after carbon dioxide enters the blood.



You will notice that there are two products from the overall chemical reaction. One is hydrogen carbonate ions and the other is hydrogen ions. This reaction always produces these two products. When one exercises the rate of formation of these two products increases.

The increased production of hydrogen ions during exercise slightly lowers blood pH. We have very sensitive chemoreceptors that are able to detect even small decreases in blood pH.

Understanding: The rate of ventilation is controlled by the respiratory control centre in the medulla oblongata.

Model sentence: The number of times that we breathe in and out per minute is controlled by an area of the medulla oblongata called the respiratory control centre.

You have probably noticed that you do not have to think about breathing. It is just something that you do. Physiological activities like breathing and heart rate are under control of your autonomic nervous system. These activities do not need to be consciously controlled. Because of the way that the autonomic nervous system works, you do not have to think about the control mechanisms at the conscious level of thought.

The muscles that are involved in breathing (see section 6.4) do need to receive electrical signals from the brain in order to keep up their life maintaining activity. These electrical impulses are coming from an area of your brainstem called the medulla oblongata. Specifically an area called the respiratory control centre. Even when you are sleeping your respiratory control centre is sending out electrical signals. These impulses are going to your diaphragm and other muscles involved in ventilation so that you continue breathing.

Application: Consequences of high altitude for gas exchange

In today's world of rapid travel by airlines, it is not uncommon for someone to be living at or near sea level on one day and then find themselves at a high altitude location the next. For example, someone flying from sea level to Quito, Ecuador, would have an altitude increase of about 2800 m in a single day. Air at high altitude locations has a lower pressure than air at sea level. This means the individual molecules within the air are further apart in high altitude locations. When you breathe air in, you are breathing in fewer oxygen molecules at high altitude as compared to lower elevations.

When someone first arrives at a high altitude location, they often feel fatigued from just normal activities like walking or climbing stairs. This is because their body tissues are receiving less oxygen. Other symptoms can include vision problems, nausea, high pulse rate and difficulty in thinking clearly. These symptoms are often called altitude sickness or mountain sickness.

Over time the human body will compensate for the lowered amount of oxygen in a process called acclimatization. The following are involved in the acclimatization process:

- an increase in the number of erythrocytes and haemoglobin
- an increase in capillaries in both muscles and lungs
- an increase in lung volume
- an increase in myoglobin in muscle tissues.

Subject vocabulary

rate of ventilation number of times breathing in and out per unit of time

respiratory control centre the area of the medulla oblongata involved in control of rate of ventilation

medulla oblongata portion of the brainstem that controls many involuntary functions; also known as medulla of the brain

autonomic nervous system that portion of your nervous system that controls unconscious activities

altitude sickness symptoms due to oxygen deprivation at high altitude

myoglobin a protein found within muscles that bonds to an oxygen molecule

General vocabulary

elevation height above sea level

fatigue physical and/or mental tiredness

nausea a feeling of sickness with an urge to vomit

Understanding: During exercise the rate of ventilation changes in response to the amount of CO_2 in the blood.

Model sentence: Exercise results in an increase of carbon dioxide in the bloodstream resulting in an increase in the rate of ventilation.

The chemoreceptors that monitor blood pH are located in the **aorta**, **carotid arteries**, and in the medulla oblongata of our brain. Each of these receptors is able to send electrical signals to the respiratory control centre of the medulla oblongata. They do this when the pH of the blood begins to decrease as exercise begins.

When the respiratory control centre receives an electrical signal as a result of a lowered pH, the control centre sends out its own electrical impulses. These impulses go to the muscles that control ventilation. The mechanism of ventilation is not changed (see section 6.4), the rate of ventilation is just increased. The opposite occurs when body activity is lowered and the pH of the blood begins to increase slightly. The respiratory control centre responds by lowering the rate of ventilation.

Application: pH of blood is regulated to stay within the narrow range of 7.35 to 7.45

As you can see, humans have a very narrow range of blood pH. There are two primary **homeostatic** mechanisms that work to keep us within that range.

1 When our rate of activity increases we produce more hydrogen ions. If a large number of hydrogen ions are left in solution, a large drop in pH can result. Instead, we have molecules that act as **buffers**. The molecules acting as buffers temporarily bond to the hydrogen ions. This takes the ions out of solution and thus they do not affect the pH of the solution. Two of the most common molecules that act as buffers are haemoglobin and a variety of plasma proteins (see Figure 15.16).

2 Even with the effect of buffering, there will still be a small decrease in blood pH when we exercise. The chemoreceptors in our carotid arteries and medulla oblongata respond to this by increasing our rate of breathing and our heart rate. These two actions work to lower the amount of carbon dioxide in our blood stream. They do this by increasing the rate of carbon dioxide released in our lungs.

Application: Causes and treatments of emphysema

In section 6.4 you learned the mechanism of gas exchange between air in the alveoli of the lungs and respiratory gases travelling in the bloodstream. The tissue making up the alveoli and the small air **ducts** bringing air in and out is very delicate tissue. Emphysema is a disease where that delicate tissue has been damaged. Often the damage is from long-term cigarette smoking. Over a long exposure, cigarette smoke will result in the destruction of alveoli and their small air ducts. This leaves wide holes where healthy lung tissue once was found. Occasionally there are other causes for emphysema:

- marijuana smoking
- exposure to **second-hand smoke**
- exposure to some types of air pollution
- exposure to some manufacturing fumes
- exposure to coal or silica dust.

If emphysema is diagnosed early, some lung regeneration is possible due to natural healing. Often the disease is not diagnosed early for a variety of reasons. When

Subject vocabulary

aorta the largest artery in the body, taking oxygenated blood away from the left ventricle of the heart

carotid arteries large arteries in the neck that carry oxygenated blood to the brain, face, and neck

homeostatic system environment in which all conditions are steadily maintained

buffer a substance in solution that resists a change in pH

emphysema a lung disease where alveoli become damaged, typically due to smoking

Synonyms

ducts .... tubes

General vocabulary

second-hand smoke smoke inhaled by one person due to the smoke exhaled by another person smoking the damage is severe, treatment typically centres around slowing further damage by stopping exposure to the causative agent. In addition, some medications can help with symptoms. Many people suffering from severe emphysema need to use additional oxygen from a container. This is given through small tubes into the nostrils.

Understanding: **Foetal haemoglobin** is different from adult haemoglobin allowing the transfer of oxygen in the **placenta** onto the foetal haemoglobin.

Model sentence: Oxygen is transferred from the mother's haemoglobin to foetal haemoglobin because the structure of foetal haemoglobin allows a greater affinity for oxygen.

A foetus produces a different form of haemoglobin as compared to the haemoglobin it will produce after birth. The comparison is often referred to as foetal vs. adult haemoglobin, but the difference is actually pre-birth haemoglobin vs. post-birth haemoglobin. Post-birth haemoglobin will bond to oxygen molecules in the baby's lungs. Pre-birth haemoglobin will be receiving oxygen from the mother's haemoglobin within **placental capillaries**. Each is specialized for its function. Study the oxygen dissociation curve shown to the right that compares foetal haemoglobin to 'adult' haemoglobin.

You will notice foetal haemoglobin has a higher affinity for oxygen molecules as compared to the mother's haemoglobin over all partial pressures except for very low and very high oxygen partial pressures. Notice that the curve for foetal haemoglobin is consistently to the left of the curve for the mother's haemoglobin. Any point selected on the *x*-axis shows that adult haemoglobin binds less oxygen at that partial pressure compared with foetal haemoglobin. This means that if an oxygen molecule is available in placental capillaries, foetal haemoglobin is more likely to bind to it than the mother's haemoglobin.

Subject vocabulary

foetal haemoglobin haemoglobin produced in a foetus before birth

placenta a structure found in the uterus that allows exchanges of gases, nutrients, and waste products between mother and foetus

placental capillaries blood vessels of the placenta that permit the exchanges of molecules between mother and foetus

Oxygen dissociation curve of maternal and foetal haemoglobin

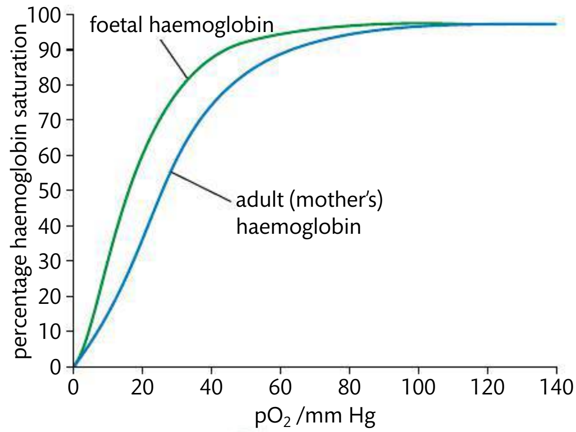


Figure 15.18 *Foetal haemoglobin has a greater affinity for oxygen than adult haemoglobin in the range of partial pressures typical of human tissues*

Skill: Analysis of dissociation curves for haemoglobin and myoglobin

Myoglobin is a molecule found within your muscle tissues. Unlike haemoglobin, myoglobin is formed of a single polypeptide, single haem group, and iron. Therefore, myoglobin can only bind with a single oxygen molecule. Myoglobin's function is to give up its bound oxygen molecule only when the muscle tissue is nearing an anaerobic condition. This typically only occurs during heavy exercise. You can think of myoglobin as providing a reserve of oxygen to delay the onset of anaerobic cell respiration. In humans, this would be lactic acid production (see Chapters 2 and 8).

You should be able to describe how this graph relates to myoglobin's ability to provide oxygen during heavy exercise.

Oxygen dissociation curve of adult haemoglobin and myoglobin

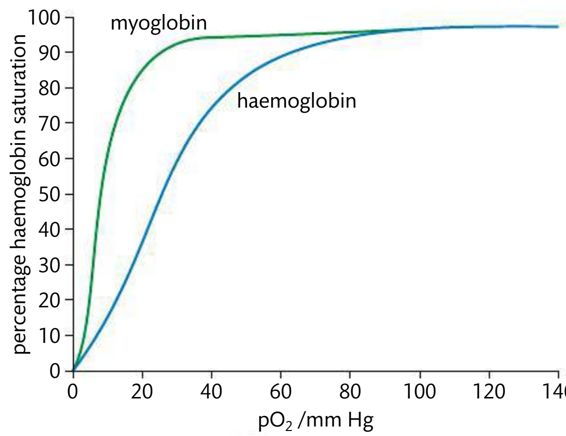


Figure 15.19 *Oxygen dissociation curves of haemoglobin and myoglobin. Myoglobin dissociates oxygen only when the oxygen partial pressure gets very low, e.g. in actively respiring muscle tissues*

Introduction

The internal assessment (IA) task for biology will consist of one investigation/scientific exploration. You will spend 10 hours doing this investigation. Your IA mark will provide 20% of your overall assessment for your IB biology score. The written assignment should be 6–12 pages in length. The individual investigation (II) can be:

- hands-on practical work
- using a spreadsheet for analysis and modelling
- extracting data from a database and analysing it graphically
- a combination of spreadsheet/database work and traditional hands-on investigation.

General information for internal assessment

- The internal assessment requires the application of your biology knowledge and skills.
- Work submitted for your IA must be your own personal work.
- Your instructor will help in making certain you have a thorough understanding of the internal assessment criteria.
- The IB animal experimentation policy must be followed.
- Your instructor will provide support and general guidance throughout the IA process.
- Your instructor may provide advice on the first draft of your IA product.
- Your instructor must be able to confirm that what you submit for your IA is your own work.

Internal assessment criteria

The following is a list of the five criteria used to assess the report of your individual investigation. Included are the total marks and the weighting for each criterion.

Criterion	Criterion total marks	Criterion weighting toward final mark
personal engagement	2	8%
exploration	6	25%
analysis	6	25%
evaluation	6	25%
communication	4	17%

Guidance on getting your individual investigation started

1 Find a topic and research question that interests you. Your instructor will usually provide suggestions on areas in biology from which to choose appropriate topics or research questions.

2 Be certain you have a purpose in mind when designing your independent investigation.

3 A research question may be as simple as, 'What is the influence of X on Y?', where X and Y are factors or variables that can be measured, controlled, or counted.

4 Be certain that anything mentioned in your research question can be measured using materials and techniques available to you in the school's lab.

5 Be precise in the writing of your research question.

6 Any organism or organisms used must be referred to by their scientific names.

7 Consider the time you have available in the planning of the independent investigation.

8 The independent or manipulated variable must be carefully considered before beginning the procedure for your independent investigation. Considerations for the independent variable are listed below.
   - The independent variable is what you are testing the effects of in your experiment.
   - The independent variable differs from one part of the experiment to another.
   - Example: You would use a range of five different concentrations of a particular fertilizer to determine the fertilizer's effects on a particular plant's growth.

9 The dependent or measured variable is whatever you will be measuring as the result of your investigation.
   - The dependent variable measures the changes in the experiment due to the variations of the independent variable.
   - The design of the table into which the measured results of the experiment will be placed is extremely important.

10 The controlled variables are the things that are kept the same in all parts of the experiment.
   - The controlled variables ensure a proper and meaningful experimental procedure.
   - The controlled variables ensure that only the independent variable really is responsible for any changes recorded.
   - A list of those controlled items which would have made a significant difference in the results should be presented.

11 Consider the number of samples you will use in your independent investigation. An adequate sample size is essential to be able to generate meaningful data. It is suggested you have at least five samples for each of the five variations of the investigation's independent variable.

12 It is expected that there will be some consideration of safety, ethics, and environmental impact. Consent forms will be expected where human volunteers are used in the protocol.

13 The procedure for your individual investigation may be based on a well-known procedure. However, it should be modified to represent a personal design and approach which will allow the collection of sufficient and reliable data.

14 Be as precise and as concise as possible in the writing of your procedure. Some things to consider are:

- The description of the steps of your procedure should be fully understandable to another person.
- Include the independent, dependent, and controlled variables in the writing of the procedure. All three of these variable types must be clearly stated in the procedure.
- Glassware, such as beakers and flasks, used should be described in the procedure to indicate volume and specific type. Standard sizes of test tubes used are usually sufficient. Test tubes used which possess unique characteristics should be fully described.
- Indicate safety measures within the procedure. Include how hot objects are to be handled. Explain any equipment used for cutting. Include the safe procedure for using any cutting or sharp instruments. Include safe procedures for handling harmful chemicals.
- Precise concentrations of any chemical solutions must be included within the procedure. Examples of concentrations may be % or moles per litre. Volumes used should be stated in ml or appropriate SI units.
- Be sure to include comments about anything in your investigation that could have an impact on the environment such as how you will properly dispose of any chemicals used.
- All measuring devices will need to be included in the procedure. This will include balances, electronic probes, any interface for electronic probes, thermometers, etc. Any unique use of any measuring device will need to be explained in the procedure.

Internal assessment criteria details

Each internal assessment criterion is presented in this section with the top-level descriptor for the maximum points. Guidance will be provided after each internal assessment criterion to help you in achieving the maximum marks possible.

Personal engagement

Marks	Top-level descriptors
2	• A personal approach is clearly evident within the investigation. • A clear explanation of the reason for choosing the topic and research question is presented. • There is clear personal interest, creativity in designing the experiment, and obvious initiative in the implementation of the investigation.

You will need to explain why you are willing to devote the suggested 10 hours of work into your specific topic and research question. This explanation may include background information involving the particular research question. Include a description as to why the investigation is significant to you. Be certain to include modifications in available procedures that indicate creativity on your part in your investigation of the research question.

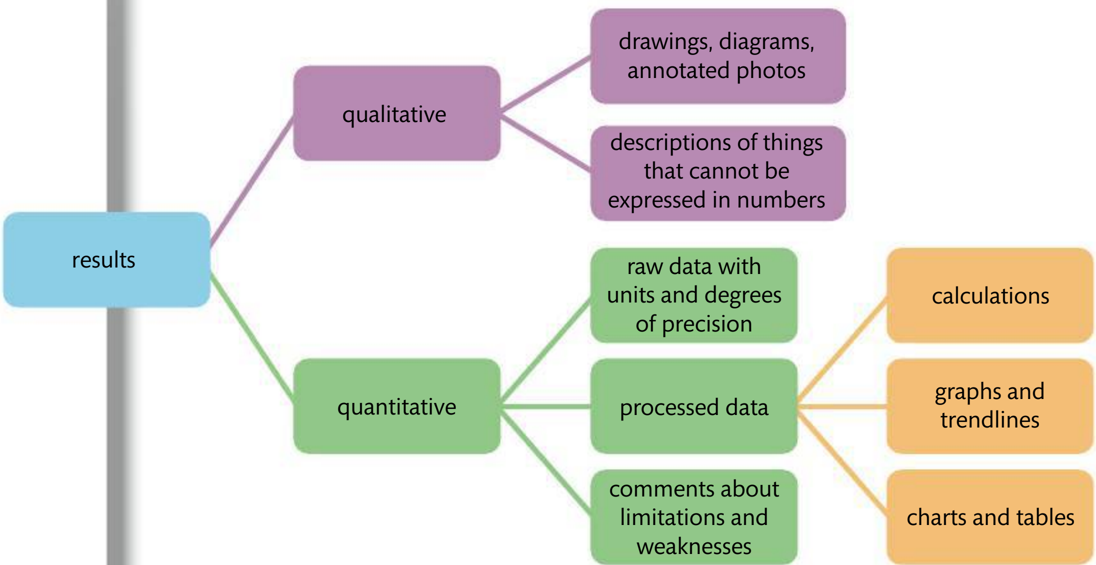
Exploration

Marks	Top-level descriptors
6	• Topic and research question are clearly stated. The research question is appropriate for this higher level investigation. • Background information is provided so a clear understanding of the research question is possible. The background information also reinforces the significance of the investigation to the student. • The procedure for the investigation is directly related to the research question. All factors and variables are presented which could have a significant effect on the procedure's outcome. The procedure will lead to the gathering of data which will bring about a proper conclusion in relationship to the research question. • Safety and ethical considerations are apparent in the procedure. Any environmental issues involving the procedure are discussed.

The exploration criterion presents a major task. That task is to ensure the research question and the procedure for the investigation are at the proper level. This requires a thorough presentation of background information which has allowed the development of a focused research question. The procedure is an extremely important part of this criterion. You will need to modify any existing procedures you find in your research so that a unique approach is presented in the search to address the research question. The number of samples used to collect data must be adequate. It is essential that all factors which may have an effect on the investigation outcome are accounted for and discussed. Be certain to keep a proper record of all sources used in this phase and all other phases, as each will need to be presented in the report bibliography. All equipment used in the experimental phase must be properly named and described for a chance at a top mark in this criterion. Describe fully any unique ways in which equipment is used in your procedure.

Analysis

Marks	Top-level descriptors
6	• Both quantitative and qualitative data are presented which allow a relevant and valid conclusion to the research question. This includes raw and processed data. • The data presented are of sufficient amount and accuracy to allow a proper conclusion to the research question. Data are presented appropriately in visual forms including tables and graphs. • Any and all uncertainties are presented completely and appropriately. • Data processing indicates a proper relevance to the research question. The processed data allow a logical conclusion to the research question.



This criterion asks to what extent your report provides evidence that you have selected, processed, analysed, and interpreted the data in the appropriate way to reach a valid conclusion to the research question. Raw data presented must include uncertainties. Both quantitative and qualitative data should be presented. Any tables presented should include a title and number. Rows and columns in the tables should be neat and orderly to allow easy interpretation. Headings of each column should include units and the degree of precision. All entries in each cell of the table should reflect the degree of precision at the heading of each column. All entries in each cell of the table should have the same number of decimal places. An appropriate method for analysing the data should be selected. Graphs presented must be proper, beginning with the independent variable being represented on the *x*-axis and the dependent variable being represented on the *y*-axis. Axes must be properly labelled with uncertainties included. Proper titles and numbers must be given for each graph. Statistical tests used must be appropriate so that a valid conclusion in relation to the research question may be deduced. Outliers should not be excluded from the processing without good reason and explanation.

Evaluation

Marks	Top-level descriptors
6	• The conclusion is detailed and is directly related to the research question. There is obvious use of data to justify the conclusion. A logical deduction from the data presented allows a valid conclusion to the research question. • The conclusion is fully explained with adequate reference to data collected and presented. • A detailed discussion of the strengths and weaknesses of the procedure is presented. • Suggestions that may bring about a more valid conclusion are included. Methods used are analysed in relation to the accuracy and reliability of data obtained in the procedure. Modifications involving the procedures utilized for future research are presented along with their justification.

This criterion assesses your work by examining your ability to provide evidence that you have selected, processed, analysed, and interpreted the data to support your conclusion. You must show your conclusion is justified by the data you have collected. You should research similar investigations carried out by scientists and published in accepted journals. This will possibly increase the credibility and reliability of your data and conclusion. Be certain to include the sources researched in your bibliography. Comparing your data to accepted scientific theory might be necessary if you cannot find similar studies to your investigation in journals. It is important to discuss your conclusion in relationship to the hypothesis you presented early in the report. Use terms such as 'confirmed by data' or 'refuted by data' to relate your conclusion to the earlier presented hypothesis. Describe any unexpected results such as outliers in the data or any surprises in the outcome. Address how your data and conclusions relate to the theory you have learned in the biology classroom.

Communication

Marks	Top-level descriptors
4	• The report is clearly focused. The process and outcomes are clearly stated. • The information presented in the report is all relevant and coherent. • Information presented demonstrates conciseness. The information is clear, understandable, and to the point. Only information relevant and essential to the research question and conclusion is presented. • Proper terms are used to describe the science of the paper. Proper names of any organisms are provided. All equipment is named and described appropriately. • Labels, decimals places, headings, titles, etc., are all presented in a proper scientific manner. • The bibliography is presented in an accepted manner. All sources used in any manner in the report are presented in the bibliography. There is a minimum of sources mentioned which are not directly used in the report.

Write your report with these terms in mind:

- clear
- concise
- logical.

These terms will help you produce a report in which you effectively communicate with your reader. Be certain to read over the procedure before submitting the final product to ensure someone else could easily repeat your procedure. It is especially important that someone else would get similar results as you if they carried out your stated procedure. Make certain your data analysis is stated, so it is obvious why and how you processed your data. Any photographs included should be annotated. The photographs must include the source if they are not your own. Photographs which are yours may simply be labelled, 'author's photo'. The terminology used throughout the report should be consistent and scientifically acceptable.

Final internal assessment suggestions

Lab reports should be written using an impersonal style. This means that words such as 'I', 'we', 'my', and 'us' should be avoided. For example, instead of saying 'Next, I added soap to the Petri dish', you should write 'Next, soap was added to the Petri dish'. The phrase 'my hypothesis' should be rewritten as 'the hypothesis'. To avoid using 'I', say things like 'it was noticed that …' instead of 'I noticed that …'. Likewise, 'It is my personal opinion that …' should be written as 'It is the investigator's personal opinion that …'.

Proofread carefully before submitting the final report. Follow any general advice provided by your teacher after they read over your first draft. Be mindful that a 6–12 page report is expected. This page limit does not mean using a small font size or miniature graphs to fit the limit. It is also important to note this project is to involve roughly 10 hours of work on your part. Be certain your report reflects properly the suggested page length and time spent.

You should feel extremely proud as you turn in your final report!

Biology extended essay

Introduction

One of the requirements of the IB Diploma is to write an extended essay. An extended essay is an in-depth study of a limited topic within a particular subject area. It provides the opportunity to carry out independent research within a subject of your choice. Biology is a subject often selected by students for their extended essay. It is a popular subject because many of the topics studied in IB Biology stimulate further research ideas in students. Laboratory work carried out in the IB Biology course also provides a base for student ideas involving possible research questions. A good research question is essential for extended essay success.

General guidelines for all extended essays

Extended essays in all subjects have the following guidelines:

- an upper word limit of 4000 words which does not include the abstract, the bibliography, the contents page, appendices, or any labelling or captioning of graphs, diagrams, illustrations or tables
- should involve a recommended 40 hours of student work
- final product is externally assessed using published criteria
- each student is allocated a faculty member with extended essay training who will provide general guidance for the project
- schools set deadlines based on each school's particular circumstances
- it should represent a unique approach to addressing a specific research question
- it must be independent research
- select a topic with a research question which is of interest to you and be certain to show that interest in the writing of the paper.

General guidelines for biology extended essays

- Most successful biology extended essays involve some sort of independent, hands-on experimental work along with literature-based research.
- The extended essay should include a detailed procedure section representing the exact steps carried out in the experimental work. This section is known as the protocol.
- Some biology extended essays that are mostly literature based do well. These literature-based extended essays in biology should include a unique analysis of raw data generated by reputable protocols and procedures.
- Any research involving organisms must be ethical. Any animal research must follow the IB published guidelines concerning the use of animals in experimental procedures.
- Extended essays based on experimental or practical work at a laboratory outside the school must have a cover letter submitted with the essay detailing the student's role in the protocol design. This letter must also specifically describe any guidance received while in this type of situation. This is especially important when the research is done at a university or research institution.
- For safety and/or academic honesty reasons, some schools do not allow students to work outside the school, so check with your teacher.

Suggested steps toward a successful project

1 Initial research and planning

- **a** Decide on your subject of interest. Pick something you are very enthusiastic about, because you will need to stay motivated for the entire process.
- **b** Think of potential research questions.
- **c** A biology extended essay must have a biological focus. It must directly relate to an organism in some specific way.
- **d** IB states clearly that biology topics dealing with symptoms and treatment of particular human diseases are very rarely the subject of successful extended essays.
- **e** Topics dealing with ethical issues, different general approaches to medical treatments, and surveys involving attitudes or opinions concerning science research are rarely successful biology extended essays.
- **f** Meet with your faculty supervisor to discuss possible topics and research questions.
- **g** One of the most important functions of the faculty supervisor is help in developing a proper research question for the extended essay
- **h** Be sure to read the general criteria in the Extended Essay Guide as well as the criteria that are specific to biology. It is also a good idea to read past extended essays to see what they are like.

2 Continued research involving the chosen research question

- **a** Research should involve a survey of the topic literature keeping a detailed account of the sources from which ideas and/or data are used.
- **b** Plan your procedure for any experimental work.
- **c** Discuss your research and procedure with your faculty supervisor.
- **d** It may be necessary to refine the topic and research question as more information is gathered. The proper focus of the research question is essential. Always check with your supervisor before making any changes to the research question.

3 Experimental work

- **a** Make certain the experimental procedure is safe and ethical in the opinion of your faculty supervisor before beginning the procedure.
- **b** Arrange for all necessary equipment, chemicals, and specific needs before beginning the experimental work. This may involve sources outside of your school. Be certain all sources of materials outside your school are acceptable to your faculty supervisor.
- **c** It is extremely important to consider the independent variables, the dependent variables, and the controlled variables in your procedure or procedures.
- **d** An essential part of any experimental work involves an adequate sample size. Sample size is important and should be discussed with your faculty supervisor.
- **e** Control groups and experimental groups must be carefully considered.
- **f** A plan should be in place for the recording of raw data before the procedure ever begins. Qualitative data and quantitative data should both be considered in the data collection and recording stage.
- **g** Processing and presentation of data are essential parts of the experimental work. Careful consideration should be given to tables, graphs, and statistical tests so that data will allow meaningful and proper conclusions.
- **h** Your faculty supervisor may give general suggestions throughout this experimental work.

4 Writing the paper

a Your essay should have a structure which allows for an acceptable and appropriate presentation. An acceptable extended essay organisation is:
- Title page
- Abstract
- Table of contents
- Introduction with research question stated early and clearly
- Hypothesis and explanation of hypothesis
- Background information (keep this precise and **concise** rather than **exhaustive**)
- Presentation of variables
- Materials used
- Protocol of experimental procedures
- Data collection and presentation
- Data analysis
- Evaluation
- Conclusion
- Bibliography
- Appendix (optional – may include details of protocols, raw data, or any calculations of the raw data. It is important to note that the paper should be sufficient without the presence of an appendix.)

b A first draft should be submitted to your faculty supervisor so that general directions may be provided in the writing of the final draft.

c The first draft should be checked against the IB marking criteria by you and your supervisor to make certain of a high mark.

d The style of the bibliography should be one used at your school. There is not a specific form of bibliography to use. It is important that some reference in the paper is made toward each bibliography source provided. Information to access online sources used must be appropriate and complete.

5 Final paper stage

a Make changes generally suggested in the first draft by your faculty supervisor.

b Proofreading is essential.

c Double-check your final paper against the 'formal presentation' criterion in the extended essay marking criteria.

d Arrange a meeting with your faculty supervisor to turn it into the final paper. You and your supervisor should go over the final paper together making certain the major sections have been included.

Synonyms

concise .... short

General Vocabulary

exhaustive very thorough and complete

The extended essay criteria and advice to achieve high marks for each criterion

Criterion	Advice
Research question – 2 marks	• A good research question is essential to a good extended essay. It should be stated early in the introduction and should be focused for a 4000 word essay. • Adequate time and thought must be put into writing the research question. • The research question should lend itself to discussion and even debate. This allows you to ultimately present a proper conclusion after the presentation of sound arguments and data concerning the research question.
Introduction – 2 marks	• This should provide an explanation of the research question. • The introduction should include discussion of the significance of the research question.

Investigation – 4 marks	• The procedure is the key.
	  ◦ Is it unique?
	  ◦ Does it allow for adequate data collection?
	  ◦ Are controls used?
	  ◦ Is the procedure truly biological in nature?
	  ◦ Is the procedure relevant to the research question?
	• If the paper has a library-based component, this criterion involves a detailed look at how the data to be analysed were obtained.
	• Look at a variety of sources to arrive at a proper investigation approach.
	• Be certain the investigation will allow gathering of data which are relevant to the research question.

Knowledge and understanding of the topic studied – 4 marks	• The essay must show a thorough understanding of the topic. • Your essay should flow in a logical way toward the development of a proper conclusion concerning the research question. • Have you shown that you clearly understand all aspects of the essay? • Do your analyses represent an obvious understanding? • Any diagrams used should be explained to demonstrate their meaning to the research question and conclusion.
Reasoned argument – 4 marks	• In your search to confirm your hypothesis, are you logical and methodical in your approach and explanation? • Is a convincing argument presented? • All arguments or data presented must relate logically to the research question. • It is wise to present alternative views as you develop your argument.

Criterion	Advice
Application of analytical and evaluative skills – 4 marks	• Has there been careful analysis of all sources used in the essay? • Have all aspects of the experiment been evaluated for appropriateness? • Is the presentation of data logical? • Has there been adequate data analysis? • All sources used and cited should include validation. • All tables and graphs must be presented appropriately. • All tables and graphs must relate to the research question and to the conclusion.
Use of language appropriate to the subject – 4 marks	• Is the language appropriate to the topic and is it correctly used? • Is it clear and precise? • Does the terminology demonstrate your level of understanding? • Provide a definition for all terms which are essential to your procedure and to your development of a proper conclusion.
Conclusion – 2 marks	• Does the conclusion flow logically from the arguments in the essay? • Is the conclusion relevant to the research question and does it relate to the original hypothesis? • Does the conclusion include unresolved questions and potential future research? • Do not introduce any new arguments or content in your conclusion. • Limitations concerning the validity of your conclusion should be mentioned.
Formal presentation – 4 marks	• This includes elements such as title page, table of contents, page numbers, appropriate illustrations, proper citations and bibliography, and appropriate appendices, if used.

Abstract – 2 marks	• This is written last and includes three elements:
	  ◦ research question
	  ◦ investigative approach
	  ◦ conclusion.
	• Is it within 300 words?

Holistic judgment – 4 marks	• This criterion is used to reward creative and unique approaches. • It also involves depth of understanding, insight, and apparent interest in the topic. • There should be a wide range of sources used in the essay as this indicates interest in the topic. • Make certain the conclusion is well supported with alternative possibilities discussed. • Sources should not just be from the internet. A range of reputable scientific journals and views should be included.

Final concerns for your extended essay

1 Be careful concerning plagiarism. Presenting someone else's ideas or work as your own is plagiarism. Be certain to give proper credit to all people whose ideas or work has been used in any way in your extended essay. A useful rule to follow: when in doubt, cite.

2 Your title page should include:
   - Title in the middle of the page. Many students use their research question as a title but this is not necessary and it often makes for a very long title to write on the cover sheet. Invent a shorter title and put your research question under it as a subtitle.
   - Your full name, candidate number, and date.
   - Word count – within the 4000 limit. To find the word count using Microsoft Word, select the text from the beginning of your introduction to the end of the conclusion and choose 'Statistics' from the 'Tools' menu. Un-tick the box that says to 'Include footnotes'. Headings and legends can be subtracted, too.

3 The abstract goes after the title page and should only be written once the essay is finished. It has specific requirements. Be certain it is not over the 300 word limit. Its word count is not included in the 4000 word count for the extended essay. The abstract is placed immediately after the title page in the final paper.

4 After the abstract is the table of contents, then the introduction. The introduction should state the research question early and clearly.

5 The introduction must present a strong reasoning for pursuing a conclusion to the presented research question. State clearly why the research question is significant for your extended essay.

6 Any experimental procedures should be clearly and appropriately presented in a way they can be easily repeated .

7 Show that ethical and safety factors have been thoroughly addressed.

8 Pages should be clearly numbered. The title page is not numbered. Sections of the paper should be clearly and appropriately labelled.

9 Citations, such as footnotes or in-line citations, must be proper and consistent. Sources not specifically used in the paper should be kept to a minimum and included in a 'Further reading' section after the bibliography.

10 All visual presentations must be clear, labelled appropriately, and must relate directly to the research question and conclusion.

11 The conclusion must be clearly related to the research question. Limitations to the conclusion should be discussed. It is suggested that a brief plan for possible further development of your research question is presented.

12 Any appendices used must be appropriate. Check with your supervisor for what should and should not go into an appendix.

Viva voce

The completion of your extended essay is signified by the *viva voce* (concluding interview). This is a 10 to 15 minute interview with your faculty supervisor. It provides an opportunity to reflect on successes and what has been learned.

Enjoy your research.

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