Contents

CHAPTER 1

Introduction to Life Sciences

1 Introduction to Life Sciences

1.1 Life Sciences Orientation ESGQ

Introduction ESGR

The aim of this chapter is to provide you with an overview of the skills that you will need to develop as a Life Scientist. In this chapter you will learn how to gather evidence using the **scientific method**. The scientific method is a systematic way of testing a theory. It involves gathering and analysing information in order to come to an objective conclusion about the validity of a theory. The scientific method requires that we constantly re-examine our understanding, by testing new evidence with our current theories, and making changes to those theories if the evidence does not meet the test. The scientific method is a powerful tool you will use throughout the Physical Sciences and Life Sciences.

What is Life Sciences? ESGS

Life Sciences is the scientific study of living things. It involves many levels of investiagtion: from the study of the interactions of organic molecules to the interactions of animals and plants with their environment. The list below contains some of the various branches of Life Sciences.

- Anatomy (plant and animal)
- Biochemistry
- Biotechnology
- Botany
- Ecology
- Entomology
- Environmental Studies
- Genetics
- Medicine
- Microbiology
- Morphology
- Physiology (plant and animal)
- Sociobiology (animal behaviour)
- Taxonomy
- Zoology

Why study Life Sciences? ESGT

Here are some reasons to study Life Sciences:

- To increase knowledge of key biological concepts, processes, systems and theories.
- To develop the ability to critically evaluate and debate scientific issues and processes.
- To develop scientific skills and ways of thinking scientifically that enables you to see the flaws in pseudo-science in popular media.
- To provide useful knowledge and skills that are needed in everyday living.
- To create a greater awareness of the ways in which biotechnology and knowledge of Life Sciences has benefited humankind.
- To show the ways in which humans have impacted negatively on the environment and organisms living in the environment.
- To develop a deep appreciation of the unique diversity of biomes In Southern Africa, both past and present, and the importance of conservation.
- To create an awareness of what it means to be a responsible citizen in terms of the environment and life-style choices that they make.
- To create an awareness of the contributions of South African scientists. item To expose you to the range and scope of biological studies to stimulate interest in and create awareness of possible specialities and fields of study.
- To provide sufficient background for further studies and careers in one or more of the biological sub-disciplines.

Specific aims ESGV

In order to guide your progress through the year, and make sure that you benefit in the ways listed above, there are three specific aims for the year:

- **Specific Aim 1: Acquire new knowledge:** your knowledge of the Life Sciences will grow this year as you acquire a new understanding of Life Sciences concepts, processes, phenomena, mechanisms, principles, theories, laws and models. You will see new connections between fields and topics, and learn to evaluate and analyse what you learn.
- **Specific Aim 2: Investigate Phenomena in the Life Sciences**: this year you will gain experience in conducting science experiments, practical work and investigations.
- **Specific Aim 3: Understand the applications of Life Sciences in everyday life**: you will gain an appreciation of the way that science applies in everyday life, as well as gain an understanding of some of the history of scientific discoveries and the relationship between indigenous knowledge and science.

An A to Z of possible careers in Life Sciences ESGW

Ever wondered what you can do with Life Sciences after school? Below are some careers which you could study:

- **Agronomist**: someone who works to improve the quality and production of crops.
- **Animal scientist**: a researcher in selecting, breeding, feeding and managing of domestic animals, such as cows, sheep and pigs.
- **Biochemist**: someone who investigates the chemical composition and behaviour of the molecules that make up living things and uses this knowledge to try understand the causes of diseases and find cures.
- **Botanist**: someone who studies plants and their interaction with the environment.
- **Developmental biologist**: studies the development of an animal from the fertilised egg through to birth.
- **Ecologist**: a person who looks at the relationships between organisms and their environment.
- **Food Scientist**: someone who studies the biological, chemical and physical nature of food to ensure it is safely produced, preserved and stored, and they also investigate how to make food more nutritious and flavourful.
- **Geneticist**: a researcher who studies inheritance and conducts experiments to investigate the causes and possible cures of inherited genetic disorders and how traits are passed on from one generation to the next.
- **Horticulturalist**: a person who works in orchards and with garden plants and they aim to improve growing and culturing methods for home owners, communities and public areas.
- **Marine biologist**: a researcher who studies the relationships between plants and animals in the ocean and how they function and develop. They also investigate ways to minimise human impact on the ocean and its effects, such as over fishing and pollution.
- **Medical doctor or nurse**: someone who uses the current latest understanding of the causes and treatments for disease to treat people who are ill or improve a person's well-being.
- **Medical illustrator**: someone who illustrates and draws parts of the human body to be used in textbooks, publications and presentations.
- **Microbiologist**: a researcher who studies microscopic organisms such as bacteria, viruses, algae and yeast and investigates how these organisms affect animals and plants.
- **Nutritionist**: someone who gives advice to individuals or groups on good nutritional practices to either maintain or improve their health and to live a healthy lifestyle.
- **Palaeontologist**: a researcher who studies fossils of plants and animals to trace and reconstruct evolution, prehistoric environments and past life.

- **Pharmacologist**: a scientist who develops new or improved drugs or medicines and conducts experiments to test the effects of drugs and any undesirable side effects.
- **Physiologist**: a researcher who studies the internal functions animals and plants during normal and abnormal conditions.
- **Science teacher**: someone who helps students in different areas of science, whether it is at primary school, high school or university.
- **Science writer**: someone who writes and reports about scientific issues, new discoveries or researcher, or health concerns for newspapers, magazines, books, television and radio.
- **Veterinarian**: someone who looks after the health and wellbeing of pets, domestic animals, animals in game parks and zoos.
- **Zoologist**: a researcher who studies the behaviour, interactions, origins and life processes of different animal groups.

FACT
Watch this interesting video about "The Times and Troubles of the Scientific Method"
See video: 2CMG

1.2 The Scientific Method ESGX

How science works ESGY

Science investigation and research requires many skills and processes to come together in order to be successful and worthwhile.

- To be accepted as a science, certain methods for broadening existing knowledge, or discovering new things, are generally used.
- These methods must be repeatable and follow a logical approach.
- The methods include formulating hypotheses and carrying out investigations and experiments to test the hypothesis.
- Crucial skills are making objective observations, taking measurements, collecting information and presenting the results in the form of drawings, written explanations, tables and graphs.
- A scientist must learn to identify patterns and relationships in data.
- It is very important to then communicate these findings to the public in the form of scientific publications, at conferences, in articles or TV or radio programmes.

The scientific method is the basic skill process in the world of science. Since the beginning of time humans have been curious as to why and how things happen in the world around us. The scientific method provides scientists with a well structured scientific platform to help find the answers to their questions. Using the scientific method there are very few things we can't investigate. Recording and writing up an investigation is an integral part of the scientific method.

What follows is a step-by-step guide to the scientific method.

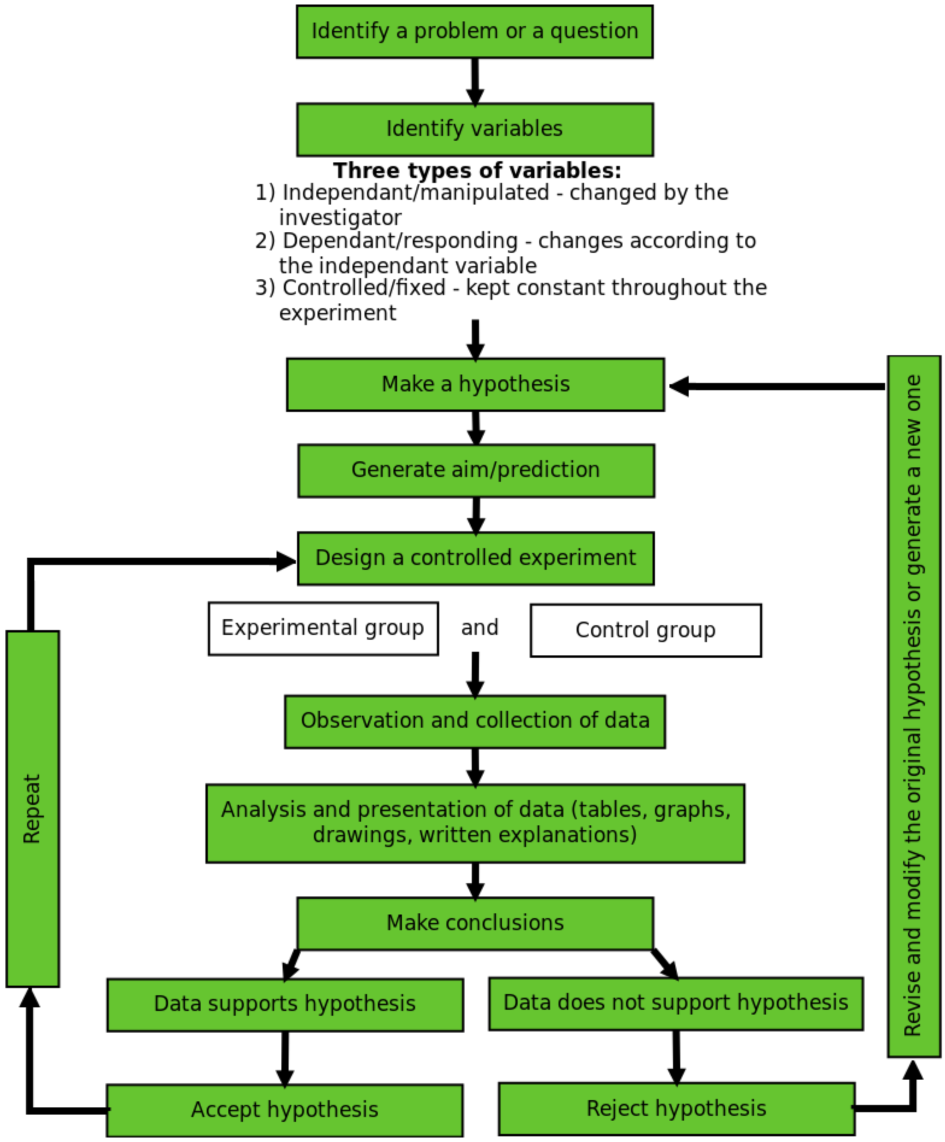


Figure 1.1: Overview of scientific method.

1. The question ESGZ

Scientists are curious people, and most investigations arise from a scientist noticing something that they don't understand. Therefore the first step to any scientific investigation is:

- Ask a question to which you want to find an answer.
  - What is happening?
  - How is it happening?
  - When is it occurring?
  - Why is it happening?

- **Example**: A farmer notices that his tomato plants that are shaded have smaller tomatoes than his plants that are in a sunny spot, which makes him wonder: 'Does the amount of sunlight a tomato plant receives affect the size of tomatoes?'

2. Introduction ESG32

Once you have a general question, background research needs to be undertaken. Your background research will ensure that you are not investigating something that has already been researched and answered. It will also tell you about interesting connections, theories, explanations and methods that people have used in the past to answer questions related to yours. Science always builds on the work of others, and it ensures that our theories are constantly improved and refined. It is important to acknowledge the work of the people upon whose work your theory relies in the form of *referencing*. It is also vital to *communicate* your findings so that future scientists can use use your work as a basis for future research.

3. Identify variables ESG33

Your background research will help you identify the factors that influence your question. Factors that might change during the experiment are called **variables**. Different types of variables are given special names. Below is a list of some important variable types:

- The **dependent variable** is the thing that you want to measure or investigate.
- The **independent variable** is a factor (or factors) that you control or change in your experiment. It will have an effect on the dependent variable.
- We call the the variables we keep constant **fixed variables**, or **controlled variables**.

Example: In this investigation, variables might include: the amount of sunshine, the types of soil in which the tomatoes are growing, the water available to each of the plants, etc. To which variable type does each factor belong?

- **Dependent variable**: mass of tomatoes
- **Independent variable**: how much light the tomato plants receive
- **Fixed/ Controlled variables**: all tomato plants will:
  - Be the same species of tomato
  - Get the same fertiliser (type and amount)
  - Grow in the same type of soil
  - Grow in the same type of container
  - Get the same amount of water
  - Can you think of more?

4. Hypothesis ESG34

Write down a *statement* or *prediction* as to what you think will be the outcome or result of your investigation. This is your hypothesis. The hypothesis should:

- be specific
- relate directly to the question you are asking
- be expressed as a statement that includes the variables involved (the 'cause' and 'effect')
- be testable
- not expressed as a question but rather as a prediction
- be written in the future tense

Example: During your background research you would have learnt that tomatoes need sunshine to make food through photosynthesis. You may predict that plants that get more sun will make more food and grow bigger. In this case your hypothesis would be: I think that the more sunlight a tomato plant receives, the larger the tomatoes will grow'.

NOTE:
A scientific investigation does not aim to *prove* a particular event occurs or a particular relationship exists. Rather, an investigation shows that it cannot disprove a particular suggestion or prediction. Therefore, it is important to note that an incorrect prediction does not mean that you have failed. It means that the experiment has brought some new facts to light that you might not have thought of before. Therefore, even if your hypothesis (prediction) turns out to be wrong, DO NOT go back and change the it!

5. Aim ESG35

- In the aim you need to state what you going to be investigating.
- Key words you can use are:
  - To determine...
  - To show that...
  - To investigate...
  - To find out...
  - To observe...
  - To measure...

Example: In this case, your aim would be: to investigate the effect of different amounts of sunlight on tomatoes.

NOTE:
In science we never 'prove' a hypothesis through a single experiment because there is a chance that you made an error somewhere along the way, or there may be an alternate explanation for the results that you observe. What you can say is that your results SUPPORT the original hypothesis.

6. Apparatus ESG36

All the apparatus that you will need for the investigation needs to be listed.

- Sizes of beakers, test tubes and measuring cylinders
- Specialised equipment that you may need must also be included (make sure that this equipment is available for your research).
- Include all chemicals and quantities that are required for your investigation.

7. Method ESG37

The next step is to test your hypothesis. An experiment is a tool that you design to find out if your ideas about your question are right or wrong. You must design an experiment that accurately tests your hypothesis. The experiment is the most important part of the scientific method. We will discuss independent and dependent variables as well as controls later. These are all important concepts to know when designing an experiment. In science, another researcher may want to repeat your method, to verify your results, improve it or do a variation of your experiment. Listing the apparatus helps others to verify that you used a suitable method, and enables them to replicate the experiment.

- Write down the scientific method in bullet format for your investigation.
- The method should be written so that a complete stranger will be able to carry out the same procedure in the exact same way and get almost identical results.
- The method should be written in the past tense using the passive voice.
- The method must be clear and precise instructions including
  - the apparatus
  - exact measurements or quantities of chemicals or substances
- Ensure that your method is written out in the correct sequence, with each step of the experiment numbered.
- State the criteria you will look for or measure to get results.
- Give clear instructions how the results should be recorded (table, graph etc.)
- Include safety precautions where possible.

8. Results ESG38

- Record your observations from doing the investigation.
- It is important that you do not write out an explanation for the results.
- Present your results in a suitable format such as tables and graphs.
- It is also important to note that not getting the result you expected is still a result. Even if there is no change at all, this is still a result that needs to be recorded.

9. Analysis of results or discussion ESG39

- The analysis of the results is stating in words what the results are often saying in tables/graphs.
- Discuss if there are there any relationships between your independent and dependent variables.
- It is important to look for patterns/trends in your graphs or tables and describe these clearly in words.

10. Evaluation of results ESG3B

- This is where you answer the question "What do the results mean?"
- You need to carefully consider the results :
  - Were there any unusual results? If so then these should be discussed and possible reasons for them can be given.
  - Discuss how you ensured the **validity** and **reliability** of the investigation.
    - **Vailidity**: Was it a fair test and did it test what it set out to test?
    - **Reliability**: If the experiment were to be repeated would the results obtained be similar?
  - The best way to ensure reliability is to repeat the experiment several times and obtain an average.
  - Discuss any **experimental errors** that may have occurred during the experiment. These can include errors in the methods and apparatus used and what make suggestions what could be done differently next time.

11. Conclusion ESG3C

The conclusion needs to link the results to the aim and hypothesis. In a short paragraph, write down if what was observed is supported or rejected by the hypothesis by restating the variables that were tested. If your original hypothesis does not match up with the final results of your experiment, do not change the hypothesis. Instead, try and explain what might have been wrong with your original hypothesis. What information did you not have originally that cause you to be wrong in your prediction.

- **Example**: after conducting your experiment you may have found that tomato plants that received more sunlight grew larger than tomato plants grown in the shade or without light. Therefore you might conclude your investigation with the following:
  - It was clear that tomato plants form bigger tomatoes when they are exposed to bright sunlight. The original hypothesis was supported.

1.3 Important principles and relationships in Life Sciences ESG3D

Surface area and volume ESG3F

Depending on the system it is advantageous to either have a large surface to volume ratio or a small surface to volume ratio.

A cell's surface area must be large enough to meet the needs of its volume. This is highlighted in the following examples:

- Flatworms and leeches have more surface area to volume to increase the area for diffusion for nutrients and respiratory gases across their whole bodies.
- In animals the shapes of organs are defined by surface area to volume requirements. For example, in the lungs there are many branches to increase the surface area through which gases can be exchanged.
- Cells with a small volume and large surface area are better suited for diffusion, ingestion and excretion because of the relatively large area of the cell membrane.

Structure and function ESG3G

In living organisms, the structure of a particular biological feature is related to what function it performs. Thus for all the structures you will study in Life Sciences, the important questions to ask are the following:

1. What makes this structure suited to its function?
2. How has the structure adapted to its function?
3. Why is this structure so efficient for its function?

1.4 Presenting data ESG3H

Biological drawings and diagrams ESG3J

Drawings and diagrams are an essential part of communication in science, and especially Life Sciences. Remember it is not an artwork or sketch! But rather it is a clear representation of what you observe which can be used to interpret what you saw.

Some rules to follow

Drawings and diagrams must:

- Be drawn in a sharp pencil for clear, smooth lines.
- Be large so that all structures can be clearly seen (at least 10 lines of paper).
- Be drawn in the middle of the page.
- Be two dimensional (no shading)!
- Have a heading or caption.
- Specify the section in which the specimen was sliced, i.e. transverse section (T/S), cross section (C/S), or longitudinal section (L/S).
- State the source of the drawing or diagram, i.e. From a biological specimen, a micrograph or a slide.
- Indicate the magnification or scale of the drawing, either in the caption or in the corner of the drawing.
- Label lines should be drawn and they must:
  - be parallel to the top of the page and drawn with a ruler.
  - not cross each other or have an arrow at the end.
  - clearly indicate the structure which is being named.
  - be aligned neatly, one below the other and preferably on one side of the page, unless there are many labels in which both sides can be used.

Activity: Identifying the key aspects of producing biological drawings

Instructions:

Make a list of what makes the above drawings good and bad.

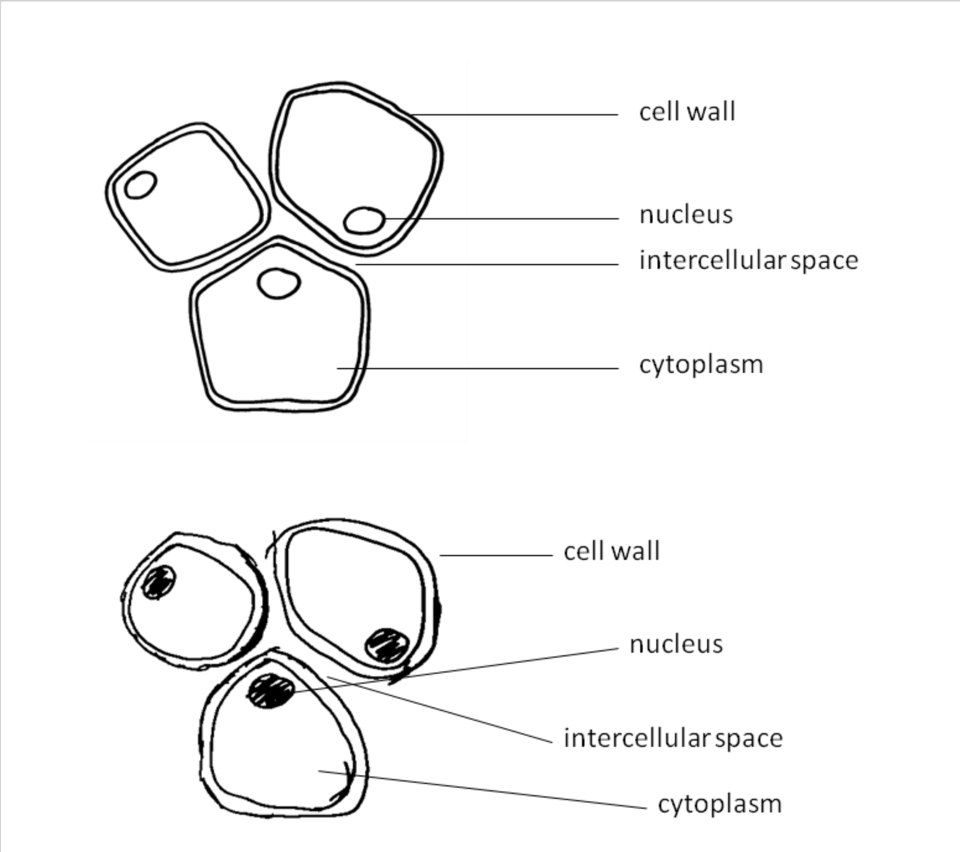


Figure 1.2: Identify the features of the images that make each one good or bad.

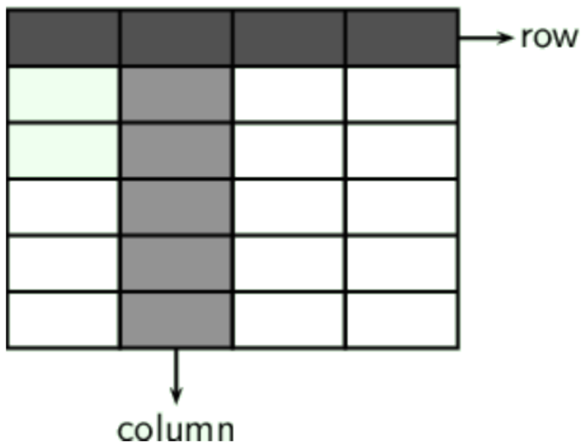
Two-dimensional (2-D) and three-dimensional (3-D) diagrams ESG3K

Diagrams of apparatus are generally drawn in two-dimensions so that the shape of each item of apparatus is simplified and looks similar to a section through the apparatus.

Tables ESG3M

What is a table?

- A table is a summary of data, using as few words as possible.
- It is a grid divided up into rows and columns.
- The heading is placed above the table.
- The heading should include both variables under investigation- the dependent and independent variables.
- Independent variable is placed in the first column.
- The column headings should mention the units that were used, eg. grams, hours, km/hr, cm.



When to use a table?

- To summarise information.
- To compare related things or aspects.
- To record the results of an experiment.
- To illustrate patterns and trends.
- To record the data which will be used to construct a graph.

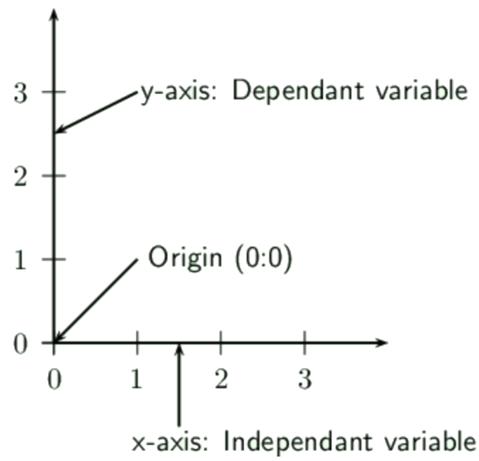
Types of Graphs ESG3N

One of the clearest and most concise ways to represent data is via graphs. Graphs can immediately provide a graphical display of trends and patterns that words and numbers in a table don't necessarily convey.

Line Graphs ESG3P

Line graphs are used when:

- The relationship between the dependent and independent variables is continuous.
- Both dependent and independent variables are measured in numbers.



Features of line graphs:

- An appropriate scale is used for each axis so that the plotted points use most of the axis/space (work out the range of the data and the highest and lowest points).
- The scale must remain the SAME along the entire axis and use easy intervals such as 10's, 20's, 50's, and not intervals such as 7's, 14's, etc, which make it difficult to read information off the graph.
- Each axis must be labelled with what is shown on the axis and must include the appropriate units in brackets, e.g. Temperature (°C), Time (days), Height (cm).
- Each point has an x and y co-ordinate and is plotted with a symbol which is big enough to see, e.g. a cross or circle.
- The points are then joined.
- With a ruler if the points lie in a straight line (see Figure 3) or you can draw a line of best fit where the number of points are distributed fairly evenly on each side of the line.
- Freehand when the points appear to be following a curve (see Figure 4).
- DO NOT start the line at the origin unless there is a data point for 0. If there is no reading for 0, then start the line at the first plotted point.
- The graph must have a clear, descriptive title which outlines the relationship between the dependent and independent variable.
- If there is more than one set of data drawn on a graph, a different symbol must be used for each set and a key or legend must define the symbols.

FACT
Table headings are always written ABOVE the table. Graph headings are always written BELOW the graph.

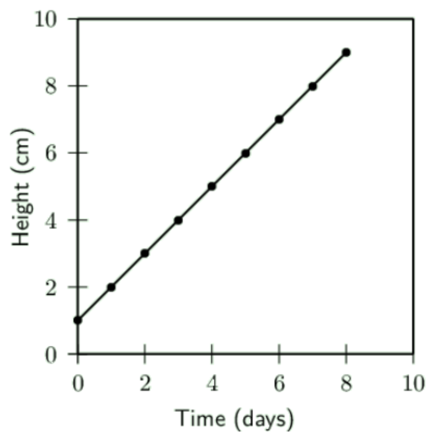


Figure 1.3: Graph showing change in plant height over 10 days.

Bar Graphs

ESG3Q

Bar graphs are used when:

- The independent variable is discontinuous (i.e. The variables on the x-axis are each associated with something different)
- Independent variables are not numerical. For example, when examining the protein content of various food types, the order of the food types along the horizontal axis is irrelevant.

Bar graphs have the following features:

- The data are plotted as columns or bars that do not touch each other as each deals with a different characteristic.
- The bars must be the same width and be the same distance apart from each other.
- A bar graph can be displayed vertically or horizontally.
- A bar graph must have a clear, descriptive title, which is written beneath the graph.

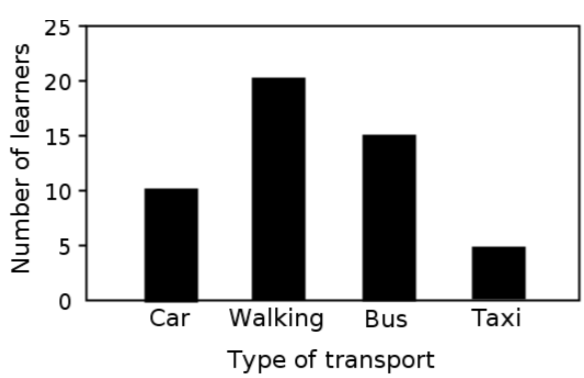


Figure 1.4: Bar graph showing how many learners use each type of transport

Histograms ESG3R

Histograms are used when:

- the independent variable (x-axis) represents information which is continuous, such as numerical ranges, i.e. 0-9, 10-19, 20-29, etc.

Histograms have the following features:

- Unlike a bar graph, in a histogram the data are plotted as columns or bars that touch each other as they are related to each other in some way.
- The numerical categories **must not** overlap, for example, 0-10, 10-20, 20-30, etc. The ranges must be exclusive so that there is no doubt as to where to put a reading, for example, 0-9, 10-19, 20-29, etc.
- The bars can be vertically or horizontally drawn.
- A histogram must have a descriptive heading with is written below the graph
- and the axes must be labelled.

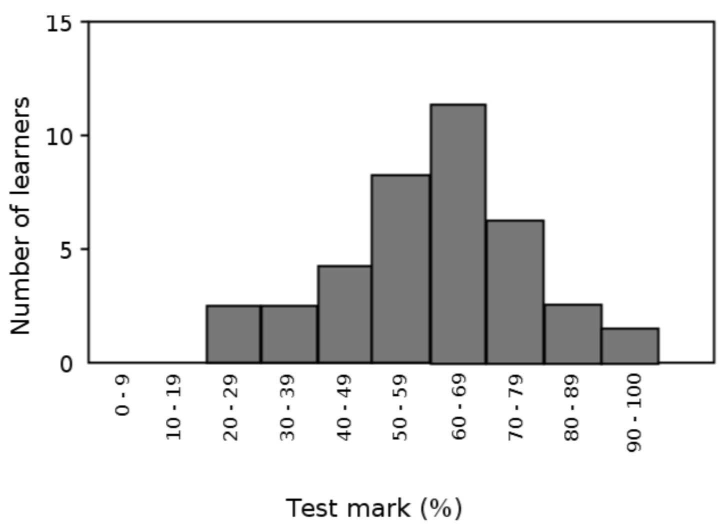


Figure 1.5: A histogram showing the number of learners in a Grade 10 Life sciences class with a particular percentage test score

Pie charts ESG3S

Pie charts are used when:

- You want to give a visual representation of percentages as a relative proportion of the total of a circle.

Pie charts have the following features:

- They are a type of graph even though they do not have any axes.
- A pie chart is a circle divided into sectors (think of them as the slices of a cake).
- 100% represents the whole complete circle, 50% represents a half circle, 25% is a quarter circle, and so on.

Example:

1. Count the number of each species and record it in a table.
2. Work out the total number of species in the ecosystem.
3. Calculate the percentage of each species.
4. Use the following formula to work out the angle of each slice:

$$a = \frac{v \times 360°}{t}$$

Category	Number of species	Percentage %	Slice angle
Insects	17	$\frac{17 \times 100}{50} = 34\%$	$\frac{34 \times 360}{100} = 122{,}4°$
Plants	16	$\frac{16 \times 100}{50} = 32\%$	$\frac{16 \times 360}{100} = 115{,}2°$
Birds	9	$\frac{9 \times 100}{50} = 18\%$	$\frac{18 \times 360}{100} = 65°$
Amphibians	8	$\frac{8 \times 100}{50} = 16\%$	$\frac{16 \times 360}{100} = 57{,}6°$

Table 1.1: Table showing recordings and calculations for construction of a pie chart

5. Use a compass to draw the circle and a protractor to measure accurate angles for each slice.
6. Start with the largest angle/percentage starting at 12 o′ clock and measure in a clockwise direction.
7. Shade each slice and write the percentage on the slice and provide a key.

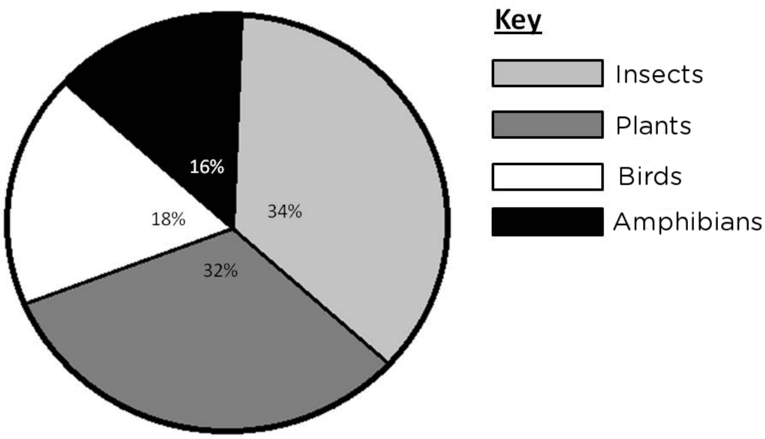


Figure 1.6: Pie chart showing the relative proportions of different categories of organisms in an ecosystem

Activity: Converting tables to graphs

Aim:

It is very important to be able to convert tables to graphs, and vice versa. Below are some exercises to practice this skill.

Questions:

1. Convert the data in the graphs below into Tables. Remember to identify which is the independent variable in the graphs and to place this in the first column of the Table.

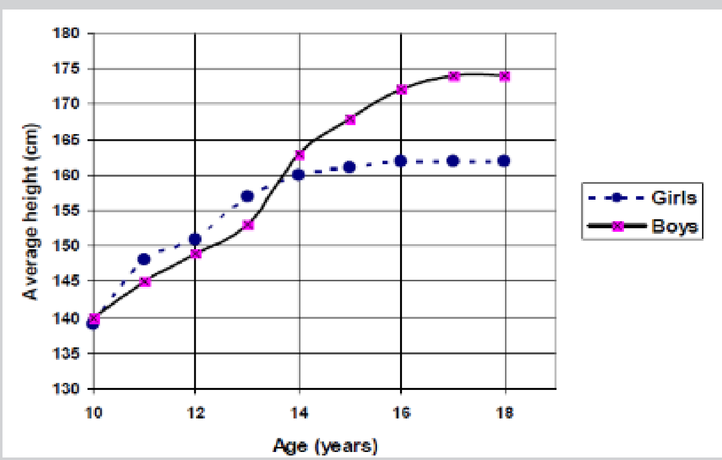


Figure 1.7: The average height in boys and girls between the ages of 10 and 18 years.

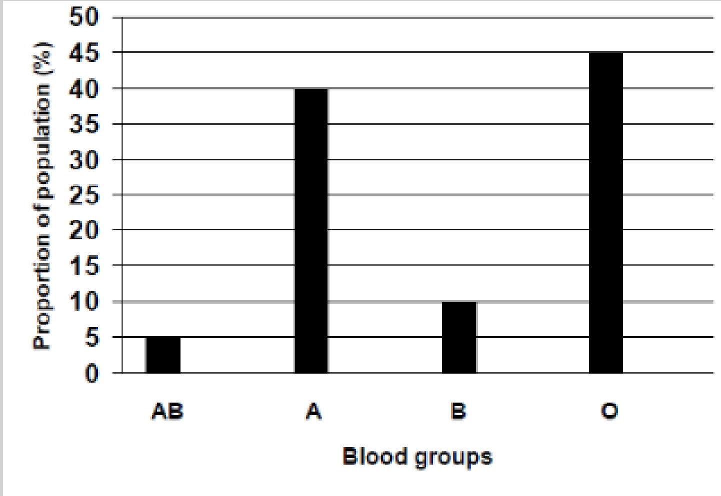


Figure 1.8: Proportion of each blood group in a small population.

2. Convert the data in the following tables into graphs. Look back at the features of each type of graph to decide which one you will use.

Favourite take away restaurant in a class of learners

Take away restaurant	Learners (%)
Kauai	40
Anat Falafel	15
Nandos	25
Burger King	20

1.5 Mathematical skills in Life Sciences ESG3T

Mathematical skills are important in Life Sciences. Below are explanations of some of the skills you will encounter:

- Scales
- Averages
- Percentages
- Conversions

NB. You must state the **units** at the end of each calculation, e.g. cm, degrees, kg, etc.

Scales ESG3V

A scale is given in a diagram, drawing or electron micrograph so that the actual size of the object that is being shown can be determined. The object could be bigger or smaller in real life.

Example: To measure the diameter of a chloroplast with a scale line of 1 μm.

1. Measure the length of the scale line on the micrograph in mm, e.g. 1 μm = 17mm
2. Measure the diameter of the organelle in millimetres, e.g. = 60mm
3. True diameter of chloroplast:

$$
\begin{aligned}
&= \frac{\text{measured size } \times \text{ true length of scale line}}{\text{measured length of scale line}} \\
&= \frac{60 \text{ mm} \times 1\ \mu\text{m}}{17 \text{ mm}} \\
&= 3{,}53\ \mu\text{m}
\end{aligned}
$$

Answer: The true diameter of the chloroplast is 3.53 μm.

Averages ESG3W

To find an average of a set of numbers, you add all the items and divide the total by the number of items.

Example: Find the average height in a class of 10 learners with the following heights in cm: 173, 135, 142, 167, 189, 140, 139, 164, 172, 181.

1. Add all 10 learners heights together to get a total.
2. Divide the total by the number of learners (10) to get the average.

Total:

$$\text{Sum} = 1602 \text{ cm}$$

Average:

$$
\begin{aligned}
\text{Average} &= \frac{1602}{10} \\
&= 160{,}2 \text{ cm}
\end{aligned}
$$

Answer: The average height of the learners is 160,2 cm

Percentages ESG3X

To calculate a percentage, multiply the fraction by 100.

Formula for calculating percentage (%):

$$\text{Percentage} = \frac{\text{Number with feature } (A)}{\text{Total number } (B)} \times 100$$

Example: There are 48 learners in your class and 4 of them are left handed. Calculate the percentage of learners in your class that are left-handed.

1. Count how many learners are left handed (A).
2. Count the total number of learners in the class (B).
3. Divide the number of left-handed learners (A) by the total number of learners (B) to get a fraction or proportion.
4. Multiply the fraction by 100.

Therefore, to calculate the percentage of learners that are left-handed:

$$\begin{aligned} &= \frac{A}{B} \times 100 \\ &= \frac{4}{48} \times 100 \\ &= 8{,}3\% \end{aligned}$$

Answer: 8,3% of the learners in your class are left-handed.

Example: Using the same class of learners, calculate the percentage of learners that are right-handed.

To calculate the percentage of the class that is right handed, one could count the number of right-handed students, and perform the percentage calculation again. Or, since the whole class is equal to 100 %, one can simply subtract the percentage of left-handed students and you will be left with the percentage of right-handed students.

The percentage of right-handed learners:

$$\begin{aligned} &= 100\% - 8{,}3\% \\ &= 91{,}7\% \end{aligned}$$

Answer: 91,7% of the learners in your class are right-handed.

Conversions ESG3Y

Below is a table with some common conversions that you will need to use in the study of Life Sciences:

From unit:	To unit (number of these units per "From unit"):			
	m	**mm**	**μm**	**nm**
m	1	1000	1 000 000	1 000 000 000
mm	10^{-3} or 1/1000	1	1000	1 000 000
μm (micrometres)	10^{-6} or 1/1 000 000	10^{-3} or 1/1000	1	1000
nm (nanometres)	10^{-9} or 1/1 000 000 000	10^{-6} or 1/1 000 000	10^{-3} or 1/1000	1

1.6 Lab safety procedures ESG3Z

The Life Science Laboratory has rules that are enforced as a safety precaution.

These rules are:

- Take care when pouring liquids or powders from one container to another. When spillages occur you need to call the teacher immediately to assist in cleaning up the spillage.
- Take care when using acids. A good safety precaution is to have a solution of sodium bicarbonate in the vicinity to neutralise any spills as quickly as possible.
- Safety goggles and/ or gloves may need to be worn when doing experimental work, working with various chemicals, or heating substances, as spitting may occur.
- When lighting a Bunsen burner the correct procedure needs to be followed.
- Remember that when heating a substance in a test tube, the mouth of the test tube must face away from you and members in your group.
- Do not to overheat the solution when heating substances in a test tube.
- Ensure that you are dressed appropriately: hair should be tied back and loose clothing that could potentially knock over the equipment or catch alight if too near a flame should be avoided.
- Before doing any scientific experiment make sure that you know where the fire extinguishers are in your laboratory and there should also be a bucket of sand to extinguish fires.
- If scalpel blades, pins and knives are used, take care not to cut yourself. If you do cut yourself and draw blood call the teacher immediately.
- When working with chemicals and gases that are hazardous a fume cupboard should be used.

CHAPTER 2

The chemistry of life

2 The chemistry of life

2.1 Overview ESG42

Introduction ESG43

In this chapter we will study the molecular structure and biological functions of key molecules important to life. We will study the chemistry of proteins, carbohydrates, lipids, vitamins and nucleic acids and will learn the role of each nutrient class in plant and animal life. We will also learn how our diet allows us to obtain sufficient quantities of each of these nutrients. There are a variety of practicals and investigations in this section, which provide an opportunity for you to practice applying the scientific method.

Key concepts

- Organic molecules always contain carbon (C), and usually also contain hydrogen (H) and oxygen (O) atoms. Some important organic molecules also contain nitrogen (N), phosphorous (P), sulfur (S), iron (Fe) and other elements.
- Water (H_2O) is an inorganic compound made up of two H atoms and one O atom. Water helps with temperature regulation, form and support, transport and lubrication and is a medium for chemical reactions.
- Minerals are required as part of a healthy diet. A deficit in essential minerals results in deficiency diseases in plants and animals.
- Fertilisers are a way that essential nutrients can be added to the soil to improve plant growth.
- Carbohydrates are made up of C, H and O. They can be in the form of monosaccharides (single sugars), disaccharides (double sugars) or polysaccharides (many sugars), and are an important energy source for plants and animals.
- Lipids are made up of C, H and O. Triglycerides are a type of lipid that contains glycerol and three fatty acid chains. Cholesterol, another type of lipid, can increase the risk of heart disease.
- Proteins are made up of C, H, O, N, and some have P, S and Fe. Proteins consist of a long chain of amino acids that fold into a very specific three-dimensional structure. Proteins are an important building block in plants and animals and play a role in the immune system and in cell communication.
- Enzymes are a type of protein that act as a biological catalyst to speed up reactions. They work by a "lock and key" mechanism and are affected by temperature and pH.

- Nucleic acids such as DNA and RNA are made of C, H, O, N and P. DNA contains the genetic information for heredity, and RNA has the instructions on how to make protein.
- Vitamins are important organic molecules that must be obtained in the diet. They often help enzymes to work properly, or act in growth or differentiation.

FACT
Because all compounds contain more than one atom, all compounds are molecules. However, not all molecules are compounds.

In order to understand the chemistry of living systems, it is important to understand how all living systems are arranged from the smallest unit (atomic scale) to the largest unit (ecosystems). A simple way to describe the levels of organisation of livings things can be given as follows:

FACT
Simulation on building a molecule
See video: 2CMH

atom →**molecule**→cell→tissue→organ→system→organism→ecosystem

2.2 Molecules for life ESG44

Although life at the macro level is diverse, the chemistry making up that life is remarkably similar. All living things are made up of basic building blocks called **elements**. An element is a substance that cannot be broken down into simpler substances using chemical means. Carbon, oxygen, hydrogen, nitrogen, sulfur, calcium, sodium and iron are examples of elements you will come across in Life Sciences.

Each element is distinguished by the composition of its **atom**. An atom is the basic unit of matter. **Molecules** are formed when one or more atoms are covalently bonded together. The atoms of a molecule can be identical, such as 0_2 or H_2 or differ such as H_2O. A **compound** is formed when atoms of *different* elements join together.

Compounds are divided into **organic** and **inorganic** compounds. Organic compounds always contain carbon, but not all compounds that contain carbon are organic. A general rule of thumb is that organic compounds contain carbon, with at least one of these carbons bonded to hydrogen atoms. Carbon dioxide is therefore an inorganic compound even though it contains carbon. The major organic compounds found in living organisms include: **carbohydrates**, **fats**, **proteins** and **nucleic acids**. These will be discussed in detail later in this chapter.

FACT
Learn about some of the amazing life-supporting properties of water
See video: 2CMJ

Substance	Percentage (%)
Inorganic	
Water	65
Mineral salts	1
Organic	
Protein	18
Carbohydrate	5
Other organic macromolecules	1

Table 2.1: The composition of macromolecules in humans by percentage.

2.3 Inorganic compounds ESG45

The role of water in the maintenance of life ESG46

As mentioned in Table 2.1, up to 65% of our bodies are made up of water. Water is an inorganic compound made up of two hydrogen atoms and one oxygen atom. Its molecular formula is H_2O. Water plays an important role in the maintenance of biological systems.

Temperature regulation: In humans, the sweat glands produce sweat which cools the body as it evaporates from the body surface in a process called *perspiration*. In a similar way, plants are cooled by the loss of water vapour from their leaves, in a process called *transpiration*.

Form and support: Water is an important constituent of the body and plays an important role in providing form and support in animals and plants. Animals, such as worms and jellyfish, use water in special chambers in their body to give their bodies support. This use of water pressure to provide body form, and enable movement is called a *hydrostatic skeleton*. Plants grow upright and keep their shape due to the pressure of water (*turgor pressure)* inside the cells.

Transport medium: Water transports substances around the body. For example, water is the main constituent of blood and enables blood cells, hormones and dissolved gases, electrolytes and nutrients to be transported around the body.

Lubricating agent: Water is the main constituent of saliva which helps chewing and swallowing and also allows food to pass easily along the alimentary canal. Water is also the main constituent of tears which help keep the eyes lubricated.

Solvent for biological chemicals: The liquid in which substances dissolve is called a solvent. Water is known as the universal solvent as more substances dissolve in water than in any other liquid.

Medium in which chemical reactions occur: All chemical reactions in living organisms take place in water.

Reactant: Water takes place in several classes of chemical reactions. During hydrolysis reactions, water is added to the reaction to break down large molecules into smaller molecules. Water can also be split into hydrogen and oxygen atoms to provide energy for complex chemical reactions such as photosynthesis.

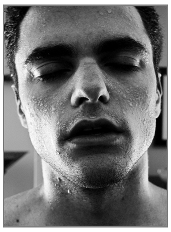
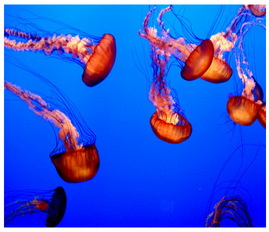
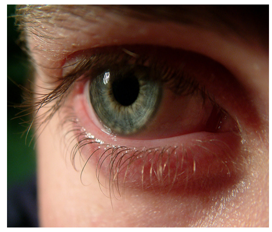
Temperature	Structure and support		Lubrication
			
Sweating helps human bodies cool down.	Jellyfish and worms use a hydrostatic (water pressure) skeleton to keep their body shape.	Water helps maintain the upright structure of plants.	Water is an important lubricant in the eye.

Table 2.2: The role of water in living organisms.

Minerals ESG47

Dietary minerals are the chemical elements that living organisms require to maintain health. In humans, essential minerals include calcium, phosphorous, potassium, sulfur, sodium, chlorine and magnesium.

Macro-elements (macro-nutrients) are nutrients that are required in large quantities by living organisms (e.g carbon, hydrogen, oxygen, nitrogen, potassium, sodium, calcium, chloride, magnesium, phosphorus and sulfur).

Micro-elements (micro-nutrients) are nutrients that are required in very small quantities for development and growth and include iron, cobalt, chromium, copper, iodine, manganese, selenium, zinc and molybdenum.

Nutrients required for human health

Table 2.3 below summarises some important minerals required for proper functioning of the human body. Proper nutrition involves a diet in which the daily requirements of the listed mineral nutrients are met.

FACT
Chlorosis is the yellowing of the leaves due to low production or loss of chlorophyll.

Mineral	Food Source	Main Functions	Deficiency Disease
Macro-nutrients			
Calcium (Ca)	most fruit and vegetables, meat, dairy products	strong bones and teeth, muscle contraction, blood clotting, nerve function	rickets, osteoporosis
Magnesium (Mg)	nuts, meat, dairy products	strong bones and teeth, nerve and muscle function, energy production	osteoporosis, muscle cramps
Phosphorus (P)	nuts, meat, dairy products	strong bones and teeth, nerve function, part of nucleic acids and cell membranes	rickets, osteoporosis
Potassium (K)	bananas, meat, dairy products	growth and maintenance, water balance, heart function	muscle cramps, heart, kidney and lung failure
Sodium (Na)	table salt, fruit and vegetables	regulates blood pressure and volume, muscle and nerve function	muscle cramps
Sulfur (S)	meat, dairy products, eggs, legumes	part of proteins, detoxifies the body, good skin, hair and nails	disorder unlikely
Micro-nutrients			
Iron (Fe)	meat, legumes	part of haemoglobin (the oxygen transport protein), part of some enzymes	anaemia
Iodine (I)	seafood, iodated salt	production of hormones by the thyroid gland, strong bones and teeth, good hair, skin and nails	goitre, stunted growth, mental problems
Zinc (Zn)	seafood, meat	immune function, male reproductive system	stunted growth, prostate problems

Table 2.3: Minerals required by humans.

Nutrients required for plant growth

The previous section examined the key nutrients important for animal growth. In Table 2.4 we will now look at the key nutrients required for plant growth.

Mineral	Source	Main Functions	Deficiency Disease
Macro-nutrients			
Calcium (Ca)	inorganic fertilisers, Ca ions in the soil	part of the plant cell wall, transport and retention of other elements	chlorosis (yellowing of the leaves due to low production or loss of chlorophyll)
Magnesium (Mg)	inorganic fertilisers, Mg ions in the soil	component of chlorophyll (pigment for photosynthesis), activates many enzymes required for growth	chlorosis
Nitrogen (N)	inorganic fertilisers in the form of nitrates, symbiotic nitrogen-fixing bacteria in roots	component of chlorophyll, nucleic acids and proteins, seed and fruit production	stunted growth, smaller leaves
Phosphorus (P)	inorganic fertilisers in the form of phosphates, low amounts in the soil	photosynthetic process, part of nucleic acids and cell membranes, root growth	stunted growth, blue/green leaves
Potassium (K)	inorganic fertilisers, K ions in the soil	needed for protein synthesis, photosynthesis, enzyme activation, opening and closing of stomata	chlorosis, curling leaf tips, brown scorching, poor fruit quality
Sulfur (S)	inorganic fertilisers	protein synthesis, root growth, chlorophyll formation, promotes activity of enzymes	chlorosis
Micro-nutrients			
Iron (Fe)	inorganic fertilisers, Fe ions in the soil	component of the enzyme that makes chlorophyll	chlorosis
Zinc (Zn)	inorganic fertilisers, Zn ions in the soil	part of growth-regulating enzyme systems	poor leaf growth
Sodium (Na)	inorganic fertilisers, Na ions in the soil	maintains salt and water balance	reduced growth
Iodine (I)	inorganic fertilisers, I ions in the soil	needed for energy release during respiration	poor growth

Table 2.4: Nutrients required for plant growth.

Fertilisers ESG48

When crops are regularly grown and harvested on the same piece of land, the soil becomes depleted of one or more nutrients. Fertilisers are natural or non-natural mixtures of chemical substances that are used to return depleted nutrients to the soil, improve the nutrient content of the soil and promote plant growth. Inorganic nutrients (such as nitrates and phosphates) are added to the soil in the form of inorganic fertilisers.

Effect of fertilisers on the environment

Using large amounts of fertilisers can be harmful to the environment. Fertilisers wash off into rivers where they are poisonous to plant and animal life. The accumulation of fertilisers in rivers can lead to a process known as **eutrophication**. This process occurs when excessive nutrients (nitrates and phosphates) from the land (typically from fertilisers) run off into rivers and lakes. This leads to high growth of water plants. Plants grow and produce food by photosynthesis which requires high quantities of oxygen. The high oxygen demand of the rapidly growing water plants removes oxygen available to other organisms in the rivers and lakes. The overgrowth of water plants also blocks sunlight from entering the water, so that plants underwater can no longer photosynthesise and stop producing oxygen. These two processes combine to deplete the water of oxygen and cause aquatic organisms to suffocate and die. The biodegradation of the dead organisms results in a massive increase in bacteria, fungi and algae degrading the dead organic matter, which also require oxygen. This further depletes the available oxygen, and further contributes to the death of fish and other aquatic species.

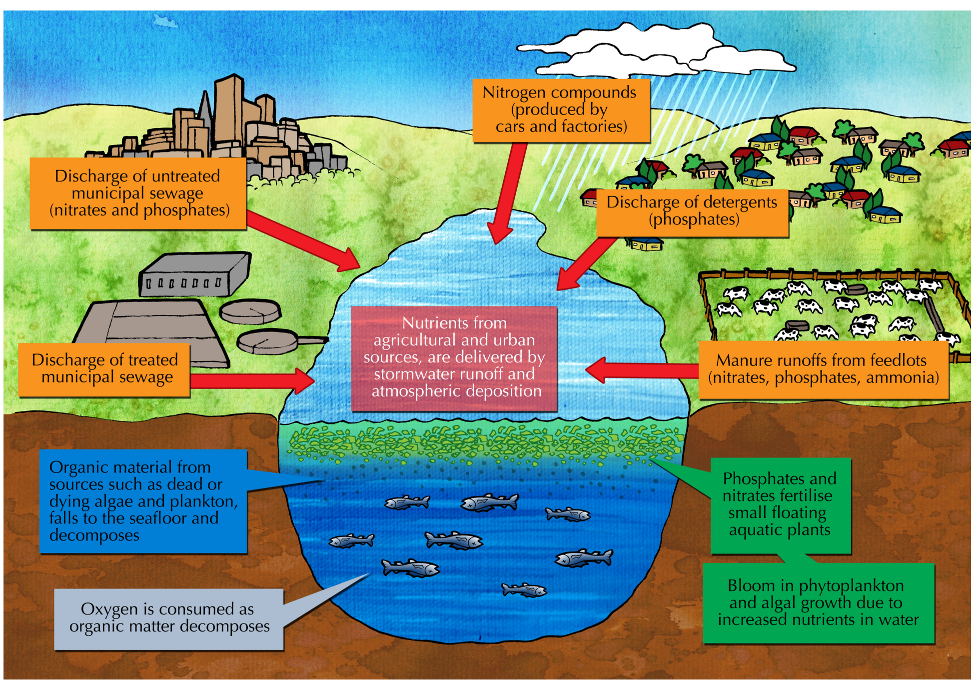


Figure 2.1: Schematic diagram showing the processes that lead to eutrophication.

Figure 2.2: Algae and dead fish in a lake that has undergone eutrophication.

Figure 2.3: Algal bloom in a river following eutrophication.

Natural fertilisers: an application of indigenous knowledge systems

The fertilisers discussed above are non-natural inorganic compounds such as nitrates, phosphates etc. However, as a means of reducing the negative impact of the inorganic fertilisers discussed earlier, organic fertilisers that occur naturally can be used. Natural fertilisers consist of organic compounds derived from manure, slurry, worm castings, peat, seaweed etc.

Natural fertilisers supply nutrients to the soil through natural processes such as composting. This means that the nutrients are released back to the soil slowly, and excessive nutrients do not wash off into rivers causing over-fertilisation and eutrophication. However, the use of organic fertilisers is more labour-intensive and the nutrient composition tends to be more variable than the inorganic fertilisers. As a result it is difficult to know for sure whether the particular nutrient required by the plant is actually being supplied by the natural fertiliser.

Figure 2.4: Sample of compost created through processes involving degradation of dead organic matter by bacteria and fungi.

Figure 2.5: A homemade compost tumbler.

2.4 Organic compounds ESG49

An organic compound is a compound whose molecules contain C, and usually at least one C-C or C-H bond. Very small carbon-containing molecules that do not follow the above rules, such as CO_2 and simple carbonates, are considered inorganic. Life on earth would not be possible without carbon. Other than water, most molecules of living cells are carbon-based, and hence are referred to as organic compounds. The main classes of organic compounds we will investigate in this section include carbohydrates, lipids, proteins and nucleic acids.

Each of these classes of compounds consists of large molecules built from small subunits. The smallest of these subunits is called a **monomer**. Several monomers bond together to form **polymers**. Each of these polymers is characterised by a specific structure owing to the chemical bonds formed. These structures are related to the function of the compound in living organisms. We will therefore study each class of compounds under the following headings:

- **Molecular make-up**: the main elements that make up the class of compounds.
- **Structural composition**: how the monomers join up together to form polymers.
- **Biological role**: the importance of these molecules to animals and plants.
- **Chemical test**: how to detect the presence of each class of compounds.

Carbohydrates ESG4B

Molecular make-up

Carbohydrates consist of carbon (C), hydrogen (H) and oxygen (O).

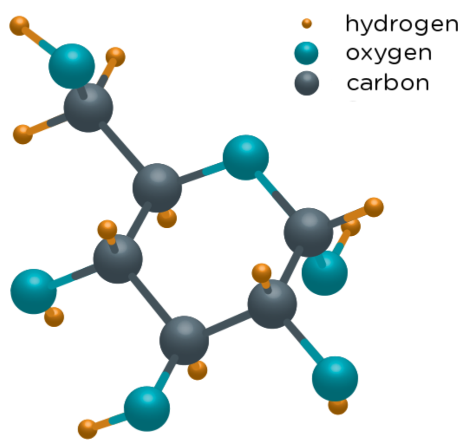


Figure 2.6: A glucose molecule is made up of carbon, hydrogen and oxygen.

Structural composition

Carbohydrates are made up of monomers known as **monosaccharides**. The monosaccharide that makes up most carbohydrates is glucose. Other monosaccharides include fructose, galactose and deoxyribose (discussed later). These monomers can be joined together by **glycosidic** bonds. When two monosaccharides are chemically bonded together, they form **disaccharides**. An example of a disaccharide is sucrose (table sugar), which is made up of glucose and fructose. Other dissacharides include lactose, made up of glucose and galactose, and maltose, made up of two glucose molecules. Monosaccharides and dissachardies are often referred to as sugars, or simple carbohydrates. Several monosaccharides join together to form **polysaccharides**. Examples of polysaccharides you will encounter include glycogen, starch and cellulose. Polysaccharides are usually referred to as complex carbohydrates as they take longer to break down.

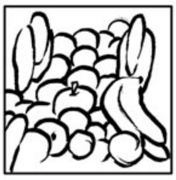
				
Fruits contain the monosaccharide: fructose	Sugar cane contains the disaccharide: sucrose (glucose + fructose)	Malt Sugar contains the disaccharide: maltose (glucose + glucose)	Milk contains the disaccharide: lactose (glucose + galactose)	Potatoes contain the polysaccharide: starch

Figure 2.7: Examples of food sources of various monosaccharides, disaccharides and polysaccharides.

Role in animals and plants

The main function of carbohydrates is as energy storage molecules and as substrates (starting material) for energy production. Carbohydrates are broken down by living organisms to release energy. Each gram of carbohydrate supplies about 17 kilojoules (kJ) of energy. **Starch** and **glycogen** are both storage polysaccharides (polymers made up of glucose monomers) and thus act as a store for energy in living organisms. Starch is a storage polysaccharide in plants and glycogen is the storage polysaccharide for animals. Cellulose is found in plant cell walls and helps gives plants strength. All polysaccharides are made up of glucose monomers, but the difference in the properties of these substances can be attributed to the way in which the glucose molecules join together to form different structures. Below are images of glycogen and starch.

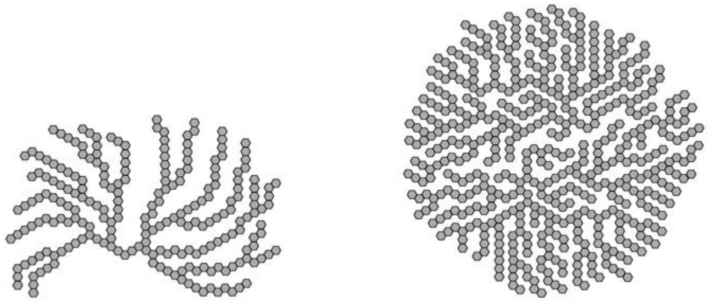
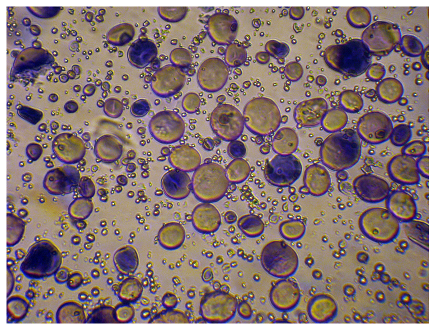


Figure 2.8: A comparison between starch and glycogen. Glycogen is more extensively branched than starch.

Chemical tests to identify presence of starch

Substances containing starch turn a blue-black colour in the presence of iodine solution. An observable colour change is therefore the basis of a chemical test for the compound.

The adjacent figure shows granules of wheat starch stained with iodine solution and photographed through a light microscope.



In the following investigation we will test a few different foods for the presence of starch.

Investigation: Test for the presence of starch (Essential investigation-CAPS)

Aim:

To test for the presence of starch.

Apparatus:

- piece of potato or bread
- lettuce leaf
- petri dish
- iodine solution
- dropper
- other food items of your choosing

Method:

1. Place a piece of potato or bread, the lettuce leaf, and your other food samples in separate petri dishes.
2. Using the dropper add a few drops of iodine solution to the food item in each petri dish.

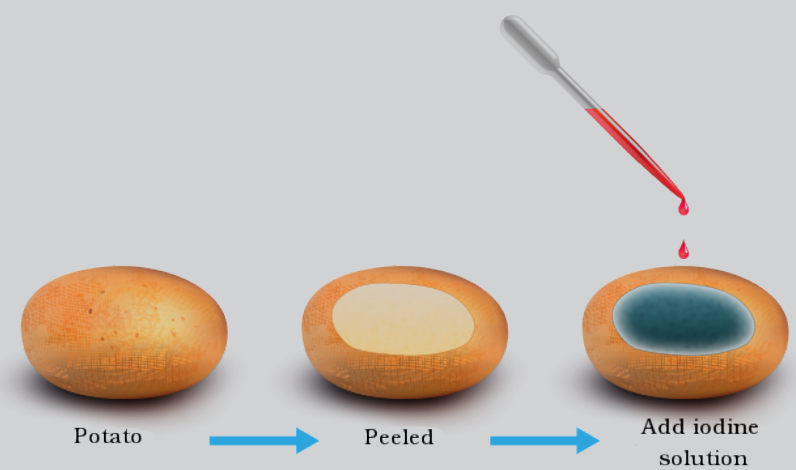


Figure 2.9: Experimental set-up: test for the presence of starch using iodine solution.

Observations:

Record your observations.

Questions:

Can this method be used to determine **how much** starch is present? Explain your answer.

FACT
Watch one of the following videos for a demonstration of the iodine solution test for starch.
See video: 2CMK
See video: 2CMM
See video: 2CMN

Chemical test to identify presence of reducing sugars

Certain monosaccharides, such as glucose, are known as **reducing sugars**. These are defined as sugars that can easily undergo oxidation reactions (i.e. lose an electron or gain an oxygen atom) and act as a **reducing agent**. In order to test for carbohydrates we typically test for the presence of reducing sugars using either the **Benedict's** or **Fehling's test**. Both solutions (Benedict's and Fehling's) contain copper sulphate which reacts with reducing sugars to produce a colour change.

FACT
Watch a video demonstration of the test for glucose.
See video: 2CMP

Investigation: Testing for the presence of reducing sugars (Essential investigation-CAPS)

Aim:

To test for presence of sugars using Benedict's or Fehling's test.

Apparatus:

- four heat resistant test tubes
- one beaker
- Bunsen burner or water bath with hot water (+50 °C)
- test tube rack (if using a water bath)
- glucose solution
- albumen solution or egg white
- starch solution
- water
- Benedict's solution OR Fehling's solution
- marking pen to mark the test tubes
- thermometer
- 10 ml syringe or measuring cylinder

Safety precautions:

- Follow the safety procedures (listed in Chapter 1) when lighting your Bunsen burner. Do not light it in a shelf or enclosed space. Remove all notebooks, papers and excess chemicals from the area. Tie back any long hair, dangling jewelry and loose clothing and never leave an open flame unattended while it is burning.
- When heating your test tubes in the heated water in the beakers ensure that the mouth of the test tubes point away from you and fellow learners.
- When handling the test tubes, especially when they are hot, use a test tube holder and wear goggles.

Method:

Prepare a water bath by filling a beaker to the halfway mark with water. Place the beaker on a tripod stand over a Bunsen flame as shown in Figure 2.10. This will serve as your water bath.

Whilst waiting for the water to reach the desired temperature, carry out the following instructions:

1. Label the test tubes 1–4.

2. Using the syringe or measuring cylinder, add the following to the test tubes:
    - test tube 1: 5 ml of 1% starch solution
    - test tube 2: 5 ml of 10% glucose solution
    - test tube 3: 5 ml 1% albumen solution
    - test tube 4: 5 ml water
3. Add 5 ml Benedict's solution to each tube.
4. Place the test tubes in the beaker of hot water on the tripod.
5. Use a thermometer to monitor the water temperature and adjust the flame to maintain the water temperature at approximately 50°C.
6. If using the water bath, place the test tubes into the test tube rack and place into the water bath with temperature set to 50°C.
7. After about 5 minutes, when a colour change has occurred in some of the test tubes, extinguish the flame, or remove the test tubes from the water bath.
8. Place the four test tubes in a test tube rack and compare the colours.

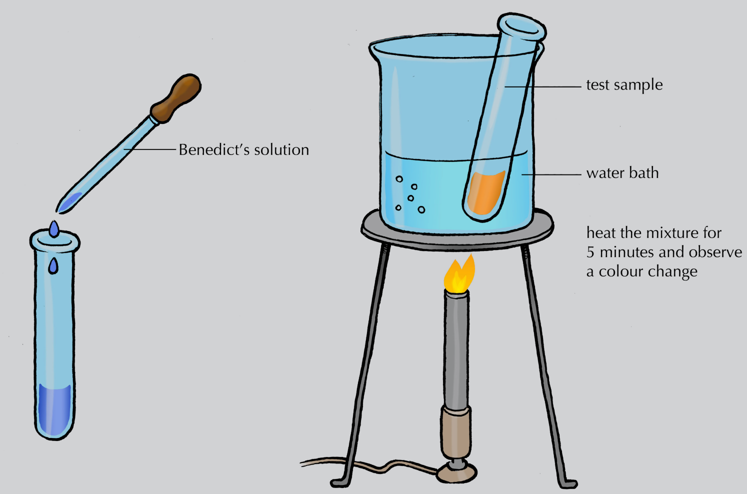


Figure 2.10: Test for reducing sugars using Benedict's test

Results:

Construct a table to record the results of this experiment. It is important to observe and record any changes that have taken place.

Tube number	Observations in each tube

FACT
Watch a video demonstration of the test for reducing sugars.
See video: 2CMQ
See video: 2CMR

FACT
When drawing organic molecules, it can easily get confusing writing out all of the 'C's and 'H's for carbon and hydrogen respectively. Scientists overcome this by drawing the carbon backbone, and leaving out the hydrogens. Carbon will always make 4 bonds with other atoms, so it is easy to figure out how many hydrogens there must be. The carbon is indicated by a point, and the bonds between carbon molecules are indicated by lines joining the points.

Questions:

1. What colour changes (if any) did you observe after heating the samples with Benedict's solution?
2. The three solutions tested are examples of the chemical substances found in cells: glucose, starch, protein (albumen). Which of the samples tested positive when the Benedict's solution was added and the test tube was heated?
3. Other than the colour, what change took place in the consistency of the Benedict's solution?
4. What can you conclude from the investigation?
5. Why was water included in test tube 4?

Lipids ESG4C

Molecular make-up

Lipids contain carbon (C), hydrogen (H) and oxygen (O) but have less oxygen than carbohydrates. Examples of lipids in the diet include cooking oils such as sunflower and olive oil, butter, margarine and lard. Many nuts and seeds also contain a high proportion of lipids.

Structural composition

Triglycerides are one of the most common types of lipids. Triglyceride molecules are made up of glycerol and three fatty acids (Figure 2.11). The fatty acid tails are made up of many carbons joined together. The number of carbons in the fatty acid chains can differ.

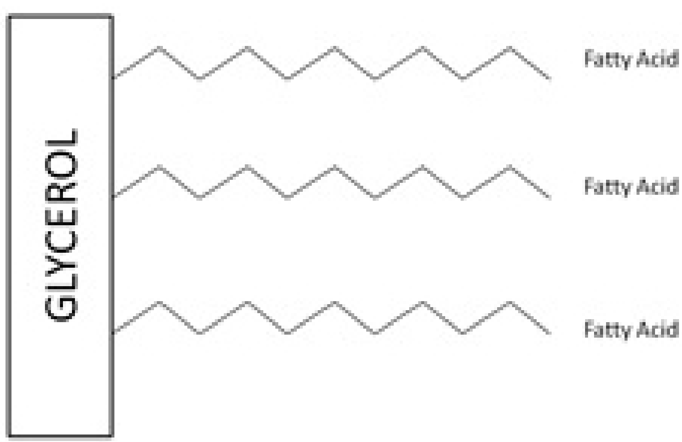


Figure 2.11: A triglyceride molecule.

Role in animals and plants

Lipids are an important energy reserve and contain 37.8 kilojoules (kJ) of energy per gram. Triglyceride lipids are broken down to release glycerol and fatty acids. Glycerol can be converted to glucose and used as a source of energy, however the majority of energy provided by lipids comes from the breakdown of the fatty acid chains. Some fatty acids are essential nutrients that cannot be produced by the body and need to be consumed in small amounts. Non-essential fatty acids can be produced in the body from other compounds.

FACT
You will learn about the important role that lipids play in cell membranes in the following chapter on **the basic units of life**.

Lipids are important for the digestion and transport of essential vitamins, help insulate body organs against shock and help to maintain body temperature. Lipids also play an important role in cell membranes.

Saturated and unsaturated fats

Carbon can form four bonds with other atoms. Most carbons in a fatty acid chain are bonded to two adjacent carbons, and to two hydrogen atoms. When each carbon atom in a fatty acid chain forms four single bonds and has the maximum number of hydrogen atoms, the fatty acid chain is called **saturated** because it is "saturated" with hydrogen atoms. However, sometimes two adjacent carbons will from a double bond. In this case the carbons taking part in the double bond are each joined to only one hydrogen. Fatty acids that have carbon-carbon double bonds are known as **unsaturated**, because the double bond can be 'broken' and an additional bond with hydrogen can be made. Double bonds are stronger than single bonds and they give the fatty acid chain a 'kink'. These kinks mean that the molecules can not pack together tightly, and the lipids are more fluid. This is why unsaturated fats tend to be liquid at room temperature, while saturated fats tend to be solid. Fatty acid chains with many double bonds are called **poly-unsaturated** fatty acids.

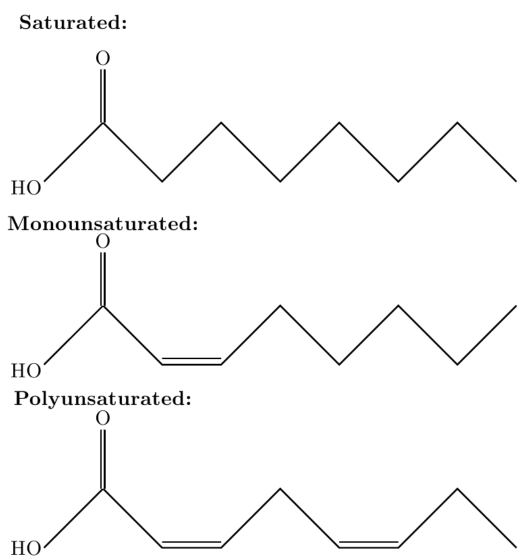


Figure 2.12: Fatty acids can be saturated, mono-unsaturated or polyunsaturated depending on the number of double bonds present. Double bonds result in "kinks" in the fatty acid chain.

FACT
You will learn more about how cholesterol can clog arteries and lead to heart disease in the chapter on **transport systems in animals**

FACT
Translucent means that an object lets some light through.

Cholesterol

Cholesterol is an organic chemical substance known as a **sterol**. You are not required to understand its molecular makeup or its structural composition. It is an important component in cell membranes. The major dietary sources of cholesterol include cheese, egg, pork, poultry, fish and shrimp. Cholesterol is carried through the body by proteins in the blood known as **lipoproteins**. A lipoprotein is any combination of lipid and protein.

Cholesterol is carried in the blood through the body by **high density lipoprotein**, **low density lipoprotein** and through **triglycerides.**

1. **Low density lipoprotein (LDL)**: Low density lipoprotein transports cholesterol around the body. It has a higher proportion of cholesterol relative to protein. It is often known as "bad" cholesterol because higher levels of LDL are associated with heart disease.
2. **High density lipoprotein (HDL)**: High density lipoprotein is the smallest of the lipoproteins. It has a high proportion of protein relative to cholesterol and is therefore often known as the "good" cholesterol. HDL transports cholesterol away from cells and to the liver where it is broken down or removed from the body as waste.

High levels of LDL can cause heart disease. Cholesterol builds up in blood vessels that carry blood from the heart to the tissues and organs of the body, called arteries. This leads to a hardening and narrowing of these vessels, which interferes with the transport of blood, and can potentially lead to a heart attack. The biggest contributor to the amount of cholesterol in your blood is the type of fats you eat. Saturated fats are less healthy than unsaturated fats as they increase the amount of LDL cholesterol in your blood.

Chemical test to detect the presence of lipids

The test for lipids relies on the fact that lipids leave a translucent 'grease spot' on brown paper bags, while non-lipid substances do not.

Investigation: Test for the presence of lipids (Essential investigation-CAPS)

Aim:

To test for the presence of lipids.

Apparatus:

- piece of paper or "fish-and-chips" paper bag
- food item e.g fries, piece of cooked meat, etc
- 10 ml of cooking oil (positive control)
- 10 ml water (negative control)

Method:

1. **Positive control**: add cooking oil to brown paper bag until it is soaked up. The part of the paper that soaks up oil should be translucent compared to the part that does not.
2. **Negative control**: wet the paper with water. The paper may become wet and soggy, but should not become translucent.
3. **Experimental samples**: stain the brown paper bag with the food item to be tested and hold it up to the light. If it is translucent, similar to the positive control, the food item contains lipid.

Observations:

Record your observations, noting any key differences between the controls and the experimental sample.

FACT
Watch a video demonstrating the test for lipids.
See video: 2CMS

Investigation: Alternative methods for testing for lipids

An alternative method to test for the presence of lipids in a sample, is to crush or dissolve the sample in ethanol. Fats and lipids dissolve in alcohol. Once your ethanol solution has been prepared, there are two ways of testing whether this sample contains lipids:

1. **Filter the ethanol solution through filter paper:** lipids that have dissolved in the ethanol will cause filter paper to go translucent. Once the alcohol evaporates away, a translucent spot will remain.
2. **Add the ethanol sample to water:** lipids cannot dissolve in water. Therefore, if the ethanol solution contains lipids, the lipids will precipitate out of solution when mixed with water, causing the solution to go milky.

Proteins ESG4D

Molecular make-up

Proteins contain carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and may have other elements such as iron (Fe), phosphorous (P) and sulfur (S).

FACT
Because the sequence of amino acids determines the way that a protein folds, if you start with a certain peptide chain, you will always get the same three-dimensional structure!

Structural composition

Proteins are made of **amino acids**. There are 20 common amino acids from which all proteins in living organisms are made. Nine of them are considered **essential amino acids**, as they cannot by synthesised in the body from other compounds, and must be obtained from the diet. Amino acids are bonded together by **peptide bonds** to form **peptides**. A long peptide chain forms a protein, which folds into a very specific three-dimensional shape. This three-dimensional shape is completely determined by the identity and order of the amino acids in the peptide chain. We often refer to **four different levels** of protein structure (Figure 2.13):

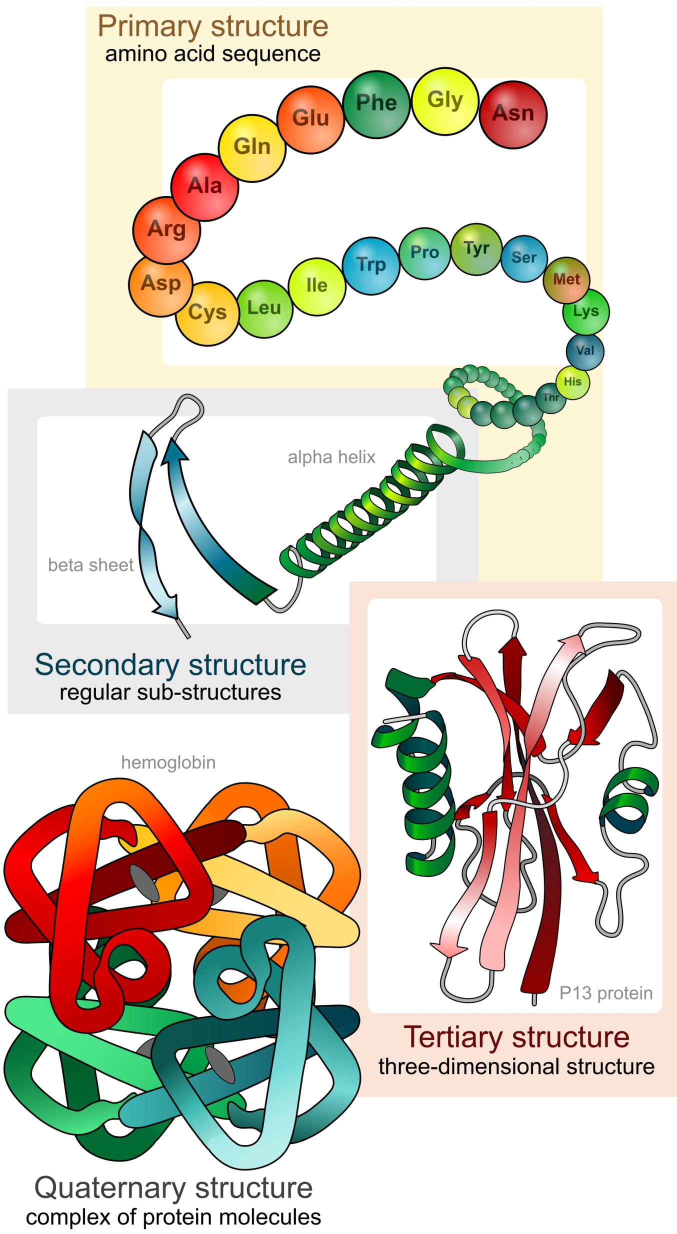


Figure 2.13: The primary, secondary, tertiary and quaternary levels of protein structure.

- **Primary structure**: This refers to the sequence of amino acids joined together by peptide bonds to form a polypeptide chain. Some proteins have fewer than a hundred amino acids, while others have several thousand.
- **Secondary structure**: This is the first level of three dimensional folding. It is driven completely by *hydrogen bonding*. Hydrogen bonding usually results in regions of the chain coiling and other regions forming sheets.
- **Tertiary structure**: This is the second level of three dimensional folding and is the overall final shape of the protein molecule. The secondary structures and unstructured regions of the chain further fold into a globular shape, driven by hydrophobic interactions (non-polar regions trying to escape the water in the cell environment) and electrostatic interactions (polar and charged regions wanting to interact with the water environment and each other).
- **Quaternary structure**: Some proteins are complex: two or more peptide chains fold into their tertiary structures, then these complete structures associate together by hydrophobic and electrostatic interactions to form the final protein.

FACT

Meat or vegetables: which is a better source of protein?
Both animal protein and protein from vegetables is good for health. But each type comes with other nutrients. So which 'package' of nutrients-meat or vegetables is better for health?

- A 180 gram steak provides 40 g of protein BUT also provides 38 g of fat which is more than the Recommended Dietary Allowance
- The same amount of salmon gives 34 g of protein and 18 g of fat.
- A cup of cooked lentils has 18 g of protein and 1 g of fat.

Role in animals and plants

Proteins are important in several crucial biological functions. Proteins are found in hair, skin, bones, muscles, tendons, ligaments and other structures and perform key structural and mechanical functions. Proteins are also important in cell communication and in the immune system. Proteins can also act as an energy reserve when broken down through digestive processes. Each gram of protein can be broken down to release 17 kJ of energy. Certain proteins called **enzymes** are important in catalysing cellular reactions that form part of metabolism.

Proteins are essential to any diet. A lack of protein results in a disease called **kwashiorkor** (Figure 2.14) or **marasmus** (Figure 2.15). Marasmus is caused by a general nutritional deficiency (starvation), and kwashiorkor is caused by a deficiency in protein specifically.

Figure 2.14: Child suffering from kwashiorkor

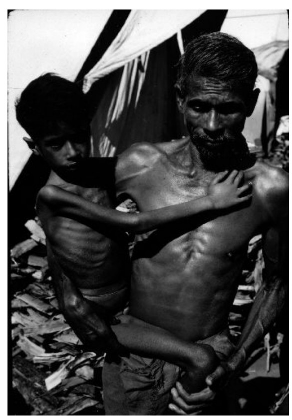


Figure 2.15: Child suffering from marasmus

FACT
Watch a video demonstration of the Biuret test for protein.
See video: 2CMT

Chemical test to detect the presence of protein

The **Biuret Test** for proteins using involves testing for the presence of the peptide bond. Biuret reagent is a copper-based reagent that turns purple when bound to protein in an alkaline solution (Figure 2.16). The more peptide bonds present, the greater the intensity of the purple colour, indicating a higher protein concentration.

The presence of protein can also be detected using **Millon's reagent**. Millon's reagent reacts with tyrosine amino acids, common to most proteins, and results in the formation of a reddish-brown precipitate when heated.

Table 2.5 below summarises the major tests and their expected results in the presence and absence of protein.

Test reagent	Positive result	Negative result
Biuret reagent	Violet/purple colour	Blue colour
Millon's reagent	Red-brown colour	White colour

Table 2.5: Observable colour changes when testing for the presence of protein.

Investigation: Test for the presence of proteins

Aim:

To use the Biuret test or Millon's reagent to test for the presence of proteins.

Apparatus:

1. Bunsen burner and a beaker containing water
2. *or* water bath with hot water (50° C)
3. Dropper or plastic pipette
4. Test tubes:
    - two with albumin solution (positive control)
    - two with sugar water (negative control)
    - test tubes with samples to be tested for the presence of protein
    - test tube with Millon's Reagent
    - test tube with solution for Biuret test

(**NOTE:** The Millon's Reagent and Biuret's solution in this experiment should be prepared for you by your teacher).

Method:

Test for protein using Millon's reagent

WARNING! Millon's reagent is highly toxic! Avoid breathing in its fumes.

1. Using the dropper or pipette, add a few drops of Millon's Reagent to the test tube containing albumin.
2. Using the dropper or pipette, add a few drops of Millon's Reagent to the test tube containing sugar water.
3. Using the dropper or pipette, add a few drops of Millon's Reagent to the test tube containing samples of your food to be tested.
4. Heat the mixtures in boiling water for 5 minutes.
5. Observe any colour changes.

Test for protein using the Biuret test

1. Using the dropper or pipette, add a few drops of the Biuret solution to the test tube containing albumin.
2. Using the dropper or pipette, add a few drops of the Biuret solution to the test tube containing sugar water.
3. Using the dropper or pipette, add a few drops of the Biuret solution to the test tube containing samples of your food to be tested.
4. Observe any colour changes.

Figure 2.16: Biuret test: this is the expected colour change if protein is present

Observations:

Record your observations, noting any key differences between the positive control, negative control and experimental samples

FACT
View a video demonstration of the experiment to test for proteins:
See video: 2CMV

FACT
Learn about what enzymes are and how they work.
See video: 2CMW

Enzymes ESG4F

Enzymes are protein molecules that help chemical reactions in living organisms to take place. The term enzyme has a specific meaning: **an enzyme is a biological catalyst that speeds up the rate of a chemical reaction without being used up in the chemical reaction itself.** Let us analyse this definition in greater detail.

Biological: Enzymes are protein molecules which are made of long chains of amino acids. These fold into unique three-dimensional structures with a region known as an **active site** where reactions take place.

Catalyst: Enzymes speed up chemical reactions without being used up in the reaction themselves. All chemical reactions require a certain minimum amount of energy to take place. This energy is known as the **free energy of activation**. Enzymes lower the energy of activation thus speeding up chemical reactions (Figure 2.17).

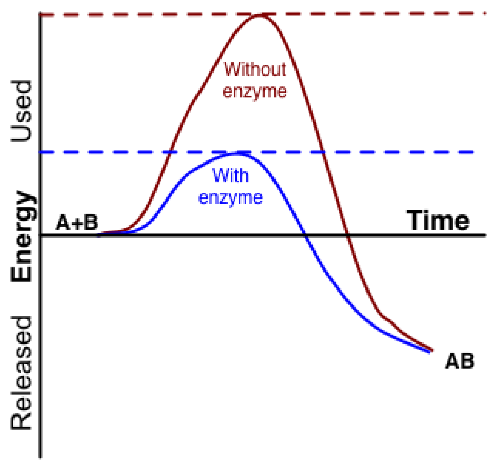


Figure 2.17: Enzymes lower the activation energy, thus making reactions occur faster.

Enzymes are not consumed by the reactions they catalyse: they do not alter the equilibrium of reactions, thus they catalyse both forward and reverse reactions. The direction in which a reaction proceeds is determined by concentration of the substrates and the products of the reactions.

Enzymes may be involved in reactions that break down or build up molecules. The breakdown reactions are known as **catabolic** reactions. The building up reactions are known as **anabolic** reactions.

The 'lock and key' model of enzyme action

Enzymes are highly specific regarding the reactions they catalyse. The specificity depends on the bonds formed between the **active site** of an enzyme and its substrate. Active sites have a specific shape that allows binding of a very specific substrate.

The highly specific nature of the enzyme-substrate binding has been compared to a "lock and key" with the enzyme as the 'lock' and the substrate as the 'key' (Figure 2.18). The substrate binds the active site to form an enzyme-substrate complex. The reaction takes place, then the product leaves the active site as it no longer fits the 'lock' in the same way as the substrate did. The enzyme remains unchanged.

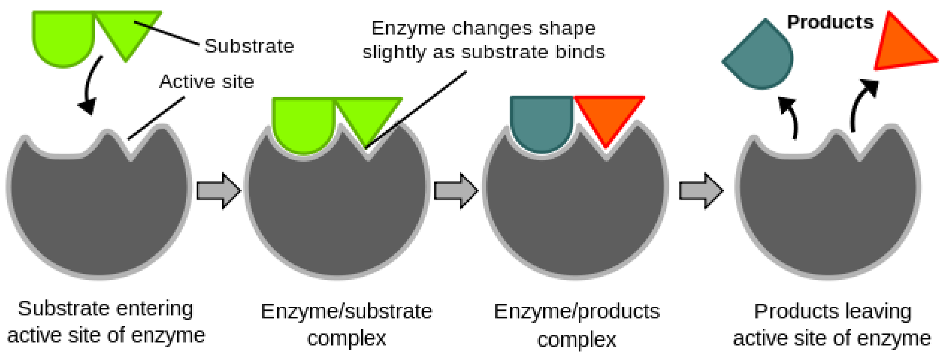


Figure 2.18: This diagram illustrates the 'lock-and-key' model of enzyme action.

Investigation: Investigating how biological washing powders work

Aim:

To test how enzymes in biological washing powders work.

Apparatus:

- two soft boiled eggs (hard boiled eggs contain denatured proteins that do not cause stains)
- two beakers
- biological washing powder (with enzymes)
- non-biological washing powder (older type of washing powder)
- water
- two measuring spoons

Method:

1. Label 3 beakers 'Bio', 'Non-Bio' and 'control' which will contain biological washing powder, non-biological washing powder and water (negative control) respectively.
2. In the beaker labelled 'Bio' dissolve 5 g of biological washing powder in 30 ml water.
3. In the beaker labelled 'Non-Bio' dissolve 5 g of non-biological washing powder in 30 ml water.
4. Pour 30 ml of tap water into the control beaker.

5. Scoop out a small amount of egg yolk.
6. Place a teaspoon with the egg yolk in each of the beakers.
7. Leave the spoons in the beakers for 1 to 2 hours.
8. Observe your results.

Results:

1. Write down your observations.
2. Suggest a reason for your observations.
3. Write a conclusion for the investigation.

Enzymes in everyday life

The properties of enzymes to control reactions have been widely used for commercial purposes. Examples of some of these uses are listed below:

- **Biological washing powders** contain enzymes such as lipases (breaks down lipids) and proteases (breaks down protein), which assist in the breakdown of stains caused by foods, blood, fat or grease. These biological washing powders save energy as they are effective at low temperatures.
- **Meat tenderisers** contain enzymes which are obtained from fruits such as papaya or pineapple. When used in meat tenderisers these enzymes soften the meat.
- **Lactose-free milk** is manufactured primarily for people who are lactose intolerant. Lactose intolerant individuals lack the enzyme lactase that digests lactose (milk sugar). Lactose is pre-digested by adding lactase to the milk.

Factors affecting enzyme action

1. Temperature

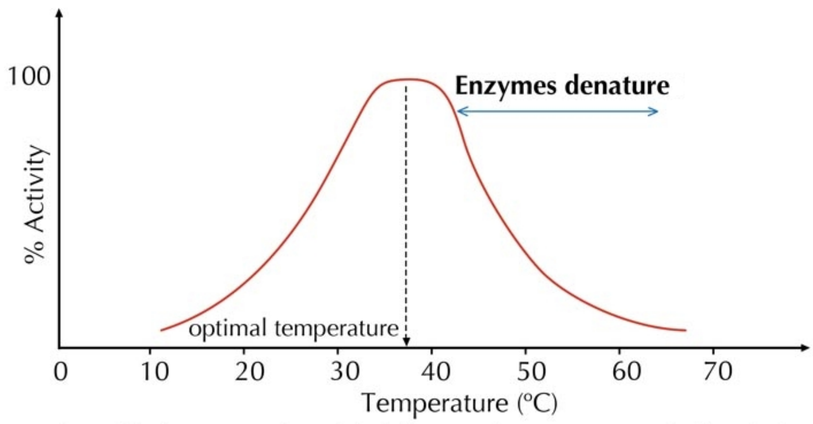
In humans, enzymes function best at 37°C (Figure 2.19). This is the optimum temperature. At very high temperatures proteins **denature**; this means that the hydrogen, hydrophobic and electrostatic interactions that result in the protein's three-dimensional shape break down, unravelling the protein into its primary structure, a long chain of amino acids. When a protein is denatured, the shape of its active site, as well as the rest of the protein shape is altered. The substrate can no longer fit in the active site of the enzyme and chemical reactions cannot take place. Low temperatures can slow down or even inactivate enzymes, as low temperature means less available kinetic energy, so that even the lower energy of activation that the enzyme allows is not available. The first graph shows the effect of temperature on enzyme activity.

2. pH

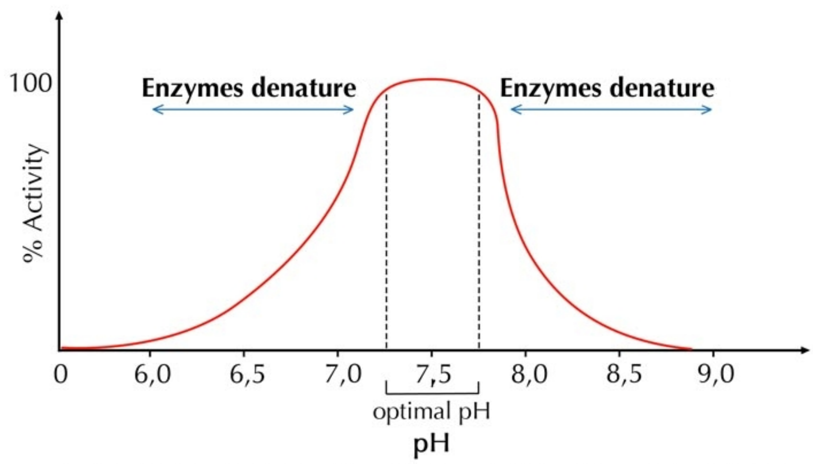
Enzyme activity is sensitive to pH. Enzymes have an optimum pH as shown on the graph, but they can function effectively within a pH range. The effectiveness of the enzyme falls sharply when the pH is outside its optimum range. An enzyme can become denatured when exposed to a pH outside its pH range, as pH affects the charge on some amino acids, and therefore affects the electrostatic interactions holding the tertiary structure together. The second graph shows the effect of pH on enzyme activity.

FACT

The optimal pH and temperature for an enzyme will be determined by the kind of living thing it is found in. The enzymes in the human body have an optimum temperature of 37 °C. Bacteria that live in compost heaps have enzymes with an optimal range in the 40's, and bacteria called hyperthermophiles (lovers of very high temperatures) that live in hot springs have enzymes with optimum temperatures above 80 °C.



A graphical representation of the influence of temperature on the functioning of a human enzyme.



A graphical representation of the influence of pH on the working of an enzyme.

Figure 2.19: Graphs showing the effect of temperature and pH on enzyme activity respectively.

In the investigation that follows, the effect of temperature on catalase enzyme activity will be investigated. Hydrogen peroxide is potentially toxic and so living tissues contain an enzyme named catalase to break it down into non-toxic compounds, namely water and oxygen. You will study the effect of the enzyme catalase on the breakdown of hydrogen peroxide. You will further examine the effect of pH and temperature on enzyme activity.

FACT
What are the best conditions for catalase enzyme? What happens when an enzyme or living tissue is put in hydrogen peroxide? Find out in this video.
See video: 2CMX

Investigation: Investigating the effect of catalase from chicken liver on hydrogen peroxide

Aim:

To demonstrate the effect of catalase on hydrogen peroxide.

Apparatus:

- 10 ml measuring cylinders
- pipette
- 3% Hydrogen peroxide solution
- scalpel
- forceps
- balance
- chicken liver at room temperature
- boiled chicken liver
- frozen chicken liver
- stirring rod

Method:

Follow the instructions below:

- Cut two square pieces weighing 0.1 g from the fresh liver sample and place each in a separate 10 ml measuring cylinder.
- Use a clean measuring cylinder to measure 3 ml water. Pour into one of the fresh liver-containing cylinders. This is your negative control.
- Use a clean measuring cylinder to measure 3 ml hydrogen peroxide. Pour into the remaining fresh liver-containing cylinder. This is your positive control.
- Wait for four minutes and then measure and record the height of the resulting oxygen bubbles in each cylinder.

Questions:

1. Name the three variables that must remain stable throughout these experiments and explain why they must be kept stable.
2. What kind of reaction is taking place?
3. How could you make this experiment more accurate?
4. In addition to temperature, what other factors influence the rate of reaction?

Investigation: PART B

Aim:

To demonstrate the effect of temperature on catalase activity.

Method:

- Add 3 ml of hydrogen peroxide to three separate 10 ml graduated measuring cylinders. Mark one cylinder "frozen chicken liver"; the second "boiled chicken liver" and the third "room temperature chicken liver".
- Cut a 0.1 g square from each of the frozen and boiled and room temperature chicken livers. Add the liver pieces to the correspondingly labelled measuring cylinder with hydrogen peroxide in it.
- Leave the pieces of liver for four minutes and measure the height of bubbles produced.

Questions:

1. Give reasons for the differences observed across the three measuring cylinders.
2. Name the dependent and independent variables in this experiment.
3. How could you make this experiment more accurate?
4. What would you conclude from your observations?

FACT
DNA can also be found inside chloroplasts and mitochondria.

Nucleic acids ESG4G

Nucleic acids, such as DNA and RNA, are large organic molecules that are key to all living organisms. The building blocks of nucleic acids are called **nucleotides**. Each nucleotide is made up of a sugar, a phosphate and a nitrogenous base. Nucleotides are joined together by **phosphodiester** bonds, which join the phosphate of one nucleotide to the sugar of the next. The phosphate-sugar-phosphate-sugar strands form a "backbone" upon which the nitrogen-containing bases are exhibited. Nucleic acids are therefore **polymers** made up of many nucleotides. Nucleic acids do not need to be obtained from the diet because they are synthesised using intermediate products of carbohydrate and amino acid metabolism.

Nucleic acids include:

- Deoxyribonucleic acid (**DNA**): which contains the 'instructions' for the synthesis of proteins in the form of genes. DNA is found in the nucleus of every cell, and is also present in smaller amounts inside mitochondria and chloroplasts.
- Ribonucleic acid (**RNA**): is important in transferring genetic information from DNA to form proteins. It is found on ribosomes, in the cytoplasm and in the nucleus.

FACT
The structure and function of the nucleus will be explained in details in the next chapter: **The basic units of life**.

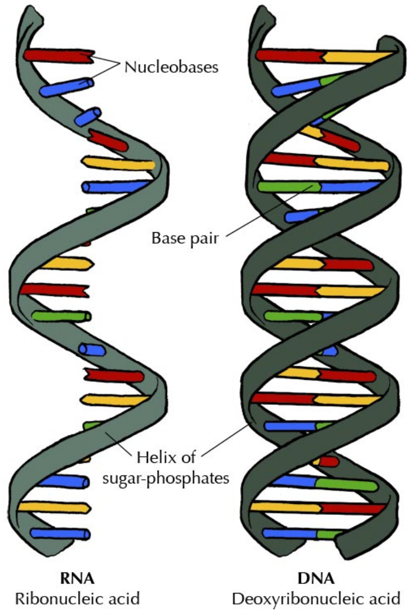


Figure 2.20: Schematic diagram of DNA and RNA: DNA is double stranded and RNA is single-stranded.

2.5 Vitamins ESG4H

Vitamins are organic compounds required by organisms as vital nutrients in limited amounts. Vitamins are therefore essential to a balanced diet. Vitamins have a variety of functions in the body. Some vitamins are coenzymes, which means that they help enzymes to catalyse a reaction efficiently. Some are responsible for regulating metabolism or act as regulators of cell and tissue growth and differentiation.

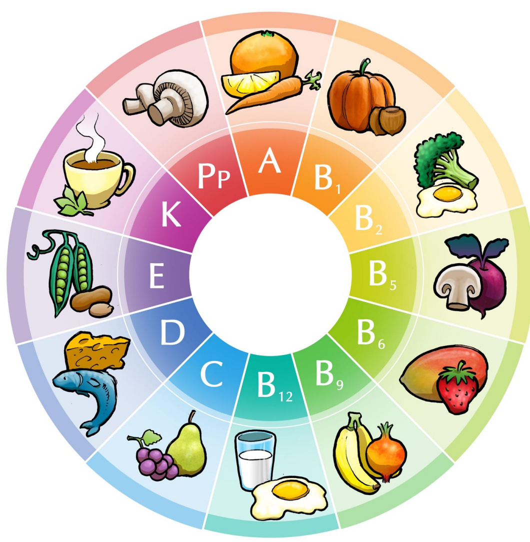


Figure 2.21: Sources of essentials vitamins.

Vitamin	Role	Food sources	Deficiency disease
Vitamin A	Needed for proper functioning of eyes	liver, carrots, egg	night blindness
Vitamin B (A group of vitamins with related functions)	Carbohydrate, protein, lipid, nucleic acid and alcohol metabolism, neurotransmitter synthesis and nerve function, red blood cell production	grains, potatoes, bananas	B1- beriberi, B3- pellagra, B6, B9, B12- anaemia
Vitamin C	Involved in iron metabolism, plays a role in the immune system, helps with the formation of collagen for wound repair	citrus fruit (oranges, lemons etc), tomatoes	scurvy (results in bleeding gums)
Vitamin D	Important in absorption of minerals from the gut (such as calcium and phosphate), works together with calcium and phosphorus in bone / teeth hardening	full cream milk, oily fish	rickets (resulting in soft bones, with bowed legs and widened wrists)
Vitamin E	Acts as an anti-oxidant	margarine, soybean oil, fortified cereals, condensed cow's milk, cheese, orange juice	depressed immune system, anaemia, poor nerve conduction

2.6 Recommended Dietary Allowance ESG4J

In order to ensure that we consume adequate quantities of all the food types, nutritionists have compiled a list of guidelines known as the Recommended Dietary Allowance (RDA). The RDA defines the required intake of each nutrient type to meet the basic nutrient needs of almost all individuals in a gender group at a given life stage. Food companies are required to advertise the nutrient composition on all products sold. This allows consumers to decide whether to purchase the food item. Table 2.6 shows the recommended dietary intake for males or females between 19 and 30 years old.

Recommended dietary allowance of vitamins and minerals

Nutrient	RDA (Male)	RDA (Female)	Unit	Top Sources
Vitamins				
Vitamin A	900	700	micrograms	carrots, carrot juice, turkey, pumpkin
Vitamin C	75	75	milligrams	orange juice, grapefruit juice, bell peppers
Vitamin D	5	5	micrograms	cereals, mushrooms, yeast, salmon, swordfish, trout, fish liver oil
Vitamin E	15	15	milligrams	fortified cereals, tomato paste, sunflower seeds
Minerals				
Calcium	1000	1000	milligrams	fortified cereals, cow's milk, cheese, orange juice
Iodine	150	150	micrograms	iodised salt
Iron	18	18	milligrams	liver, pilchards, red meat, spinach
Phosphorous	700	700	milligrams	maize-meal, milk, wheat flour
Potassium	4700	4700	milligrams	potatoes, bananas, tomato paste, orange juice
Sodium	1500	1500	milligrams	onion soup mix, table salt

Table 2.6: RDA for males and females between 19 years and 30 years.

Macronutrients

The table below shows the relative quantities of macronutrients recommended for average adult (25-year old) male and female individuals.

Substance	Amount (males)	Amount (females)	Sources of nutrient
Water	2 L/day	2 L/day	water
Carbohydrates	300 g/day	230 g/day	rice, potatoes, pasta, bread, mealie meal, fruits
Protein	56 g/day	46 g/day	duck, chicken, turkey, beef, fish, eggs, legumes (pulses and lentils), nuts, seeds, milk
Fat	70 g	70 g	sunflower oil, olive oil, butter, margarine, lard, avocados, coconut, nuts, seeds, oily fish
Cholesterol	As low as possible	As low as possible	egg yolk, chicken giblets, turkey giblets, beef liver

FACT

Did you know?

Malnutrition, which is the lack of a balanced diet, is a major problem in South Africa. Key vitamins have been added to wheat and maize-meal in order to provide the recommended amounts. Iodine has been added to salt. The nutritional needs of new-born babies are unique. A major challenge in South Africa is to encourage women to breastfeed children for their first six months after birth. Only 25% of babies are breastfed in this way. This leads to high levels of malnutrition, diarrhoea and poor growth.

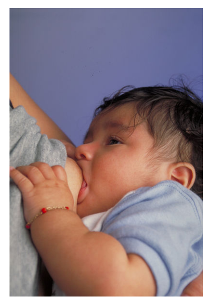


Figure 2.22: Breastfeeding infants for first 6 months of life is vital to the infants' survival.

Working out your daily nutrient intake

From our understanding of recommended dietary allowance we can understand what it is we consume and how important it is to our diet. The activity below requires you to use the information provided in these tables (and any other information you can find) in order to evaluate your diet with regards to the recommended daily allowances.

FACT
What makes up a balanced diet?
See video: 2CMY

Activity: Measuring your daily nutrient intake (Essential investigation-CAPS)

1. Keep a food diary for 3 days by writing down the food you eat. Make sure to note the time you eat, the type of food you eat, and how much of it you consume.
2. Pick one of the days you recorded (that is the most typical of your normal diet), and draw a pie chart with the energy component of each food item you consumed. Make sure your pie chart includes a key. (See the Introduction to Life Skills Chapter if you are unsure of how to do this.)
3. Draw another table with each food class (vitamins, proteins, carbohydrates, etc) listed. In one column, list the recommended dietary allowance and in the next column list the estimated amount of the food type you consume on a daily basis.
4. Which food types do you consume in excess? Which ones do you consume too little of? What are the consequences of each?

The table below lists the energy components of some common food items. Study it and answer the following questions:

1. Which food has the highest energy value? Why?
2. Name the key food items you would include in a balanced diet

Nutrient composition of some common foods

Food type	Energy (kJ)	Protein (g)	Carbohyd (g)	Total Fat (g)	Sodium (mg)	Iron (mg)	Vitamin A (IU)	Vitamin C (mg)
rice, brown (250 ml)	969	5	48	2	10	0.9	0	0
Muffin, blueberry (50 g)	824	4	34	5	317	1.1	24	1
Beansprouts(25 ml)	274	6	14	0	12	2.5	41	21
Carrots raw (1 medium)	145	1	8	1	35	0.4	22644	7
Apples, raw, with skin (7cm diameter)	341	0	21	2.6	0	0.2	73	8
Egg white, raw (1 egg)	69	3	0	0	54	0	0	0
Lamb stew (250 ml)	914	33	0	9	69	2.7	0	0
Chicken roasted (1/2 breast)	218	30	0	10	69	0.6	107	0

2.7 Summary ESG4K

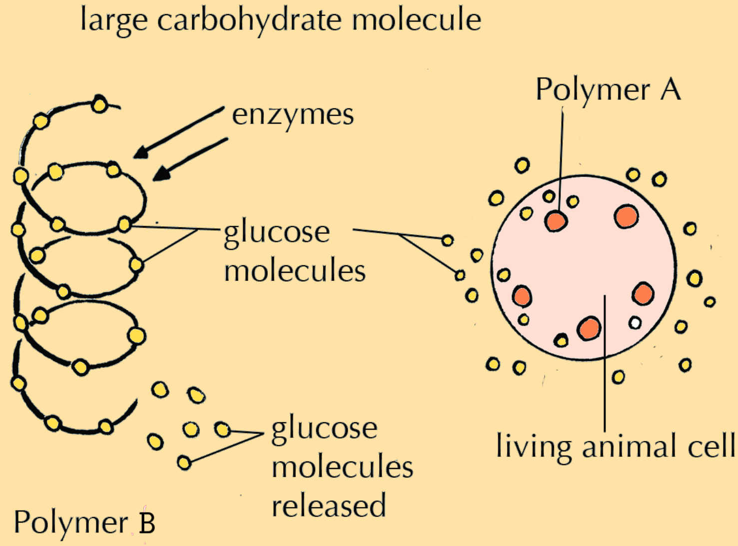
FACT
Watch this interesting summary about biological molecules.
See video: 2CMZ

- Cells are made up of organic and inorganic molecules which in turn are made up of atoms bonded together.
- Living organisms need to consume organic and inorganic compounds, which they break down for energy and use as building blocks for the components of life.
- Essential compounds are those that a living organism cannot build itself from other molecules, but must obtain from its environment.
- Plants may require a supply of inorganic nutrients through natural and non-natural fertilisers. An excess of non-natural fertilisers supplied to plants may result in eutrophication of rivers and lakes.
- Proteins, carbohydrates and fats are key organic molecules required for growth and survival of living organisms. All three are large molecules (polymers) made up of smaller molecules (monomers). We can test foods for the presence of these molecules.
- Each of these compounds has essential functions in living organisms, for example: fats (storage); proteins (growth); carbohydrates (energy); nucleic acids (store genetic information); vitamins (variety of functions in the body). An inadequate supply of these can result in diseases of malnutrition (e.g kwashiorkor, marasmus, scurvy, rickets etc).
- The class of proteins known as enzymes is important in speeding up chemical reactions in living organisms. Enzymes work under specific pH and temperature conditions known as 'optimal conditions'. They may become denatured or deactivated under unfavourable conditions.
- The Recommended Dietary Allowance is a measure of how much of the various organic and inorganic nutrients we require in our diet. The specific allowance is different across age groups and sexes. It is a useful guide to maintaining a balanced diet.

Exercise 2 – 1: End of chapter exercises

1. Which one of the following is not a biological role of water?
   a) prevents deficiency diseases
   b) dissolves biochemical compounds
   c) provides a medium in which chemical reactions take place
   d) involved in the hydrolysis of foodstuffs
2. Which combination of the following substances is best to prevent rickets?
   a) magnesium, phosphorus and carrots
   b) phosphorus, calcium and fish liver oil
   c) iron, calcium and liver
   d) iodine, iron and oranges

3. The diagram below is a **schematic drawing**, which means that the molecules represented may not resemble their actual chemical shape. Use the information provided in the diagram to answer the following questions:



   a) What is the polymer A that is found in an animal cell?
   b) What is the function of polymer A in the body?
   c) What could polymer B be?

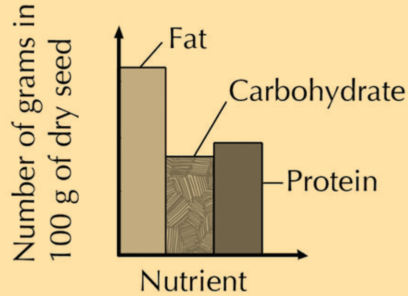
4. The table below gives nutrients present in various dry seeds.

Seed	Number of grams of nutrients in 100g of dry seed		
	Fat	Carbohydrates	Protein
Green peas	1	57	24
Sunflower seeds	47	2	25
Maize	5	74	10
Peanuts	45	22	25

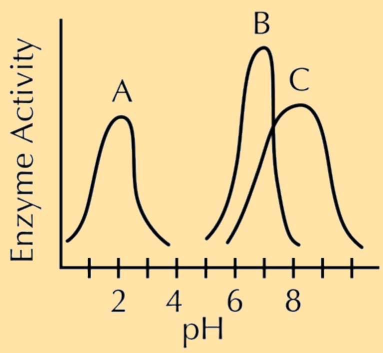
The following histogram shows the different amounts of nutrients found in one of the four seeds.

The chart shows the nutrients found in:

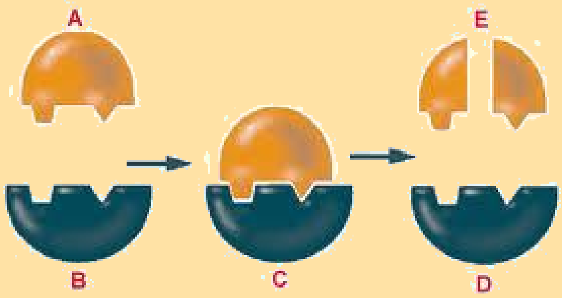
   a) green peas
   b) sunflower seeds
   c) maize
   d) peanuts



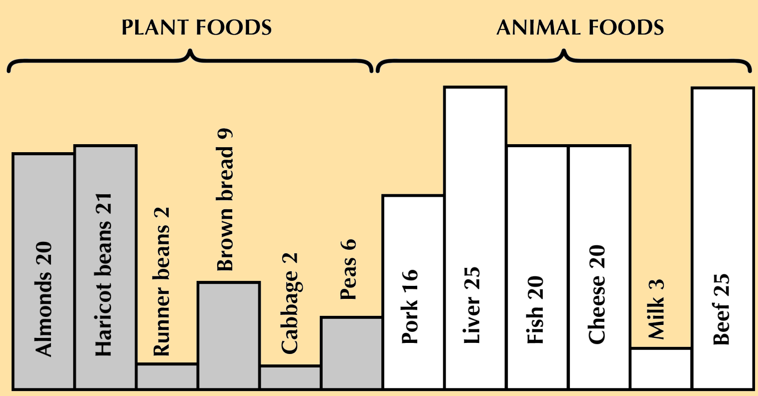
5. The graph below illustrates that enzymes:
   a) are pH-specific
   b) catalyses a specific substrate
   c) are denatured at high pH
   d) are sensitive to low pH



6. The following diagrams show the enzyme lock-and key method of action. Label each of the letters.



7. Explain briefly how you would test for glucose.
8. Study the graph below. The graph shows total protein (in grams) present in a 100 grams of different food items. Use the graph to answer questions below.



The numbers represent grams of protein per 100 grams

a) Name the two foods from which vegetarians would obtain the most protein.

b) Which foods contains only 2% protein?

c) Which food would be the best for a non-vegetarian person who is suffering from kwashiorkor and anaemia?

d) Name and explain the process which proteins undergo when heated excessively.

9. Study the information in the following diagrams and the table below, for three different meals X, Y and Z.

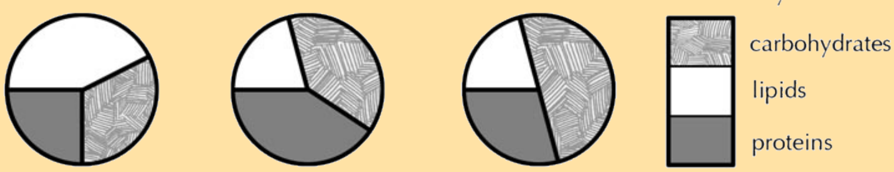
Composition of three different meals

X: Coke, white bread, hamburger patty, potato chips, peas

Y: milk, wholewheat roll and meat, lettuce and tomato, apple

Z: two glasses of bitter beer, brown bread and meat, lettuce and tomato

Analysis of different components of each meal



Nutrient content of meal X

Nutrient content of meal Y

Nutrient content of meal Z

Meals	Energy (kJ)	Vitamin C (mg)	Calcium (mg)
X	2900	25	70
Y	2100	47	265
Z	2600	40	170

a) Name three polysaccharide carbohydrates in meal X.

b) Giving one reason for each answer, which meal will:

i. provide the greatest source of energy?

ii. be most suitable for the development of healthy bones and teeth?

iii. be least suitable for people who are prone to scurvy?

c) Meal Z is relatively low in lipids (fat) yet high in energy content. Which of the food components in Z provides the energy?

d) Which of the three meals can be regarded as the healthiest? Give three reasons for your answer.

10. The following information (given in the table below) appeared on a box of breakfast cereal. Use this information in the table to assist you in answering the questions that follow.

Nutrient	per 100 g of product	per serving (50 g)	Recommended daily allowance (RDA)
Vitamin C	35 mg	18 mg	35 mg
Vitamin B1	0,8 mg	0,4 mg	0,5 mg
Vitamin B2	0,3	0,15	0,6
Niacin (Vit B7)	4,0	2,0	8,0
Calcium	450 mg	225 mg	562,5 mg
Iron	8 mg	4 mg	16 mg
Energy	1 750 kj	875 kj	3 125 kj

a) How many servings does a person need to provide the RDA of energy?

b) Which organic compounds are the most important energy providers?

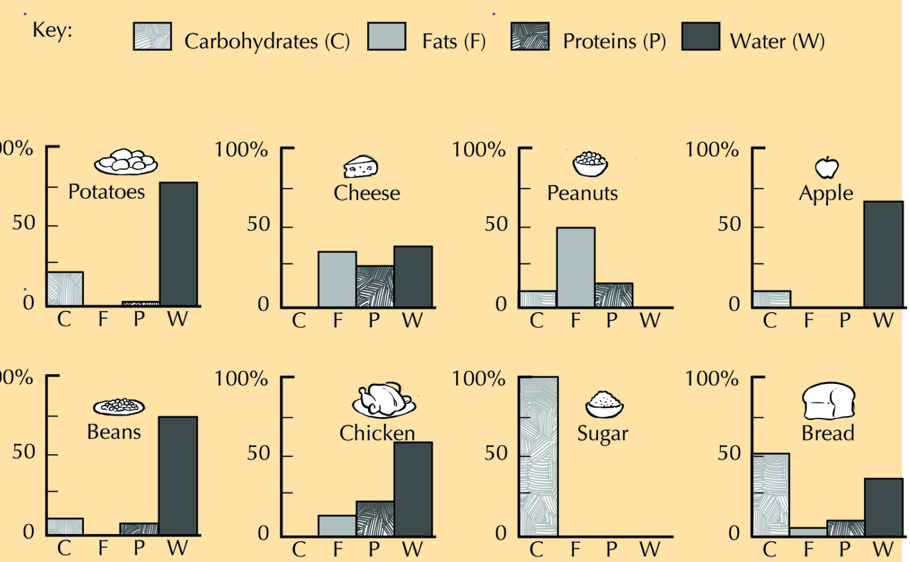
c) How much energy do the vitamins in the cereal provide?

d) What deficiency disease could result if a person does not obtain adequate amounts of vitamin B1?

e) Explain the role of iron in the diet.

f) Consider the RDA of energy (3125 kJ). Do you think this amount is realistic for your requirements? Explain your answer.

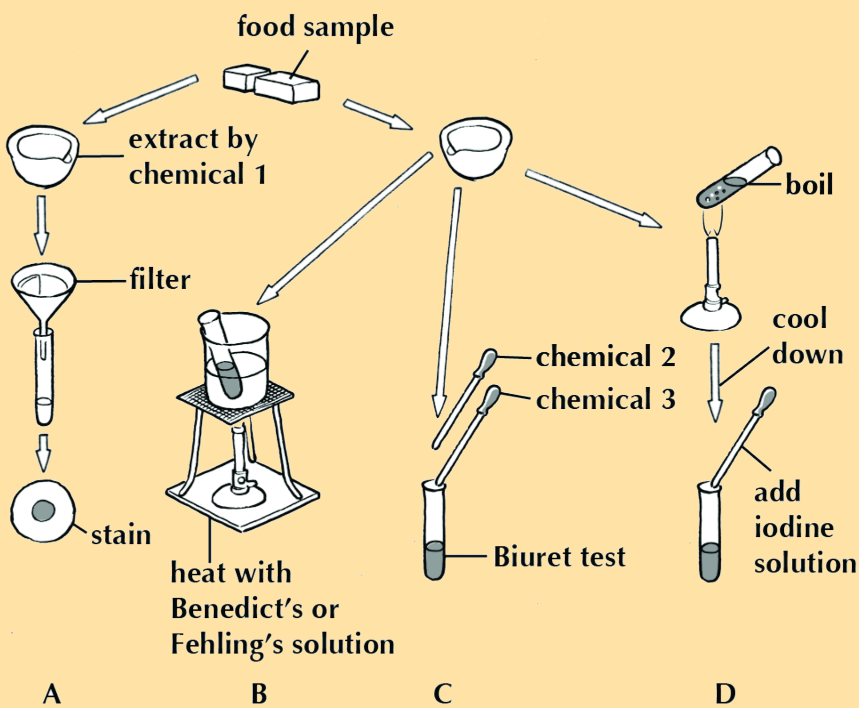
11. The histograms below show the percentage of carbohydrates, fats, proteins and water in eight types of foods.



From the information provided in the histograms above, name two types of food that:

a) Contain more than 25% of a nutrient that is involved in the formation of an insulating layer
b) Would best help to prevent kwashiorkor
c) Will form only monosaccharides and amino acids after digestion
d) Are not involved in the formation of cell membranes
e) Contain more than 50% of a nutrient which is the primary source of energy

12. The diagram shows the apparatus used in various organic food tests. Study it and answer the questions that follow:



a) Name the nutrients tested for in each of the experiments numbered A, B, C and D.
b) Identify the chemicals numbered 1, 2 and 3.
c) State the colour change for a positive reaction in each of the test tubes used in the experiments numbered B, C and D.
d) Identify each of the compounds A, B and C. In each case give a reason for your answer.
   Which compound (A, B or C)
   i. serves as a main source of energy in cellular respiration
   ii. is most likely to form part of an enzyme

13. The figure below shows the differences between the upper and lower basin of a water body.

    a) What has caused the key differences between the upper and lower basin?
    b) What could have been added to the water in the lower basin to cause it to look milky-green?

Figure 2.23

Check answers online with the exercise code below or click on 'show me the answer'.

1. 2CN2	2. 2CN3	3. 2CN4	4. 2CN5	5. 2CN6	6. 2CN7
7. 2CN8	8a. 2CN9	8b. 2CNB	8c. 2CNC	8d. 2CND	9a. 2CNF
9b. 2CNG	9c. 2CNH	9d. 2CNJ	10a. 2CNK	10b. 2CNM	10c. 2CNN
10d. 2CNP	10e. 2CNQ	10f. 2CNR	11a. 2CNS	11b. 2CNT	11c. 2CNV
11d. 2CNW	11e. 2CNX	12a. 2CNY	12b. 2CNZ	12c. 2CP2	12d. 2CP3
13. 2CP4					

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CHAPTER 3

Cells: the basic units of life

3 Cells: the basic units of life

3.1 Overview ESG4M

Introduction ESG4N

"In the year of 1657 I discovered very small living creatures in rain water." — Antonie van Leeuwenhoek, the Father of Microbiology, on discovering cells. Together with Robert Hooke's discoveries, van Leeuwenhoek's findings laid the foundations of microbiology.

Key concepts

- The invention of microscopes allowed us to see life at the microscopic level.
- Cell walls are present in plants, bacteria and fungi and provide a rigid support structure.
- Cell membranes are semi-permeable and have a fluid rather than a fixed structure. Substances move across them by diffusion, osmosis, facilitated transport and active transport.
- Cells contain organelles with structures adapted to perform specific functions within the cell.
- Cells differ in size, shape and structure in order to carry out specialised functions. Cells with similar structures and functions associate to form tissues.
- Plant and animal cells differ in many crucial ways.

The previous chapter discussed the various organic molecules that make up living organisms. In this chapter we will look at the cellular level of organisation of living things.

atom →molecule→**cell**→tissue→organ→system→organism→ecosystem

3.2 Molecular make up of cells ESG4P

Cells are the basic structural and functional units of all living organisms. Cells are made up of the compounds you learnt about in the previous chapter: carbohydrates, fats, proteins, nucleic acids and water. The word 'cell' was first used by the 17th century scientist Robert Hooke to describe the small pores in a cork that he observed under a microscope. Cells are very small structures.

The human body is made up of 10^{13} cells. Each of these is too small to see with the human eye and it is through the development of microscopic techniques that we have been better able to visualise and understand them.

Microscopy ESG4Q

Early attempts to magnify images of objects through grinding of glass lenses eventually gave rise to the earliest microscope. In 1600, Anton van Leeuwenhoek, a Dutch microbiologist used a simple microscope with only one lens to observe blood cells. He was the first scientist to describe cells and bacteria through observation under microscope. By combining two or more lenses, the magnification of the microscopes was improved, thus allowing scientists to view smaller structures.

The **dissecting microscope** is an optical microscope used to view images in three dimensions at low resolution. It is useful for low-level magnification of live tissue. The development of the **light microscope**, (Figure 3.5) which uses visible light to magnify images allowed for up to 1000X magnification of objects through which scientists were able to view individual cells and internal cell structures such as the cell wall, membrane, mitochondria and chloroplasts. However, although the light microscope allowed for 1000X magnification, in order to see even smaller structures such as the internal structure of organelles, microscopes of greater resolving power (with up to 10 000X magnification) were required.

With the development of **electron microscopes** the microscopic detail of organelles such as mitochondria and chloroplasts became easier to observe. The **Transmission Electron Microscope** (TEM) was developed first, followed by the **Scanning Electron Microscope** (SEM). TEM is used to view extremely thin sections of material. Beams of electrons pass through the material and are focused by electromagnetic lenses. In SEM the electrons are bounced off the surface of the material and thus produce a detailed image of the external surface of the material. They produce a 3D image by picking up secondary electrons knocked off the surface with an electron collector. The image is then amplified and viewed on a screen. Examples of each of the image types produced by these microscopes are given in Figures 3.1 to 3.3.

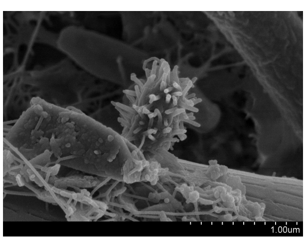


Figure 3.1: **SEM**: A natural community of bacteria growing on a single grain of sand.

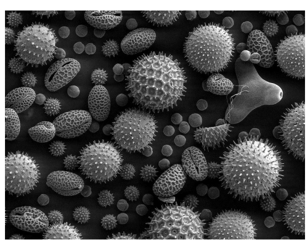


Figure 3.2: **SEM**: These pollen grains show the characteristic depth of field of SEM micrographs.

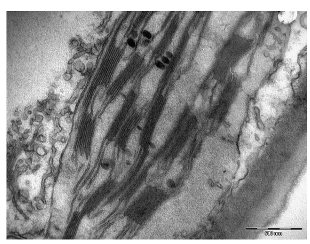


Figure 3.3: **TEM**: Image of chloroplast, showing thylakoid discs within a eukaryotic cell.

FACT
Sections for TEM have to be so thin that they have to be prepared using a special piece of equipment called an ultramicrotome.

FACT
Transmission electron microscopes can magnify an image 50 million times.

Figure 3.4: Transmission electron microscope in use.

The apparatus most commonly used in lab microscopy exercises is a simple light microscope. Figure 3.1 shows an annotated diagram of a light microscope with a description of the function of each part. The main parts are described in the table that follows and the function of each part is explained.

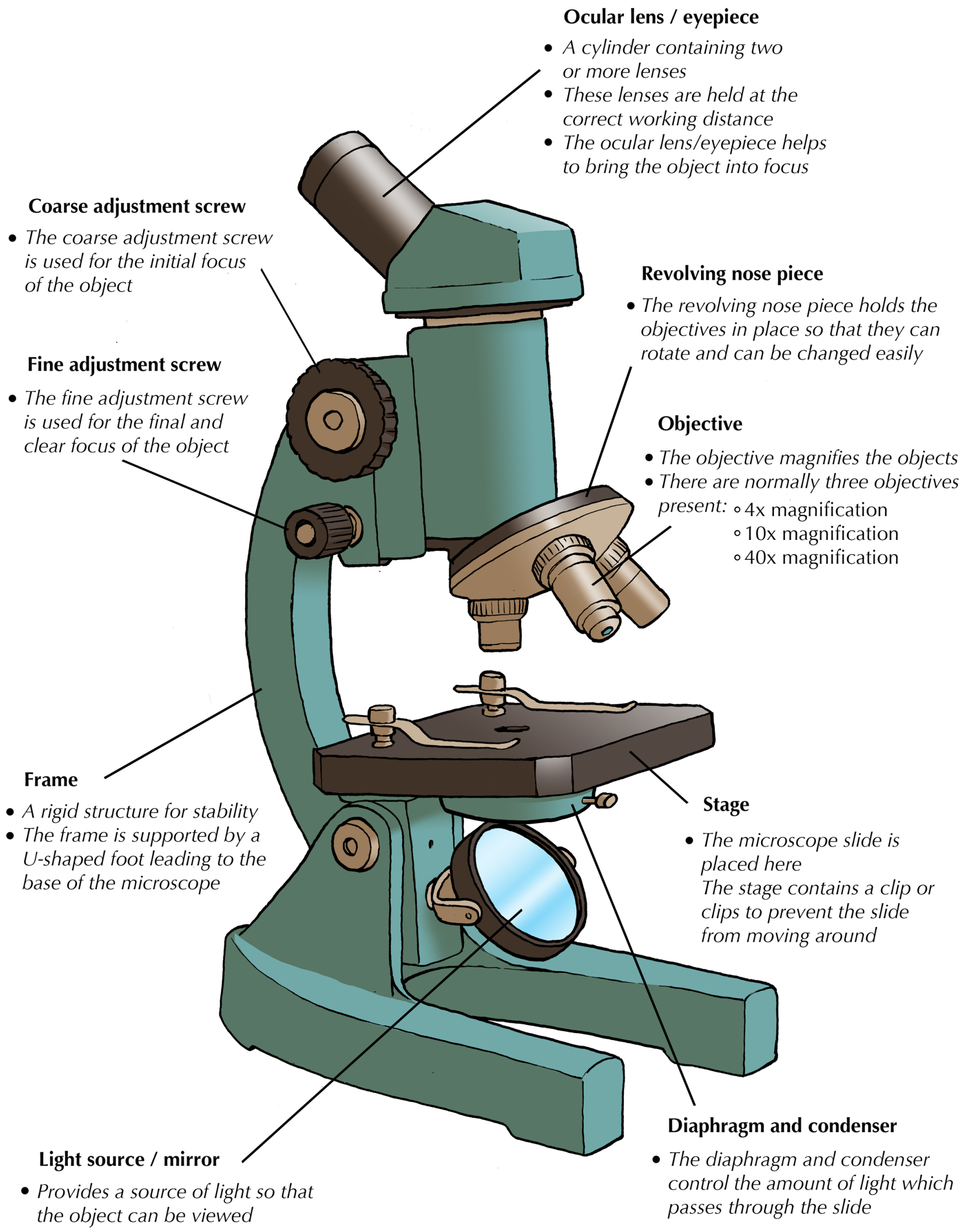


Figure 3.5: Light microscope

Part of the microscope	Description
Ocular lens/ eyepiece	- A cylinder containing two or more lenses. - These lenses are held at the correct working distance. - The ocular lens/eyepiece helps to bring the object into focus.
Revolving nose piece	The revolving nose piece holds the objectives in place so that they can rotate and can be changed easily.
Objective	The objective magnifies the objects. There are normally three objectives present: • 4X magnification • 10X magnification • 40X magnification
Coarse adjustment screw	The coarse adjustment screw is used for the initial focus of the object. By moving the stage up and down, bringing the object closer to or further away from the objective lens.
Fine adjustment screw	The fine adjustment screw is used for the final and clear focus of the object.
Frame	- A rigid structure for stability. - The frame is supported by a U-shaped foot leading to the base of the microscope.
Light source / mirror	- Provides a source of light so that the object can be viewed.
Diaphragm and condenser	The diaphragm and condenser control the amount of light which passes through the slide.
Stage	- The microscope slide is placed here. - The stage contains a clip or clips to prevent the slide from moving around. - There is a hole in the stage which allows light through.

Table 3.1: The parts of a microscope.

NOTE:
The ocular, rotating nosepiece and objectives are held above the stage by the arm.

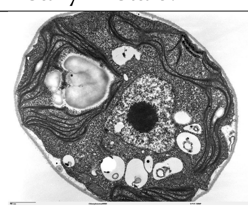
FACT
WARNING: if using a mirror for illumination instead of a light bulb, never reflect direct sunlight as you could damage your eyes.

How to use a microscope correctly

1. When handling or carrying the microscope, always do so with both hands. Grasp the arm with one hand and place the other hand under the base for support.
2. Turn the revolving nosepiece so that the lowest power objective is in position.
3. Place the microscope slide on the stage and and fasten it with the stage clip(s).
4. Look through the eyepiece and adjust the diaphragm for the greatest amount of light.
5. While looking at the slide on the stage from the side, turn the coarse adjustment screw so that the stage is as close to the objective lens as possible. **WARNING: Make sure you do not touch or damage the slide.**
6. Slowly turn the coarse adjustment screw until the image comes into focus.
7. Now use the fine adjustment screw to move the stage downwards until the image is clearly visible. **Never move the lens towards the slide.**
8. You can readjust the light source and diaphragm for the clearest image.
9. When changing to the next objective lens use the fine adjustment screw to focus the image. **WARNING: Never use the coarse adjustment screw for the strongest objective lens.**
10. Do not touch the glass part of the lenses with your fingers.
11. When finished, move the stage and objective as far away from each other as possible and remove the slide.
12. Disconnect the power source and cover the microscope.
13. Carry the microscope by holding it firmly by the "arm" and "base" and when walking it should be near your chest.

NOTE:
Remember that microscopes are expensive scientific equipment and need to be handled with care to prevent damaging them. Proper lens paper should be used when cleaning dust or dirt off any lenses. Avoid getting moisture on the objective lenses. Dust and moisture are the biggest enemies of microscopes.

Differences between the light microscope and transmission electron microscope

Property	Light Microscope	Transmission Electron Microscope
Source	Light	Beam of electrons
Resolution (how far apart two objects must be in order to be distinguished as separate)	Under optimal conditions (clean lenses, oil immersion), the resolution is 0,2 micrometres or 2 thousands of a millimetre	Resolution of a transmission electron microscope is about 0,05 nanometres (nm) which is about 0,5 millionth of a millimetre. This means that a transmission electron microscope has about 10 000 times the resolving power of a light instrument
Material (alive/ dead)	Alive or dead. Bright field or phase contrast microscopes enable viewer to observe living cells. Specimens need to be stained.	Dead. Electron microscope images are produced by passing an electron beam through tissues stained with heavy metals.
Example of microscope image	 Bacterial spores as seen under light microscope.	 *Chlamydomonas reinhardtii*, a single celled green algae, as seen under the transmission electron microscope.

Calculating magnification ESG4R

Microscopes magnify an image using a lens found in the eye-piece, which is also known as the **ocular lens.** The image is further magnified by the **objective** lens. Thus the magnification of a microscope is: **magnification power of the eye-piece x the power of the objective lens**.

Example: if the eyepiece magnification is 5X and the objective lens' magnification is 10X, the image of the object viewed under the microscope is 50X bigger than the object:

$$\begin{aligned}\text{overall magnification} &= \text{power of eyepiece} \times \text{power of objective}\\ &= 5 \times 10\\ &= 50 \times \text{the original size}\end{aligned}$$

Calculating the field of view

When viewing an object through a microscope, the diameter of the circle through which you view the object is known as the **field of view.**

As the magnification increases, the field of view decreases.

To measure the field of view, use a microscope slide with a tiny ruler printed on it. For example, the size of the field of view shown below under low power magnification is approximately 1 mm.

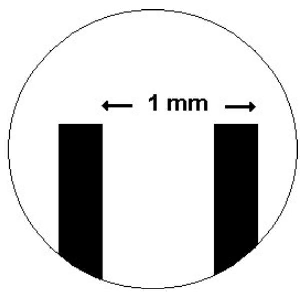


Figure 3.6: Field of view is approximately 1 mm.

Once the size of the field of view is known, we can estimate the size of the objects being viewed under the microscope. At 10 X magnification, the field of view is 1,0 mm. If the magnification is increased to 100 X, what will the new field of view be?

1,0 mm at 10 X magnification

$$\text{new field of view} = \frac{\text{current magnification}}{\text{new magnification}} \times \text{current field of view}$$

x mm at 100 X magnification

$$\begin{aligned}\text{new field of view} &= \frac{\text{current magnification}}{\text{new magnification}} \times \text{current field of view}\\ x &= \frac{10}{100} \times 1{,}0 \text{ mm}\\ &= 0{,}1 \text{ mm}\end{aligned}$$

If magnification is increased 10-fold, the field of view will decrease 10-fold. Thus it will become 0.1 mm. What this means is that at higher magnification, we are able to see objects of smaller and smaller size within our field of view. This is why at higher magnification, the field of view becomes smaller.

At 500 X magnification, the field of view of a microscope is 0,05 mm. What will the field of view be at 100X magnification?

$$\begin{aligned} x &= \frac{500}{100} \times 0{,}05 \text{ mm} \\ &= 0{,}25 \text{ mm} \end{aligned}$$

Calculating magnification and using scale bars

When drawing cells or cellular structures, your diagrams will usually be much larger than the actual size of the structures you will be drawing. The magnification is given by:

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

When a scale bar is provided with the diagram, the magnification is given by:

$$\text{magnification} = \text{drawing size} \times \frac{\text{scale given}}{\text{measured length of scale}}$$

Worked example 1: Calculating overall magnification

QUESTION

Calculate the overall magnification of a compound light microscope with a magnification of 10 X due to the eyepiece and a magnification of a 100X due to the objective lens.

SOLUTION

Using the formula:

$$\begin{aligned} \text{overall magnification} &= \text{power of eyepiece} \times \text{power of objective} \\ &= 10 \times 100 \\ &= 1000 \times \text{the original size} \end{aligned}$$

Worked example 2: Calculating size of object from its microscopic image

QUESTION

If the measured length of the magnified beetle larva image shown below was 2 centimetres (20 mm), the ocular magnification of the microscope is 5 X and you are using an objective lens magnification of 10 X, what is the actual length of the larva in millimetres?

Figure 3.7: A beetle larva as seen under a light microscope.

SOLUTION

Step 1: Calculate the total magnification

Use the same formula as above

$$\begin{aligned}\text{overall magnification} &= \text{power of eyepiece} \times \text{power of objective}\\ &= 5 \times 10\\ &= 50 \times \text{the original size}\end{aligned}$$

Step 2: Now calculate the size of the object

If the image is 50 X larger than the object, what is the size of the object? Calculate this by simple proportion given in the formula below.

$$\begin{aligned}\text{Size } &= \frac{\text{size of image}}{\text{overall magnification}}\\ &= \frac{20 \text{ mm}}{50}\\ &= 0{,}4 \text{ mm}\end{aligned}$$

Worked example 3: Calculating actual size given of a structure given scale bar on an image

QUESTION

Calculate the actual length of AB from the image shown in the micrograph given with the scale bar given below.

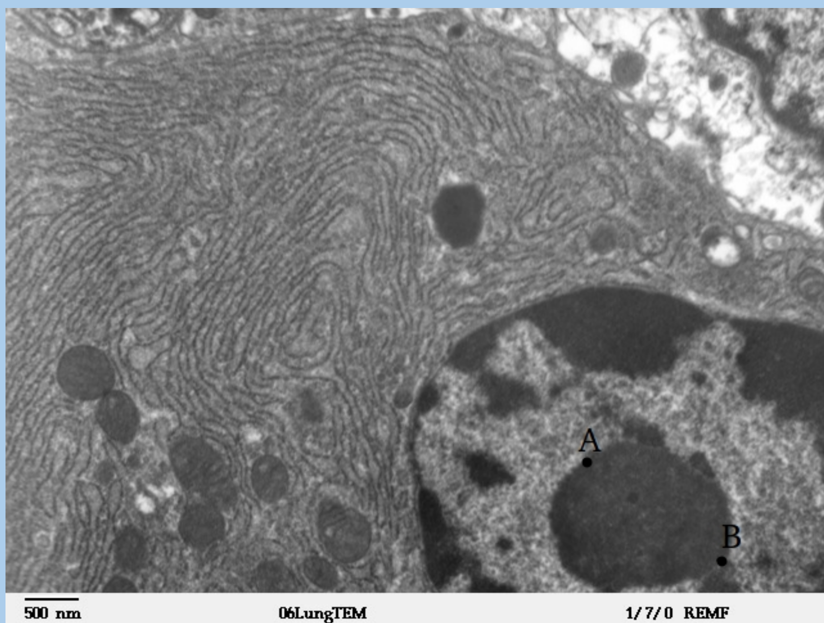


Figure 3.8: Electron micrograph showing rough endoplasmic reticulum with a scale bar given

SOLUTION

Step 1: Measure the length AB shown in the diagram

This should be approximately 20 mm

Step 2: Work out the length AB

Given that the measured length of the scale bar is approximately 5 mm, work out the length AB:

$$\begin{aligned}
\text{Size} &= \frac{\text{length of AB on diagram}}{\text{measured length of scale bar}} \times \text{number on scale bar} \\
&= \frac{20\text{ mm}}{5\text{ mm}} \times 500\text{ nm} \\
&= 2000\text{ nm} \\
&= 2\ \mu\text{m}
\end{aligned}$$

FACT
DNA (the hereditary information of cells) is passed from 'parent' cells to 'daughter' cells during cell division. You will learn more about this in the following chapter: **Cell division**.

3.3 Cell structure and function ESG4S

Cell theory ESG4T

The cell theory developed in 1839 by microbiologists Schleiden and Schwann describes the properties of cells. It is an explanation of the relationship between cells and living things. The theory states that:

- all living things are made of cells and their products.
- new cells are created by old cells dividing into two.
- cells are the basic building blocks of life.

The cell theory applies to all living things, however big or small. The modern understanding of cell theory extends the concepts of the original cell theory to include the following:

- The activity of an organism depends on the total activity of independent cells.
- Energy flow occurs in cells through the breakdown of carbohydrates by respiration.
- Cells contain the information necessary for the creation of new cells. This information is known as 'hereditary information' and is contained within DNA.
- The contents of cells from similar species are basically the same.

Cells are the smallest form of life; the functional and structural units of all living things. Your body contains several billion cells, organised into over 200 major types, with hundreds of cell-specific functions.

Some functions performed by cells are so vital to the existence of life that all cells perform them (e.g. cellular respiration). Others are highly specialised (e.g. photosynthesis).

Figure 3.9 shows a two-dimensional drawing of an animal cell. The diagram shows the structures visible within a cell at high magnification. The structures form the **ultrastructure** of the cell.

FACT
The human body cannot break down the cellulose in cell walls because we do not produce the enzyme cellulase.

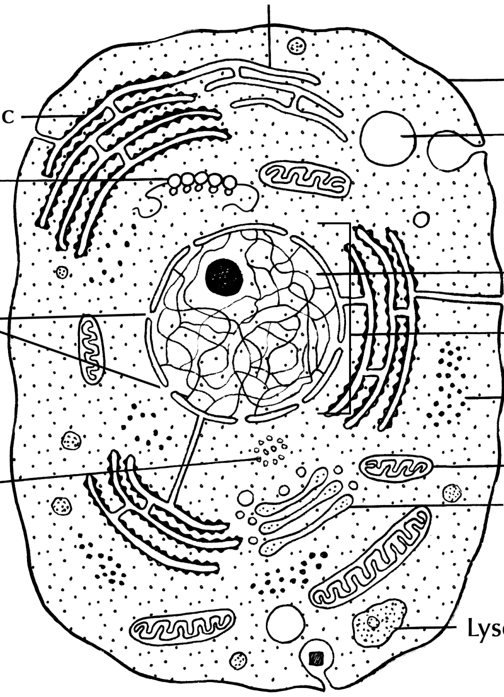


Figure 3.9: Diagram of the cell ultrastructure of an animal cell.

We will now look at some of the basic cell structures and organelles in animal and plant cells.

Cell wall ESG4V

The cell wall is a rigid non-living layer that is found outside the cell membrane and surrounds the cell. Plants, bacteria and fungi all have cell walls. In plants, the wall is comprised of cellulose. It consists of three layers that help support the plant. These layers include the middle lamella, the primary cell wall and the secondary cell wall.

Middle lamella: Separates one cell from another. It is a thin membranous layer on the outside of the cell and is made of a sticky substance called pectin.

Primary cell wall: Is on the inside of the middle lamella and is mainly composed of cellulose.

Secondary cell wall: Lies alongside the cell membrane. It is is made up of a thick and tough layer of cellulose which is held together by a hard, waterproof substance called lignin. It is only found in cells which provide mechanical support in plants.

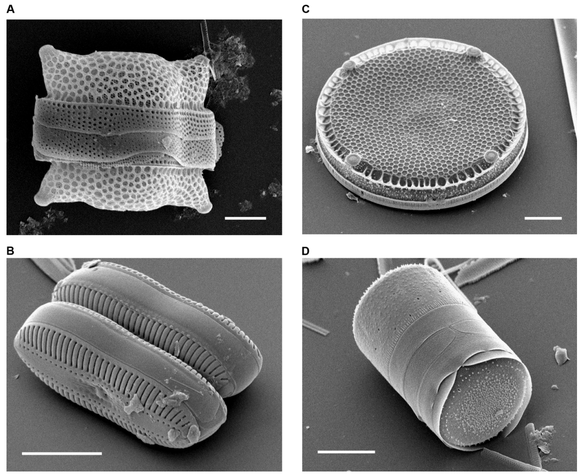


Figure 3.10: Scanning electron microscope micrographs of diatoms showing the external appearances of the cell wall. Scale bar: **A, B, D:** 10 um, **C** 20 um

Functions of the cell wall

- The main function of the wall is to protect the inner parts of the plant cell, it gives plant cells a more uniform and regular shape and provides support for the plant body.
- The cell wall is completely permeable to water and mineral salts which allows distribution of nutrients throughout the plant.
- The openings in the cell wall are called plasmodesmata which contain strands of cytoplasm that connect adjacent cells. This allows cells to interact with one another, allowing molecules to travel between plant cells.

Cell membrane ESG4W

The **cell membrane**, also called the plasma membrane, physically separates the intracellular space (inside the cell) from the extracellular environment (outside the cell). All plant and animal cells have cell membranes. The cell membrane surrounds and protects the **cytoplasm**. Cytoplasm is part of the protoplasm and is the living component of the cell.

The cell membrane is composed of a double layer (bilayer) of special lipids (fats) called **phospholipids**. Phospholipids consist of a **hydrophilic** (water-loving) head and a **hydrophobic** (water-fearing) tail. The hydrophobic head of the phospholipid is **polar** (charged) and can therefore dissolve in water. The hydrophobic tail is **non-polar** (uncharged), and cannot dissolve in water.

The lipid bilayer forms spontaneously due to the properties of the phospholipid molecules. In an aqueous environment, the polar heads try to form hydrogen bonds with the water, while the non-polar tails try to escape from the water. The problem is solved by the formation of a bilayer because the hydrophilic heads can point outwards and from hydrogen bonds with water, and the hydrophobic tails point towards one another and are 'protected' from the water molecules (Figure 3.11).

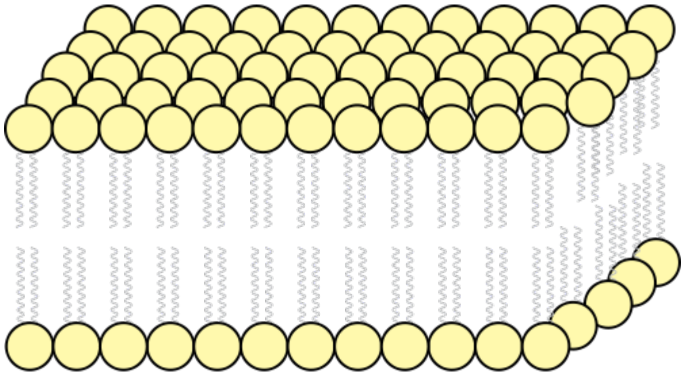


Figure 3.11: The lipid bilayer showing the arrangement of phospholipids, containing hydrophilic, polar heads and hydrophobic, non-polar tails.

FACT
Recall the structure if lipid molecules from the previous chapter on **the chemistry of life**.

FACT
Watch a video about the cell membrane.
See video: 2CPB

All the exchanges between the cell and its environment have to pass through the cell membrane. The cell membrane is **selectively permeable** to ions (e.g. hydrogen, sodium), small molecules (oxygen, carbon dioxide) and larger molecules (glucose and amino acids) and controls the movement of substances in and out of the cells. The cell membrane performs many important functions within the cell such as osmosis, diffusion, transport of nutrients into the cell, processes of ingestion and secretion. The cell membrane is strong enough to provide the cell with mechanical support and flexible enough to allow cells to grow and move.

Structure of the cell membrane: the fluid mosaic model

S.J. Singer and G.L. Nicolson proposed the Fluid Mosaic Model of the cell membrane in 1972. This model describes the structure of the cell membrane as a **fluid** structure with various protein and carbohydrate components diffusing freely across the membrane. The structure and function of each component of the membrane is provided in the table below. Table 3.2 refers to the components of the cell membrane shown in the diagram in Figures 3.11 and 3.12.

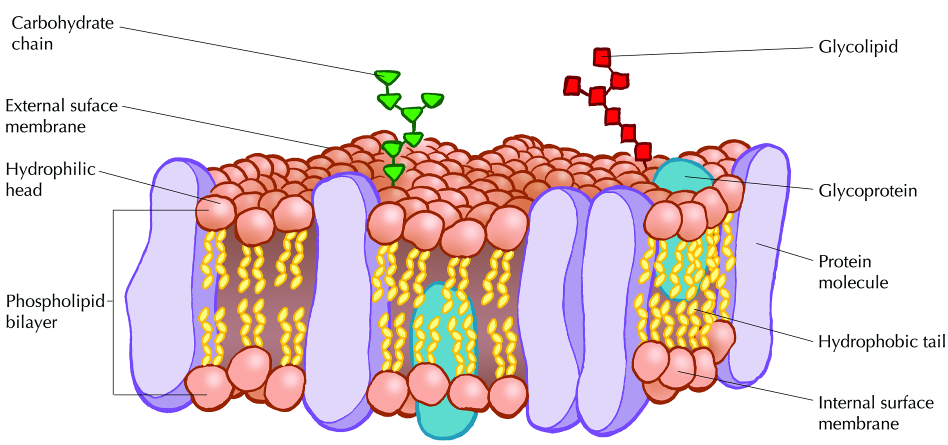


Figure 3.12: Fluid mosaic model of the cell membrane.

FACT
A further description of the fluid mosaic model can be viewed at:
See video: 2CPC

FACT
Learn about the different ways that molecules can travel across cell membranes.
See video: 2CPD

Component (see Figure 3.12)	Structure	Function
Phospholipid bilayer	Consists of two layers of phospholipids. Each phospholipid has a polar, hydrophilic (water-soluble) head as well as a non-polar, hydrophobic (water-insoluble) tail.	It is a semi-permeable structure that does not allow materials to pass through the membrane freely, thus protecting the intra and extracellular environments of the cell.
Membrane proteins	These are proteins found spanning the membrane from the inside of the cell (in the cytoplasm) to the outside of the cell. Membrane proteins have hydrophilic and hydrophobic regions that allow them to fit into the cell membrane.	Act as carrier proteins which control the movement of specific ions and molecules across the cell membrane.
Glycoproteins	Consist of short carbohydrate chains attached to polypeptide chains and are found on the extracellular regions of the membrane.	These proteins are useful for cell-to-cell recognition.
Glycolipids	Carbohydrate chains attached to phospholipids on the outside surface of the membrane.	Act as recognition sites for specific chemicals and are important in cell-to-cell attachment to form tissues.

Table 3.2: Structure and function of components of the cell membrane.

Movement across membranes ESG4X

Movement of substances across cell membranes is necessary as it allows cells to acquire oxygen and nutrients, excrete waste products and control the concentration of required substances in the cell (e.g oxygen, water, hormones, ions, etc). The key processes through which such movement occurs include **diffusion, osmosis, facilitated diffusion** and **active transport.**

1. Diffusion

Diffusion is the movement of substances from a region of high concentration to low concentration. It is therefore said to occur **down a concentration gradient**. The diagram below shows the movement of dissolved particles within a liquid until eventually becoming randomly distributed.

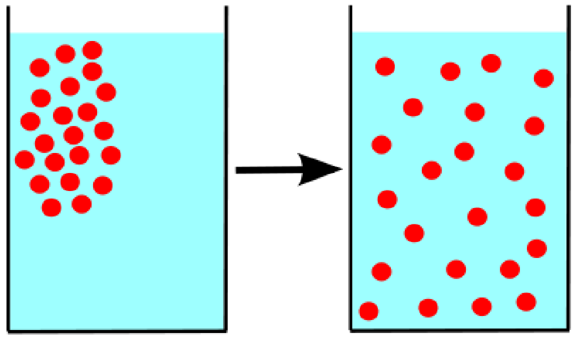


Figure 3.13: **Diffusion** is the movement of molecules from a region of higher concentration to a lower concentration. It is a passive process (i.e. does not require input of energy).

FACT
Watch diffusion taking place by clicking on the following link.
See video: 2CPF

Diffusion is a **passive process** which means it does not require any energy input. It can occur across a living or non-living membrane and can occur in a liquid or gas medium. Due to the fact that diffusion occurs across a concentration gradient it can result in the movement of substances into or out of the cell. Examples of substances moved by diffusion include carbon dioxide, oxygen, water and other small molecules that are able to dissolve within the lipid bilayer.

Investigation: Observing diffusion

Aim:

To observe diffusion.

Apparatus:

- 500 ml beaker
- large funnel
- plastic straw
- potassium permanganate crystals

Method:

1. Fill a beaker with water and allow it to stand for a few minutes so that water movement stops.
2. Place a large funnel into the water so that it touches the bottom of the beaker. Drop a few small potassium permanganate crystals through the straw. Remove the funnel carefully and slowly.
3. Observe the size of the area that is coloured by the potassium permanganate at the beginning of the experiment, after 5 minutes and then after 20 minutes.

FACT
Watch osmosis taking place by clicking on the following link.
See video: 2CPG

Questions:

1. What do you observe happening in the beaker?
2. What can you conclude based on your observations?
3. Explain how using hot water would affect the results of this experiment (remember that when you explain you need to give a reason for your answer).

2. Osmosis

When the concentration of solutes in solution is low, the water concentration is high, and we say there is a **high water potential**. Osmosis is the movement of water from a region of higher water potential to a region of lower water potential across a semi-permeable membrane that separates the two regions. Movement of water always occurs down a concentration gradient, i.e from higher water potential (dilute solution) to lower potential (concentrated solution). Osmosis is a passive process and does not require any input of energy. Cell membranes allow molecules of water to pass through, but they do not allow molecules of most dissolved substances, e.g. salt and sugar, to pass through. As water enters the cell via osmosis, it creates a pressure known as *osmotic pressure*.

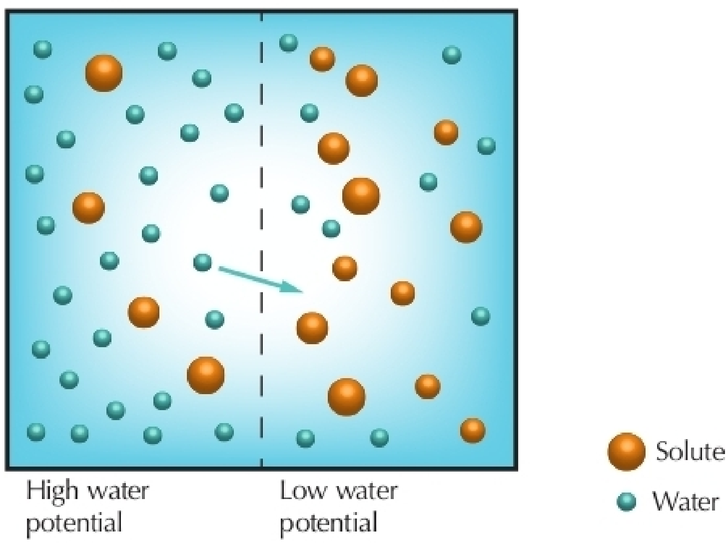


Figure 3.14: Osmosis is the movement of water from an area of high water potential to an area of low water potential across a semi-permeable membrane.

In biological systems, osmosis is vital to plant and animal cell survival. Figure 3.15 demonstrates how osmosis affects red blood cells when they are placed in three different solutions with different concentrations.

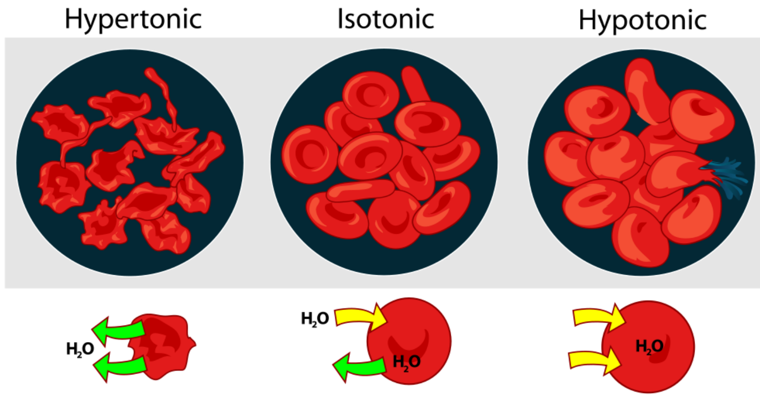


Figure 3.15: The effect of hypertonic, isotonic and hypotonic solutions on red blood cells.

Hypertonic (concentrated)	**Isotonic**	**Hypotonic** (dilute)
The medium is concentrated with a lower water potential than inside the cell, therefore the cell will lose water by osmosis.	The water concentration inside and outside the cell is equal and there will be no nett water movement across the cell membrane. (Water will continue to move across the membrane, but water will enter and leave the cell at the same rate.)	The medium has a higher water potential (more dilute) than the cell and water will move into the cell via osmosis, and could eventuality cause the cell to burst.

Plant cells use osmosis to absorb water from the soil and transport it to the leaves. Osmosis in the kidneys keeps the water and salt levels in the body and blood at the correct levels.

Investigation: Predicting the direction of osmosis

Aim:

To predict the direction of osmosis.

Apparatus:

- 500 ml beaker
- large potato
- potato peeler/scalpel
- two pins
- concentrated sucrose/sugar solution. To obtain this, add 100 g of sugar to 200 ml of water.

FACT
Watch an illustration of diffusion and osmosis.
See video: 2CPH

Method:

1. Peel off the skin of a large sized potato with a scalpel/potato peeler.
2. Cut its one end to make the base flat.
3. Make a hollow cavity in the potato almost to the bottom of the potato.
4. Add the concentrated sugar solution into the cavity of the potato, filling it about half way. Mark the level by inserting a pin at the level of the sugar solution (insert the pin at an angle into the cavity at the level) (Figure 3.16 A).
5. Carefully place the potato in the beaker containing water.
6. Observe what happens to the level of the sugar solution in the potato.
7. After 15 to 20 minutes, mark the level by inserting the second pin at the level of the sugar solution (insert as the first pin) (Figure 3.16 B).

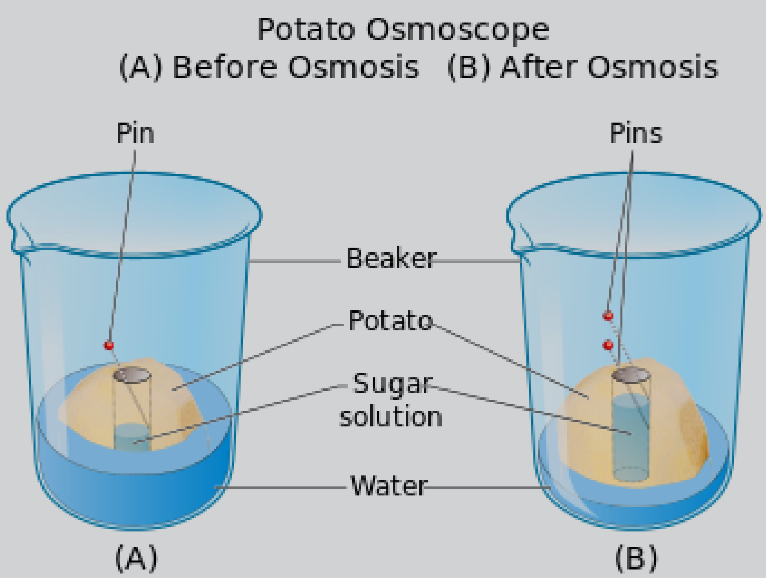


Figure 3.16: Using a potato to investigate osmosis.

Questions:

1. What do you observe happening to the level of the solution inside the potato?
2. What conclusion can you draw based on your observation?
3. What conditions were met in this experiment that makes this type of transport different to diffusion?

3. Facilitated diffusion

Facilitated diffusion is a special form of diffusion which allows rapid exchange of specific substances. Particles are taken up by carrier proteins which change their shape as a result. The change in shape causes the particles to be released on the other side of the membrane. Facilitated diffusion can only occur across living, biological membranes which contain the carrier proteins. A substance is transported via a carrier protein from a region of high concentration to a region of low concentration until it is randomly distributed. Therefore movement is *down a concentration gradient*.

FACT
ATP and ADP are molecules involved with moving energy within cells. You do not need to know these names in full and will learn more about them later.

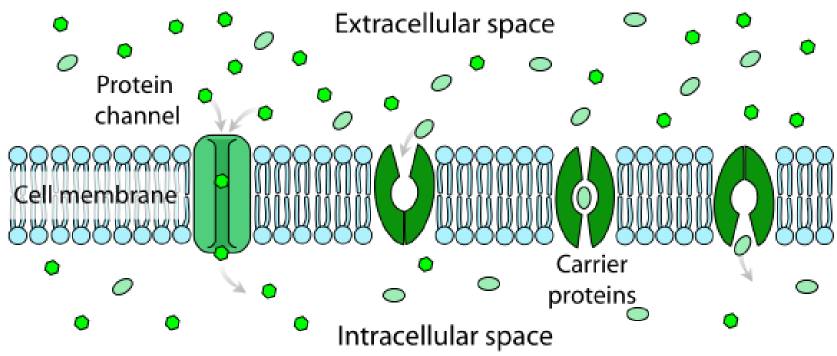


Figure 3.17: Facilitated diffusion in cell membrane, showing ion channels and carrier proteins.

Examples of substances moved via facilitated diffusion include all polar molecules such as glucose or amino acids.

4. Active transport

Active transport is the movement of substances *against* a concentration gradient, from a region of *low concentration* to *high concentration* using an input of energy. In biological systems, the form in which this energy occurs is **adenosine triphosphate (ATP)**. The process transports substances through a membrane protein. The movement of substances is selective via the carrier proteins and can occur into or out of the cell.

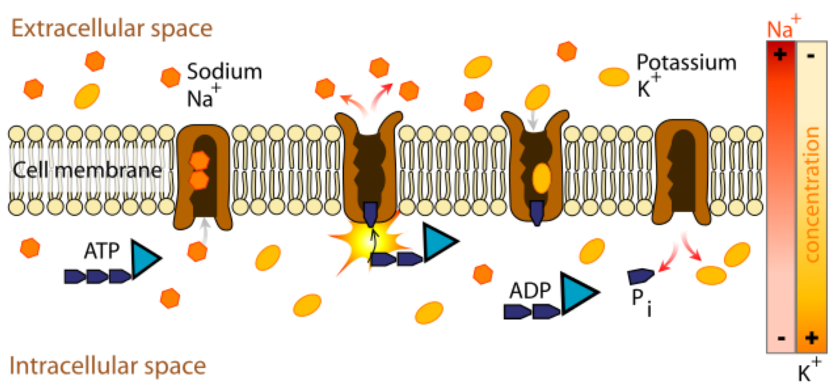


Figure 3.18: The sodium-potassium pump is an example of primary active transport.

Examples of substances moved include sodium and potassium ions as shown in Figure 3.18

FACT

REVISIONYou may have encountered the terms cytoplasm, nucleoplasm and protoplasm earlier in Grade 9. **Cytoplasm** is the part of the cell that is within the cell membrane and excludes the nucleus. **Nucleoplasm** is the substance of the cell nucleus, i.e. everything within the nucleus that is not part of the nucleolus. **Protoplasm** is the colourless material comprising the living part of a cell, including the cytoplasm, nucleus and other organelles.

3.4 Cell organelles ESG4Y

We will now look at the key organelles that make up the cell. It is important to bear in mind that structure and function are closely related in all living systems. When studying each organelle, ensure that you observe the specific structures (from micrographs) that allow the organelle to perform its specific function.

Cytoplasm ESG4Z

The cytoplasm is the jelly-like substance that fills the cell. It consists of up to 90% water. It also contains dissolved nutrients and waste products. Its main function is to hold together the organelles which make up the cytoplasm. It also nourishes the cell by supplying it with salts and sugars and provides a medium for metabolic reactions to occur.

All the contents of prokaryotic cells are contained within the cytoplasm. In eukaryotic cells, all the organelles are contained within the cytoplasm except the nucleolus which is contained within the nucleus.

Functions of the cytoplasm

- The cytoplasm provides mechanical support to the cell by exerting pressure against the cell's membrane which helps keep the shape of the cell. This pressure is known as **turgor** pressure.
- It is the site of most cellular activities including metabolism, cell division and protein synthesis.
- The cytoplasm contains ribosomes which assist in the synthesis of protein.
- The cytoplasm acts a storage area for small carbohydrate, lipid and protein molecules.
- The cytoplasm suspends and can transport organelles around the cell.

Nucleus ESG52

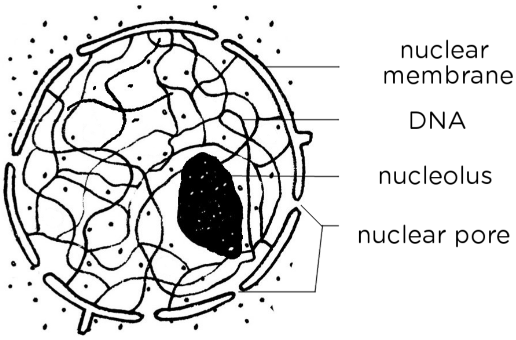
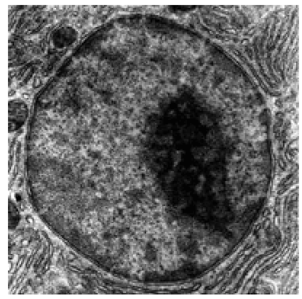
The nucleus is the largest organelle in the cell and contains all the cell's genetic information in the form of DNA. The presence of a nucleus is the primary factor that distinguishes eukaryotes from prokaryotes. The structure of the nucleus is described below:

Nuclear envelope: two lipid membranes that are studded with special proteins that separates the nucleus and its contents from the cytoplasm.

Nuclear pores: tiny holes called nuclear pores are found in the nuclear envelope and help to regulate the exchange of materials (such as RNA and proteins) between the nucleus and the cytoplasm.

Chromatin: thin long strands of DNA and protein.

Nucleolus: the nucleolus makes RNA another type of nucleic acid.

Schematic Diagram	Micrograph
 Figure 3.19: Diagram showing the basic structures of the animal cell nucleus.	 Figure 3.20: An electron micrograph of a cell nucleus showing a densely staining nucleolus.

Functions of the nucleus

- The main function of the cell nucleus is to control gene expression and facilitate the replication of DNA during the cell cycle (which you will learn about in the next chapter).
- The nucleus controls the *metabolic* functions of the cell by producing mRNA which encodes for enzymes e.g. insulin.
- The nucleus controls the *structure* of the cell by transcribing DNA which encodes for structural proteins such as actin and keratin.
- The nucleus is the site of ribosomal RNA (rRNA) synthesis, which is important for the construction of ribosomes. Ribosomes are the site of protein translation (synthesis of proteins from amino acids).
- Characteristics are transmitted from parent to offspring through genetic material contained in the nucleus.

Mitochondria ESG53

A mitochondrion is a membrane bound organelle found in eukaryotic cells. This organelle generates the cell's supply of chemical energy by releasing energy stored in molecules from food and using it to produce ATP (adenosine triphosphate). ATP is a special type of "energy carrying" molecule.

Structure and function of the mitochondrion

Mitochondria contain two phospholipid bilayers: there is an outer membrane, and an inner membrane. The inner membrane contains many folds called cristae which contain specialised membrane proteins that enable the mitochondria to synthesise ATP. Inside the inner membrane is a jelly-like matrix.

FACT
During cell division, DNA contracts and folds to form distinct structures called chromosomes. The chromosomes are formed at the start of cell division.

FACT
The genetic material of eukaryotic organisms is separated from the cytoplasm by a membrane whereas the genetic material of prokaryotic organisms (like bacteria) is in direct contact with the cytoplasm.

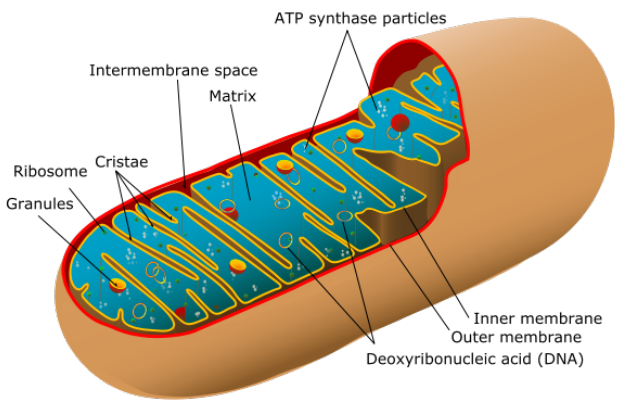
FACT
Mitochondria also contain DNA, called mitochondrial DNA, (mtDNA) but it makes up just a small percentage of the cell's overall DNA content. All mitochondrial DNA in humans is derived from the mother's side.

FACT
Powering the cell: mitochondria
See video: 2CPJ

FACT
In Life Sciences it is important to note that whenever a structure has an increased surface area, there is an increase in the functioning of that structure.

Listed from the outermost layer to the innermost compartment, the compartments of the mitochondrion, are:

- Outer mitochondrial membrane
- Intermembrane space
- Inner mitochondrial membrane
- Cristae (folds of the inner membrane)
- matrix (jelly-like substance within the inner membrane)

Schematic Diagram	Micrograph
 Figure 3.21: The major structures of the mitochondrion in three dimensions.	 Figure 3.22: Electron micrograph of a mitochondrion.

The table below relates each structure to its function.

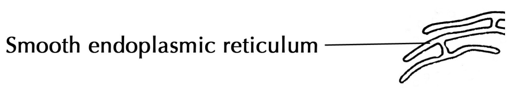
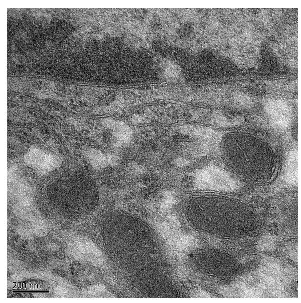
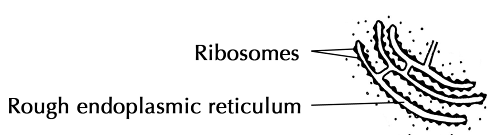
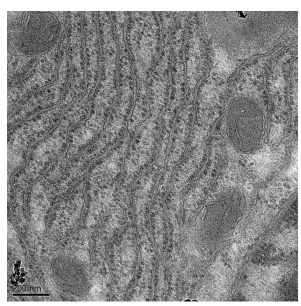
Structure	Function	Adaptation to function
Outer mitochondrial membrane	Transfer of nutrients (e.g lipids) to mitochondrion.	Has large number of channels to facilitate transfer of molecules.
Intermembrane space	Stores large proteins allowing for cellular respiration.	Its position between two selectively permeable membranes allows it to have a unique composition compared to the cytoplasm and the matrix.
Inner membrane	Stores membrane proteins that allow for energy production.	Contains folds known as *cristae* which provide increased surface area, thus enabling production of ATP (chemical potential energy).
Matrix	Contains enzymes that allow for the production of ATP (energy).	The matrix is contains a high quantity of protein enzymes which allow for ATP production.

Endoplasmic reticulum ESG54

The endoplasmic reticulum (ER) is an organelle found in eukaryotic cells only. The ER has a double membrane consisting of a network of hollow tubes, flattened sheets, and round sacs. These flattened, hollow folds and sacs are called cisternae. The ER is located in the cytoplasm and is connected to the nuclear envelope. There are two types of endoplasmic reticulum: smooth and rough ER.

Smooth ER: does not have any ribosomes attached. It is involved in the synthesis of lipids, including oils, phospholipids and steroids. It is also responsible for metabolism of carbohydrates, regulation of calcium concentration and detoxification of drugs.

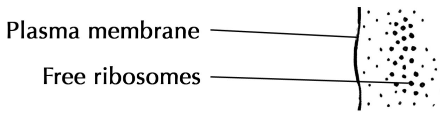
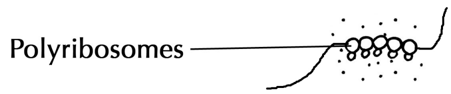
Rough ER: is covered with ribosomes giving the endoplasmic reticulum its rough appearance. It is responsible for protein synthesis and plays a role in membrane production. The folds present in the membrane increase the surface area allowing more ribosomes to be present on the ER, thereby allowing greater protein production.

Schematic Diagram	**Micrograph**
Smooth endoplasmic reticulum	
	
Rough endoplasmic reticulum	
	

FACT
The Golgi body was discovered by the Italian physician Camillo Golgi. It was one of the first organelles to be discovered and described in detail because it's large size made it easier to observe.

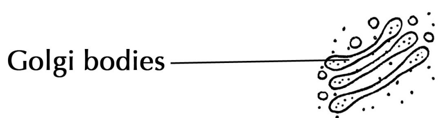
Ribosomes ESG55

Ribosomes are composed of RNA and protein. They occur in the cytoplasm and are the sites where protein synthesis occurs. Ribosomes may occur singly in the cytoplasm or in groups or may be attached to the endoplasmic reticulum thus forming the rough endoplasmic reticulum. Ribosomes are important for protein production. Together with a structure known as messenger RNA (a type of nucleic acid) ribosomes form a structure known as a polyribosome which is important in protein synthesis.

Diagram: Free Ribosome	**Diagram**: Polyribosome
 Figure 3.23: Free ribosomes found within cytoplasm.	 Figure 3.24: Diagram of several ribosomes joined together on a strand of mRNA to form a polyribosome.

Golgi body ESG56

The Golgi body is found near the nucleus and endoplasmic reticulum. The Golgi body consists of a stack of flat membrane-bound sacs called cisternae. The cisternae within the Golgi body consist of enzymes which modify the packaged products of the Golgi body (proteins).

Schematic Diagram	**Micrograph**
 Figure 3.25: Diagram showing Golgi bodies found in animal cells.	 Figure 3.26: TEM Micrograph of Golgi body, visible as a stack of semicircular black rings near the bottom.

Functions of the Golgi body

It is important for proteins to be transported from where they are synthesised to where they are required in the cell. The organelle responsible for this is the Golgi Body. The Golgi body is the sorting organelle of the cell.

Proteins are transported from the rough endoplasmic reticulum (RER) to the Golgi. In the Golgi, proteins are modified and packaged into vesicle. The Golgi body therefore receives proteins made in one location in the cell and transfers these to another location within the cell where they are required. For this reason the Golgi body can be considered to be the 'post office' of the cell.

Vesicles and lysosomes ESG57

Vesicles are small, membrane-bound spherical sacs which facilitate the metabolism, transport and storage of molecules. Many vesicles are made in the Golgi body and the endoplasmic reticulum, or are made from parts of the cell membrane. Vesicles can be classified according to their contents and function. Transport vesicles transport molecules within the cell.

Lysosomes are formed by the Golgi body and contain powerful digestive enzymes that can potentially digest the cell. Lysosomes are formed by the Golgi body or the endoplasmic reticulum. These powerful enzymes can digest cell structures and food molecules such as carbohydrates and proteins. Lysosomes are abundant in animal cells that ingest food through food vacuoles. When a cell dies, the lysosome releases its enzymes and digests the cell.

Vacuoles ESG58

Vacuoles are membrane-bound, fluid-filled organelles that occur in the cytoplasm of most plant cells, but are very small or completely absent from animal cells. Plant cells generally have one large vacuole that takes up most of the cell's volume. A selectively permeable membrane called the **tonoplast**, surround the vacuole. The vacuole contains **cell sap** which is a liquid consisting of water, mineral salts, sugars and amino acids.

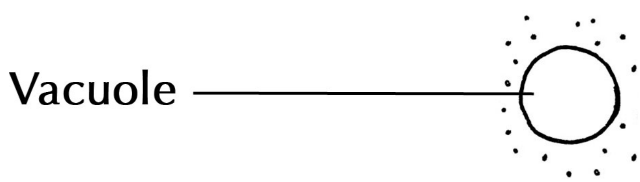


Figure 3.27: A vacuole.

Functions of the vacuole

- The vacuole plays an important role in digestion and excretion of cellular waste and storage of water and organic and inorganic substances.
- The vacuole takes in and releases water by osmosis in response to changes in the cytoplasm, as well as in the environment around the cell.
- The vacuole is also responsible for maintaining the shape of plant cells. When the cell is full of water, the vacuole exerts pressure outwards, pushing the cell membrane against the cell wall. This pressure is called turgor pressure.
- If there is not sufficient water, pressure exerted by the vacuole is reduced and the cells become flaccid causing the plant to wilt.

Centrioles ESG59

Animal cells contain a special organelle called a centriole. The centriole is a cylindrical tube-like structure that is composed of 9 microtubules arranged in a very particular pattern. Two centrioles arranged perpendicular to each other are referred to as a **centrosome**. The centrosome plays a very important role in cell division. The centrioles are responsible for organising the microtubules that position the chromosomes in the correct location during cell division. You will learn more about their function in the following chapter on Cell Division.

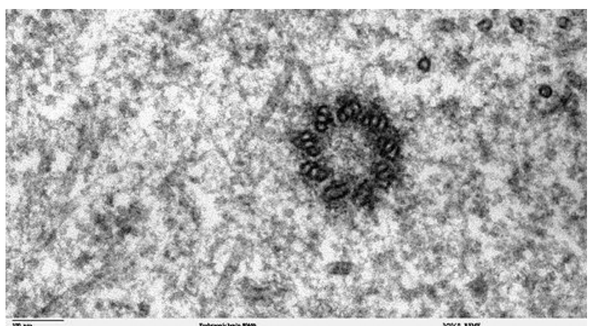


Figure 3.28: A TEM micrograph of a cross-section of a centriole in an animal (rat) cell.

Plastids ESG5B

Plastids are organelles found only in plants. There are three different types:

1. **Leucoplasts**: White plastids found in roots.
2. **Chloroplasts**: Green-coloured plastids found in plants and algae.
3. **Chromoplasts**: Contain red, orange or yellow pigments and are common in ripening fruit, flowers or autumn leaves.

Figure 3.29: Plastids perform a variety of functions in plants, including storage and energy production.

FACT
The colour of plant flowers such as an orchid is controlled by a specialised organelle in a cell known as the chromoplast.

Chloroplast

The chloroplast is a double-membraned organelle. Within the double membrane is a gel-like substance called stroma. Stroma contains enzymes for photosynthesis. Suspended in the stroma are stack-like structures called grana (singular = granum). Each granum is a stack of thylakoid discs. The chlorophyll molecules (green pigments) are found on the surface of the thylakoid discs. Chlorophyll absorbs energy from the sun in order for photosynthesis to take place in the chloroplasts. The grana are connected by lamellae (intergrana). The lamellae keep the stacks apart from each other.

FACT
This video shows the fascinating inner life of a cell:
See video: 2CPK

The structure of the chloroplast is neatly adapted to its function of trapping and storing energy in plants. For example, chloroplasts contain a high density of thylakoid discs and numerous grana to allow for increased surface area for the absorption of sunlight, thus producing a high quantity of food for the plant. Additionally, the lamellae keeping the thylakoids apart maximise chloroplast efficiency, thus allowing as much light as possible to be absorbed in the smallest surface area.

Schematic Diagram

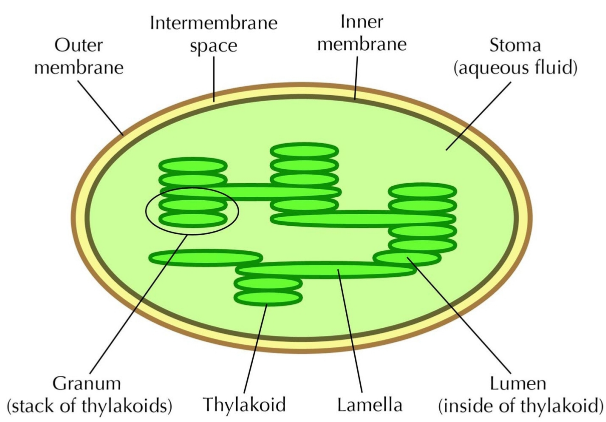


Figure 3.30: Structure of chloroplast.

Micrograph

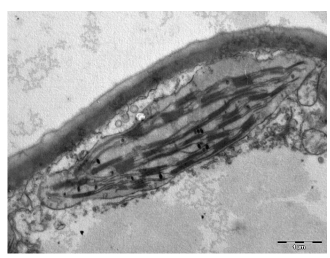


Figure 3.31: Electron micrograph of chloroplast with grana and thylakoids.

The differences between plant and animal cells ESG5C

Now that we have looked at the basic structures and functions of the organelles in a cell, you would have noticed that there are key differences between plant and animal cells. The table below summarises these differences.

Animal Cells	Plant Cells
Do not contain plastids.	Almost all plants cells contain plastids such chloroplasts, chromoplasts and leucoplasts.
No cell wall.	Have a rigid cellulose cell wall in addition to the cell membrane.
Contain centrioles.	Do not contain centrioles.
Animals do not have plasmodesmata or pits.	Contain plasmodesmata and pits.
Few vacuoles (if any).	Large central vacuole filled with cell sap in mature cells.
Nucleus is generally found at the centre of the cytoplasm.	Nucleus is found near the edge of the cell.
No intercellular spaces found between the cells.	Large intercellular air spaces found between some cells.

Investigation: Examining plant cells under the microscope

Aim:

To study the microscopic structures of plant cells.

Apparatus:

- onion
- blade
- slides and coverslips
- brushes
- compound microscope
- tissue paper
- forceps
- dropper
- iodine solution
- watchglass
- petri dish containing water

Method:

1. Peel off the outer most layer of an onion carefully, using a pair of forceps.
2. Place the peeled layer in a watchglass containing water. Make certain that the onion peel does not roll or fold.
3. Using a scalpel or a thin blade, cut a square piece of the onion peel (about 1 cm^2).
4. Remove the thin transparent skin from the inside curve of a small piece of raw onion and place it on a drop of iodine solution on a clean slide.
5. Cover the peel with a coverslip ensuring that no bubbles are formed.
6. Using a piece of tissue paper wipe off any excess iodine solution remaining on the slide.
7. Observe the onion skin under low power of the microscope and then under high power.
8. Draw a neat diagram of 5-10 cells of the typical cells you can see.

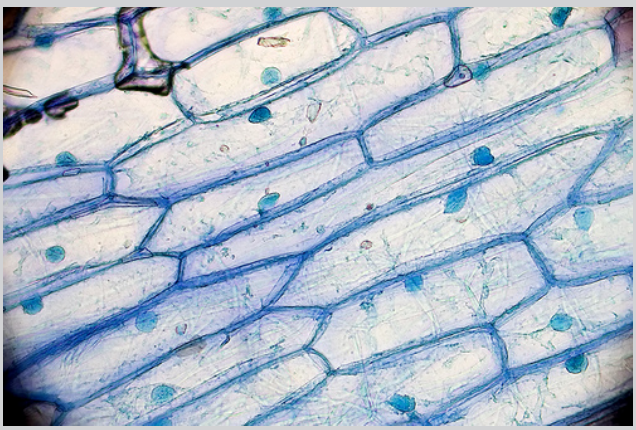


Figure 3.32: Onion cells stained with methylene blue.

Investigation: Examining animal cells under the microscope

Aim:

To study the microscopic structures of human cheek cells under a compound microscope.

Apparatus:

- clean ear bud
- clean slide
- methylene blue

- dropper
- water
- tissue paper
- forceps
- microscope

Method:

1. Place a drop of water on a clean glass slide.
2. Using a clean ear bud, wipe the inside of your cheek. The ear bud will collect a moist film.
3. Spread the moist film on a drop of water on a clean glass slide, creating a small smear on the slide.
4. Use a coverslip to cover the slide gently.
5. Place one or two drops of stain on the side of the cover slip.
6. Use a piece of tissue to remove the excess dye.
7. Observe the cheek cells under low power magnification and then under high power magnification.

Questions:

1. What are the shapes of epidermal cells of the onion peel and the human cheek cells?
2. Why is iodine used to stain the onion peel?
3. What is the difference between the arrangement of cells in onion cells and in human cheek cells?
4. Why is a cell considered the structural and functional unit of living things?

Figure 3.33: Cheek epithelial cells.

Project: Cell organelles

You are required to compile a report on one of the organelles you have studied in class, or any other organelle you choose. Your report must include the following information.

- **Past**
  - The discovery of the organelle
  - All past understanding of the organelles structure and/or function that has now changed
  - The importance of the discovery of the organelle to cell science
- **Present**
  - The presently understood structure and function of the organelle
  - A 2-dimensional picture of the organelle showing all the relevant structures of the organelle
  - An electron-microscope picture of the organelle showing the structure of the organelle
  - An understanding of the importance of the organelle to human survival
- **Future**
  - What remains to be discovered or fully understood?
  - Any important role of the organelle could potentially play with the development of future technology (i.e. in industry or medicine).
- **Any other additional information or interesting facts you wish to include.**

Project: Diagrams of cells

Diagrams of the cell are very well understood but they often give us the wrong impression about how complicated cells really are. This assignment will help you understand the complexity of cells.

1. Find and submit a hard copy of five micrographs showing different cell organelles.
2. Draw and label two organelles to demonstrate your drawing, labelling and interpretive skills.

Pay close attention to the following:

- The organelles should each comfortably occupy an A5 page.
- The organelles must each have a heading that includes the view, title and magnification.

FACT
Revise everything you have learnt about cells by watching this video.
See video: 2CPM

- Drawings must follow the drawing skills you have learnt. One drawing must be the same size as the micrograph, the other must be exactly half the size.
- Your drawings must have a correct scale line.
- State the source of your micrographs according to the Harvard convention.
- Marks will be awarded for neatness: present your work as a uniform set.
- You must select hard copies well so that are of high quality and can be easily recognisable.
- Your images may be of the same organelle but only if the images show some significant variation.

3.5 Summary ESG5D

The discovery of cells:

- All living organisms are made of cells.
- Cells are very small therefore magnifying instruments such as lenses and microscopes are used to view them.
- By using a light microscope the simple features of cells can be studied. The light microscope uses a beam of light focused by various glass lenses.
- Electron microscopes have higher power of magnification than the ordinary light microscope, therefore allowing us to see very small structures inside the cells. These microscopes use a beam of electrons focused by electromagnets to magnify objects instead of light rays and lenses.
- Robert Hooke (1665) used a light microscope to examine non-living cork cells.
- Antonie van Leeuwenhoek was the first person to observe living cells using a microscope.
- The development of cell theory was from the study of microscopic cells.

Cell structure and function

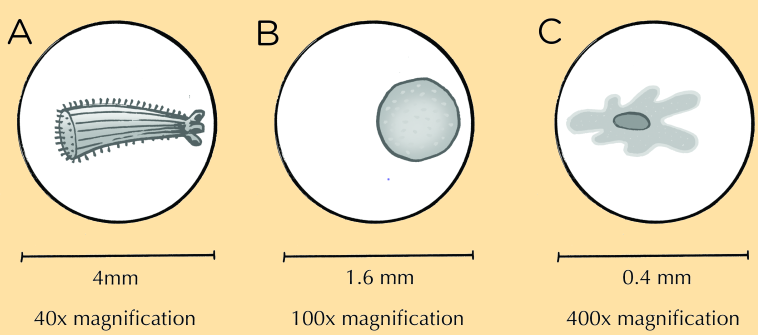
- All cells have the same basic structure. They are all surrounded by a cell membrane and contain cytoplasm and organelles.
- Cells have different sizes, shapes and structures in order to carry out specialised functions.
- The cell membrane is made of phospholipids and proteins and controls substances which move in and out of the cell.
- The structure of the cell membrane is referred to as the Fluid Mosaic Model.

- The nucleus is made up of a nuclear membrane with nucleopores, chromatin material and the nucleolus inside the nucleoplasm.
- Mitochondria release chemical potential energy (ATP) for the cell during cellular respiration.
- Ribosomes are important for protein production.
- Cytoplasm is used for storage and circulation of various materials.
- Endoplasmic reticulum transports substances from one part of the cell to another.
- The Golgi body modifies, secretes, packages and distributes various organic molecules (proteins and lipids) around the cell.
- Vacuoles are used for storage. In plant cells these are large, whilst in animal cells, if present, are very small.
- Lysosomes are mainly found in animal cells.
- Centrioles are only found in animal cells.
- The cell wall is found only in plant cells and is made up of cellulose. The cell wall gives the plants shape, support and protection.
- Plastids are found only in plant cells. There are three types of plastids:
  - chloroplasts contain chlorophyll and their function is the production of food by photosynthesis
  - chromoplasts give colour to fruits and flowers
  - leucoplasts are white and are used mainly for starch storage

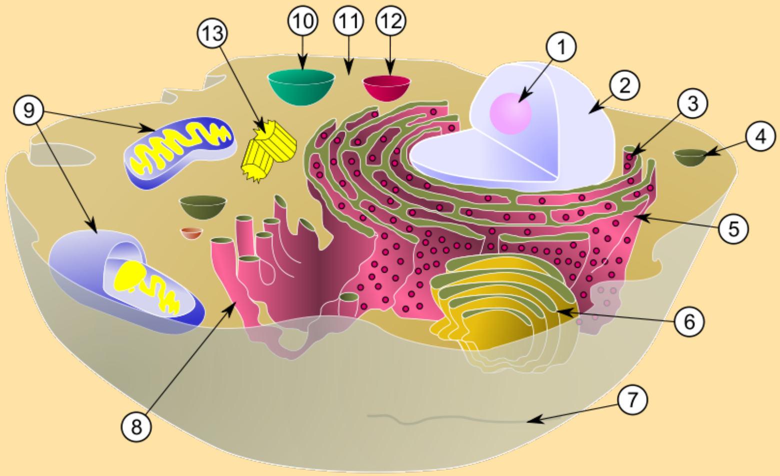
3.6 End of chapter exercises ESG5F

Exercise 3 – 1:

1. Examine the three images below. Use calculations Explain which organism would be the smallest when viewed with the naked eye. Show all the calculations you used to arrive at your answer.



2. Below is a three-dimensional diagram of the cell. Provide the name and function of the following numbered structures:



The following difficult to distinguish structures have been done for you:

- **4-vesicle:** spherical sacs that facilitate storage, metabolism and transport of molecules.
- **7-cell membrane:** selectively permeable to control the passage of substances into and out of the cell.
- **10-vacuole:** storage of sugars, minerals and pigments and help maintain water balance in the cell.
- **12-lysosome:** contain powerful digestive enzymes that digest damaged cell structures and food molecules.

3. Multiple answers are provided for each question. Write **only the letter** of the correct answer next to the corresponding number.

    a) Active transport is the movement of a substance from a:

        i. high concentration to a low concentration.
        ii. high water potential to a low water potential.
        iii. isotonic solution.
        iv. low concentration to a high concentration.

    b) Protoplasm consists of:

        i. nucleoplasm and nucleolus.
        ii. cytoplasm and nucleoplasm.
        iii. cytoplasm and organelles.
        iv. membranes and organelles.

    c) This organelle is responsible for transporting substances around the cell:

        i. ribosome
        ii. Golgi body
        iii. nucleus
        iv. endoplasmic reticulum

d) The nucleus does **not** control:

   i. hereditary transmission
   ii. cellular respiration
   iii. metabolism
   iv. structure

e) The energy that a molecule possesses while moving:

   i. potential energy
   ii. kinetic energy
   iii. magnetic energy
   iv. mechanical energy

f) Which of the following is **not** a product of cellular respiration?

   i. CO_2
   ii. H_2O
   iii. O_2
   iv. ATP

4. Give the correct biological **term** for each of the following. Write only the **term** next to the relevant question number.

   a) Part of the cell that consists of about 90% water.
   b) Often referred to as the powerhouse of the cell.
   c) Pigment found in green plants.
   d) The part of a plant cell that is composed of cellulose.
   e) The fluid inside the vacuole.
   f) The movement of a substance against a concentration gradient.
   g) The structure that distributes substances made in the cell.

5. Choose the correct **option** for each of the following questions. Write only the **term** next to the relevant question number.

   a) What structure contains DNA and regulates most of the processes within the cell?

      i. mitochondria
      ii. chloroplast
      iii. nucleus
      iv. nucleolus

   b) What is a cell membrane?

      i. thin flexible barrier around the cell that regulates transport
      ii. rigid cover that provides support for the cell
      iii. the place where light energy, water and carbon dioxide are used
      iv. special organelle that converts solar energy to chemical energy

c) Which two organelles contain their own DNA genome, separate from the nuclear genome?

   i. lysosomes and transport vesicles
   ii. endoplasmic reticulum and Golgi apparatus
   iii. cilia and flagella
   iv. mitochondria and chloroplast
   v. ribosomes and vacuoles

6. Tabulate four differences between animal and plant cells.
7. a) Name a structural adaptation of the mitochondria that makes it suited to its function:
   b) Name one structural adaptation of chloroplasts.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 2CPN	2a. 2CPP	3a. 2CPQ	3b. 2CPR	3c. 2CPS	3d. 2CPT
3e. 2CPV	3f. 2CPW	4a. 2CPX	4b. 2CPY	4c. 2CPZ	4d. 2CQ2
4e. 2CQ3	4f. 2CQ4	4g. 2CQ5	5a. 2CQ6	5b. 2CQ7	5c. 2CQ8
6. 2CQ9	7a. 2CQB	7b. 2CQC			

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CHAPTER 4

Cell division

4 Cell division

4.1 Overview ESG5G

Introduction ESG5H

In this unit you will learn how we are able to replicate our cells through the process of cell division called **mitosis**. Mitosis is absolutely vital to the survival of all organisms, as without it unicellular organisms would not be able to reproduce and multicellular organisms would not be able to grow or heal after damage. However, uncontrolled mitosis can result in cancer, a potentially fatal condition. In this chapter we will review the stages of mitosis in plants and animal cells. We will then discuss how cancer is caused and some treatments that are available.

Key concepts

- The cell cycle is divided into two main stages: interphase and the mitotic phase.
- During interphase cells grow in size and replicate their DNA.
- Chromosomes are present in the nuclei of all cells and consist of two chromatids joined by a centromere.
- Mitosis is the process by which cells distribute their replicated DNA to two daughter cells.
- The mitotic phase consists of five stages: prophase, metaphase, anaphase, telophase and cytokinesis.
- Mitosis is the means of reproduction in unicellular organisms that undergo asexual reproduction.
- Mitosis is required for growth and repair in multicellular organisms.
- Cancer is a disease of uncontrolled mitosis.
- Cancer is caused by carcinogens and is treated through surgery, radiation and chemotherapy.

4.2 The cell cycle ESG5J

The **cell cycle** is the series of events that takes place in a cell that results in DNA replication and cell division. There are two main stages in the cell cycle. The first stage is **interphase** during which the cell grows and replicates its DNA. The second phase is the **mitotic phase** (M-Phase) during which the cell divides and transfers one copy of its DNA to two identical daughter cells.

Figure 4.1 provides a brief overview of what takes place during each of the key events of the cell cycle.

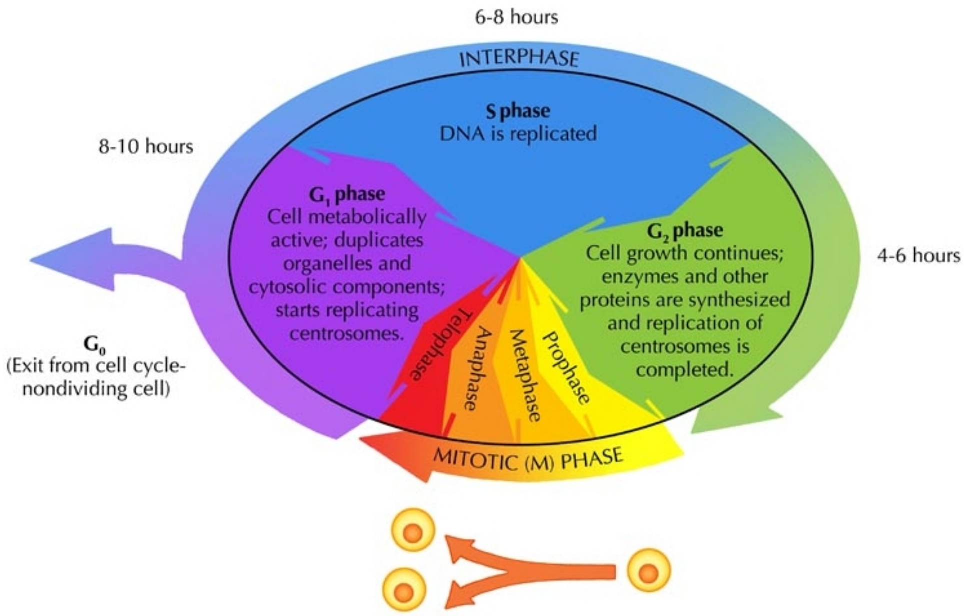


Figure 4.1: The sequence of events in the cell leading to division of a cell into two daughter cells is known as the cell cycle and is shown above.

FACT
Some cells no longer need to divide and exit the cell cycle. These cells may exit the cell cycle permanently, such as neurons, or they may exit the cell cycle temporarily. These cells are said to be in G_0. G_0 is not a stage of the cell cycle.

FACT
In cells without a nucleus (prokaryotic cells e.g. bacteria), there are many copies of the DNA floating around the whole cell. The prokaryotic cell cycle occurs through a process termed binary fission. In cells with a nucleus (eukaryotes) all the DNA is inside the nucleus and so a more complicated cell cycle is required for replication.

Interphase ESG5K

Interphase is the longest phase of the cell cycle. During this phase the cell grows to its maximum size, performs its normal cellular functions, replicates its DNA, and prepares for cell division. This stage is divided into three parts: **G_1, G_2** and **S phases**.

G_1 phase: Occurs just after the two daughter cells have split and the cells have only one copy of their DNA. Cells in this stage synthesise proteins and increase in size. Cells can remain in this stage for a long time.

S phase: Is the stage during which DNA replication occurs. The cell makes an identical copy of each of its **chromosomes**. Chromosomes are found inside the nucleus of the cell and consist of long strands of DNA that contain the genetic information of the cell.

G_2 phase: Occurs after the DNA had been duplicated in S phase. During this phase the cell may continue to grow and undergo normal cellular functions. Towards the end of this phase the cell will start to replicate its organelles in preparation for mitosis.

Interphase (G_1, S and G_2 phases) accounts for approximately 90% of the cell cycle, with the other 10% being taken up by mitosis.

FACT
Learn about chromosomes in this video.
See video: 2CQD

FACT
Human cells have 46 chromosomes. (23 from the mother and 23 from the father).

Mitotic Phase ESG5M

The mitotic phase (M phase) is composed of two tightly coupled processes: **mitosis** and **cytokinesis**. During mitosis the chromosomes in the cell nucleus separate into two identical sets in two nuclei. This is followed by **cytokinesis** in which the cytoplasm, organelles and cell membrane split into two cells containing roughly equal shares of these cellular components. We will now describe what takes place during the stages of M-phase, which includes the four broad phases of mitosis (prophase, metaphase, anaphase, telophase) and the fifth phase of cytokinesis:

1. prophase
2. metaphase
3. anaphase
4. telophase
5. cytokinesis

1. Prophase

During prophase, the **chromatin** material shortens and thickens into individual chromosomes which are visible under the light microscope. Each chromosome consist of two strands or **chromatids** joined by a **centromere** (Figure 4.2).

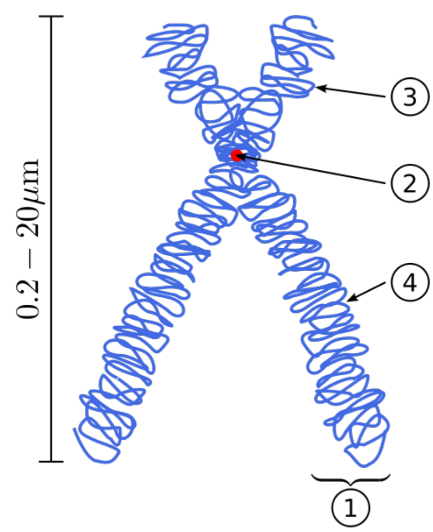
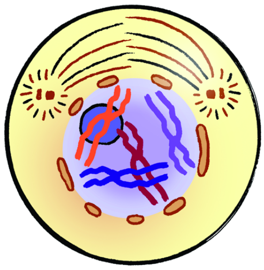
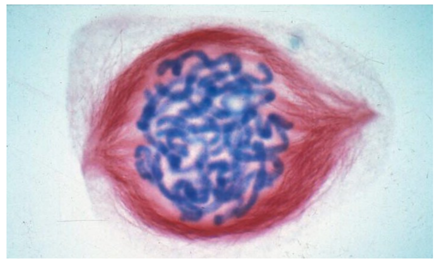


Figure 4.2: Chromosome structure showing (1) Chromatid, (2) Centromere, (3) Short and (4) Long arms of chromosome.

As prophase progresses, the nuclear membrane and nucleolus disintegrates. In animal cells the **centrioles** separate and move to opposite poles. The centrioles give rise to the spindle fibres which form between the poles. In plant cells there are no centrioles to move to the poles, so spindle fibres form in the cytoplasm.

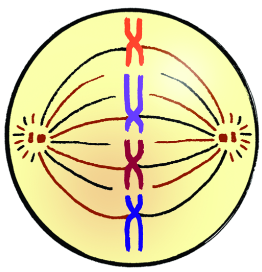
Schematic diagram: animal cell	**Micrograph**: plant cell
	

FACT

HINT: The stages of the cell cycle (**i**nterphase, **p**rophase, **m**etaphase, **a**naphase, **t**elophase) can be remembered by using the mnemonic **IPMAT**.

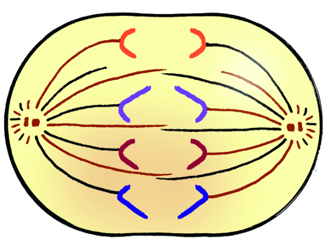
2. Metaphase

During metaphase, chromosomes line up on the **equator** of the cell. The chromosomes appear in a straight line across the middle of the cell. Each chromosome is attached to the spindle fibres by its centromere.

Schematic diagram: animal cell	**Micrograph**: plant cell
	

3. Anaphase

During anaphase the chromatids are pulled to opposite poles of the cell by the shortening of the spindle fibres. The chromatids are now called **daughter chromosomes**.

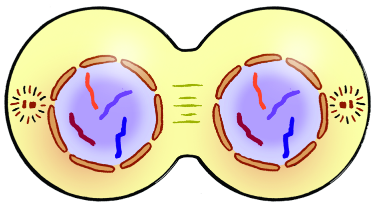
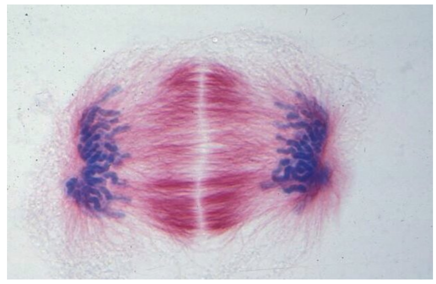
Schematic diagram: animal cell	**Micrograph**: plant cell
	

FACT
In plant cells there are no centrioles to move to the poles, so spindle fibres form in the cytoplasm.

FACT
See mitosis in action.
See video: 2CQF

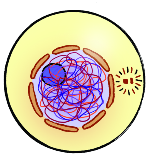
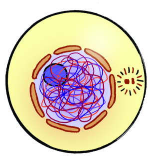
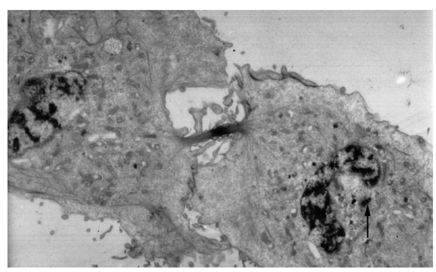
4. Telophase

During telophase, a nuclear membrane reforms around the daughter chromosomes that have gathered at each of the poles. The daughter chromosomes uncoil to form chromatin once again. The nuclear membrane reforms.

Schematic diagram: animal cell	**Micrograph**: plant cell
	

5. Cytokinesis

The cytoplasm then divides during a process called **cytokinesis**. Cytokinesis is not a stage of mitosis but the process of the cytoplasm splitting into two. In an animal cell the cell membrane constricts. This **invagination** or in-folding of the cytoplasm divides the cell in two. In a plant cell a **cross wall** is formed by the **cell plate** dividing the cytoplasm in two.

Schematic diagram: animal cell		**Micrograph**
		

There are now two **genetically identical** daughter cells which are identical to the parent cell and to each other.

4.3 The role of mitosis ESG5N

FACT
Hair has the highest rate of mitosis. An average hair grows 0.3 mm every day and 1 cm every month.

The process of mitosis is essential for growth and repair processes of eukaryotic organisms: mitosis is how we are able to replace our fingernails and hair as well as how our skin is replaced. The table below summarises the role of mitosis in various processes in eukaryotic organisms.

Living Process	**Role of Mitosis**
Development and growth	The number of cells increases by mitosis enabling organisms to grow from a single cell to a complex multicellular organism.
Cell replacement	Cells are constantly lost and replaced by new ones in the body, for example in the skin and in the gut. In addition, red blood cells live for only four months, and are replaced by mitosis.
Replacement of damaged plant or animal tissue (regeneration)	Some organisms use mitosis to replace body parts. For example starfish replace lost arms by mitosis.
Asexual reproduction	Some organisms such as the hydra use mitosis to produce genetically identical offspring. The process is known as budding. Mitosis is also the method by which yeast cells multiply.

Table 4.1: The role of mitosis in eukaryotic organisms.

Figure 4.3 shows asexual reproduction in a ciliate organism. Asexual reproduction uses mitosis.

Figure 4.3: Asexual reproduction: ciliate undergoing cytokinesis.

4.4 Cancer ESG5P

Introduction ESG5Q

Cancer is a group of diseases characterised by uncontrolled cell division which leads to growth of abnormal tissue. This means that a cancer is essentially a **disease of mitosis**. Cancer begins when a single cell is **transformed**, or converted from a normal cell to a cancer cell. Cancer cells grow and divide uncontrollably to form a mass of cancer cells called a **tumour**. As the tumours grow, they squash healthy cells, steal their nutrients and prevent them from working normally. Cancer cells differ from normal cells in a number of ways:

1. **Cancer cells don't listen to signals to stop growing**: Normal cells listen to signals from the body to stop growing and dividing. However cancer cells do not respond to signals from the body and keep on dividing.
2. **Cancer cells grow new blood vessels**: As the tumour grows larger, it begins to release proteins from the cell to attract new blood vessels. Blood vessels draw nutrients away from healthy cells and therefore starve them while allowing the growth of the tumour. The new blood vessels also enable cancer cells to enter the bloodstream and spread to other parts of the body.
3. **Cancer cells spread around the body**: Another feature of cancer cells is that they can spread around the body (metastasise). Tumours that have the ability to spread to other parts of the body are called **malignant**. Cancer cells can spread to surrounding tissues via the bloodstream or via the lymph system.

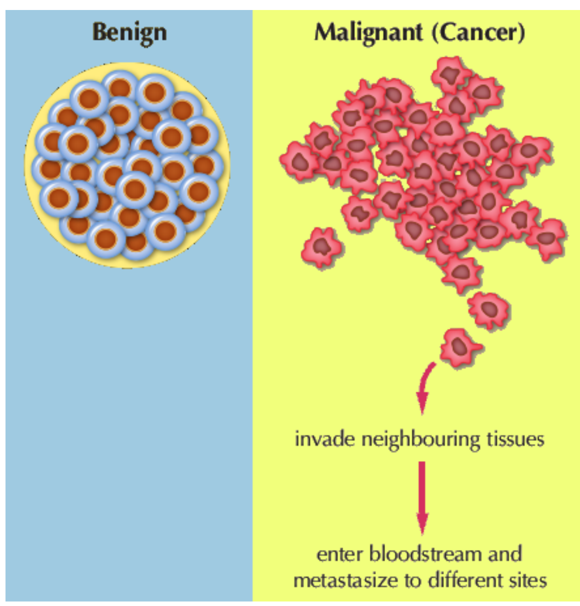


Figure 4.4: Benign tumours are unable to metastasise. Malignant tumours are able to metastasise away from the original tumour site.

As previously mentioned, cancer cells are **malignant** which means they are able to invade tissues and spread to other parts of the body. Some tumours cannot spread to other tissues and are called **benign** tumours. Benign tumours are non-cancerous.

Types of cancers

Cancer can affect almost any tissue in the body. A list of some common cancers includes:

- Breast cancer
- Lung cancer
- Oesophageal cancer
- Leukaemia (blood cancer)
- Melanoma (skin cancer)

Cancers often spread to different organs, however it remains the same type of cancer as the original cancer, it is simply referred to as a metastasis. Therefore melanoma (skin cancer) that spreads to the liver is not liver cancer, but a melanoma metastasis to the liver.

FACT
Watch some videos to learn more about how normal cells turn cancerous.
See video: 2CQG
See video: 2CQH
See video: 2CQJ
See video: 2CQK

FACT
There are hundreds of different types of cancer. For a comprehensive list visit: http://en.wikipedia.org/wiki/List_of_cancer_types

FACT
Watch this video to learn more about how gene mutations and cancer.
See video: 2CQM

Causes of cancer ESG5R

Cancer is caused by agents called **carcinogens**. Carcinogens cause cancer by damaging DNA which can no longer code for the important regulatory functions of the cell cycle. Some viruses can also increase the likelihood of getting certain types of cancer. Human papillomavirus (HPV), the disease that causes genital warts, can increase a woman's risk of cervical cancer, and infection with hepatitis B or C increases the risk of liver cancer. In addition, some people are born with genetic mutations that they have inherited from their parents that increase their chances of getting cancer. However a genetic predisposition to cancer does not mean that you will get cancer. If you have a family history of cancer it simply means it is more important for you to limit your exposure to carcinogens. Examples of some carcinogens include:

- cigarette smoke
- radiation
- x-rays
- UV light
- food additives
- several dangerous chemicals

FACT
Carcinogens can cause a **DNA mutation** that occurs in one of several **genes** that normally function to control growth. E.g the *BRCA1*, or "Breast Cancer Gene". The *BRCA1* gene normally functions to suppress tumour formation; but if a genetic mutation occurs it does not work properly, and tumour formation can begin. Mutations in this gene does not mean that a person will develop breast cancer, but they have an increased risk for breast cancer.

Beliefs and attitudes concerning cancer ESG5S

There are some common misconceptions about cancer:

- **It is people's fault if they get cancer**: Although there are ways to try and decrease your risk of getting cancer, it is not always possible. Cancer is caused by random mutations in DNA, and sometimes people get cancer purely by chance.
- **Cancer is a death sentence**: Sometimes when the cancer is very advanced there is not much to be done to save a person, but there are many cancers that respond well to treatment when detected early. Depending on the type and the stage of the cancer, people can survive cancer and go on to live healthy happy lives.
- **If someone in your family has cancer you might get it too**: Although there are some cancers that are more common in certain families due to an inherited genetic mutation, a family history of cancer does not mean than you will also get cancer. However, if a certain type of cancer runs in your family it is good to see a doctor for regular screenings.
- **Cancer is contagious and you can catch it from others**: Cancer cannot be spread from one person to another.
- **A positive attitude can cure cancer**: There is plenty of evidence that a positive attitude can help a person with cancer feel better and stay healthier for longer, however it is not the only factor that determines whether someone will recover or not.
- **Only old people get cancer**: Although cancer is more common in older people, children and babies can also get cancer. Leukaemia is a common childhood cancer.
- **Only females get breast cancer**: Although breast cancer is more common in females, males can also get breast cancer.
- **Only pale people get skin cancer**: Although skin cancer is more common in people with light skin (melanin, the pigment that makes your skin dark is also protective), people with dark skin can also get skin cancer.

Cancer treatment ESG5T

Cancer is usually treated using conventional methods that are based on Western evidence-based medicine. However, many people like to use a holistic approach to treat cancer, and therefore also use indigenous methods to manage symptoms. The following sections will introduce some conventional and indigenous methods for treating cancer.

Conventional methods ESG5V

The conventional medical approaches to treating cancer include **radiation therapy, chemotherapy** and **surgery**.

1. Radiation therapy

Radiation therapy is the use of high energy electromagnetic radiation to kill cancer cells. The radiation damages the DNA inside the cancer cells, causing them to die. Radiation damages healthy cells too; therefore the treatment is targeted directly at the tumour.

Figure 4.5: Radiation therapy uses high energy electromagnetic radiation to kill cancer cells.

Figure 4.6: Chemotherapy is the use of chemical treatments targeted at cancer cells.

2. Chemotherapy

Chemotherapy is the use of special drugs to treat cancer. Most chemotherapy drugs are cytotoxic (toxic to cells) and work by damaging the cell's DNA. Chemotherapy specifically tries to prevent cell division, and so it is very toxic to cancer cells which are characterised by uncontrolled cell division. However, unfortunately, these drugs also damage healthy cells that divide rapidly, such as blood cells and cells found in hair follicles, lining the mouth, stomach and intestine and the skin. Because of the damage to rapidly dividing healthy cells, the side-effects from chemotherapy include hair loss, mouth ulcers, nausea, sores, anaemia and infections due to a lowered immune system.

A combination of drugs which act in slightly different ways to halt cell division are often given together. Patients often receive chemotherapy according to a regime, where they receive doses of chemotherapy for a time period, followed by a break that allows the healthy cells in their bodies to recover. Usually a chemotherapy regime consists of a few cycles of chemotherapy doses and breaks for recovery.

FACT
Chemotherapy targets cells that are rapidly dividing so patients undergoing chemotherapy often lose their hair and feel nauseous (because the intestinal lining in the stomach is killed).

FACT
Some people are born with mutations in genes involved in regulating the cell cycle. For example in colorectal cancer (cancer of the colon) some people have mutations in the mismatch repair genes. Mismatch repair genes fix damaged DNA. If they are not working properly it enhances a person's risk of getting cancer. People who have a close family member who got cancer when they were under 40 years of age need to be regularly tested for damaged genes.

3. Surgery

Surgery involves removal of either the whole tumour, part of the tumour and sometimes even whole organs or body parts. When a small section of the tumour is removed this is called **biopsy**. Frequently surgery is followed by either radiation therapy or chemotherapy and sometimes both.

Indigenous methods ESG5W

In addition to the conventional methods of treatment described, many people seek alternative forms of treatment. In South Africa, individuals commonly use traditional medicines like African Potato *(Hypoxis hemerocallidea)* and "Cancer bush" *(Sutherlandia frutescens),* to boost the immune system while undergoing conventional treatments.

Figure 4.7: African potato is used as a remedy against cancer in some forms of traditional medicine.

Figure 4.8: "Cancer bush" used in certain forms of indigenous treatments for cancer.

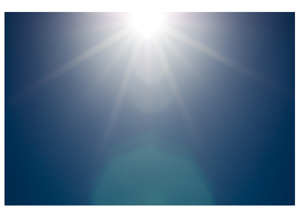
The cancer bush (*Sutherlandia frutescent, uNwele)* is an indigenous medicinal plant which the Khoi and Nama people used to wash wounds and to reduce high fevers. The early settlers also used this bush to treat chicken pox, eye problems and internal cancers. Cancer patients often lose weight and suffer muscle wastage and a tonic made from this bush may improve appetite, decrease anxiety and slow down the weight loss.

Prevention of cancer ESG5X

The risk of developing any one of the many types of cancer can be reduced by eating a healthy diet, exercising regularly and avoiding smoking and alcohol. The sooner cancer is detected the easier it is to treat. Therefore it is also advisable for people to get regular screenings. The following page contains some guidelines to lower your risk of developing cancer:

- **Avoid smoking**: avoid smoking cigarettes and avoid enclosed areas where people smoke (this avoids passive smoking).
- **Avoid alcohol**: limit alcohol, as excessive alcohol consumption can lead to increased risk of oesophageal, liver and breast cancer.
- **Healthy diet**: avoid (or limit) very processed foods or burnt food, both of which contain carcinogens.
- **Regular physical activity**: partake in physical activity on a regular basis. Regular exercise improves general health and helps one to maintain an ideal body weight, thereby lowering the risk of many cancers.
- **Sun protection**: limit exposure to the sun and damage by ultraviolet radiation. Try to stay out of the sun between 10 am and 3 pm, wear high SPF sunscreen that protects against UVA and UVB, and wear a hat, sunglasses, and protective clothing.
- **Regular screenings**: cell or tissue abnormalities can sometimes be detected before they become cancerous. Regular pap smears can prevent cervical abnormalities developing into cervical cancer and getting moles and skin conditions checked can prevent dangerous skin cancer. Cancer can also be detected at the early treatable stages by going for regular mammograms (for breast cancer), or prostate exams (for prostate cancer) as adults. The frequency of these exams will be age and risk dependent.

FACT
Watch this video about how our bodies help protect us from cancer despite the constant bombardment of environmental carcinogens.
See video: 2CQN

Ways to decrease cancer risk		
		
Avoid smoking	Avoid excessive alcohol consumption	Eat a healthy diet
		
Regular physical activity	Sun protection	Regular screenings

Activity: Cancer and smoking

Aim:

Investigating the relationship of smoking and cancer.

Instructions:

Look at the graph below and answer the questions that follow:

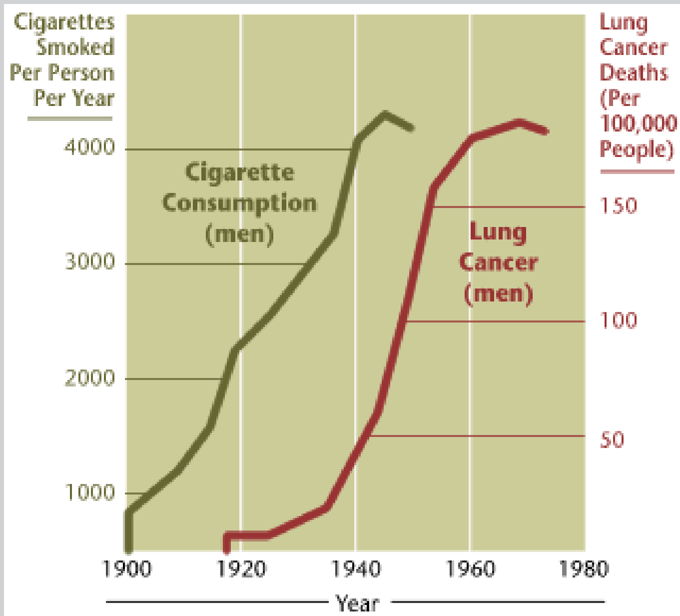


Figure 4.9: Graph showing correlation between smoking and lung cancer (courtesy NHI).

Questions:

1. In what year was the first incidence of lung cancer seen in male smokers?
2. How many years was this after the introduction of cigarettes?
3. In which year did the average number of cigarettes smoked per year reach a peak?
4. Approximate how many years it takes most male smokers to develop cancer? Clue: Compare the number of years seen between the two line graphs for 1000, 2000, 3000 and 4000 cigarettes per year. Add the years together and divide by 4 to get the average time (in years) taken for smokers to develop cancer.
5. What can you say about the shape of the two graphs? Do they look similar or different? What does this mean?
6. What was the death rate from lung cancer in 1950? Express your answer as a percentage and show your working.
7. Suggest a reason why the number of cigarettes smoked shows a decrease after 1945.

Activity: Research on cancer

Aim

To research and present information on one of the human cancers

Resources required

1. Science journals such as "New Scientist", "Scientific American" and any other journals you can find.
2. Use the Internet widely including the websites below:
    - Howard Hughes Medical Institute: contains links for educators and learners on a variety of approaches to determining causes and potential cures for cancer: http://www.hhmi.org/
    - Whitehead Institute for cancer research. This is one of the world's leading cancer research labs where you can find interactive videos, links to other resources and information about a variety of cancers: http://wi.mit.edu/

Instructions

Using the resources available, you are required to research ONE of the cancers affecting humans. In particular you are required to:

- Write a report under the following main headings:
    - **Discuss the major causes of the cancer**: Discuss cancer with respect to its genetic and/or environmental causes and how the cancer spreads within a particular individual.
    - **Describe the common beliefs and attitudes concerning the particular cancer you have chosen to research**: Present the popular (common) attitudes people have about cancer, its treatment and how cancer is caused in the first place.
    - **Describe the major forms of treatment available** : What are the major treatments available. Provide an analysis of these under the sub-headings "Modern biotechnological methods" and "Traditional methods".
    - **Describe the prevalence of the cancer type**: Prevalence refers to how common a cancer is in a particular location. Provide statistics in the form of histograms and pie charts of how prevalent the cancer is in different age groups, races and genders.
- At the end of your report, provide a complete list of references of websites, articles and other sources of information used in compiling the report.
- Include any pictures, diagrams and information that you think may be relevant to your report.

4.5 Summary ESG5Y

Mitosis and the cell cycle

- During interphase the DNA replicates.
- The process of mitosis occurs in four stages: prophase, metaphase; anaphase and telophase.
- Cytokinesis differs in plant and animal cells. In animal cells the cytoplasm invaginates and divides the cell in two, and in a plant cell the cell is divided in two by the cell plate which forms the cell wall.
- Mitosis ensures growth of tissues and organisms.
- Damaged and worn out tissues are repaired and replaced by new cells through mitosis.
- Single-celled (unicellular) organisms like amoeba often reproduce asexually by mitosis.

Cancer

- Cancer is caused by DNA mutations.
- Abnormal and uncontrolled cell division results in tumour formation.
- Tumours affect the functioning of the tissue or organ.
- Cancer cells can enter the bloodstream or lymph and spread to distant parts of the body and form new tumours (metastasise).
- Cancers are caused by substances called carcinogens.
- Carcinogens such as certain chemicals, radiation, viruses and genetics can be the cause of certain cancers.
- Cancers can be treated by various methods including surgery, radiation, chemotherapy and traditional medicines.

4.6 End of chapter exercises ESG5Z

Exercise 4 – 1:

1. Multiple answers are provided for each of the questions below. You are required to choose the most appropriate answer for each question. Write down the letter only.

    a) During which stage does DNA replication occur?

        i. prophase
        ii. anaphase
        iii. metaphase
        iv. none of the above

b) Which of the following statements is correct?

i. The chromosomes shorten and thicken during prophase.
ii. The nucleolus reappears following telophase.
iii. Interphase is characterised by little cellular activity, as the cell is resting to prepare for the next mitotic event.
iv. All of the above.

c) Which of the following is not true?

i. Only plant cells grow a cell plate.
ii. Animal and plant cells both contain centrioles.
iii. Metaphase is is when the chromosomes line up on the equator of the cell.
iv. All of the above.

d) There are two copies of DNA in the cell during:

i. G_1 phase
ii. telophase
iii. G_2 phase
iv. all of the above

2. Study the onion root-tip slides below and Identify the stage of mitosis (most stages are represented more than once).

i	ii	iii
		
iv	v	vi
		

3. What is the difference between a benign and a malignant tumour?
4. Name five preventative measures or behaviours that will decrease your chances of developing cancer.

5. Cancer in South Africa. Look at the following table showing the percentage of deaths by cancer type in South Africa in 2000.

Cause of death	Percentage in all people	Percentage in men	Percentage in women
Tracheal/ Bronchal/ Lung cancer	16.5	21.9	10.9
Oesophageal cancer	13.4	16.7	9.9
Cervical cancer	8.4		17.2
Breast cancer	7.7	0.2	15.6
Liver cancer	6.4	7.8	4.9
Colorectal Cancer	6.2	5.4	6.9
Prostate cancer	6.1	11.8	
Stomach cancer	5.6	6.5	4.7
Pancreatic cancer	3.7	3.7	3.7
Leukaemia	3.5	3.8	3.2

a) What medical procedures should women take to detect breast cancer early?

b) Draw a bar graph to show the percentage deaths for each type of cancer for men and women.

c) Which type of cancer is the most common in:

   i. men

   ii. women

Check answers online with the exercise code below or click on 'show me the answer'.

1a. 2CQP 1b. 2CQQ 1c. 2CQR 1d. 2CQS 2. 2CQT 3. 2CQV
4. 2CQW 5a. 2CQX 5b. 2CQY 5c. 2CQZ

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CHAPTER 5

Plant and animal tissues

5 Plant and animal tissues

5.1 Overview ESG62

Introduction ESG63

'If you want to understand function, study structure.'- Francis Crick in his book "What Mad Pursuit: A Personal View of Scientific Discovery" (1988).

The relationship between structure and function is important to understanding this chapter and is important to the study of Life Sciences in general. This chapter requires you to build on the concepts you understood in the section on cell structure.

Key concepts

- Tissues are group of similar cells that are structurally adapted to perform a particular function.
- Cells are adapted for specific functions through a process of cell differentiation.
- Examples of plant tissues include: xylem, phloem, parenchyma, collenchyma, sclerenchyma, epidermis and meristematic tissue.
- Examples of animal tissues are: epithelial tissue, connective tissue, muscle tissue and nerve tissue.
- Various plant tissues are important ingredients in traditional medicine.
- Biotechnology is a modern science that involves manipulating the properties of tissues and cells.
- Many tissues group together to form an organ, which has a very specific role in an organism.
- The leaf is an example of a plant organ that is made up of a number of tissues that collectively enable the process of photosynthesis.

Previous chapters have discussed the molecular and cellular levels of organisation of living organisms. In this chapter we will examine how similar cells associate together to form tissues.

atom →molecule→cell→**tissue**→organ→system→organism→ecosystem

5.2 Tissues ESG64

Tissues are made up of a group of similar cells that are adapted for a particular function. Organs are then formed by the functional grouping together of multiple tissues.

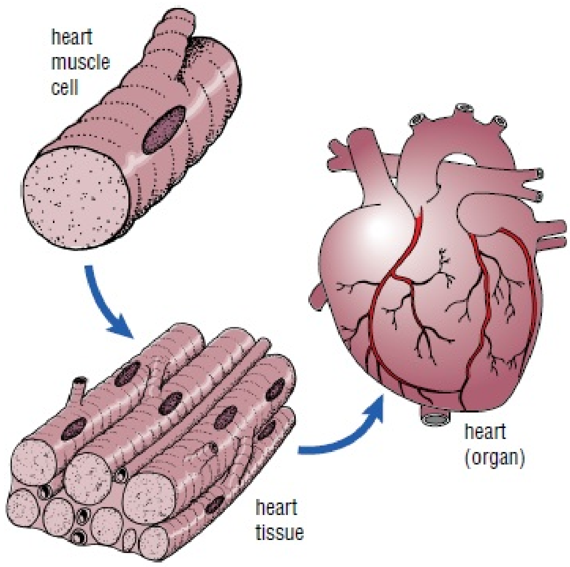


Figure 5.1: The diagram above depicts how several cells adapted for the same function work in conjunction to form tissues, and together form an organ.

In this chapter we will be studying plant and animal tissues, starting with plant tissues.

FACT
There are over 200 000 types of plant species in the world. Green plants provide the Earth's oxygen, and also directly or indirectly provide food for all animals because of their ability to photosynthesise. Plants also provide the source of most of our drugs and medicines. The scientific study of plants is known as **botany.**

FACT
Learn more about plant tissues:
See video: 2CR3

5.3 Plant tissues ESG65

Plants are typically made up of roots, stems and leaves. Plant tissues can be broadly categorised into dividing, **meristematic** tissue or non-dividing, **permanent** tissue. Permanent tissue is made up of **simple** and **complex** tissues.

It is important that for each tissue type you understand:

- where it is located
- what its key structural features are and how these relate to function
- how each tissue type looks under the microscope
- how to draw biological diagrams of each structure

Figure 5.2 provides an overview of the types of plant tissues being studied in this chapter.

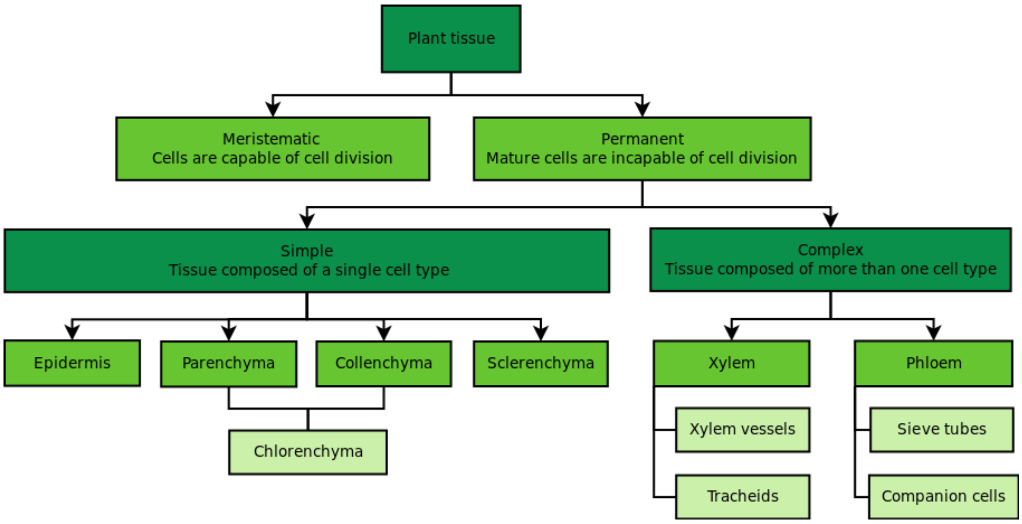
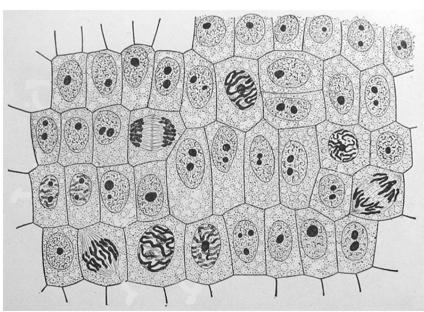
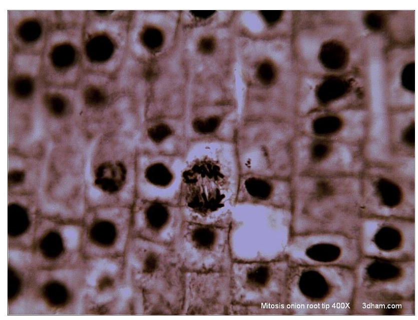


Figure 5.2: The diagram above depicts how several cells adapted for the same function work in conjunction to form tissues.

Meristematic tissue ESG66

Meristematic tissue is **undifferentiated tissue**. Meristematic tissue contains actively dividing cells that result in formation of other tissue types (e.g. vascular, dermal or ground tissue). **Apical** meristematic tissue is found in buds and growing tips of plants. It generally makes plants grow taller or longer. **Lateral** meristematic tissue make the plant grow thicker. Lateral meristems occur in woody trees and plants. Examples of lateral meristematic tissue include the vascular cambium that results in the rings you see in trees, and **cork cambium** or 'bark' found on the outside of trees.

Diagram	Micrograph
 Figure 5.3: Meristematic cells in the growing root-tip of the onion, from a longitudinal section.	 Figure 5.4: Micrograph of meristematic tissue.

The following table highlights how the structure of the meristematic tissue is suited to its function.

Structural adaptation	Function
Cells are small, spherical or polygonal in shape.	This allows for close packing of a large number of cells.
Vacuoles are very small or completely absent.	Vacuoles provide rigidity to cells thus preventing rapid division.
Large amount of cytoplasm and a large nucleus.	The lack of organelles is a feature of an undifferentiated cell. Large amount of nuclear material contains the DNA necessary for division and differentiation.

Table 5.1: Structural adaption and function of meristematic tissue.

Meristematic tissue is found in root tips as this is where roots are growing and where dividing cells are produced. Figure 5.5 shows a micrograph image of a root tip.

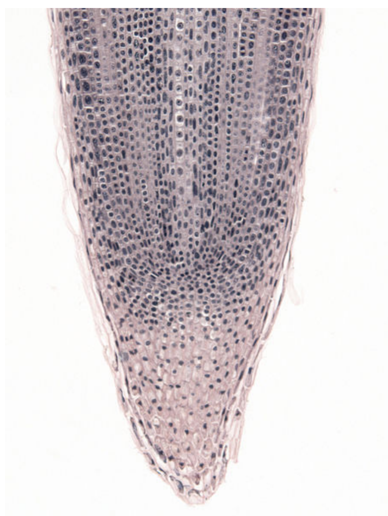


Figure 5.5: Image shows meristematic tissue in a root tip as observed under an electron microscope.

Permanent tissues ESG67

The meristematic tissues give rise to cells that perform a specific function. Once cells develop to perform this particular function, they lose their ability to divide. The process of developing a particular structure suited to a specific function is known as **cellular differentiation**. We will examine two types of permanent tissue:

1. **Simple permanent tissues**
    - epidermis
    - parenchyma
    - collenchyma
    - sclerenchyma
2. **Complex permanent tissues**
    - xylem vessels (made up of tracheids and vessels)
    - phloem vessels (made up of sieve tubes and companion cells)

Epidermis tissue ESG68

The epidermis is a single layer of cells that covers plants' leaves, flowers, roots and stems. It is the outermost cell layer of the plant body and plays a protective role in the plant. The function of key structural features are listed in Table 5.2.

Structure	Function
Layer of cells covering surface of entire plant.	Acts as a barrier to fungi and other microorganisms and pathogens.
Layer is thin and transparent.	Allow for light to pass through, thereby allowing for photosynthesis in the tissues below.
Epidermal tissues have abundant **trichomes** which are tiny hairs projecting from surface of epidermis. Trichomes are abundant in some plant leaves.	Leaf trichomes trap water in the area above the stomata and prevent water loss.
Root hairs are elongations of epidermal cells in the root.	Root hairs maximise the surface area over which absorption of water from the soil can occur.
Epidermal tissues in leaves are covered with a waxy **cuticle**.	The waxy outer layer on the epidermis prevents water loss from leaves.
Epidermal tissues contain **guard cells** containing chloroplasts.	Guard cells control the opening and closing of the pores known as **stomata** thus controlling water loss in plants.
Some plant epidermal cells can secrete poisonous or bad-tasting substances.	The bitter taste of the substances deter browsing and grazing by animals.

Table 5.2: Table showing structural adaptations of epidermis tissue.

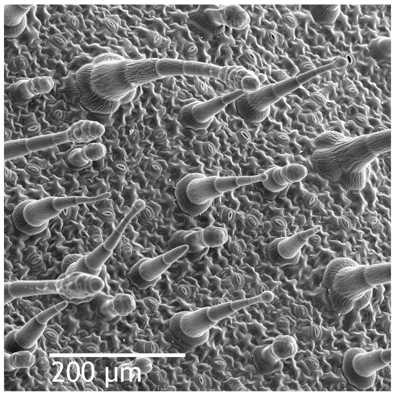


Figure 5.6: Scanning electron microscope image of *Nicotiana alata* (tobacco plant) upper leaf surface, showing trichomes (also known as 'hairs') and a few stomata.

FACT

The chemicals in trichomes make plants less easily digested by hungry animals and can also slow down the growth of fungus on the plant. As such they act as a form of protection for the plant against predation.

Guard cells and Stomata ESG69

A **stoma** is a pore found in the leaf and stem epidermis that allows for gaseous exchange. The stoma is bordered on either side by a pair of specialised cells known as **guard cells**. Guard cells are bean shaped specialised epidermal cells, found mainly on the lower surface of leaves, which are responsible for regulating the size of the stoma opening. Together, the stoma and the guard cells are referred to as **stomata**.

The stomata in the epidermis allow oxygen, carbon dioxide and water vapour to enter and leave the leaf. The guard cells also contain chloroplasts for photosynthesis. Opening and closing of the guard cells is determined by the turgor pressure of the two guard cells. The turgor pressure is controlled by movements of large quantities of ions and sugar into the guard cells. When guard cells take up these solutes, the water potential decreases causing water to flow into the guard cells via osmosis. This leads to an increase in the swelling of the guard cells and the stomatal pores open.

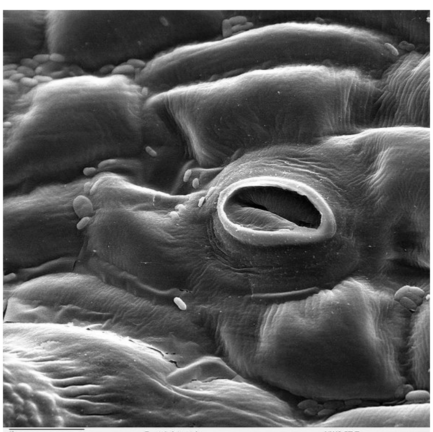


Figure 5.7: Stomata in a tomato leaf as seen under a scanning electron microscope.

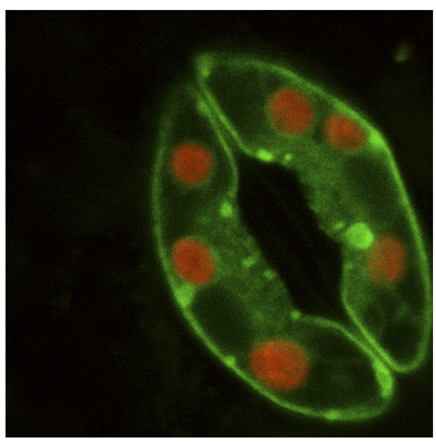


Figure 5.8: Microgrpah of *Arabidopsis thaliana* stoma showing two guard cells exhibiting green fluorescence, with chloroplasts staining red.

Activity: Practical investigation of leaf epidermis

Aim:

To observe epidermal cells and stomata.

Materials:

- leaves of *Agapanthus*, Wandering Jew *(Tradescantia*) or similar plants that have epidermis that strips off easily
- microscopes
- microscope slides and cover slips
- dissecting needles
- scissors

Instructions:

1. Rip a piece of leaf lengthwise and check for 'thinner bits' near the edges, which will be epidermal tissue (ensure that you have *lower* epidermis because this is where the guard cells are found).
2. Use the scissors to cut off a small section of epidermis and mount it in water on a microscope slide. Cover with a cover slip.
3. Focus the slide on low power and search for a section of the sample that does not have air bubbles over the stomata.
4. Enlarge the part of the specimen you chose and focus on high power.
5. Adjust lighting if necessary and draw one stoma and its guard cells. Label all parts.

Questions:

1. Describe the shape of the guard cells and normal epidermal cells.
2. Which epidermal cells have chloroplasts?
3. Describe the wall thickness around the guard cells and account for any visible differences.

We will now look at parenchyma, collenchyma and sclerenchyma cells. Together these tissue types are referred to as **ground tissues.** Ground tissues are located in the region between epidermal and vascular tissue.

Parenchyma tissue ESG6B

Parenchyma tissue forms the majority of stems and roots as well as soft fruit like tomatoes and grapes. It is the most common type of ground tissue. Parenchyma tissue is responsible for the storage of nutrients.

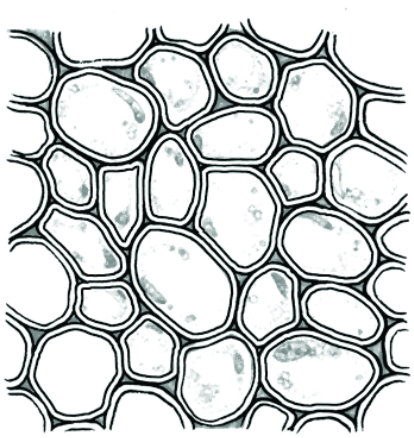


Figure 5.9: Parenchyma tissue found in cells responsible for storage.

Parenchyma	
Structure	**Function**
Thin-walled cells.	Thin walls allow for close packing and rapid diffusion between cells.
Intercellular spaces are present between cells.	Intercellular spaces allow diffusion of gases to occur.
Parenchyma cells have large central vacuoles.	This allows the cells to store and regulate ions, waste products and water. Also function in providing support.
Specialised parenchyma cells known as **chlorenchyma** found in plant leaves contain chloroplasts.	This allows them to perform a photosynthetic function and responsible for storage of starch.
Some parenchyma cells retain the ability to divide.	Allows replacement of damaged cells.

Table 5.3: Structure and function of parenchyma.

Activity: Observing parenchyma cells.

Aim:

To observe the structure of fresh parenchyma cells.

Materials:

- banana
- petri dishes or watch glasses
- dissection needles
- iodine solution
- microscopes, microscope slides and cover slips

Instructions:

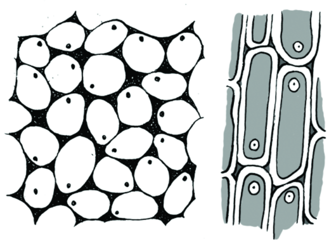
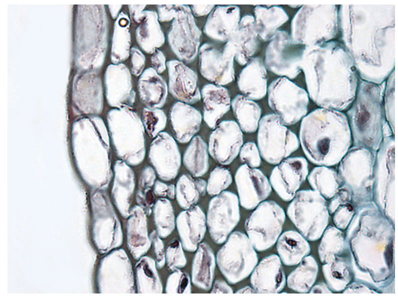
1. Use the dissecting needle to lift off a small piece of the soft banana tissue.
2. Put the sample onto a petri dish or watch glass and mash it slightly using the dissecting needle (and a pencil if you want).
3. Lift a small sample of the tissue onto a microscope slide on which you already have placed a drop of iodine solution. Put the cover slip on.
4. Observe the cells under low power and find a section where the cells are lying separate, not all over each other.
5. Enlarge this section and focus carefully to see if you can find nuclei in some of the cells (they will be bigger than the purple plastids and transparent).
6. Draw 2 or 3 cells and label.

Questions:

1. Describe the shape of the cells and their wall thickness.
2. What are the plastids called which appear purple and what is their function?

Collenchyma tissue ESG6C

Collenchyma is a simple, permanent tissue typically found in the shoots and leaves of plants. Collenchyma cells are thin-walled but the corners of the cell wall are thickened with cellulose. This tissue gives strength, particularly in growing shoots and leaves due to the thickened corners. The cells are tightly packed and have fewer inter-cellular spaces.

Collenchyma	
Diagram	**Micrograph**
 Figure 5.10: Collenchyma cells are thin walled with thickened corners.	 Figure 5.11: Light microscope image of collenchyma cells.

Collenchyma	
Structure	**Function**
Cells are spherical, oval or polygonal in shape with no intercellular spaces.	This allows for close packing to provide structural support.
Corners of cell wall are thickened, with cellulose and pectin deposits.	Provides mechanical strength.
Cells are thin-walled on most sides.	Provides flexibility, allowing plant to bend in the wind.

Table 5.4: Structure and function of collenchyma tissue.

FACT
Collenchyma tissues make up the strong strands observed in stalks of celery.

FACT
The growth of collenchyma tissue is affected by mechanical stress on a plant. For instance if the plant is constantly shaken by the wind the walls of collenchyma may be 40–100% thicker than those that are not shaken.

FACT
Learn more about permanent simple tissues.
See video: 2CR4

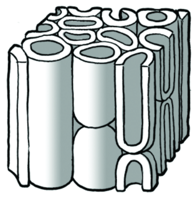
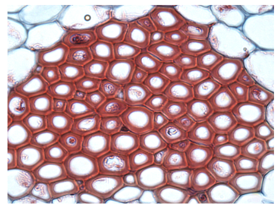
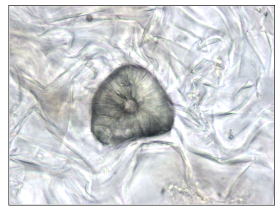
Sclerenchyma tissue ESG6D

Sclerenchyma is a simple, permanent tissue. It is the supporting tissue in plants, making the plants hard and stiff. Two types of sclerenchyma cells exist: **fibres** and **sclereids**.

Sclerenchyma fibres are long and narrow and have thick lignified cell walls. They provide mechanical strength to the plant and allow for the conduction of water.

Sclereids are specialised sclerenchyma cells with thickened, highly lignified walls with pits running through the walls. They support the soft tissues of pears and guavas and are found in the shells of some nuts.

FACT
A useful way to remember the difference between collenchyma and sclerenchyma is to remember the 3 Cs pertaining to collenchyma: thickened at **c**orners, contain **c**ellulose, and named **c**ollenchyma.

Sclerenchyma		
Diagram	**Micrograph**	
 Figure 5.12: Sclerenchyma tissue provides support in plants.	 Figure 5.13: Cross-section of sclerenchyma fibres.	 Figure 5.14: Sclereid.

Sclerenchyma	
Structure	**Function**
Cells are dead and have lignified secondary cell walls.	This provides mechanical strength and structural support. The lignin provides a 'wire-like' strength to prevent from tearing too easily.
Sclereids have strong walls which fill nearly the entire volume of the cell.	Provide the hardness of fruits like pears. These structures are used to protect other cells.

Table 5.5: Structure and function of sclerenchyma tissue.

Sclerenchyma tissues are important components in fabrics such as flax, jute and hemp. Fibres are important components of ropes and mattresses because of their ability to withstand high loads. Fibres found in jute are useful in processing textiles, given that their principal cell wall component is cellulose. Other important sources of fibres are grasses, sisal and agaves. Sclereid tissues are the important components of fruits such as cherries, plums or pears.

Activity: Observing sclerenchyma in pears

Aim:

To observe sclerenchyma stone cells (sclereids) in pears.

Materials:

- soft, ripe pear
- microscopes, microscope slides and cover slips
- iodine solution
- dissecting needles or forceps

Instructions:

1. Use the forceps or needle to lift a small piece of soft pear tissue onto your microscope slide.
2. Add a drop of iodine solution.
3. Mash the tissue slightly to separate the cells.
4. Cover with a cover slip and observe under low power. You should focus on the groups of dark "stones" that appear amongst the rounded parenchyma cells of the pear. Try to find one or two stone cells or sclereids that are separate from the rest.
5. Enlarge a good specimen (or focus on the edge of a group where one cells sticks out) and adjust the lighting.
6. Look carefully while you focus up and down to see the long, narrow PITS running through the extremely thick walls of these cells.
7. These "stone cells" are called sclereids. They are a modified form of sclerenchyma found in pears, guavas and the shells of nuts for extra support.
8. Also observe the large round cells around the sclereids.

Questions:

1. Do you see cytoplasm inside the stone cells? Are they living or dead cells?
2. What tissue type do the large round cells around the sclereids belong to?

Activity: To investigate sclerenchyma fibres

Aim:

To see sclerenchyma fibres in tissue paper.

Materials:

- cheap toilet paper (single ply)
- iodine solution or water
- microscopes and slides

Instructions:

1. Tear a tiny piece of toilet paper off the sample and mount it in water or iodine solution.
2. Place on a cover slip and examine under the microscope on low power.
3. Focus on the torn edge of the paper and observe the long sclerenchyma fibres.
4. Observe on high power.

Questions:

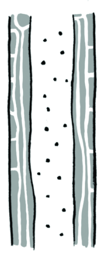
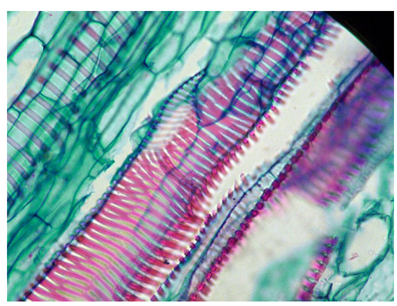
1. Describe the shape of these cells.
2. Are they living or dead cells?
3. Suggest their function.

We will now examine the complex permanent tissues. Remember the difference between simple and complex permanent tissues is that simple permanent tissues are made up of cells of the same type whereas complex permanent tissues are made up of more than one cell type that combine to perform a particular function. We will examine the **vascular** tissues, xylem and phloem tissues next.

Xylem tissue ESG6F

Xylem has the dual function of supporting the plant and transporting water and dissolved mineral salts from the roots to the stems and leaves. It is made up of vessels, tracheids, fibres and parenchyma cells. The vessels and tracheids are non-living at maturity and are hollow to allow the transport of water. Both vessels and tracheids have lignin in their secondary walls, which provides additional strength and support.

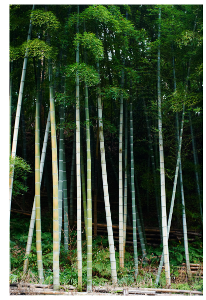
Xylem vessels are composed of a long chain of straight, elongated, tough, dead cells known as vessel elements. The vessel elements are long and hollow (lack protoplasm) and they make a long tube because the cells are arranged end to end, and the point of contact between two cells is dissolved away. The role of xylem vessels is to transport water from roots to leaves. Xylem vessels often have patterns of thickening in their secondary walls. Secondary wall thickening can be in the form of spirals, rings or pits.

Diagram	Micrograph
 Figure 5.15: Longitudinal section through a xylem vessel to show hollow lumen to allow for transport of water and nutrients.	 Figure 5.16: Xylem vessel fibres with rings of lignin thickening.

Tracheids have thick secondary cell walls and are tapered at the ends. The thick walls of the tracheids provide support and tracheids do not have end openings like the vessels. The tracheids' ends overlap with one another, with pairs of pits present which allow water to pass through horizontally from cell to cell.

FACT

In addition to transporting water and mineral salts from roots to leaves, xylem also provides support to plants and trees because of its tough lignified vessel elements.



Structure	Function
Long cells	Form effective conducting tubes for water and minerals
Dead cells: no cytoplasm	No obstruction to water transport
Thick, lignified walls	Support the plant and are strong enough to resist the suction force of transpiration pull, so they don't collapse
Pits in cell walls	Allow lateral water transport to neighbouring cells
Tracheids have tapered ends	Improved flexibility of the stem in wind
Vessels elements have open ends	Water is transported directly to the next cell
No intercellular spaces	Added support for the stem
Living parenchyma cells in between xylem	Form vascular rays for water transport to the cortex of the stem
Patterns of secondary wall thickening	Improve flexibility of the stem in wind and allow the stem to stretch as it lengthens

Table 5.6: Structure and function of xylem tissue.

Activity: Observing the patterned secondary walls in the xylem of fresh plant tissue

Aim:

To observe the patterned secondary walls in the xylem of fresh plant tissue.

Materials:

- celery stalk, rhubarb stalks or pumpkin stems *(macerated - chop them across and boil them in water for 3 minutes, then add an equal amount of glycerine. Cool before using. It can be stored for a few months in the refrigerator.)*
- microscopes and slides
- dissecting needles
- petri dishes or watch glasses
- eosin solution

FACT
Do you remember that sucrose is made up of glucose and fructose monosaccharides? Plants transport sucrose rather than glucose because it is less reactive and has less of an effect on the water potential.

Instructions:

1. Lift a small piece of celery / any other tissue chosen from the dish and transfer it to a watch glass or petri dish.
2. Use the dissecting needle and a pencil to *tease* the tissue apart (separate the thread-like, thicker cells away from each other). Try to get the long cells away from each other, otherwise bundles will be too thick to allow you to see individual cells. Ignore the thin walled parenchyma cells around them.
3. Transfer the plant tissue to a microscope slide and add eosin solution. Separate a bit more if necessary.
4. Examine under low power, focusing on the bundles of xylem vessels. Look for long bundles of fairly wide cells with *thickening in the form of rings or spirals*. Do not confuse xylem vessels with the more common and much narrower sclerenchyma fibres - fibres have walls all the same thickness, have no spirals or rings and they are pointed at the end. If necessary, make a second slide if you did not find xylem.
5. Move a good part to the centre and enlarge. Examine the secondary walls of these cells.

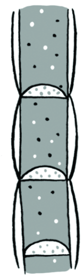
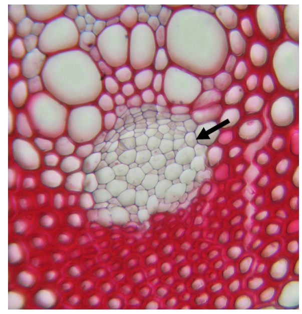
Questions:

1. Describe the shape of xylem vessels.
2. What secondary walls patterns do you see?
3. Suggest the function of such secondary walls.

Phloem tissue ESG6G

Phloem tissue is the living tissue responsible for transporting organic nutrients produced during photosynthesis (mainly as the carbohydrate **sucrose**) to all parts of the plant where these are required. The phloem tissue is made up of the following major types of cells:

- **sieve elements**: these are conducting cells which transport sucrose.
- **parenchyma cells**: which store food for transport in phloem.
- **companion cells**: are associated with parenchyma cells and control the activities of sieve tube elements, since the latter have no nuclei. Companion cells are responsible for providing energy to the sieve elements to allow for the transport of sucrose. Companion cells play an important role in loading sieve tubes with sucrose produced during photosynthesis. Companion cells and sieve tube elements are connected via connecting strands of cytoplasm called plasmodesmata.
- **fibres**: unspecialised cells and supportive cells.

<table>
<tr><th>Diagram</th><th>Micrograph</th></tr>
<tr><td>
Figure 5.17: Longitudinal section: phloem tissue transports nutrients throughout the plant.</td><td>
Figure 5.18: Cross-section: the arrow indicates the location of the phloem in the vascular bundle.</td></tr>
</table>

In the table below, the key structural features of the phloem are related to their function.

Structure	Function
Companion cells	
Contain large number of ribosomes and mitochondria.	Due to absence of organelles or nuclei in sieve tubes, companion cells perform cellular functions of the sieve tube.
Has many plasmodesmata (intercellular connections) in the wall attached to the sieve tube.	Allows transfer of sucrose-containing sap over a large area.
Sieve tubes	
Sieve tube elements are long conducting cells with cellulose cell walls.	Form good conducting tubes over long distances. Allows for transfer over a large area.
They are living cells with no nucleus or organelles such as vacuoles or ribosomes.	Allows for more space to transport sap. It is also why sieve elements need companion cells to carry out all cellular functions.

Table 5.7: Structure and function of phloem tissue.

FACT
Watch a video about the different tissue types in animals
See video: 2CR5

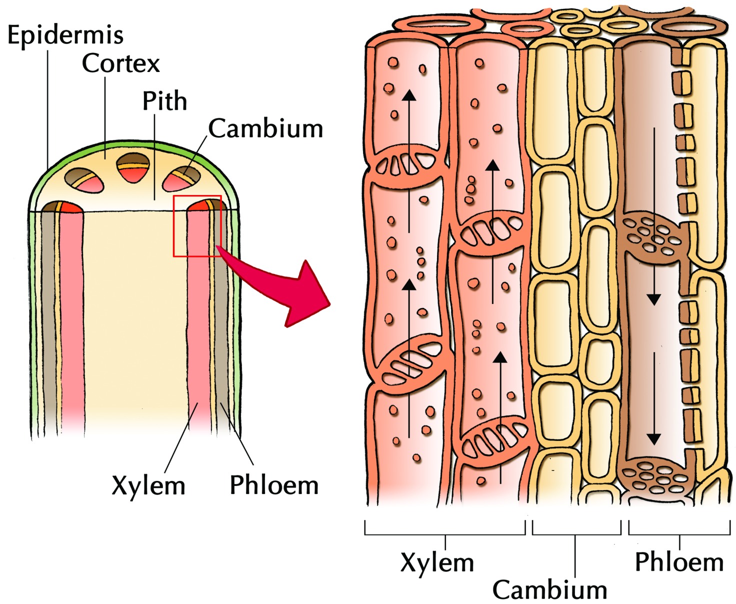


Figure 5.19: Xylem and phloem are the main transport vessels in plants. The figure above shows how vascular tissues are arranged in a vascular bundle.

5.4 Animal tissues ESG6H

Tissues are groups of similar cells that perform a particular function. We will be examining human tissues as an example of animal tissues.

Human bodies, like most animal bodies, are made up of four different types of tissue:

1. **Epithelial tissue** forms the outer layer of the body and also lines many of the bodies cavities where it has a protective function.
2. **Connective tissue** assists in support and protection of organs and limbs and depending on the location in the body it may join or separate organs or parts of the body.
3. **Muscle tissue** enables various forms of movement, both voluntary and involuntary.
4. **Nerve tissue** is responsible for the carrying of electrical and chemical signals and impulses from the brain and central nervous system to the periphery, and vice versa.

We will now look at each tissue type, examining its structure and function as well as its specific location in the body. You will be expected to recognise microscope images of each tissue type and produce biological drawings.

Epithelial tissue ESG6J

Epithelial tissues are formed by cells that cover surfaces (e.g. skin) and line tubes and cavities (e.g. digestive organs, blood vessels, kidney tubules and airways). Epithelial tissue usually consists of a single layer of cells, however in certain cases there may be more than one layer. All epithelial tissues are free surfaces attached to the underlying layers of a basement membrane.

There are different types of epithelial tissue which are named according to the number of layers they form and the shape of the individual cells that make up those layers. **Simple epithelium** refers to a **single** layer of cells. **Stratified epithelium** refers to **two or more** layers of cells. Squamous epithelium refers to flattened cells, cuboidal epithelium refers to cells that are cube-shaped and columnar epithelium refers to vertically elongated cells. Ciliated epithelium refers to epithelial cells that contain many tiny hair-like projections.

FACT
Pseudostratified epithelium refers to epithelium consisting of one layer but looking as though it consists of more than one layer.

FACT
The skin is the largest human organ.

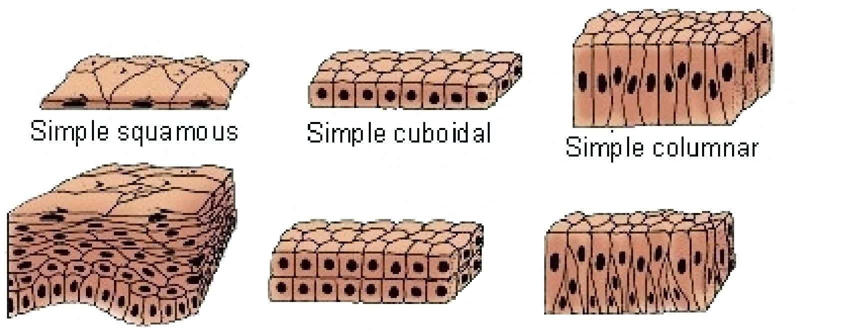


Figure 5.20: The different types of epithelial tissue found in mammals.

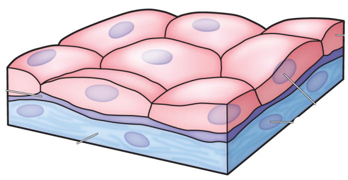
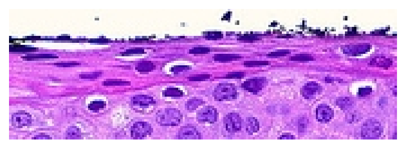
General functions of epithelial tissue

- Provides a barrier between the external environment and the organ it covers.
- Specialised to function in secretion and absorption.
- Protects organisms from microorganisms, injury, and fluid loss.
- Excretes waste products such as sweat from the skin.

The different types of epithelial tissue are classified according to their shape. The major categories we are going to examine are **squamous, columnar** and **cuboidal** epithelium.

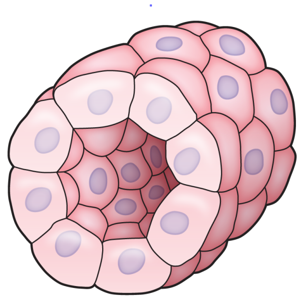
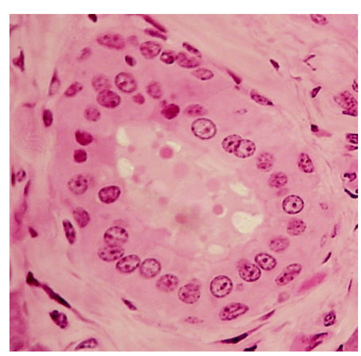
Squamous Epithelium

Location in body	Structure	Function
Simple: capillaries, alveoli (in lungs);	Thin and flat cells that are elliptically shaped and lie on basement membrane. Simple squamous epithelium is one-cell thick.	Responsible for diffusion. Thin structure allows for movement of substances across the cells.
stratified: skin	Stratified squamous epithelium consists of many layers of thin, flat cells.	Provides a protective covering.

Diagram	Microscopic image
	

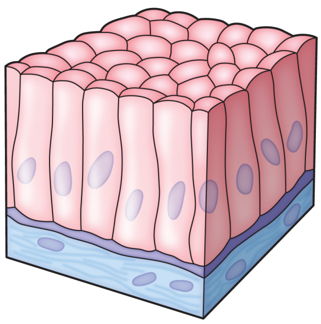
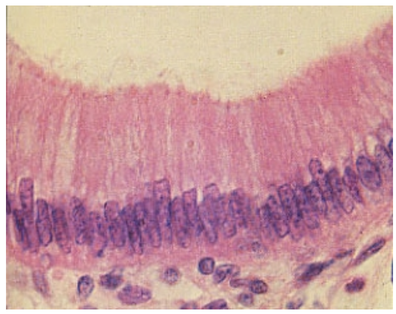
Cuboidal Epithelium

Location in body	Structure	Function
Kidney tubules or glands (regions of the body responsible for excretion).	Cube-like in structure; may occasionally have structures called **microvilli** on surface to aid absorption.	Serve a protective function against bacteria and the wearing away of certain organs by lining various structures. Also prevent water loss.

Diagram	Microscopic image
	

Columnar Epithelium

Location in body	Structure	Function
Digestive tract, reproductive organs	Elongated cells, nuclei located at the base of the cell. Cells connected by tight junctions and receive their nutrients from the basement membrane.	Main function is protective. Prevents against bacterial infection. Can also secrete mucus to protect surface from damage.

Diagram	Microscopic image
	

A sub-type of columnar epithelium called **ciliated columnar epithelium** is found in some places in the body. Ciliated columnar epithelium contain little finger-like projections called **cilia**. These cilia beat in a wave-like motion to move particles, mucus or other substances around the body. Ciliated epithelium is found in the trachea and bronchi of the respiratory system and in the fallopian tubes of the female reproductive tract.

Muscle tissue ESG6K

There are three types of muscle tissue:

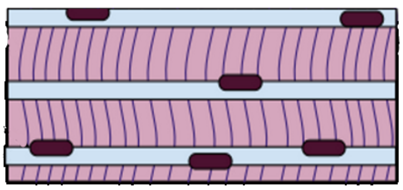
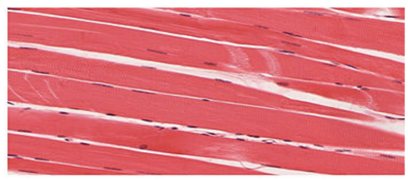
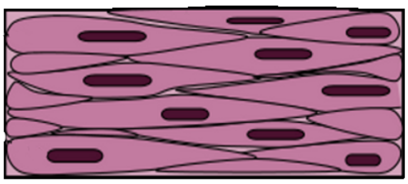
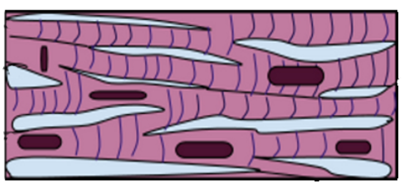
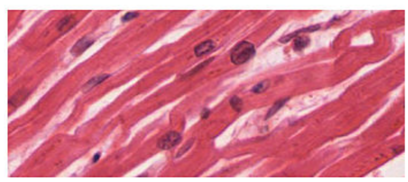
1. skeletal
2. smooth
3. cardiac

Skeletal and cardiac muscle are striated. Striated muscle cells are striped, with regular patterns of proteins responsible for contraction. Striated muscle contracts and relaxes in short bursts, whereas smooth muscle contracts for longer.

1. Skeletal muscle is a voluntary muscle. It is striated in appearance. Skeletal muscle tissue has regularly arranged bundles. It is anchored by tendons and is used to effect skeletal muscle movement, such as **locomotion**, and maintain posture. The muscles have a reflex action but can also respond to conscious control.

2. Smooth muscle is an involuntary, non-striated muscle with tapered ends. It is found within the walls of blood vessels such as arteries and veins. Smooth muscle is also found in the digestive system, urinary tract and in the trachea. It is responsible for involuntary rhythmic contractions of peristalsis, required for moving food down the alimentary canal, and for the dilation and construction of blood vessels to control blood pressure.

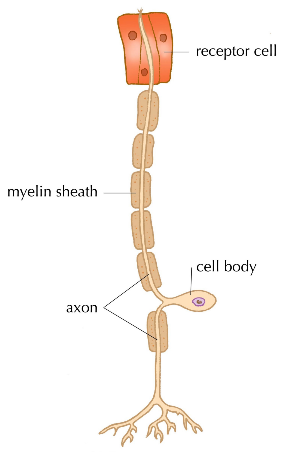
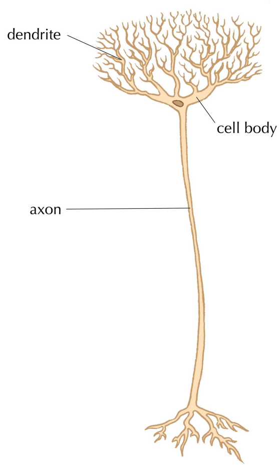
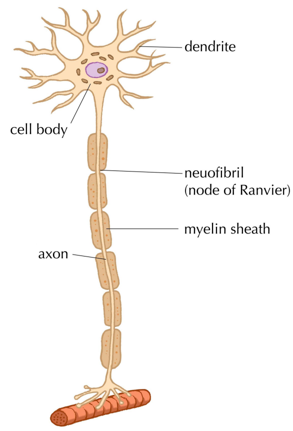
3. Cardiac muscle is the major tissue making up the heart. It is an involuntary muscle that is striated in appearance. However, unlike skeletal muscle, cardiac muscle connects at branching, irregular angles. The connected branches help with coordinated contractions of the heart.

Diagram	Micrograph
Skeletal Muscle 	
Smoothe Muscle 	
Cardiac Muscle 	

Nervous tissue ESG6M

Cells making up the central nervous system and peripheral nervous system are classified as nervous tissue. In the central nervous system, nervous tissue forms the brain and spinal cord. In the peripheral nervous system the nervous tissue forms the cranial nerves and spinal nerves, which include the sensory and motor neurons.

The function of nerve tissue is to transmit nerve impulses around the body. Nerves consist of a **cell body** (soma), **dendrites**, which receive impulses, and **axons** which send impulses. The axons of neurons are surrounded by a myelin sheath. The myelin sheath consists of layers of myelin, a white fatty substance. The myelin sheath's main function is to insulate nerve fibres and it also increases the speed of the impulses transmitted by the nerve cell. There are three types of nerve cells: sensory neurons, interneurons and motor neurons.

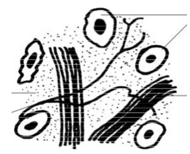
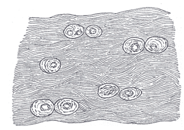
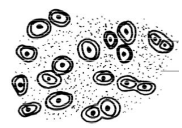
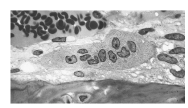
Sensory neuron	Motor neuron	Interneuron
 b) Sensory neuron (unipolar)	 c) Interneuron (multipolar)	 a) Motor neuron (multipolar)
Sensory neurons are responsible for sending information about the environment (called stimuli) to the central nervous system. They are activated by touch, light, temperature, pressure, hearing etc. Sensory nerve cells (or sensory neurons) carry impulses (electrical signals) from a receptor to the central nervous system (CNS).	These neurons are very short compared to the sensory and motor neurons. The connectors or interneurons connect a sensory neuron with a motor neuron. The impulse travels from the cell body at the head end along the short axon to the dendrites.	Motor neurons carry impulses from the CNS to muscles or glands. In most cases the motor neuron causes muscle contraction (movement), but motor neurons can also cause secretion of substances by glands. The motor neuron causes a response via chemicals known as neurotransmitters.

Connective tissue ESG6N

Connective tissue is a biological tissue that is important in supporting, connecting or separating different types of tissues and organs in the body. All connective tissue is made up of cells, fibres (such as collagen) and extracellular matrix. The type of intercellular matrix differs in different connective tissues.

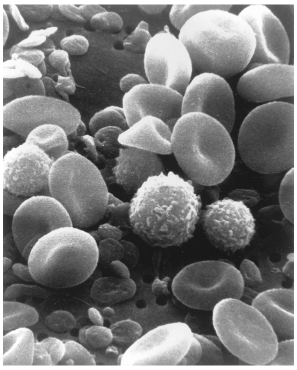
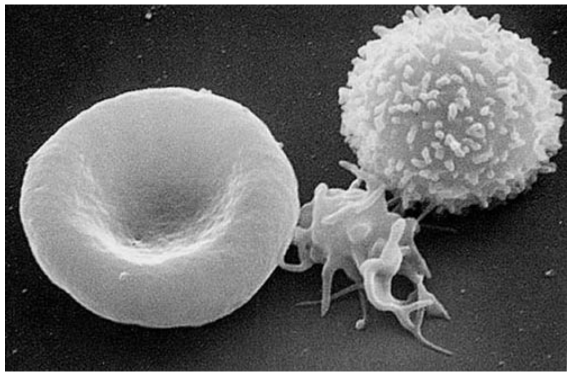
FACT
All connective tissues are characterised by cells separated from each other and found in some type of intercellular matrix.

There are different types of connective tissues with different functions. The following table lists some of the different types of connective tissue.

Connective tissue type	Structure	Function	Location	Diagram/Photo
Areolar (loose connective)	jelly matrix; has network of elastic fibres which attach together	holds the organs in place, cushions and protects organs (acts as a packing material)	surrounds blood vessels and nerves found in the mesentry which surrounds the intestine	
White fibrous	consists of non-elastic fibres	acts as a shock absorber, transfers or absorbs forces	in tendons, ligaments and many tough membrane sheaths that surround organs	
Cartilage	rubbery matrix, can be flexible or rigid	gives structure, shape and strength; reduces friction; provides support	joints, nose, sternum, trachea	
Bone tissue	made up of collagen fibres; mineralised with calcium and phosphates to make it solid	provides strength and support; creates red blood cells and white blood cells	bones found all over the body	

Blood ESG6P

Blood is regarded as a specialised form of **connective** tissue because it originates in the bones and has some fibres. Blood is composed of red blood cells, white blood cells and platelets. These components are suspended in a yellow fluid known as plasma.

Electron micrographs of blood cells	
 Figure 5.21: Scanning electron microscope image of circulating blood showing several red and white blood cells.	 Figure 5.22: Scanning electron microscope image of a white blood cell (right), a platelet (centre) and a red blood cell (left).

Red blood cells: called erythrocytes are made in the red bone marrow. They do not have a nucleus and are biconcave in shape. Their biconcave shape makes them flexible so that they can squeeze through narrow capillaries. It also gives them a bigger surface to volume ratio, so that they absorb and release gases faster. Red blood cells have a short life span of approximately 120 days. Red blood cells contain the protein known as haemoglobin. Haemoglobin contains the pigment known as heme that has an iron (Fe) at its centre that combines with oxygen. Haemoglobin releases oxygen as required and takes up carbon dioxide. Red blood cells transport oxygen from the lungs to the tissues and returns carbon dioxide from the tissues to the lungs.

Figure 5.23: Human red blood cells.

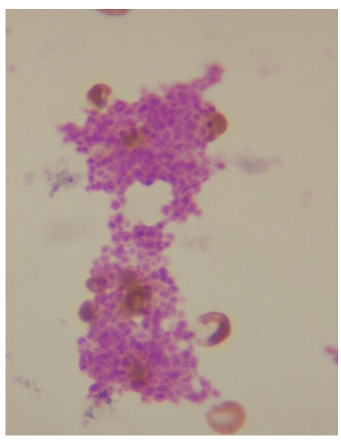


Figure 5.24: Platelets clumping together to form a blood smear. Platelets are largely responsible for wound repair and healing.

White blood cells: Are commonly known as leukocytes and are produced in the yellow bone marrow and lymph nodes. The cells have one or more nuclei. White blood cells are slightly larger than red blood cells and are more irregular in shape. Their main function is to protect the body from diseases. There are several types of white blood cells.

Platelets: Also known as thrombocytes are produced in the bone marrow and are fragments of bone marrow cells. They have no nuclei. Platelets assist in the clotting of blood and prevent excessive bleeding.

Plasma: Plasma is the pale-yellow component of blood that allows the rest of the components of blood to float in suspension. It makes up about 55% of total blood volume. It contains dissolved proteins, hormones, urea and carbon dioxide. Its main functions are to transport nutrients, cells and metabolic waste products and maintain blood volume.

FACT
The number of leukocytes is often a measure of disease. They make up approximately 1% of blood in a healthy adult. A change in the amount of leukocytes can often be used to diagnose disease.

FACT
Plasma donations are important in blood transfusion. During World War 2, the blood plasma transferred to wounded soldiers was important in saving thousands of lives.

Figure 5.25: American wounded soldier receiving blood plasma in August, 1943

5.5 Applications of indigenous knowledge and biotechnology ESG6Q

Traditional medicines ESG6R

In The World Health Organisation definition of traditional medicine, they incorporate a list of plant and animal product-based therapies as well as spiritual practices as part of traditional medicine. Up to 80% of people in African and Asian countries rely on traditional medicines for their basic health care needs. In South Africa, broadly, there are two types of practitioners: herbalists and diviners. Herbalists use plants to prescribe remedies to ailments. Diviners are said to communicate with ancestral spirits in order to diagnose problems and ailments. In Africa, traditional healers rely on up to 4000 plants for remedies. *Pygneum*, a traditional medicine has been used in Africa and elsewhere to treat early forms of cancer for example.

FACT
In 2007, a research team from University of KwaZulu-Natal found that plant extracts from 16 plants used by local healers as 'muti' were highly effective in treating high blood pressure.

Due to the high cost of modern Western health care systems and technologies, there has been a recent focus on researching African traditional remedies and medicines. Traditional African medicine may well have healing properties that have been recognised through generations of use, and passed on in a cultural system. Because of the potential to reach greater masses at lower cost, there has been an attempt to combine traditional African medicine into the continent's health care systems. An example of this a 48-bed hospital that was opened in Kwa-Mhlanga, South Africa, in 2010. The hospital treats patients using a combination of traditional methods and Western healing methods.

Modern biotechnology ESG6S

In this section we will examine some aspects of biotechnology that have been applied in modern medicine. Modern medicine is informed by medical research, and medical research is based on the scientific method. Therefore, these therapies are based on investigations that have results that are reproducible. We will examine five achievements of modern medicine and discuss the underlying ethical issues these new treatments and technologies present:

1. Immunity and vaccines
2. Antibiotics
3. Blood transfusions
4. Cloning
5. Stem cell research

FACT
Watch a humorous video about the history of vaccination.
See video: 2CR6

1. Immunity and vaccines ESG6T

Immunity is the body's resistance to infection by bacteria, viruses and other pathogens. The body defends itself against infection through a variety of means, such as physical, chemical and cellular barriers to infection.

- **Physical barriers** include the skin, saliva, tears and mucus. They also include hairs in the lining of the respiratory tract known as cilia.
- **Chemical barriers** include the various allergic responses that result in inflammation or swelling. These are caused by a chemical response system that results in the body releasing chemicals to attack any foreign objects entering the body. White blood cells known as eosinophils are normally responsible for the allergic response.
- **Cellular mechanisms** exist to fight bacterial infections. These include *neutrophils, macrophages and* which attack pathogens and ″engulf″ and eat them through a process of phagocytosis.

The above defence mechanisms described are part of the **innate** immune system. The body also has an **adaptive** immune system which 'remembers' each pathogen that invades the body based on the specific markers on the pathogen. These markers are known as antigens. When a foreign organism invades, the adaptive immune system launches an antigen-specific response which destroys the infectious agent.

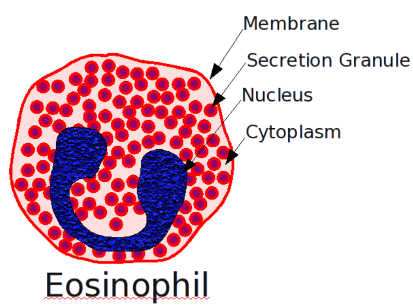


Figure 5.26: Eosinophils are important in controlling the allergic reaction.

FACT
Learn about the discovery of penicillin and antibiotics.
See video: 2CR7

FACT
What are blood types? Watch this video to find out!
See video: 2CR8

Vaccination is the most effective method of eradicating infectious diseases. It has resulted in the eradication of smallpox throughout the world and has greatly reduced diseases such as polio, measles and tetanus. Vaccination involves injecting components of the infectious agent in a non-toxic form in order to stimulate an individual's adaptive immune system. An immune response is produced against the vaccine, resulting in the production of T-lymphocyte memory cells. When a repeat infection occurs, the body is able to mount an effective and rapid immune response due to the presence of memory cells.

2. Antibiotics ESG6V

Antibiotics are another example of a biotechnological advance in medicine. Antibiotics stop or inhibit the growth of certain disease-producing bacteria. These substances were originally found in organisms such as fungi and can now be chemically manufactured. Antibiotics can be administered to patients intravenously as injections, or in the form of tablets, syrups or suspensions.

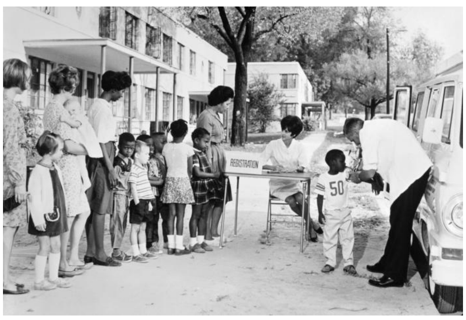


Figure 5.27: A vaccination campaign in the US.

Figure 5.28: Antibiotics.

3. Blood transfusions ESG6W

Blood transfusions often save the lives of people whom have lost large amounts of blood due to trauma caused by accidents and surgery. Before a person receives blood from a blood donor, the blood has to be typed to see if the donor is a match for the recipient. Blood is classified based on the presence of **antigens** in the red blood cells. An antigen is a molecule recognised by the immune system. There are four different types of blood groups. Recipients can only be given blood which is compatible to their own blood.

- Blood Group A has antigen A only
- Blood Group B has antigen B only
- Blood group AB has both antigen A and B
- Blood Group O has neither antigens A or B

The table below shows the different ABO Blood Groups and compatibility for blood transfusions.

Blood group	Blood donor (person giving blood)	Blood recipient (person requiring blood)
A	A and AB	A and O
B	B and AB	B and O
AB	AB only	All groups
O	All groups	O only

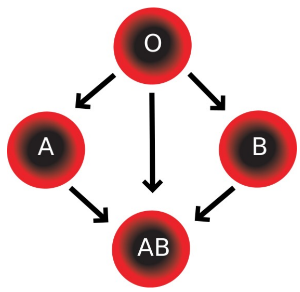


Figure 5.29: Red blood cell compatibility chart. In addition to donating to the same blood group, type O blood donors can give to A, B and AB; blood donors of types A and B can give to AB.

Furthermore, the Rhesus factor of both the recipient and donor need to be determined. The Rhesus factor is another type of antigen found on the surface of red blood cells. Approximately 85% of the population has this protein and are know to be Rhesus positive. The remaining 15% of the population are Rhesus negative because this protein is not present in their red blood cells.

So, blood group A negative means the recipient has antigen A, but does not have the Rhesus factor, a recipient who is O positive means the recipient has neither antigen A or B but does have the Rhesus factor. It is important that a person receiving a blood transfusion receives blood from a donor that is compatible in both blood group and Rhesus factor.

4. Cloning ESG6X

Cloning is the process by which a genetically identical copy of an organism is produced. In nature, cloning occurs when organisms such as plants, insects or bacteria reproduce asexually. The copied material is referred to as a **clone**. There are three main types of cloning:

- Gene cloning: involves cloning of small sections or regions of DNA.
- Reproductive cloning: produces copies of whole animals or cells.
- Therapeutic cloning: produces stem cells for experiments to attempt to replace injured or diseased tissues.

FACT
Learn how Dolly the Sheep was cloned.
See video: 2CR9

Some plants have been producing identical clones of themselves through natural processes for millions of years. Through the production of a 'runner' (stolon) for instance, strawberry crops produce genetically identical offspring. The new plant is referred to as a clone. Similar cloning occurs in grasses, potato crops and onions. Artificial cloning occurs through either **vegetative propagation** or through **tissue propagation**. Propagation is the process by which existing organisms produce more offspring.

Vegetative propagation is an ancient form of cloning plants. It involves taking a leaf cutting from a plant and growing it into a new plant. Vegetative propagation occurs because of the presence of a mass of unspecialised cells known as a **callus**. Callus cells grow, divide and form various specialised cells such as roots and stems, eventually producing a grown plant.

Figure 5.30: Growing new *Plumeria* plants from cuttings.

Tissue culture propagation is a more recent practice which involves taking pieces of specialised roots, isolating the cells and growing them in a nutrient-rich culture. In the culture, the specialised cells become transformed into undifferentiated cells. These are similar to the calluses formed above. The calluses then get treated with chemicals that trigger the growth of new plants that are identical to the original plant from which the root pieces were taken as shown in the diagram below. This method of cultivating new plants is known as **tissue culture**.

Artificial cloning of organisms

The technique used to clone whole animals, such as sheep is referred to as **reproductive cloning**. In reproductive cloning, scientists remove a mature **somatic cell** from the organism that is to be cloned. A somatic cell is any cell in the body that does not serve a reproductive purpose. In these cells, both sets of chromosomes (from the mother and father) are present. An example of a somatic cell is a skin cell. The nucleus is removed from the 'donor' somatic cell and added to a 'recipient' cell.

The recipient cell is usually an egg cell, from which the nucleus has been removed, so that only the cytoplasm remains (a denucleated cell). The clone produced can then be transferred into a **surrogate mother's** womb. A surrogate organism is one which acts as a substitute for another. In this case, the clone is transferred to a surrogate so the embryo can develop.

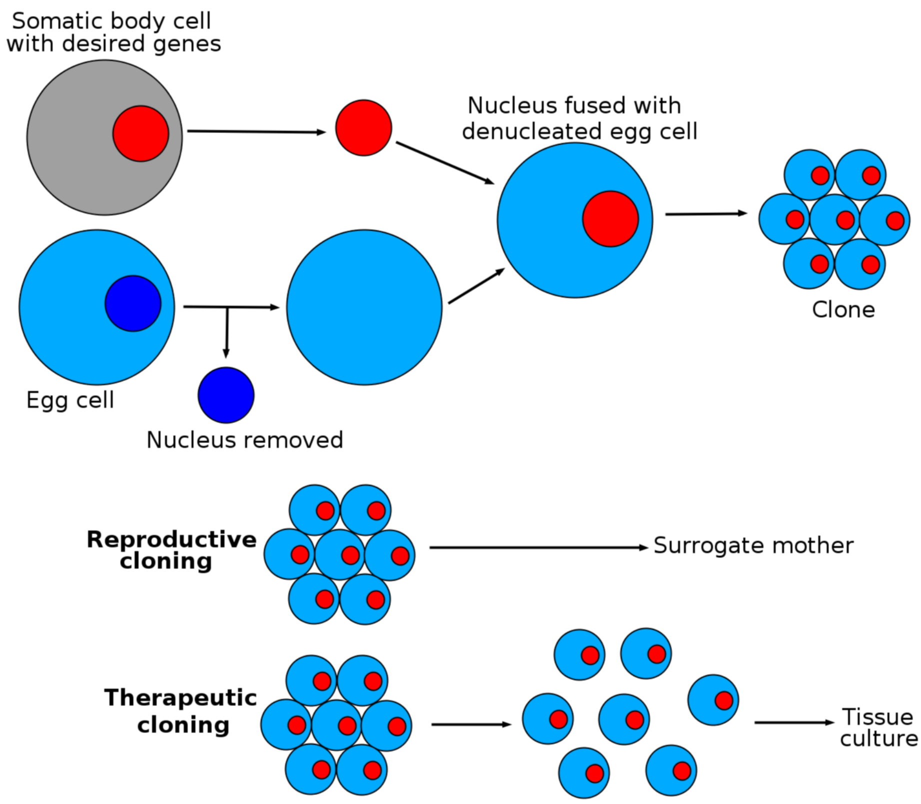


Figure 5.31: The cloning processes for reproductive and therapeutic cloning. Reproductive cloning is used for cloning of whole organisms e.g Dolly the Sheep.

FACT
Are you confused about stem cells? Watch this entertaining video that explains what stem cells are and why they are so exciting.
See video: 2CRB

5. Stem cell research ESG6Y

Stem cells are cells found in all multicellular organisms. Stem cells can differentiate into any type of cell such as a red blood cell, nerve cell, etc. The two types of stem cells are **embryonic stem cells** and **adult stem cells**. Embryonic stem cells can specialise into any cell type, while adult stem cells usually have some restrictions as to what type of cell they can become. Adult stem cells are produced in various tissues including the liver and the bone marrow. Embryonic stem cells are obtained from embryos and can be created *in vitro* (in the laboratory). Multiple embryos are generated through *in vitro* fertilisation methods, in which egg cells are harvested from the mother and fertilised by sperm cells from the father, outside of the body. The embryos that are not implanted into a patient are frozen or stored. Some of them are destroyed. The potential uses for stem cells include:

- **Spinal cord injury:** Repairing damaged nerve tissue after paralysis.
- **Brain damage:** Replacing or regenerating neurons in degenerative conditions like Parkinson's disease or after a stroke.
- **Cancer:** Creating new cells to replace cancerous cells e.g. bone marrow transplants for people with leukaemia.
- **Burn treatment:** New skin cells that match the donor may be grafted onto burn victims.

FACT
Recall that in Chapter 4 you learnt that individuals with cancer can be treated through chemotherapy and radiation. However, these therapies often destroy healthy cells along with cancerous cells. The use of adult stem cells which derive from the bone marrow and liver tissue is important in replacing the healthy cells damaged by chemotherapy.

Figure 5.32 shows how embryonic cells differentiate to form nerve cells.

The use of stem cells and embryonic stem cells in particular, is controversial, with many people opposed to it for moral, religious or philosophical reasons. The objection is largely based on what happens to the unused embryos.

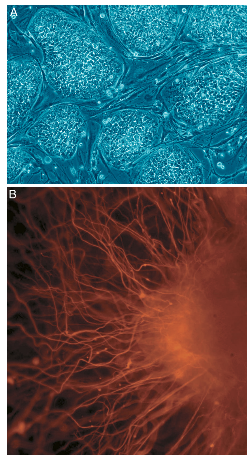


Figure 5.32: A) undifferentiated embryonic stem cells and B) nerve cells forming from embryonic cells.

Ethical issues ESG6Z

The use of science in cloning has created a lot of debate and controversy. Mainly, the debate is whether the methods used for cloning result in cells that have the potential to form full-grown organisms. The key ethical questions that arise are therefore:

- What to do about fused cells (known as embryos) that are not used for either therapeutic or reproductive purposes?
- By selecting certain genes for reproduction using cloning are we not favouring certain types of characteristics over others?
- Much of the cloning is conducted by private companies and this raises concerns that the public might not be able to benefit from the research being conducted.
- In the case of human cloning, if the embryos created are alive, do they have the rights of a normal human being?
- Are there better alternatives to stem cell research?

Legislation around stem cell research ESG72

Due to the issue of stem cell research being so controversial, different countries have very different laws governing how it is to be conducted.

Some European countries such as Finland, Sweden, Belgium, Greece, Britain, Denmark and Netherlands allow stem cell research using human embryos while some such as Germany, Austria, Ireland, Italy and Portugal do not.The United States of America has divided opinions on stem cell research, with some of its States providing funding for stem cell research while others do not. India, Iran, South Korea, China and Australia are supportive of stem cell research. South Africa continues to support stem cell research.

Potential applications of cloned animals ESG73

Reproductive cloning may allow copies of animals to be made for benefits in agriculture and medicine. Sheep such as Dolly have been cloned to overproduce a high quantity of a protein important for blood clotting in humans. It may soon be possible to clone extinct species of animals.

Drawbacks of cloning animals may include the fact that most cloned species are unable to develop into healthy animals. Dolly for example was only one of 277 cloned embryos. There have been significant health effects of cloning including increase in birth size and a variety of defects in vital organs such as the liver, brain and heart.

FACT
In June 2012, the South African plastic surgeon, Dr Ridwan Mia, led a breakthrough surgery, saving the life of a three year old burn victim by transplanting skin cells cloned from the victim's cells. Pippie Kruger, the burn survivor, initially had a 10% chance of survival. However, the doctors obtained some of her skin cells, transported them to a laboratory in the USA, where they were cloned in order to produce millions of extra cells. These cells were transplanted into Pippie, resulting in the complete success of her skin grafting surgery.

Ethical biotechnology ESG74

- In medicine modern biotechnology finds promising applications in such areas as: drug production, pharmacogenomics (how a person's genes affects their response to drugs), and genetic testing (or genetic screening): techniques in molecular biology detect genetic diseases.
- To test the developing foetus for Down syndrome, amniocentesis and chorionic villus sampling can be used.

5.6 The leaf as an organ ESG75

You have learnt about individual tissues found in plants and animals. We will now look at how tissues join together to form organs. An organ is a collection of tissues joined together as a structural unit in order to perform a common function. In later chapters we will look at the various organs found in animals. In this section, we will discuss how a plant leaf is an example of an organ. We will present its structure with respect to its functions in photosynthesis, gaseous exchange and transport.

Leaves are typically found in vascular plants, which have lignified tissues (xylem) that enable them to conduct water. Leaves are usually flat and thin to allow for maximum gaseous exchange and capture of light. The organisation of the leaf has evolved to allow maximum exposure of chloroplasts to light, and to absorb carbon dioxide. Leaves have stomata, pores found in the leaf epidermis, which allow the plant to regulate the exchange of carbon dioxide, oxygen and water vapour with the atmosphere. The shape and structure of leaves varies considerably from one plant to another. This depends on the climate, available light intensity, presence of grazing animals, nutrients and competition from other plants. Leaves are either **dorsiventral** or **isobilateral**. Dorsiventral leaves have both surfaces differing from each other in appearance and structure. Isobilateral leaves have both surfaces looking the same. Leaves can also store food and water and are modified to perform these functions.

Leaf structure ESG76

The leaf is a collection of tissues which include:

1. The **epidermis** which covers the upper and lower surfaces.
2. The **mesophyll** inside the leaf which is rich in chloroplasts.
3. The veins contain the **vascular tissue** (where xylem and phloem are present).

1. Epidermis

Epidermal cells form the outer layer covering a leaf, separating internal tissues from the external environment.

Epidermis tissue has several functions:

- protection against water loss via stomata and a waxy cuticle
- regulation of gaseous exchange
- secretion of metabolic compounds

2. Mesophyll cells

The mesophyll is located between the upper and lower layers of the leaf epidermis, and is mostly made up of **parenchyma** (ground tissue) or **chlorenchyma** tissue. The mesophyll is the primary location for photosynthesis and is divided into two layers, the upper palisade layer and the spongy mesophyll layer.

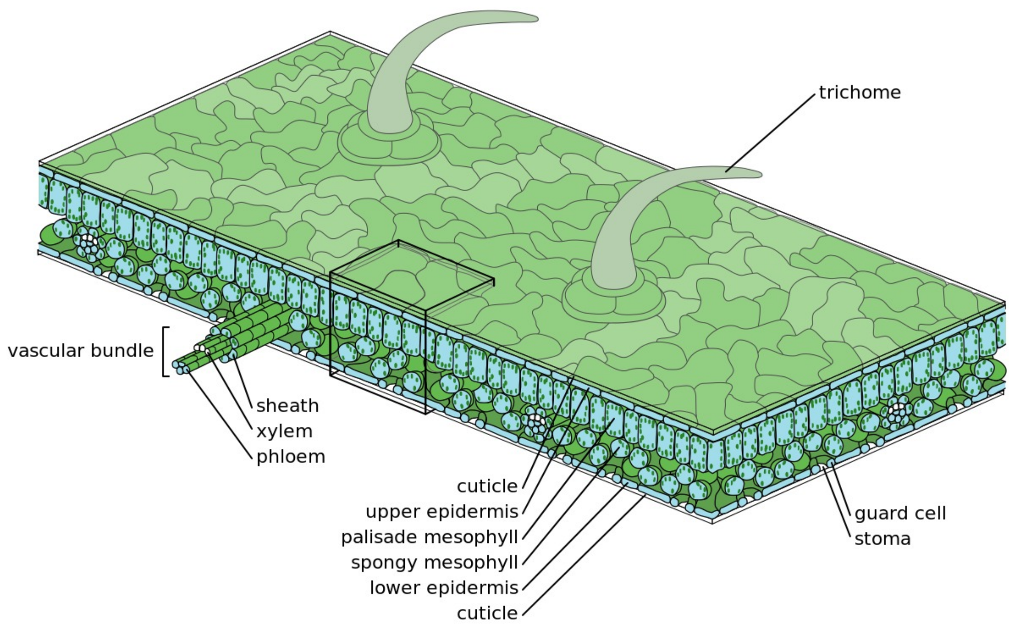
The **upper palisade layer** lies beneath the upper epidermis and consists of vertically elongated cells that are tightly packed together to maximise the number of cells exposed to sunlight. In addition, these cells contain many chloroplasts, thus maximising their photosynthetic ability. The palisade layer thickness depends on the extent of exposure to the sun. Leaves that are exposed to the sun have a thicker palisade layer. Those that are typically found in the shade have a thinner palisade layer.

Beneath the upper palisade layer is the **spongy mesophyll**. The cells in the spongy mesophyll are slightly rounder and less densely packed and have air spaces to allow for gaseous exchange.

3. Vascular Tissue

Vascular tissue is made up of the xylem and phloem vessels you learnt about earlier in this chapter. Xylem transports water and minerals to the leaf. Phloem transports dissolved sucrose made in the leaf out of its site of synthesis to the rest of the leaf. Most leaves have a bundle sheath around the xylem and phloem, consisting of sclerenchyma or collenchyma, for extra support.

The figures below show the leaf and tissue structure of a dicot plant.



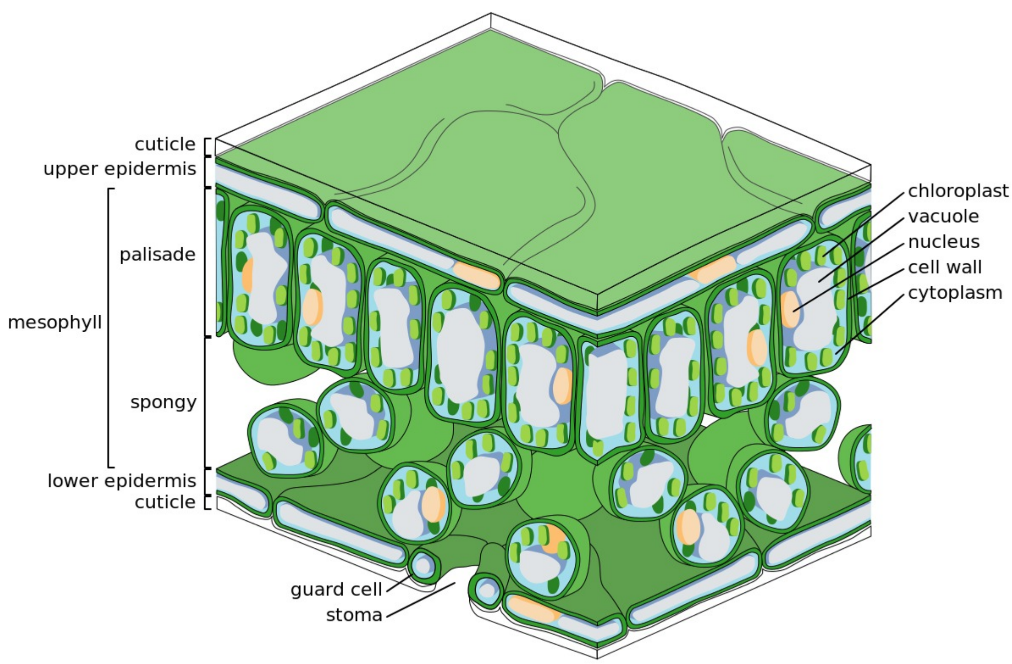


Figure 5.33: Leaf structure.

FACT
You will learn more about the transport processes in plants in: **Support and transport systems in plants**.

Transport of substances into and out of the leaf ESG77

The leaf is designed to transport water, sugars, carbon dioxide and oxygen across its surface. Each of these involves separate processes and cells which we will discuss below.

Movement of oxygen and carbon dioxide

Stomata are the site of gaseous exchange in the leaf. There are two major metabolic processes that take place in plants that involve the exchange of oxygen and carbon dioxide:

- **Photosynthesis:** takes place during the day when the chloroplasts can absorb radiant energy from the sun. Photosynthesis requires carbon dioxide and releases oxygen as a by-product. Therefore, during daylight hours, the concentration of carbon dioxide is low in the leaf and the concentration of oxygen is high. As a result, during the day, carbon dioxide enters the leaf and oxygen is released.
- **Cellular Respiration:** occurs continuously throughout the day and night. Cellular respiration requires oxygen and releases carbon dioxide as a waste product. During the day, the plant can use some of the oxygen from photosynthesis for cellular respiration. During the night, when photosynthesis stops, the concentration of oxygen in the plant drops and the concentration gradient switches: the concentration of carbon dioxide is high and the concentration of oxygen is low. Therefore at night time, oxygen enters the leaves, and carbon dioxide is released.

Movement of water into leaf

Water is constantly being lost by the leaf through transpiration. This results in the cells in the mesophyll having a lower water concentration than the vascular bundles. Water thus moves down a concentration gradient from the xylem vessel into the living cells of the mesophyll layer and to the surface of the mesophyll cell walls. This causes water to move up from the stem by means of transpirational pull. The movement of water is maintained because water molecules constantly evaporate into leaf inter-cellular air space out of the stomatal pore and into the atmosphere.

Movement of sugars

Chloroplasts found in the palisade layer capture radiant energy from the sun to make glucose via photosynthesis. This glucose is used to make the simple sugar sucrose. Sucrose is transported to the rest of the plant through the phloem vessels present in the vascular tissue in the leaf. Plants convert sugars to starch for long-term storage.

Opening and closing of stomata

The opening and closing of the stomata is important for gaseous exchange, transpiration and the movement of sugars. Stomata open when it is bright and when there is high humidity. When water concentration in the soil is low, indicating that the plant is dry, chemical changes in the plant result in the closing of the stomata.

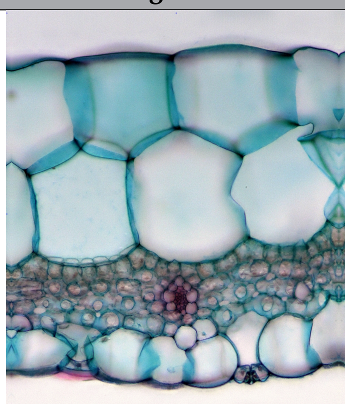
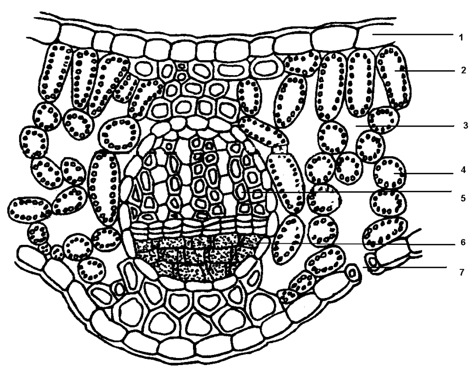
Activity: Examining leaf structure under a microscope

Aim:

To identify different tissues found in plant leaf.

Questions:

Study the image shown and answer the questions given below.

Figure A	Figure B
	

1. Compare Figures A and B. Which of the numbered structures shown in B can you identify from Figure A?
2. Which of the numbered structures shown in B are absent in A?
3. The image given in Figure A is of a Spiderworts leaf. They grow in a part of Canada where the sun shines in the morning and it is cloudy in the afternoon. Describe what changes you would expect to see to the structures in the plant leaf during the day. How would these changes compare to a plant that grows during hot, sunny days and cold, dry nights?

5.7 Summary ESG78

- Cells which are similar in structure group together to form tissues performing a particular function. Tissues form organs which combine to allow organisms to exist.
- Plant and animal cells have structures related to their functions.
- Plant tissues are broadly divided into Dividing or Meristematic and Permanent tissues.
- Meristematic cells are small, have high amounts of cytoplasm and a large nucleus to assist in their role in cell division.
- Permanent tissues are further divided into simple permanent (which have only one type of cell) and complex permanent (which have different types of cell coming together to perform a particular function). The simple permanent tissues include (with their function in brackets): Epidermis (protection), Parenchyma (storage), Collenchyma (support) and Sclerenchyma tissues (strength and structural support). Complex tissues are made up of the xylem and phloem.
- Xylem tissue is important in the transport of water and mineral salts. Phloem tissue is structured to allow the transport of organic compounds required for the plant (typically in the form of sucrose). Together the parenchyma, collenchyma and sclerenchyma are referred to as ground tissue. The xylem and phloem make up the vascular tissue.
- Animal tissues are made up of epithelial, connective, muscle and nerve tissue.
- Epithelium is made up of flat squamous cells, cuboidal cells or columnar cells in single or multiple layers. Epithelial cells are involves in secretion of enzymes, protective substances such as mucus and they provide a supportive function.
- Muscle tissue is made up of cardiac muscle, skeletal muscle and smooth muscle. Cardiac and skeletal muscle are striated. Smooth muscle and cardiac muscle are involuntary muscles whereas skeletal muscle is under voluntary control.
- Connective tissues are composed of areolar and fibrous connective tissues, cartilage, bone and blood. They provide strength and support, reduce friction and act as shock absorbers.
- Blood is made up of red blood cells (transport oxygen), white blood cells (responsible for immune response) and platelets (important in blood clotting).
- Nerve tissue is responsible for receiving stimuli from the environment (sensory neurons), processing it (interneurons) and sending impulses to muscles or glands (motor neurons) so that we can respond to the stimuli.
- Traditional healers and traditional medicine is an application of indigenous knowledge of plant and animal tissues.
- Modern Biotechnology is focused on a variety of applications of technology.

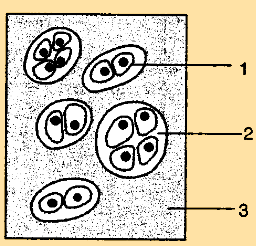
- Vaccines and antibiotics enhance the body's immunity. Vaccines rely on T-memory-cell derived immunity to fight subsequent infections.
- Immunity relies on the natural mechanisms (skin, mucus etc) as well as cellular mechanisms (T-cells and B-cells) fighting viral and bacterial infections.
- Blood transfusion is a way of replacing lost blood. It requires accurate blood type matching.
- Cloning of plant tissues requires either a piece of the plant tissue through vegetative propagation or chemical treatment to produce calluses in tissue culture propagation.
- Cloning of animal tissues occurs through the process of reproductive cloning. It can result in the replacement of a whole organism or, through therapeutic cloning the creation of stem cells.
- There are broad legal and ethical questions regarding cloning of organisms as well as the use of stem cells. These differ from country to country.

The leaf as an organ

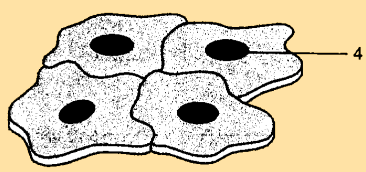
- Plant leaf is an example of an organ, as it consists of a group of tissues that form part of a structural unit performing a common function.
- Plant leaves are adapted to absorb light in order for photosynthesis to occur as well as to manufacture sugars for transport to the rest of the plant.
- The major processes for which leaves are therefore adapted are photosynthesis, transpiration and gaseous exchange. Leaves transport oxygen, carbon dioxide, water and sucrose.
- Water is lost from the plant through transpiration out of stomata in the leaf. The movement of carbon dioxide and oxygen is through diffusion in and out of the leaf stomata.
- Sugar manufactured in the leaf is transported through the phloem vessel.
- Stomata open and close in response to a variety of environmental stimuli.

Exercise 5 – 1: End of chapter exercises

1. Answer the following questions based on the drawings below.



A



B

a) Provide labels for 1, 2, 3 and 4.
b) Which tissue, A or B, is found in the rib cage?
c) Which tissue, A or B, is found in the lining of blood vessels?

2. Tissues come together to form a/an
   a) organ
   b) organ system
   c) body system
   d) organelle
3. What kind of tissue can parenchyma tissue be described as being?
   a) simple tissue
   b) complex tissue
   c) xylem
   d) phloem
4. Which of the following is not a simple tissue?
   a) xylem
   b) parenchyma
   c) collenchyma
   d) sclerenchyma
5. What is the key difference between meristematic and permanent tissue?
   a) the ability to conduct photosynthesis
   b) the ability to divide
   c) the ability to move
   d) the complexity to perform a function
6. Which type of tissue has lignified walls?
   a) parenchyma
   b) collenchyma
   c) sclerenchyma
   d) cambium
7. Explain the statement 'Tissues exhibit division of labour'. Give examples.
8. Why do plants have more dead tissues compared to animals?
9. List the characteristics of meristematic tissues.
10. Which tissues are responsible for secondary growth in plants?
11. What are the key features which allow you to tell that a tissue type is collenchyma?
12. Thando was shown two slides of plant tissues: parenchyma and sclerenchyma. Which of the features given below would be crucial in identifying sclerenchyma and why?

a) location of nucleus
b) size of cells
c) thickness of cell walls
d) position of vacuoles

13. Why do meristematic cells lack vacuoles?
14. Considering the plant leaf as an organ, describe the main tissues that come together to form the organ. What is the role of each tissue type? Why are they all important in the functioning of the organ?

Check answers online with the exercise code below or click on 'show me the answer'.

1a. 2CRC 1b. 2CRD 1c. 2CRF 2. 2CRG 3. 2CRH 4. 2CRJ
5. 2CRK 6. 2CRM 7. 2CRN 8. 2CRP 9. 2CRQ 10. 2CRR
11. 2CRS 12. 2CRT 13. 2CRV 14. 2CRW

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CHAPTER 6

Support and transport systems in plants

6.1 Overview ESG79

Introduction ESG7B

In the previous chapter, the structure of plant and animal tissue was introduced. This chapter focuses on the plant tissues that transport food and water around the plant. As you have previously learnt, plant leaves use sunlight, carbon dioxide and water to make food (sugars) during photosynthesis. In this chapter we will examine how the phloem and xylem tissue transport food and water within the plant. Which cells are responsible for moving food throughout the plant? How are the tissues adapted for their functions in transporting either water or food? What do these cells look like under the microscope?

Throughout this chapter we will emphasise the relationship between structure and function. We will study how different types of leaves are structurally adapted to minimise water loss. We will also learn how stomata are able to respond to environmental conditions in order to regulate the rate of water loss from the leaf during transpiration.

Key concepts

- The plant is made up of the root and stem where tissues with dividing (meristematic) cells are contained.
- Secondary growth of trees is measurable by observing the annual rings within tree trunks and can be used to infer climate change.
- Transpiration, the loss of water vapour from plant leaves, is influenced by factors such as temperature, light intensity, wind and humidity.
- Wilting is a processes that results from loss of water through transpiration and guttation is a process that results from high root pressure.
- Water and minerals are taken up into the xylem tissue present in roots and transported to leaves in the plant.
- Manufactured food (sugar) is translocated, via phloem tissue, from sites of manufacture (in the leaves) to other parts of the plant where sugars are used or stored.

---

atom →molecule→cell→**tissue**→**organ**→**system**→organism→ecosystem

6.2 Anatomy of dicotyledonous plants ESG7C

Differences between Monocotyledons and Dicotyledons ESG7D

All plants are classified as **producing seeds** or **not producing seeds**. Those that produce seeds are divided into flowering (angiosperms) and non-flowering (gymnosperms). Flowering plants are further divided into **monocotyledonous** and **dicotyledonous** (monocot and dicot) plants.

Figure 6.1: Flowering plants such as the acacia tree.

Figure 6.2: Gymnosperms are non-flowering plants such as pine trees or "black spruce" shown above.

In angiosperms, the **cotyledon** is part of the seed of the plant. The number of cotyledons (mono- or di-) is used to classify flowering plants. Monocotyledonous plants have one cotyledon, dicotyledonous plants have two. Plants belonging to each group have a number of features in common, such as the leaf and root structure, the strength of the stem, the flower structure and flower parts. Some differences between monocots and dicots are summarised in Figure 6.3.

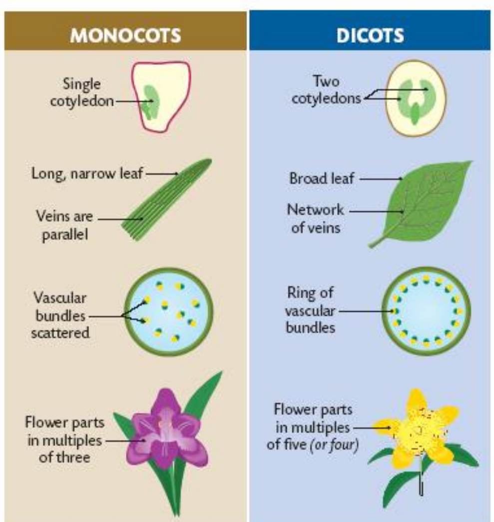


Figure 6.3: A comparison between monocots and dicots.

In addition to the differences listed above, monocots and dicots have important differences in their roots. Monocots have a network of fibrous roots and dicots have tap roots.

In the previous chapter you learnt about the key plant tissues involved in support and transport functions, namely the xylem, phloem, collenchyma and sclerenchyma. Recall that these tissues are involved in both transport and supporting roles in plants. In different parts of the plant, tissues are arranged differently. In this section, we will study the overall structure (or anatomy) of dicotyledonous plants.

Root anatomy ESG7F

Root systems are responsible for the following functions:

- **absorption** of water and organic compounds.
- **anchoring** of the plant body to the ground.
- **storage** of food and nutrients.

When a seed germinates, the first structure to appear is the root or the **radicle**. This becomes the **primary root**. Other roots that branch out of the primary root are called **secondary roots** (Figure 6.4). The growing root tip is protected by the **root cap** as it moves through the coarse soil. The root cap is slimy in nature to facilitate easy movement. Above the root cap is the **apical meristem**. In this meristematic region, cells divide continuously by mitosis to produce new cells. In addition to mitosis, newly divided cells undergo elongation in the same direction of root lengthening.

Figure 6.4: Primary and secondary root system of a cotton plant.

Above the region of cell elongation, thousands of tiny **root hairs** are found in the root hair region. The function of the root hairs is to absorb water and dissolved mineral salts from the soil. As the root grows, it thickens and may produce **lateral roots** in the mature region as shown in Figure 6.5.

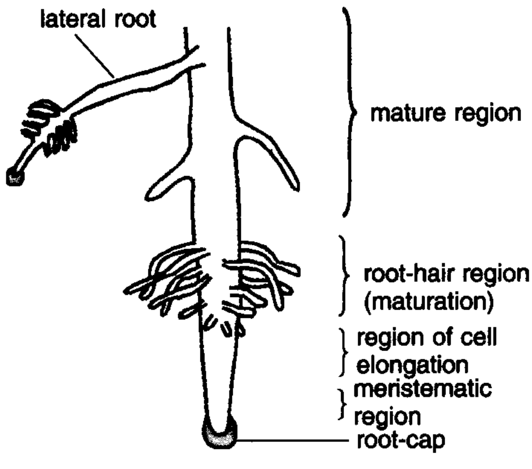


Figure 6.5: The dicotyledonous root.

There are two major types of root system:

1. **Taproot system**: root system comprising one primary root and many secondary roots branching off the primary root. Examples of taproots include carrot and beetroots where the roots serve a storage function. Taproots are found in dicotyledonous plants.
2. **Fibrous root system**: system with no dominant primary root but many secondary roots of similar size. Fibrous (adventitious) root systems are common in monocotyledons. Examples include coconuts and grasses.

Tissue distribution in the root

The different tissues in the root have a distribution which is common to all dicotyledonous plants and is shown in Figure 6.6.

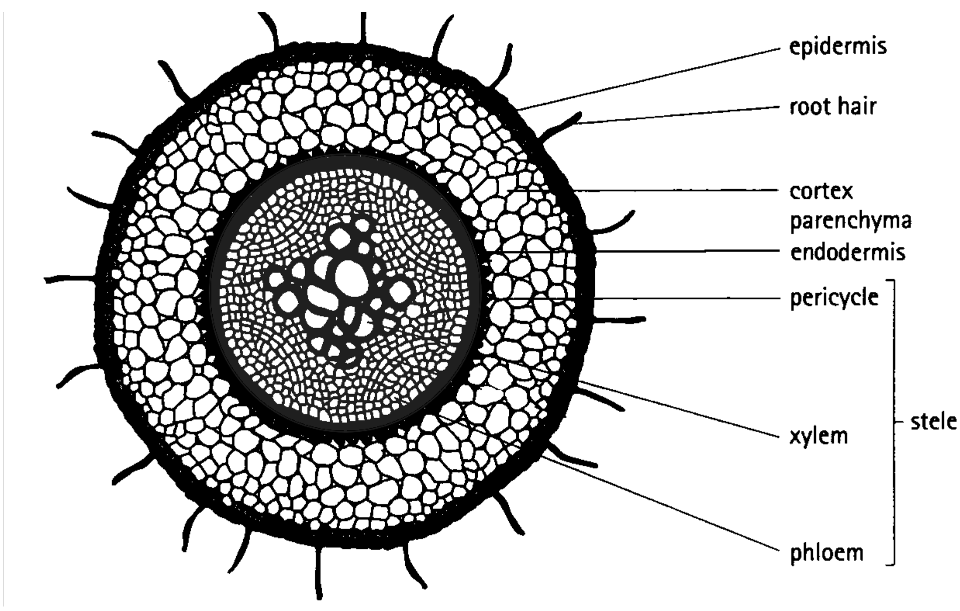


Figure 6.6: Dicotyledonous root profile showing the major tissues found in the root system which also aid in transport.

The epidermis is a single layer of cells on the outside that protects the inner tissues. The epidermal layer of the root has no waterproof cuticle as this would prevent the absorption of water. Structurally, the cells of the root hair (shown in Figure 6.7) have large central vacuoles and cover a large surface area which allows water to enter these cells readily via osmosis.

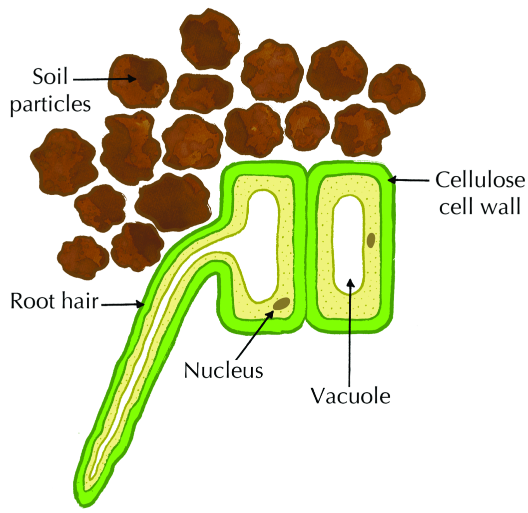


Figure 6.7: Diagram of a root hair cell.

The cortex consists of *parenchyma* cells. These large, thin-walled cells have leucoplasts to store starch and large vacuoles to store water and dissolved sugars. Intercellular spaces between parenchyma cells facilitate the movement of water from the root hair cells on the outside of the plant to the xylem on the inside of the plant.

The endodermis forms the innermost layer of the cortex. It is a layer of tightly-packed, modified parenchyma cells. The radial and transverse cell walls are thickened with a water-impermeable, waxy suberin layer, known as the **Casparian strip**. This layer helps to regulate the flow of water from the cortex into the stele, rather than allowing the water to spread to all the root cells. To aid in directing water, there are also thin-walled passage cells in the endodermis, directly opposite the xylem, allowing water to move into the xylem rapidly.

The stele, or **vascular cylinder** (responsible for transporting water and minerals), consists of the pericycle, phloem, cambium and xylem. The **pericycle** is the outermost layer of the stele, and consists of one or more rows of thin-walled meristematic parenchyma cells. It is in close contact with the xylem and phloem tissues of the root. It functions in the formation of lateral roots.

The phloem tissue is responsible for transporting food from the leaves of the plant to the cells of the root. The **cambium** separates the xylem and phloem tissues from each other. This is the area where secondary growth of xylem and phloem tissues occur. **Xylem** tissue is responsible for transporting water and dissolved mineral salts to the xylem tissue of the stem and leaves.

These cells are strengthened with lignin for support. The pits in the cell walls allow for the lateral movement of water. Figure 6.8 shows stained root tissues visualised by confocal microscopy. It shows the internal structure of root cells, including the epidermis, cortex, endodermis and pericycle.

FACT
Confocal microscopy is an advanced kind of microscopy which allows us to stain various cell types or structures with different colours, and visualise them in 3D, using special lasers and computer software.

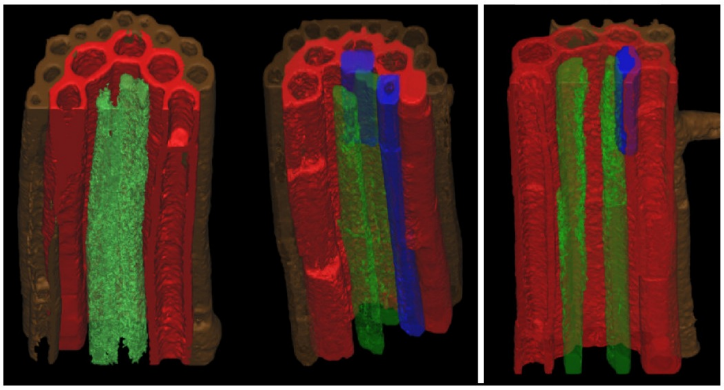


Figure 6.8: Stained root tissues as visualised by confocal microscopy. Colour key: brown, epidermis; red, cortex; blue, endodermis; green, pericycle.

Stem anatomy ESG7G

Stems usually grow above the soil surface and towards the light from the sun. Depending on the hardness of the stem, we can distinguish between **herbaceous** stems, which are leafy non-woody structures, and **woody** stems. Woody stems are harder than herbaceous stems.

Stems have four main functions.

- **Support for the plant** as it holds leaves, flowers and fruits upright above the ground. Stems keep the leaves in the light and provide an attachment for flowers and fruits.
- **Transport** of water, mineral salts and sugars between roots and shoots in the xylem and phloem.
- **Storage** of nutrients.
- **Production of new living tissue**: stems contain meristematic tissue which generates new tissue.

The main stem develops from the **plumule of the embryo** and the lateral branches develop from the buds. Nodes and internodes are regions found on the stem. Nodes are the regions from which leaves and lateral branches develop, and the regions between nodes are known as internodes (shown in Figure 6.9). **Stomata**, or pores, can be found in stems of younger plants. We will subsequently discuss the tissues present in the dicot stem. The trunk of a tree (shown in Figure 6.10) is the stem.

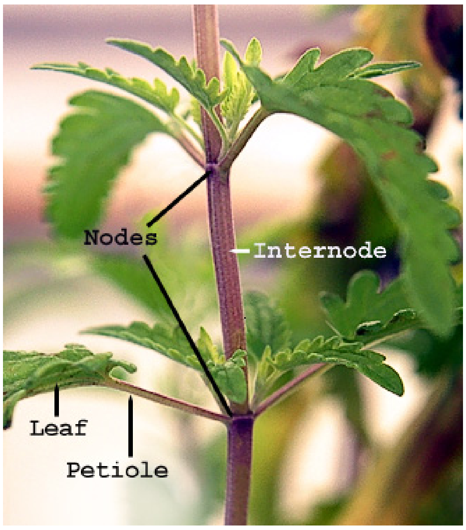


Figure 6.9: Stem showing internode and nodes plus leaf petioles.

Figure 6.10: Photo of a redwood. The trunk of the tree is its stem.

The internal structure of the dicotyledonous stem

Figure 6.11 shows a schematic arrangement of tissues in a dicotyledonous stem. Details of each tissue type are described in this section.

Epidermis: A single layer of cells that covers the stem, and is in turn covered by a waxy cuticle. The waterproof cuticle helps prevent water loss and thus prevents the inner tissues drying out. Since the function of the epidermis is to protect underlying tissues, epidermal cells are tightly packed and have thickened walls. The epidermis may contain hair-like outgrowths known as trichomes, and stomata with guard cells. Stomata present in the epidermis allow for transpiration and gaseous exchange for respiration and photosynthesis.

Cortex: A region which comprises of **collenchyma** and **parenchyma**.

- **Collenchyma**: A few layers of living cells that lie under the epidermis. These cells are not lignified but do have unevenly thickened cell walls. Collenchyma cells are thickened in the corners, but thin-walled elsewhere. The thickened corners strengthen the stem and provide support, while the thin-walled sections allow for flexibility in the wind. Collenchyma cells contain chloroplasts which produce food for the plant during photosynthesis.
- **Parenchyma**: Found beneath the collenchyma cells and makes up the bulk of the cortex. The cells are thin-walled, and there are intercellular spaces which are important in gaseous exchange. Parenchyma stores synthesised organic food (mostly starch) produced elsewhere in the plant.

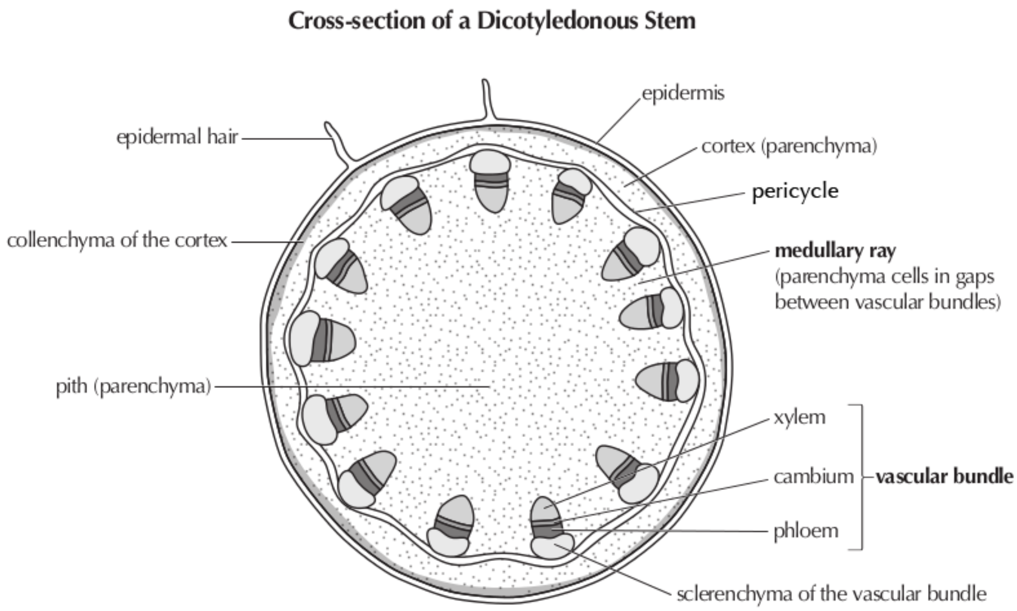


Figure 6.11: Cross-section of a dicotyledonous stem showing tissue distribution.

Vascular cylinder or **stele**: Comprised of the **pericycle**, **vascular bundles** and **pith**

- **Pericycle**: Commonly found in roots and, in lower vascular plants, also in stems. In higher vascular plants, however, a distinct layer of cells may not be present. The pericycle, if present, may be composed of either thin walled parenchyma cells or sclerenchyma cells with relatively thin or heavily thickened walls. In plants undergoing secondary growth, the pericycle contributes to the vascular cambium often diverging into a cork cambium.
- **Vascular bundles**: Characteristically organised in a ring inside the pericycle of the dicot plant. Mature vascular bundles are made up of water-conducting xylem, cambium, and food-conducting phloem. The phloem is located on the outside of the bundle and the xylem towards the centre (see Figure 6.11). The phloem and xylem is separated by meristematic tissue known as cambium, which is responsible for **secondary thickening**. Xylem has lignified cell walls which helps it fulfil its two important roles, namely; strengthening and supporting the stem, and transporting water and minerals from the root system to the leaves. The function of phloem is to transport synthesised food from the leaves to other parts of the plant.
- **Pith (or medulla)**: Occupies the large, central part of the stem. The pith is made up of thin-walled parenchyma cells containing intercellular spaces. Where the parenchyma extends between vascular bundles as thin bands it is known as medullary rays, and can be continuous with the pith and cortex of the parenchyma. The cells of the pith store water and starch, while the intercellular spaces allow for gaseous exchange. The medullary rays facilitate transport of substances from xylem and phloem to the inner and outer parts of the stem.

Investigation: Examining the structure of the root and stem

Aim:

To examine the structure of the root and stem.

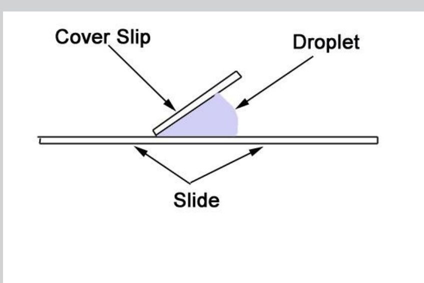
Apparatus:

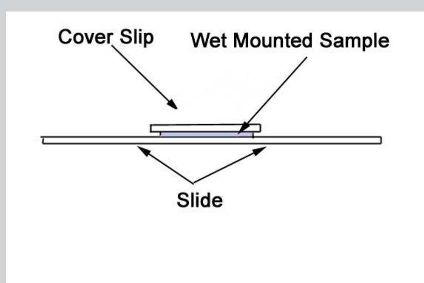
- light microscope
- scalpel or knife
- celery stalk (stem)
- carrot (root)
- glass slide
- iodine solution (stain) or water
- cover slip
- dissecting needle or tweezers
- paper and pencil
- blotting paper or paper towel or tissue
- for variation you can also try using other vegetables

Method:

Prepare a temporary mount using the irrigation method:

1. Cut a very thin slice (cross section) from the middle of the celery stem and the carrot root. Although you will not be able to see microscopic details of the carrot tissue under a microscope, the differentiation by colour will be evident.
2. Place this section on a glass slide, in the centre.
3. Add a drop of iodine solution on top of the sample to stain it. This makes it more visible under the microscope. Water can be used if iodine is not available.
4. Place the coverslip next to the droplet, as shown in the diagram, then lower it slowly onto the glass slide. This will prevent bubbles forming under the coverslip. You can use a dissecting needle to lower the the coverslip into position. The drop will spread outward and suspend the sample between the slide and the coverslip.





5. **Call your teacher.**
6. Switch on the microscope making sure the lowest objective is in position (the 4 X objective).
7. Place your slide on the stage.
8. Focus the image under the 4 X objective (lowest objective) and view the structure of the celery stem. Switch to the 10 X objective to look a little more closely. To see details of the structure of plant tissue, use the 40 X objective. Carefully observe all of the parts and different tissues.
9. Once you are able to see specific tissue types, call your teacher.
10. Make a biological drawing of your specimen as viewed under the microscope. Take note of the magnification and draw a scale bar. Label your diagram according to the tissues you have learnt about.

Secondary growth ESG7H

Plants, like other living organisms need to grow, and they do this by mitosis. Cell growth is limited to the specialised cells that make up meristematic tissue. Meristematic tissue consists of small cells that are unspecialised. These cells divide by mitosis to form new cells that can **differentiate** i.e. undergo changes in their structure. When groups of cells differentiate they form specialised tissue (e.g. xylem, phloem, epidermal cells). There are different types of meristematic tissue:

- **Primary meristematic tissue** is found in the tips of roots, stems and buds. When the cells divide, new cells are produced which causes the plant to grow in length. This is referred to as **primary growth.**
- **Secondary meristematic tissue** originates from permanent tissue, usually parenchyma tissue which divides by mitosis. **Cambium** is secondary meristematic tissue that is found in roots and stems. When these cells divide by mitosis it results in the plant becoming **wider.** This is called **secondary growth**.

Secondary growth is seen clearly if you examine the stump of a tree. During every growing season the stem of a plant increases in width. This is known as secondary thickening. Towards the end of the first year of growth, the parenchyma cells between the vascular bundles become meristematic. This means that they actively start dividing by mitosis, and link up with the cambium that occurs in the vascular bundles to form a cambium ring in the stem (see Figure 6.12). The cells in the cambium ring start dividing to form secondary phloem (on the outside of the cambium ring) and secondary xylem (on the inside of the cambium ring). Each year another ring of secondary phloem and secondary xylem is formed, making the stem grow wider.

FACT
The vascular cambium and cork cambium are different and should not be confused!

FACT
Watch this video to learn about the oldest trees on Earth!
See video: 2CRX

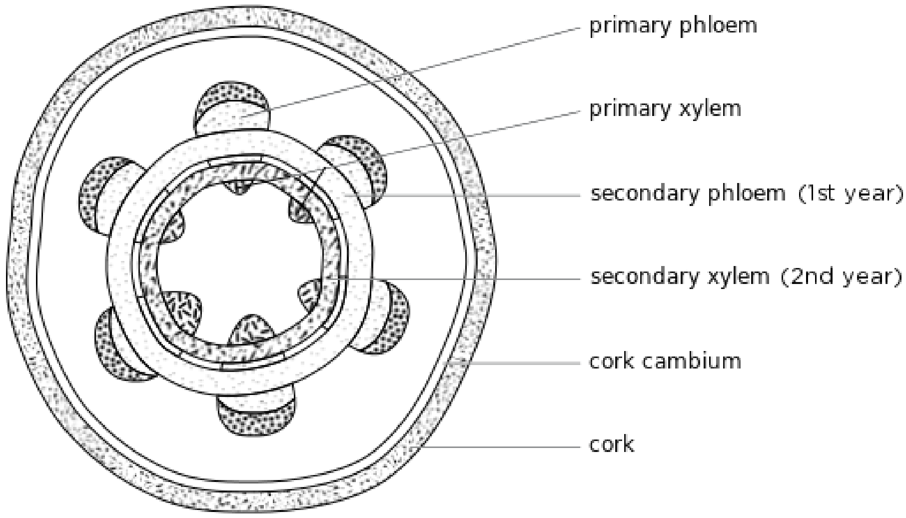


Figure 6.12: Process of secondary thickening in stems.

It is not possible to see the layers of secondary phloem but the secondary xylem layers are visible. These form rings called **annual rings** which can be used to work out the age of a plant.

As new rings are formed each year, the older rings are pushed inward and the xylem vessels collapse due to the pressure. The wood in the centre becomes denser and harder than the wood at the surface and is called **heartwood**. The youngest annual rings found on the outside transport water. This wood is not as dense and is called **sapwood**. The light-coloured rings are called spring wood. They are formed during spring and summer when the growing conditions are favourable. These rings are therefore relatively broad and light in colour as the xylem cell walls are thin. The dark-coloured rings are called autumn wood. They are formed during autumn and winter when the growing conditions are unfavourable. The rings are therefore relatively narrow and dark in colour as the xylem cell walls are thick. Rings may be thicker in some years than in others, depending on the amount of rain and nutrients received.

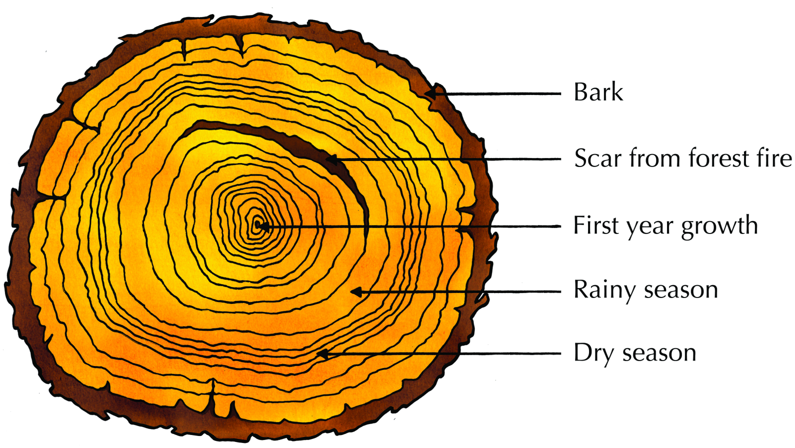


Figure 6.13: The annual rings in a tree trunk give a measure of the tree's age as well as the environmental conditions of the tree's growth.

There is another type of cambium in plants called **cork cambium**. Cork cambium forms when an outer layer of parenchyma in the cortex becomes meristematic and produces cortex cells to the inside and cork cells to the outside. This forms the dry outer cells of the bark on a stem.

FACT
Turgidity, or turgor pressure, refers to the water content of cells and how this lends structural support to the plant. When cells absorb water, the vacuoles fill up and the cytoplasm increases, pushing against the cell membranes, which in turn push against the rigid cell walls. This makes the cells rigid, or turgid.

Investigation: Observing annual tree rings to assess age and climatic conditions

Aim:

Background

Every year a tree forms a new layer of xylem around the trunk. This forms tree rings, which are visible as circles in a cross section of a tree that has been cut down. Each tree ring, or wood layer, consists of two colours of wood; light wood that grows in spring and summer and dark wood that grows in autumn and winter. Tree rings can be counted to give you a rough estimate of the age of a tree. Occasionally a tree will form many rings in one year or miss forming rings in a year. The width of the tree rings is greater in years where good growing conditions occur. In years with droughts or low temperatures, the trees will produce narrower rings. Therefore, by looking at the tree rings you can get an idea of the weather affecting a tree in a particular year. Scientists can use this information to help determine the weather patterns of the past as well as events such as forest fires, earthquakes, and volcanic eruptions. The study of past events using the growth rings of trees is known as dendrochronology (dendros = tree, chronos = time).

Method:

1. Examine a section of a tree trunk/stem provided by your teacher and count the tree rings, starting with the innermost ring. Measure the width of each ring using a ruler, or make a note of whether a ring is narrow or wide. Make a note of any scars caused by events such as fires or pests.
2. Draw a bar graph showing the width of your tree rings for every year of the tree's life.
3. How old is this tree? What can you say about the climatic conditions throughout the life of this tree?

6.3 Transpiration ESG7J

Transpiration is a process that involves loss of water vapour through the stomata of plants. Transpiration is thought to be a 'necessary cost or evil' to allow the plant to absorb water from the soil. It is an inevitable process.

FACT
Capillary action occurs when the adhesion of water molecules to the walls of the vessel is stronger than the cohesive forces between the water molecules. Have you ever seen fluid in a drinking straw move higher than the level of the fluid in the glass? This happens due to capillary action. The narrower the straw, the greater the capillary action, and therefore, the higher the fluid will rise in the straw.

FACT
Cohesion refers to the intermolecular, attractive forces that hold molecules in solids and liquids together. Imagine a drop of water on a waxy surface like wax paper. Even if the drop slides and rolls around, the water molecules will stay together due to the cohesive forces. **Adhesion** is the ability of a substance to stick to an unlike substance. If you were to take the same piece of wax paper and turn it upside down, some water droplets would still adhere to the paper. This indicates that there must be an attraction between

Transpiration is important in plants for three major reasons:

1. **Cooling of the plant**: the loss of water vapour from the plant cools down the plant when the weather is very hot.
2. **The transpirational pull**: when the plant loses water through transpiration from the leaves, water and mineral salts from the stem and roots moves, or is 'pulled', upwards into the leaves. Water and is therefore taken up from the soil by osmosis and finally exits the plants through the stomata.
3. **Plant structure**: young plants or plants without woody stems require water for structural support. Transpiration helps maintain the turgidity in plants.

Transpirational pull: results from the evaporation of water from the surfaces of the mesophyll layer in the leaf to the atmosphere, through the stomata. Evaporation of water from the leaves surface causes a negative pressure (suction force) in the xylem that pulls water from the roots and soil. This results in water being drawn up the xylem vessel.

Transpirational pull draws water from the roots to the leaves because of the effects of **capillary action**. The primary forces that create the capillary action are *adhesion* and *cohesion*. Adhesion is the attraction that occurs between water and the surface of the xylem, and cohesion is the attraction between water molecules. We will revisit transpirational pull and capillarity later in the chapter when we examine how water is transported in the plant.

Factors affecting the rate of transpiration ESG7K

There is a close inter-relationship between transpiration and leaf structure. The rate at which transpiration occurs refers to the amount of water lost by plants over a given time period. Plants regulate the rate of transpiration by opening and closing of stomata (Figure 6.14).

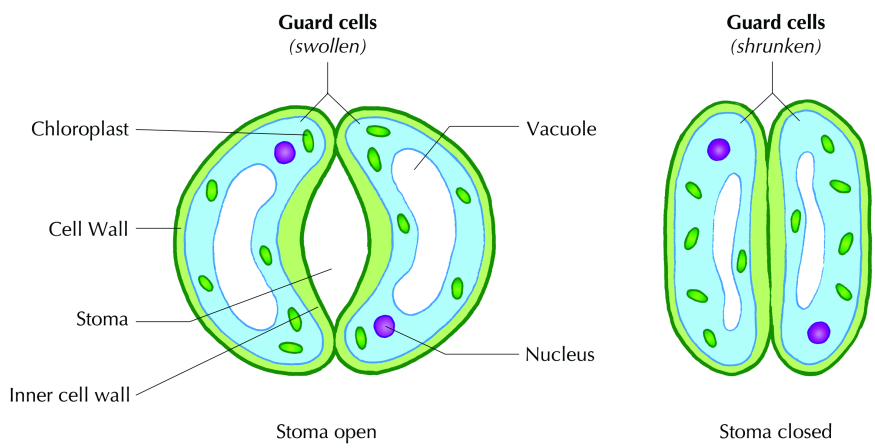


Figure 6.14: The opening and closing of stomata. Different environmental conditions trigger both the opening and closing of stomata.

There are, however, a number of external factors that affect the rate of transpiration, namely: temperature, light intensity, humidity, and wind.

the water and the wax paper. However, in this case the water-water cohesive force is stronger than the adhesive force between the molecules of the wax paper and the water.

Temperature

Temperature affects the transpiration rate in two ways. Firstly, at warmer temperatures water molecules move faster, and the rate of evaporation from stomata is therefore much faster. Secondly, the water-holding capacity of warm air is greater than that of cold air. Assuming that cold air and warm air contain the same amount of water, the cold air may be saturated, and therefore have a shallow water concentration gradient, while the warm air may will be able to hold more water vapour, and will therefore have a steeper water concentration gradient.

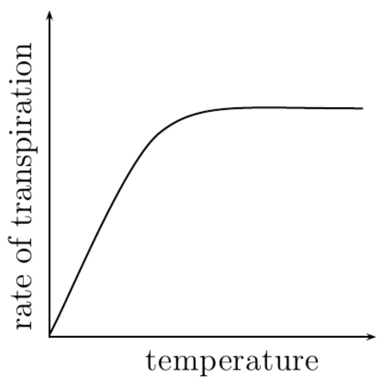


Figure 6.15: Temperature vs transpiration rate.

Light intensity

At high light intensity, the rate of photosynthesis increases. As photosynthesis increases, the amount of stored glucose in the guard cells increases. This lowers the water potential of the leaf (i.e. the contents of the leaf are less dilute). As the water potential decreases, more water enters the guard cells making them more turgid. The turgor pressure of the guard cells leads to an opening up of stomata resulting in transpiration.

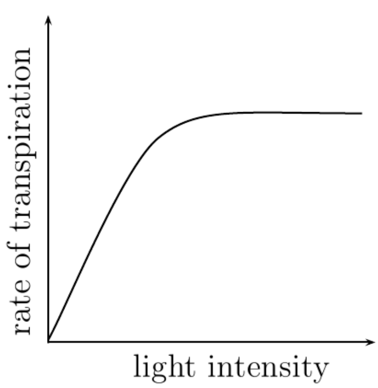


Figure 6.16: Transpiration vs light intensity.

Relative humidity

The amount of water vapour in the air is referred to as the humidity. Water always moves *down* a concentration gradient. Therefore when the humidity is high (lots of water vapour in the air) the water potential gradient between the inside of the leaf stomata and the atmosphere is shallow and the rate of transpiration will be low. However, if the atmosphere is dry, there will be a steep water concentration gradient between the humid inside of the stomata and the outside air and the rate of transpiration will therefore be fast.

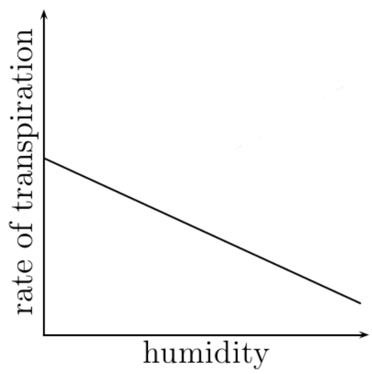


Figure 6.17: Transpiration vs humidity.

Wind

When water is lost from the leaf it forms a thin layer outside the leaf. This reduces the water potential between the leaf and the atmosphere outside. When there is wind, this layer is blown away, thus maintaining the water potential gradient across the leaf.

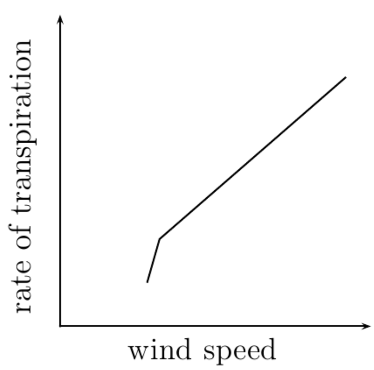


Figure 6.18: Wind speed vs transpiration.

Measuring the rate of transpiration ESG7M

To measure the rate of transpiration we use a piece of equipment called a **potometer.** A potometer measures how factors such as light, temperature, humidity, light intensity and wind will affect the rate of transpiration. The main type of potometer is the 'bubble' potometer shown in Figure 6.19. The potometer measures the amount of water lost from a leafy shoot by monitoring the rate at which an air bubble moves along the narrow tube as the leafy shoot sucks up water to replace the water lost by the transpiration of the plant. As the leafy twig transpires, the air bubble moves to towards the plant. The quicker the air bubble moves, the faster the leafy twig is transpiring.

FACT
A potometer provides an indirect measurement of the transpiration rate – it measures how fast water is absorbed, which is related to how fast water vapour is being lost. It cannot measure how fast water vapour is being given off directly.

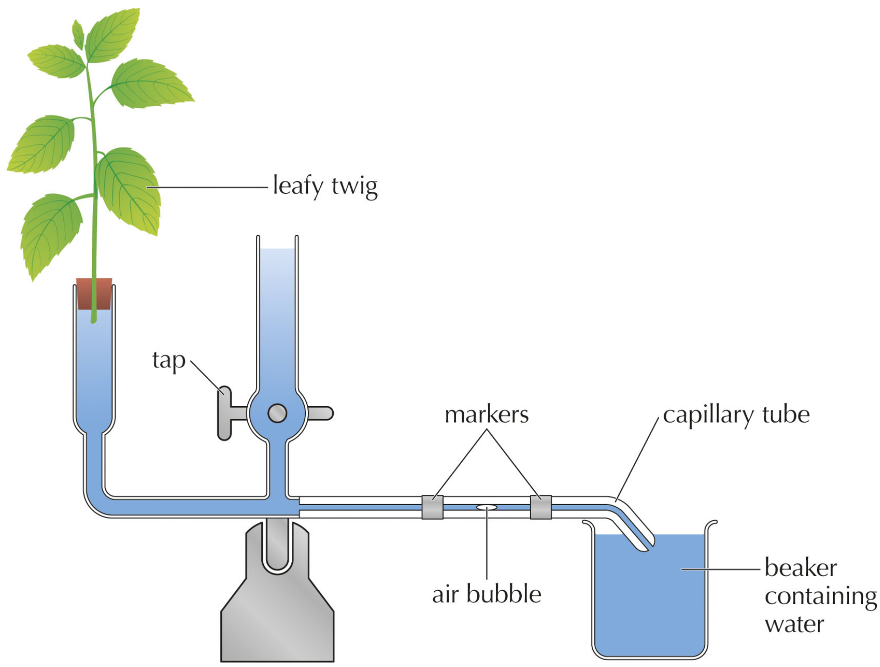


Figure 6.19: Potometer measures the rate of transpiration.

Investigation: Determining the effect of environmental conditions on transpiration rate using a potometer

Aim:

To determine the effect of environmental conditions on transpiration rate using a simple potometer.

Apparatus:

- drinking straw or clear plastic tubing
- soft green leafy shoot
- Vaseline
- marking pen

- play dough / putti/ Prestick
- plastic bag
- elastic band
- ruler

Method:

A potometer measures the rate of transpiration by measuring the movement of water into a plant. The following experiment uses a simple hand made potometer. The class will be divided into four groups. Each group will investigate a different factor and then all the results can be shared at the end of the investigation.

Perform the following steps under water:

1. Cut the stem of the leafy shoot (at an angle to increase the surface area) **under water** . The reason we cut it under water is to prevent air bubbles entering the xylem vessel. You must use a very sharp knife or new scalpel and cut at an angle in order to increase surface area for water uptake in the xylem. Florists who cut plants before immersing them in water follow the same procedure for this reason.
2. Test to make sure the stem of the leafy twig will fit snugly into the top of the straw.
3. Remove the leafy shoot from the straw and set aside, keeping the stem submerged, and the leaves above water.
4. Fill the straw with water. Place your finger over one end of the straw to stop the water from running out.
5. Put the leafy shoot into the open end and seal it with play dough/ putti/ Prestick while removing it from water *keeping your finger on the straw.*

Perform the following steps above water:

6. Seal with Vaseline. Make sure it is air tight and water tight. If not, all the water will run out when you take your finger off the straw.
7. Mark the water level on the straw.
8. Place your potometer under one of the following conditions for one hour:
    - as is, in a warm, sunny place (no wind)
    - as is, in a warm, windy place
    - with a plastic bag tied around the leaf, in a warm, sunny place
    - a shady place.
9. Every 10 minutes use a marking pen to mark the change in water level on the straw. Continue taking measurements for 1 hour.
10. Measure the distance the water moves during each time interval.

Results:

Each of the four groups that investigated different environmental conditions should contribute their results for the final analysis.

1. Draw a table and record the class' results.
2. Plot a bar graph to compare the total distances the water moved in the different straws in 1 hour under the four different environmental conditions.
3. At the end of the experiments, all students must plot the following line graphs:
    a) the effect of temperature on the rate of transpiration
    b) the effect of light intensity on the rate of transpiration
    c) the effect of relative humidity on the rate of transpiration
    d) the effect of wind on the rate of transpiration

Observations:

Record your observation from the table, bar graph and line graphs.

Conclusions:

1. What can you conclude from this investigation?
2. Give two ways in which you can improve your experimental results.

Questions:

1. Why is it important to cut the stem at an angle under the water?
2. Which part of the stem does the straw represent?
3. Which four factors are you investigating?
4. Under which condition is the highest rate of transpiration?
5. Name one possible error that could have occurred in your investigation.
6. What are the potential limitations of this investigation?

Investigation: Determining the effect of light intensity on transpiration

Aim:

To determine the effect of light intensity on transpiration.

Apparatus:

- plants
- plastic bag
- piece of string
- graduated measuring cylinder

Method:

1. Use at least three plants of the same species and as close to the same size as possible (think of why this might be important).
2. Ensure that all three plants are exposed to the same amount of light.
3. Use clear plastic bags to completely cover all the leaves of each plant.
4. Tie the bottom of the plastic around the main stem of the plant, allowing the water lost from the plant to collect inside the bag. Try not to crush the leaves of the plant with the bag.
5. Place the bags on the plants early in the morning. Leave the bags on all day and check for signs of water drops inside. If there are water drops, shake the bag so that the water drops to the bottom of the bag.
6. At the end of the day, carefully remove the bags to ensure that you do not lose any water. It will help if you tilt the plant slightly while removing the bags.
7. Collect the water inside a measuring cylinder and measure how much water the plant has lost.
8. Tie a new plastic bag around the plant and leaver overnight. item The following morning, collect and measure the water that was released by the plant overnight.

Results:

1. Record the amount of water lost during the day and during the night.
2. Using the three plants, figure out the average water loss for each time period.
3. Plot a bar graph comparing the average amount of water loss in the day and night.

Observations:

Write down anything you observed about the plants, the plastic bags and the rate of water loss from the plant.

Conclusions:

What can you conclude regarding the rate of transpiration at different light intensities? Was there higher or lower water loss when you left the plant overnight compared to when you monitored it throughout the day?

Questions:

1. How can you improve this experiment to determine the effects of different light intensities on transpiration?
2. In this experiment what are the key variables we are controlling for? Have we properly controlled for these?

Advantages of transpiration	Disadvantages of transpiration
Cools the plant down.	Excessive water loss causes the plant to wilt.
Assists in the transport of water from the soil.	
Important for transport of water through the xylem.	
Regulates the concentration of cell sap.	
Distribution of salts and minerals in the plant.	

Table 6.1: Table comparing the advantages and disadvantages of transpiration.

Structural adaptations of plants to reduce rate of transpiration ESG7N

When the rate of transpiration is too high, it can have detrimental effects on the plant, as you will see in the next section on wilting and guttation. For this reason, plants have developed structural adaptations to minimise the amount of water loss.

- **Position of stomata:** Stomata are found on both surfaces of the leaf but there are usually more on the ventral (lower) surface of the leaf. This means that less water vapour is lost because the ventral side of the leaf is in the shade and therefore does not get as hot.
- **Sunken stomata:** Some plants such as xerophytes have sunken stomata as a way of preventing water loss. Xerophytes (pronounced "zero-phytes") are plants that are normally found in hot, dry areas such as deserts. The sunken stomata creates a small pocket of moist air. The high humidity in the air pocket reduces the water potential gradient between the leaf air spaces and the exterior, and therefore decreases the rate of transpiration.

- **Thickened cuticle:** Some plants that occur in dry places have a thick cuticle that reduces transpiration.
- **Hairs on leaves:** Hairs trap a small layer of water vapour that works in three ways to reduce transpiration:
  - creates a pocket of moist air to reduce the water potential gradient.
  - increases the sheen on leaves to make them more reflective.
  - the combination of the above effects result in a cooling effect that also decreases transpiration.
- **Reduction of leaf size:** Small leaves have a smaller surface area for transpiration to occur.
- **Leaf spines:** Some plants have spines instead of leaves. Spines usually have thicker cuticles and a very small surface area, which decreases transpiration.
- **Leaf arrangement:** Vertical leaf arrangement (like proteas) decrease the surface area exposed to the sun in the heat of the day, In rosette arrangements the upper leaves shield the lower leaves from the Sun.
- **Rolling of leaves:** When leaves roll up, water vapour gets trapped in the tunnel made by the leaf, therefore reducing the water potential gradient, and therefore reducing the rate of transpiration.

Figure 6.20: Desert plants like cactus have thick cuticles to avoid water loss.

Figure 6.21: Hairy leaves to trap water.

Figure 6.22: Spiny leaves have a small surface area to decrease transpiration.

6.4 Wilting and guttation ESG7P

We just discussed transpiration, and how leaves are constantly losing water vapour to the environment. However, what happens when there is not enough water in the soil to replace the water that was lost? Similarly, what happens when there is too much water? In the next section we discuss wilting, and why plants wilt and get 'floppy' in hot weather or after a long drought. We will also look at ways that plants can rid themselves of extra water when there is too much water in the environment and the plant has to cope with high root pressure and a low transpiration rate.

Wilting

ESG7Q

Plants need water to maintain turgor pressure. Turgor pressure is what provides the plant with much of its structural support. Have a look at Figure 6.23 which shows the effect of osmosis on the turgidity of cells.

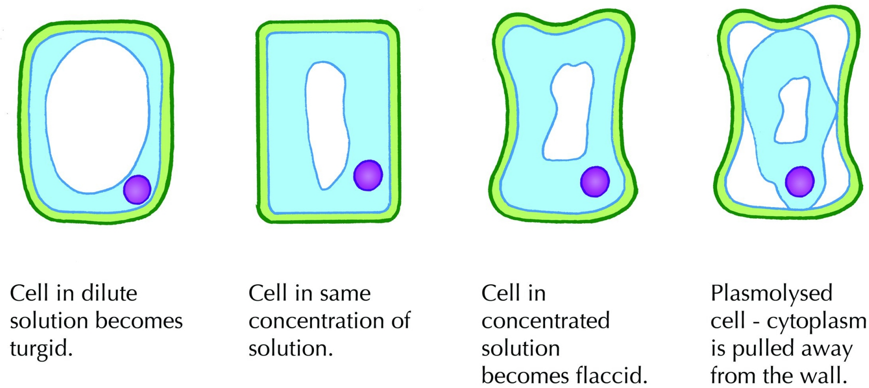


Figure 6.23: Cells in solutions with different concentrations

Wilting refers to the loss of rigidity or structure of non-woody parts of plants (Figure 6.24). It occurs when turgidity of plant cells is lost. When a cell absorbs water, the cell membrane pushes against the cell wall. The rigid cell wall pushes back on the cell making the cell turgid. If there is not enough water in the plant, the large central vacuole of the cell shrinks and the cytoplasm decreases, resulting in decreased pressure being exerted on the cell membrane, and in turn, on the cell wall. This results in the cell becoming flaccid (floppy). When the cells of a plant are flaccid, the entire plant begins to wilt. Wilting occurs due to lower availability of water which may be due to:

- **Drought conditions**: where the soil moisture drops below conditions that allow plants to grow.
- **Low temperatures**: which prevent the plants vascular transport system from functioning;
- **High salinity** (salt concentration): which causes water to diffuse from plant cells to the soil, thus inducing shrinking of cells.
- **Bacterial or fungal infections**: that block the plant's vascular system.

Figure 6.24: Crops wilt due to a lack of water.

Figure 6.25: Guttation in plant leaves

Guttation ESG7R

Guttation is the "oozing out" or exuding of drops of water on the tips or edges of leaves of some vascular plants. An example of guttation is visible in Figure 6.25.

Below is an explanation of how guttation occurs:

- At night, when it is dark, less transpiration occurs since the stomata are closed.
- When soil moisture is very high, water will enter the plant roots because the water potential of the roots is lower than that of the surrounding soil.
- Thus, water accumulates in the plant, resulting in *root pressure*.
- The root pressure forces some water to exit the leaf tip or edge structures called *hydathodes* or water glands, forming drops.
- Root pressure is what drives the flow of water out of the plant leaves, rather than transpirational pull.

For guttation to occur there must be a high water content in the soil to create the root pressure. The transpiration rate must be slow in order for the root pressure to be higher than the transpirational pull. Guttation must not be confused with transpiration. Table 6.2 highlights the differences between guttation and transpiration.

Guttation	Transpiration
Occurs early morning and at night	Occurs during the day when it is hot
Takes place through hydathodes	Takes place through the stomata
Water is lost in liquid form through the hydathodes	Water is lost as vapour via the stomata
Caused by root pressure	Caused by high water potential
Water droplets are found on the margin of the leaf	Water vapour transpiration takes place mostly in the lower surface of the leaf

Table 6.2: Table comparing guttation and transpiration.

6.5 Uptake of water and minerals in the roots
ESG7S

In the first section of this chapter, we looked at the structure of the dicotyledonous root and stem and compared the different cells in the specialised tissues of the plant root and stem. Now we will look at how these specialised cells help the plant to absorb water from the soil and transport it to the stem, where it can then be transported to the rest of the plant.

Movement of water through the dicotyledonous root ESG7T

Water is found in the spaces between the soil particles. Water and mineral salts first enter through the cell wall and cell membrane of the root hair cell by osmosis. Root hair cells are outgrowths at the tips of plants' roots (Figure 6.26). They function solely to take up water and mineral salts. Root hair cells do not perform photosynthesis, and do not contain chloroplasts as they are underground and not exposed to sunlight. These cells have large vacuoles which allow storage of water and mineral salts. Their small diameter (5-17 micrometres) and greater length (1500 micrometres) ensure they have a large surface area over which to absorb water and mineral salts. Water fills the vacuole of the root hair cell.

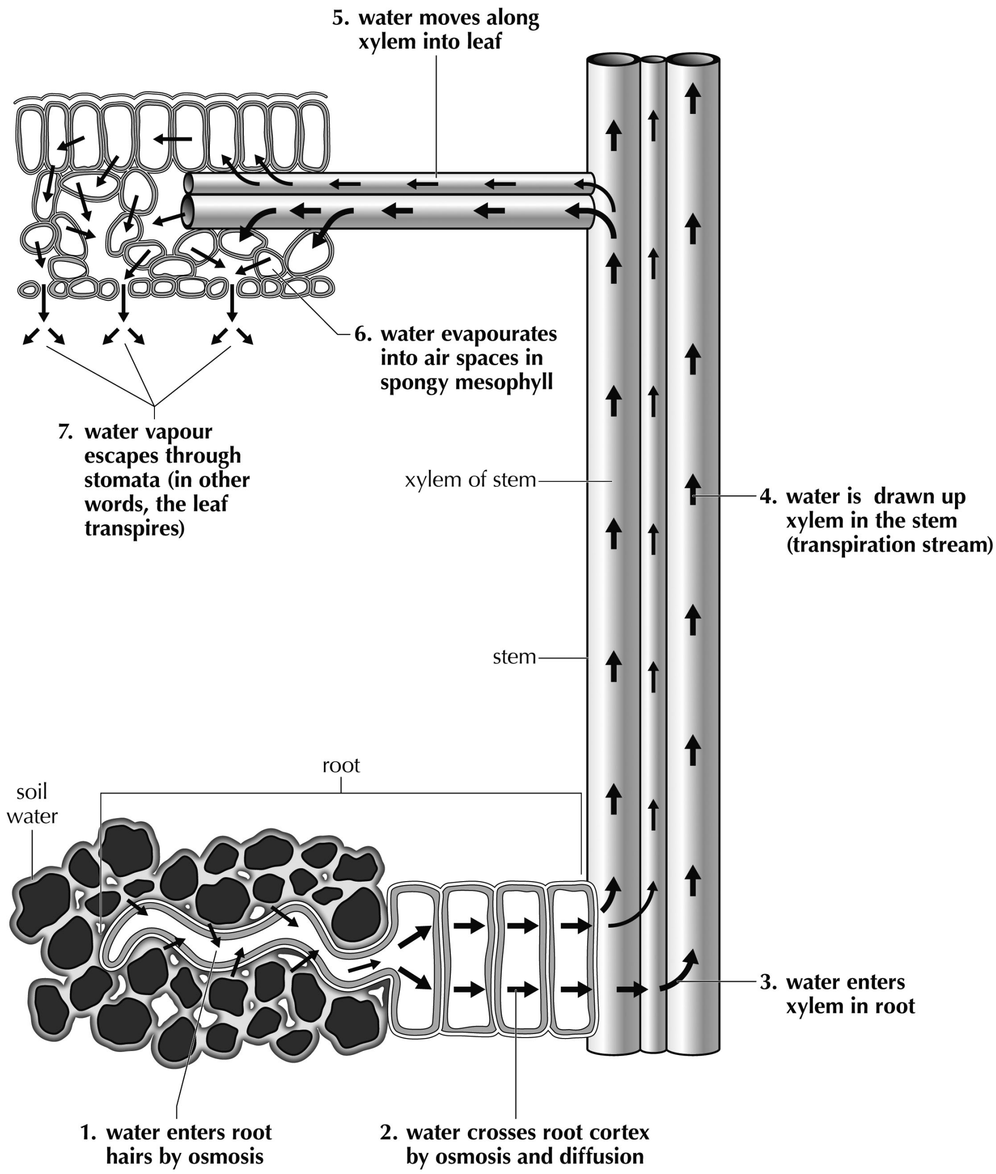


Figure 6.26: Step-by-step transport of water in plants, from the roots to the xylem.

FACT
Learn how water is transported from the soil to the leaves of a plant.
See video: 2CRY

FACT
Learn how transpiration helps with the transport of water to the leaves.
See video: 2CRZ

FACT
Capillarity: refers to the ability of a liquid to flow through narrow spaces (capillary pressure).

The following list summarises how the root hair is adapted to absorb water from the soil:

- There are many, elongated root hairs to increase the total root surface area for water absorption.
- They have thin walls to speed up the intake of water by osmosis.
- They have large vacuoles to absorb water quickly and transport it to the next cells.
- The vacuoles have salts, which speed up water absorption from soil water.
- Root hairs do not have cuticles, as this would prevent water absorption.

Water can now move from the root hair cells and across the parenchyma cells of the cortex in two major ways. Some water passes through the cells by *osmosis*. Most water travels either in, or between the cell walls (of the parenchyma cells) by simple *diffusion*. The water must pass through the endodermis to enter the xylem. Once water is in the xylem of the root, it will pass up the xylem of the stem.

Transport of water and minerals to leaves ESG7V

We have dealt with the transport of water in plants from the soil into the root xylem. Now we need to discuss how the water is transported against gravity from the roots to the leaves where it is needed for the process of photosynthesis.

Water travels to the leaves via the stem. Recall, that three processes are necessary for the transport of water in plants, namely; transpiration, capillarity and root pressure. All three of these processes are passive and do not require an input of energy.

Transpiration: Constant water loss via transpiration from the leaves causes a negative water pressure in the leaves. The negative pressure in the leaves works like a 'suction' force, pulling the water up the stem.

Capillary Action: Water moves up the stem in response to the 'suction' caused by transpiration because of two forces: adhesion and cohesion. Cohesion is the tendency for water molecules to stick together and adhesion is the tendency for water molecules to stick to other surfaces, such as the inside of the xylem vessels. Stem xylem is structurally adapted to take advantage of capillarity, because they are very long with a narrow diameter.

Root Pressure: Water can also be moved up the stem via a 'push' force from the roots. Water is constantly being absorbed by the roots due to the negative water potential in the root cells. This movement of water into the roots can cause the water pressure inside the roots to become high, resulting in a force that 'pushes' water up the stem xylem.

Investigation: Examining water uptake by the stem

Aim:

To examine water uptake by the stem.

Apparatus:

- water
- food colouring dye (available at supermarket)
- white flower on a stem, e.g. Impatiens, carnation or chrysanthemum
- scissors
- two jars, cups or measuring cylinders
- plastic tray
- sticky tape

Method:

1. Fill one jar with plain water, and one with water containing several drops of food colouring dye.
2. Take the flower and carefully cut the stem lengthwise, either part way up the stem or right up to the base of the flower (try both, the results will be different!)
3. Put one half of the stem into the jar containing plain water and one half of the stem into the jar containing food colouring dye. To make it easier to insert the stalks without breaking them, it helps to wedge paper underneath the jars so that you can tilt them towards each other. Tape the jars or cylinders down onto a tray so that they do not fall over.
4. Observe the flowers after a few hours and the next day, and note where the dye ends up in the flower head. You can leave the flowers up to a week but be sure to make sure that they have enough water.

Variation: Instead of using one cylinder with water and one with food dye, use two different colour food dyes (e.g. blue and red). At first the flower will show two separate colours, but as time goes by the whole flower will show both dyes. This is because water can move sideways between xylem vessels through openings along their length. The ability of water to move laterally between vessels is useful for when air becomes trapped in a vessel, causing a blockage. If you cut the stem right up to the base of the flower, this will limit movement between the xylem vessels.

Variation: Try using celery stalks with leaves. Cut open the celery stalk (cross-section) and you will see darker-coloured little holes/ spots. These are the vessels.

Results:

Record your observations and results

Conclusions:

What did you conclude from this experiment?

Movement of manufactured food ESG7W

Plants use sunlight, carbon dioxide and water to manufacture glucose, yielding oxygen as a by-product. Sunlight or radiant light is captured by the green pigment chlorophyll inside of chloroplasts to provide the energy for photosynthesis to occur. Once the food is manufactured in the leaves it needs to be distributed to the entire plant so that the glucose can be used by each cell for respiration and some of the photosynthetic products are then stored for later use.

The glucose is manufactured mainly in the palisade cells where there are more chloroplasts, and then passes into the phloem. Plants usually transport food in the form of the sugar sucrose because it is less reactive than glucose. Sucrose is transported to where it is needed in the the plant via phloem sap, and may be stored in roots, stems or fruit. Transport of food material from leaves to other parts of the plant is called **translocation**. Understanding the phloem structure is important to understanding how it transports food.

Figure 6.27: Aphids feeding on phloem sap which is rich in sucrose.

How the phloem functions

While the transport of water is usually unidirectional in xylem (upward or lateral), the movement of sugars in the phloem is multi-directional, and occurs by **active transport**, an energy-dependent process. Sucrose is actively transported *against* a concentration gradient into sieve-tube elements. The sieve-tube elements have no nuclei but the adjacent companion cells do. Companion cells are closely associated with sieve tubes and carry out all the cellular functions of the sieve tubes.

The cytoplasm of sieve tubes and companion cells is connected through numerous channels called **plasmodesmata**. These cytoplasmic connections allow the companion cells to regulate the content and activity of the sieve tube cytoplasm. The companion cells also help load the sieve tube with sugar and the other metabolic products that they transport throughout the plant. This lowers the water potential of the sieve-tube element, causing water to move in by osmosis, creating a pressure that pushes the sap down the tube. The metabolising cells of the plant actively transport sugars out of sieve-tube elements, producing exactly the opposite effect. The diagram below illustrates how the overall process works.

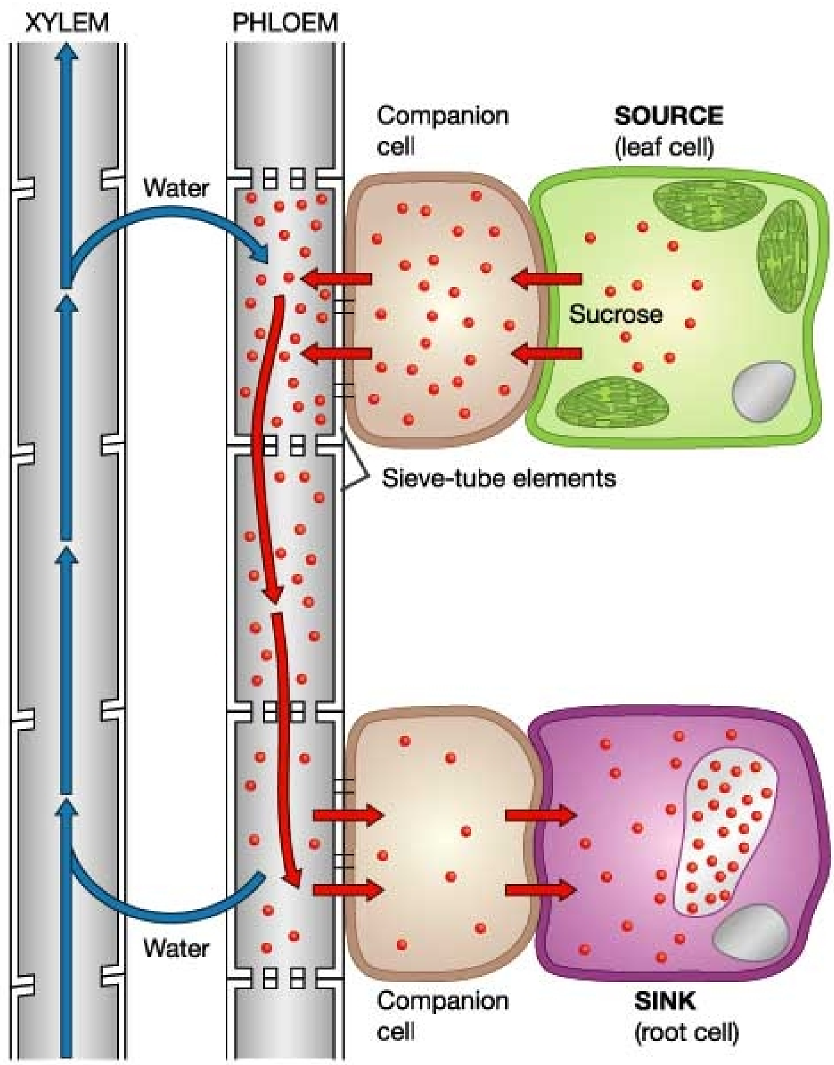


Figure 6.28: Diagram showing movement in the xylem and phloem vessels. Water movement is upwards in the xylem and lateral into and out of the phloem. Lateral movement also occurs into and out of the companion cells accompanying the phloem vessel.

6.6 Summary ESG7X

- **Anatomy of dicotyledonous plants**: Structures discussed in the previous chapter (collenchyma, sclerenchyma, xylem and phloem) are important in carrying out the transport functions.
- **Root anatomy and function:** The root is important in absorption, anchorage and storage of food. It is made up of the epidermis, cortex, endodermis and stele (consisting of xylem, phloem and pericycle).
- **Stem anatomy and function:** Stems contain an epidermis, cortex and vascular cylinder (consisting of pericycle, xylem, phloem, cambium and pith). Stems are important for growth, support, storage and transport of water, mineral salts and manufactured sugars.
- **Secondary growth:** Secondary growth is the thickening of the stem or root as new layers of xylem and phloem are formed by mitosis. It is carried out by cambium and results in stems and roots becoming thicker as the plant ages / matures. Secondary thickening results in the annual rings found in trees that can be used to work out the age of a tree.
- **Transpiration**: Transpiration is the loss of water from the stomata of plants. It creates a 'suction' or transpirational pull that is important for the movement of water through the plant. Transpiration is affected by environmental conditions e.g wind, temperature, humidity and light intensity. The rate of transpiration is measured using a potometer. In order to prevent excessive transpiration, plants have developed adaptations such as thickened cuticle, position of stomata, hairs on leaves, reduction of leaf size, leaf spines, leaf arrangements and rolling of leaves.
- **Translocation**: Translocation is the transport of food material (sugars), synthesised in the leaves, to other parts of the plant via phloem. This mode of transport is multi-directional, but requires energy as it occurs by active transport against a concentration gradient. Phloem vessels consist of sieve-tube elements and companion cells which are connected by plasmodesmata. Companion cells act as the regulators and energy stores of the phloem.
- **Wilting and guttation** are processes of water loss in the plant. Wilting entails excessive loss of water through plasmolysis resulting in excessive cell death, at times resulting in death of the entire plant. Guttation is the release of water via the hydathodes due to high humidity.

Exercise 6 – 1: End of chapter exercises

1. The water loss in two plants was recorded over a 12 hour period. Study the information below and then answer the questions that follow. The results for the two plants were recorded in the following table.

Time of Day	06:00	08:00	10:00	12:00	14:00	16:00	18:00
Water loss in Plant A (cm^3)	0,0	0,4	1,6	6,0	9,0	8,0	7,6
Water loss in Plant B (cm^3)	0,2	0,7	4,0	14,0	19,0	18,2	17,7

   a) What is the correct biological term for water loss in a plant?
   b) From which plant was the greatest amount of water loss recorded?
   c) Assuming the plants were kept in identical conditions; suggest two possible ways that the plant that lost less water may have differed structurally from the plant that most more water.
   d) Which time of day was the greatest water loss recorded for both Plants A and B. Why do you think this is so?
   e) At 18h00 the rate of water loss was lower. Why did this occur?
   f) What is the apparatus that was used in the laboratory to measure the rate of water loss in plants A and B?

2. What do you understand by guttation and how does the process of guttation occur?
3. Tabulate the differences between guttation and transpiration.
4. Briefly discuss the movement of water through the dicotyledonous root.
5. Give a short explanation for the following:
   a) capilliarity
   b) dicotyledon
   c) transpiration
   d) water potential gradient
6. On a hot day in the middle of a drought, what can you expect the leaves of a plant to look like? Draw a diagram to describe your answer.
7. List the environmental conditions that would result in the highest rate of transpiration.
8. Name four defining characteristics of a monocotyledonous plant.
9. In a short paragraph, explain how secondary thickening in a stem comes about.
10. Name and briefly discuss the adaptation of leaves to minimise transpiration.

11. Name the two main ways that water can travel through the parenchyma of the root.
12. Explain the difference between cohesion and adhesion.
13. During transpiration, the movement of water through the xylem is largely due to:

    a) mitosis
    b) capillary action
    c) osmosis
    d) all of the above

14. Stomata:

    a) are found in plant roots
    b) permit the intake of carbon dioxide
    c) prevent the intake of oxygen
    d) all of the above

15. Water can be lost by a plant through which process(es)?

    a) guttation
    b) transpiration
    c) condensation
    d) a and b

16. What environmental condition(s) always lead to an increase in transpiration rate in each plant tested?

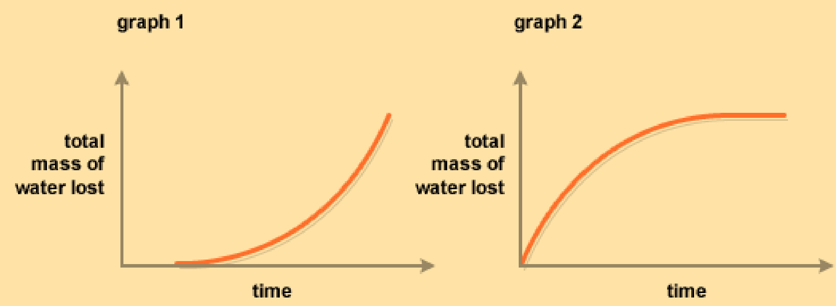
    a) heat
    b) wind
    c) light
    d) all of the above

17. Wind appears to increase the rate of transpiration in a plant. This is most likely due to the fact that:

    a) humidity increased
    b) evaporation increased
    c) stomata were forced to close
    d) all of the above

18. Describe how light intensity is responsible for an increase or decrease in the transpiration rate.

19. Study the two graphs below which show water loss from a plant over a period of time, and answer the following question:



Which graph could show water loss under increasing external humidity? Give reasons for your answer.

20. Describe how each of the following adaptations results in a decrease in the transpiration rate:
    a) Spiny leaves
    b) Rolled leaves
    c) Waxy cuticle
21. Complete the following sentences:
    a) Translocation refers to the ...
    b) Xylem tissue in plants is responsible for the transport of ...
    c) The roots absorb water through the ...
22. Draw a table showing how the structure of root hairs is adapted for their function.

Check answers online with the exercise code below or click on 'show me the answer'.

1a. 2CS2	1b. 2CS3	1c. 2CS4	1d. 2CS5	1e. 2CS6	1f. 2CS7
2. 2CS8	3. 2CS9	4. 2CSB	5. 2CSC	6. 2CSD	7. 2CSF
8. 2CSG	9. 2CSH	10. 2CSJ	11. 2CSK	12. 2CSM	13. 2CSN
14. 2CSP	15. 2CSQ	16. 2CSR	17. 2CSS	18. 2CST	19. 2CSV
20a. 2CSW	20b. 2CSX	20c. 2CSY	21a. 2CSZ	21b. 2CT2	21c. 2CT3
22. 2CT4					

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CHAPTER 7

Support systems in animals

7 Support systems in animals

7.1 Overview ESG7Y

Introduction ESG7Z

In this chapter we will be studying the different types of skeletal structures. We will focus in particular on the human skeleton. In Grade 12 you will come to know how our skeletal structure evolved. For now, you will be introduced to the main features and functions of the human skeleton. By focusing on specific structures of the human skeleton, we once more emphasise a common theme of our study of Life Sciences: that **structure** is related to **function**.

Key concepts

- Some of the main types of skeleton found in living things are the hydrostatic skeleton, endoskeleton and exoskeleton. Each of these skeletal types have advantages and disadvantages.
- Skeletal structures are adapted for the transition from an aquatic to a terrestrial existence where greater support was required.
- The human skeleton consists of the axial skeleton and the appendicular skeleton.
- The main functions of the skeleton are to allow for movement, provide protection, provide support, store minerals, produce blood cells and allow for hearing.
- It is important to understand the relationship between structure and function of bones, cartilage, tendons and ligaments.
- Joints connect pieces of skeleton and allow independent movement of neighbouring pieces. Joints are of three types: fixed, partly movable and freely movable (synovial joints). Synovial joints are of either ball-and-socket, hinge, pivot, or gliding structure.
- Skeletal muscle is attached to the skeleton through tendons and ligaments. The structure of voluntary skeletal muscle is made up mainly of myofibrils which allow for muscle contraction. This contraction is used to move part of the skeleton.
- Diseases affecting the skeleton include rickets in children, and osteoporosis and arthritis in adults.

7.2 Skeletons ESG82

FACT
As you will learn in the chapter **History of Life on Earth**, many of these structural adaptations allowed animals to move from water onto land.

The skeleton is the supporting structure of an organism. There are three different types of skeletons: hydrostatic skeletons, endoskeletons and exoskeletons.

- **Hydrostatic skeleton**: Water exerts pressure on muscular walls, for example, in jellyfish.
- **Exoskeleton**: The stable chitinous or mineralised outer shell of an organism, for example, the shell of a grasshopper or prawn.
- **Endoskeleton**: A cartilaginous or mineralised support structure inside the body, for example, in humans and other vertebrates.

In this chapter we will be looking at support systems in animals and investigating the human skeletal system in some depth.

The evolutionary development of the skeleton ESG83

Body support provided by water

The earliest forms of life evolved in the oceans. The fact that this is an aquatic environment is key. Water is about 1000 times denser than air. The high density of water allows organisms to float, due to a physical, upward force inherent in liquids known as buoyancy.

Buoyancy allowed organisms to grow and reach large sizes because the buoyancy force supported the body weight of these animals. However, the density of water also provides resistance to movement, and animals had to adapt to ensure that they were able to move efficiently through water.

Figure 7.1: The animal above is a jellyfish. It uses its muscles to contract against the hydrostatic skeleton to bring about movement.

An early adaptation by organisms was the ability to change the hydrostatic pressure within different chambers of their bodies to enable quick movement. This resulted in the development of **hydrostatic skeletons**. Animals with this type of skeleton include jellyfish, octopus and sea anemones. The changing shape of the animal reduces both friction and drag.

Over time, in order to refine movement and improve protection from predators, some organisms developed a hard chitinous **exoskeleton**. Exoskeletons first developed in the aquatic environment in ancient arthropods. Animals with this type of skeleton include crustaceans like crabs and lobsters.

Eventually, there were some animals that developed a skeletal structure internal to the body, which would become the vertebrate group of animals. These animals have an **endoskeleton**. Initially, all endoskeletons were made of cartilage, which is a dense rubbery type of tissue. Later, endoskeletons of bone evolved.

Figure 7.2: Crustaceans, such as this crab, developed a protective exoskeleton.

Figure 7.3: The first vertebrates evolved in the oceans. This fish has an internal endoskeleton that makes it streamlined and allows it to move rapidly through water.

The adaptation of the skeleton to a terrestrial environment

The two major requirements for survival on land are the development of a suitable support system and an air breathing mechanism. One of the biggest problems encountered by animals moving from water to land was the loss of the effect of buoyancy. In order to counter this, animals needed to develop strong limbs and had to adapt the skeleton to support their body weight on land. Moving effectively on land is essential, particularly if one needs to avoid predators, catch prey, or adapt to a particular habitat. Different skeleton types have solved these problems in different ways.

Animals with exoskeletons like arthropods (a class of animals including insects, crustaceans and arachnids) transitioned from sea to land long before the vertebrates (organisms with endoskeletons). A major factor in their success was the **exoskeleton** which provides attachment for muscles controlling **locomotion** (movement of appendages). Exoskeletons also provided some protection from dessication (water loss).

Figure 7.4: This beetle is an example of a insect. Insects have a protective exoskeleton that made it possible for them to colonise land millions of years ago.

Amphibians with **endoskeletons** , like frogs and newts, live both on the land and in the water. Their skeletons have adapted to give advantages in both conditions. They have calcified bones to support their body weight under the force of gravity. Their skull is light and flattened, for both motility on land and a streamlined shape for moving easily in water. Their pectoral girdle is adapted to give support for the forelimbs, which absorb the body weight when landing after a jump.

Figure 7.5: Amphibians were the first vertebrates to colonise land. They begin their life-cycle in water, and emerge onto land as adults.

Depending on their means of locomotion, terrestrial animals needed to adapt their shapes and skeletons to overcome the effects of gravity.

Limbless animals, such as snakes, had to overcome drag and friction. Flying animals such as birds and bats need light skeletons and very strong sternums for wing muscle attachment. Animals that support their bodies clear of the ground needed an energy efficient way of maintaining balance. For this reason, the leg bones of most animals are held directly underneath the body. In this position they act as props or struts and it is the bones rather than the muscles that take most of the strain of the body's weight.

Figure 7.6: Land vertebrates often have legs placed directly beneath the body. The legs acts as struts, and are the most energy-efficient way to keep the body suspended above the ground.

Hydrostatic skeleton ESG84

A hydrostatic skeleton is a structure found in many cold-blooded and soft-bodied organisms. It consists of a fluid-filled cavity, which is surrounded by muscles. The cavity is called a **coelom** and in some animals this cavity is filled with a blood-like substance called **haemocoel**. The fluid presses against the muscles, which in turn contract against the pressure of the fluid. The fluid is incompressible and thus maintains a constant volume against which the muscles can contract. The hydrostatic skeleton prevents the collapse of the body. The muscles in the body act against the fluid and in doing so bring about movement. If the body is segmented, the pressure of the fluid is localised in a few segments at a time. Hydrostatic skeletons occur in flatworms, round worms, earthworms, starfish and slugs.

Note that starfish and other Echinoderms have an outer skeleton of calcareous (chalky) ossicles (little bones) or spicules which are like little spines for protection. This outer skeleton encloses a water vascular system with tube feet that are moved by fluid pressure changes (it serves as a hydrostatic skeleton which controls movement).

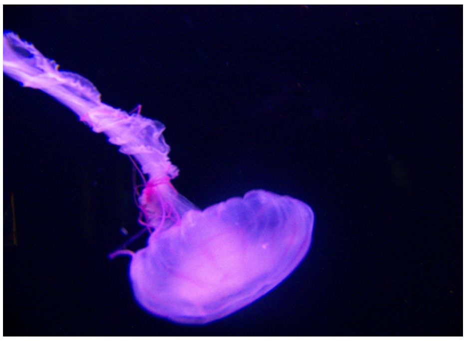


Figure 7.7: The animal above is a jellyfish. It uses its muscles to contract against the hydrostatic skeleton to bring about movement.

Figure 7.8: The animal depicted above is an Echinoderm - a starfish - which uses its tube feet for movement.

Advantages of a hydrostatic skeleton

- **Fluid shape:** This allows organisms with hydrostatic skeletons to fit through oddly shaped passages, which is useful for burrowing or swimming.
- **Strength:** Creatures with hydrostatic skeletons can squeeze between spaces and expand, making a 'prying open' movement which allows them to force their way into various regions of rock and soil surfaces.
- **Healing:** Healing takes place faster in organisms with hydrostatic skeletons than in organisms with bone structures. This is because the haemocoel contained within the hydrostatic skeleton is made up mostly of water, and thus, can be refilled quickly. This allows many organisms with hydrostatic skeletons such as earthworms to grow back their body mass after damage.
- **Lightweight:** The hydrostatic skeleton allows the animal to move in a more flexible manner as it requires very little muscle mass for movement.
- **Circulation:** The fluid cavity allows circulation of nutrients and waste.
- **Protection:** The hydrostatic skeletons cushions the internal organs of the animal from shock.
- **Suited to environment:** Hydrostatic skeletons are suited for life in moist or aquatic environments, depending on the animal's adaptations.

Disadvantages of a hydrostatic skeleton

- **Structure and surface for attachment:** The hydrostatic skeleton lacks a structure and does not have surfaces for the attachment of muscles or limbs.
- **Lack of protection:** There is very little protection for the internal organs.
- **Dessication:** A moist or water habitat is essential for survival of these animals in order to prevent dessication (drying out).

- **Limited strength:** Terrestrial animals with hydrostatic skeletons cannot increase their body size as they would collapse under their own body weight.

Exoskeleton ESG85

An exoskeleton is an external skeleton that supports and protects an animal's body. The skeleton is non-living and consists of a cuticle strengthened by chitin, a substance secreted by the epidermis (skin). Crustaceans such as crabs have their exoskeleton further strengthened by calcium carbonate. There are muscles attached to the inside of the exoskeleton which provides the resistance needed for muscle action.

The exoskeleton is confined to animals such as insects, spiders, scorpions, crabs etc., all of which belong to the Phylum Arthropoda (jointed-legged and jointed-bodied animals). The exoskeleton acts as a hard outer covering, and is made up of a series of plates or tubes. We often call large exoskeletons 'shells'. Exoskeletons first appeared in the fossil record during the time of the **Cambrian explosion** and comprises a substantial portion of our fossil record.

Figure 7.9: Picture of jumping spider, a type of arthropod.

Advantages of the exoskeleton

- **Muscle attachment:** The exoskeleton forms the point of attachment of internal muscles needed for locomotion thereby providing better leverage for muscle action.
- **Protection:** The exoskeleton protects the soft internal tissues and organs.
- **Support:** The exoskeleton provides structural support and shape.
- **Prevents Dessication:** The exoskeleton prevents desiccation (drying out) on land.
- **Light-weight:** The exoskeleton of insects has a low density and is therefore lightweight, to allow for flight.
- **Diversity:** The mouth-parts can be modified for biting, sucking, piercing grasping thus providing for a diversified diet for organisms possessing an exoskeleton compared to those that do not.

Disadvantages of the exoskeleton

- **Size restriction:** The final body size is limited because as the body size increases, the surface area to volume ratio decreases. The larger the animal, the heavier the exoskeleton, making movement more difficult.

- **Non-living skeleton does not grow with animal:** The overall growth of the animal is restricted due to periodic moulting. Since the exoskeleton restricts growth, moulting is required to accommodate for increases in the size of the animal.
- **Vulnerability during moulting:** The animal is vulnerable when it is in the moulting process, because the new skeleton is very soft until the new exoskeleton has dried and hardened.
- **Sites of structural weakness:** Exoskeletons are weaker at the joints.

Endoskeleton ESG86

This skeleton is found inside the body and can consist of bone (all vertebrates except sharks) or cartilage (sharks) and some endoskeletons consist of both.

Advantages of the endoskeleton

- **Living:** Endoskeletons consist of living tissue, so it is able to grow steadily within the animal enabling some to reach a large size.
- **Structure and support:** The endoskeleton provides shape and structural support.
- **Structural diversity and adaptation:** The bones can vary in size and shape to support the animal's mass.
- **Flexible:** The endoskeleton is jointed which allows for flexible movement and support.
- **Muscle attachment:** The muscles attach directly to the skeletal bones to allow for movement and support.
- **Protection:** The endoskeleton protects the vital organs such as the heart and lungs which are protected by the ribcage.
- **Diversified locomotion:** The development of an endoskeleton has allowed for animals to become successfully adapted to locomotion in the environment in which they live. Vertebrates (organisms with a vertebral column and an endoskeleton) have become adapted to move in a number of different modes of locomotion, e.g. running, jumping, swimming, and flying.

Disadvantages of the endoskeleton

- **Vulnerable to external environment:** The endoskeleton does not offer the animal any protection from the exterior, be it a physical attack or changes in environmental conditions. The animal is therefore very vulnerable.
- **Susceptible to disease:** The skeleton consists of living tissue so is susceptible to infections and disease.

7.3 Human skeleton ESG87

Humans have a living **endoskeleton** (internal skeleton) made of bone, cartilage and connective tissue. At birth, the human skeleton consists of over 270 bones. However, in adults this number has reduced to 206 bones due the fusion of smaller bones into larger structures. The adult skeleton (Figure 7.10) is made up of the **axial skeleton** and the **appendicular skeleton** (Figure 7.11).

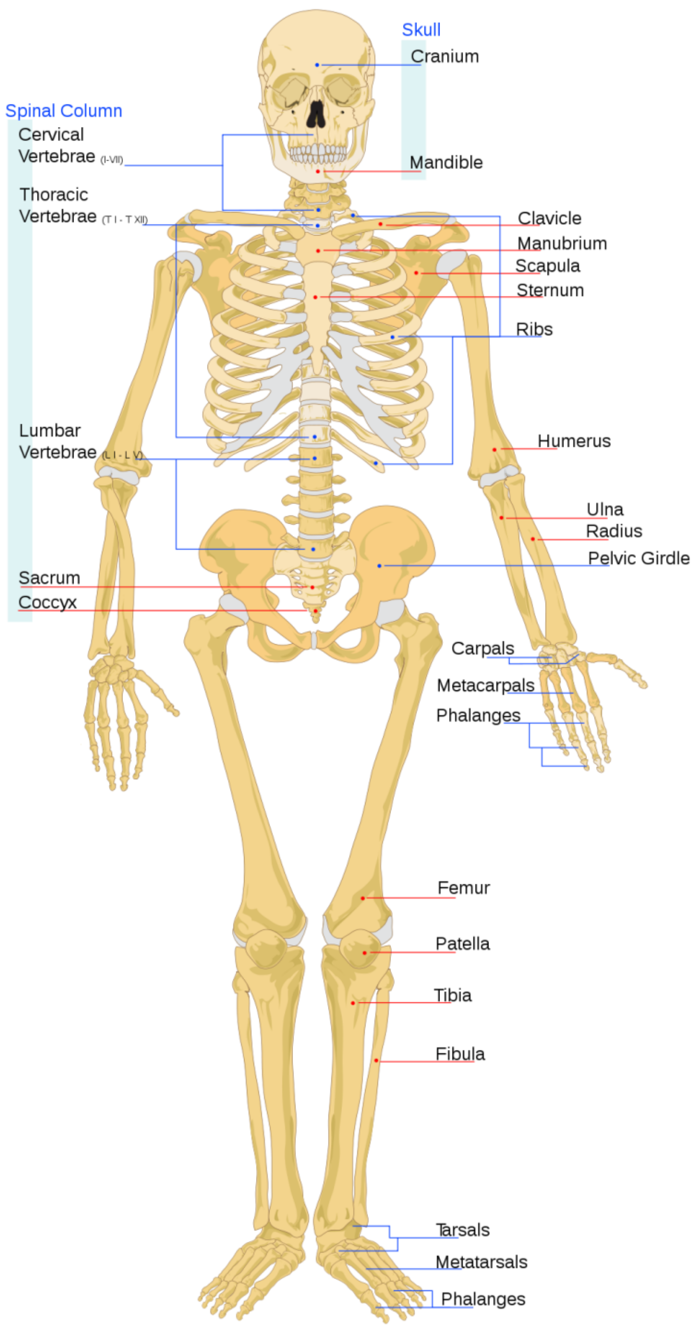


Figure 7.10: Diagram showing an overview of the main skeletal features of the human skeleton.

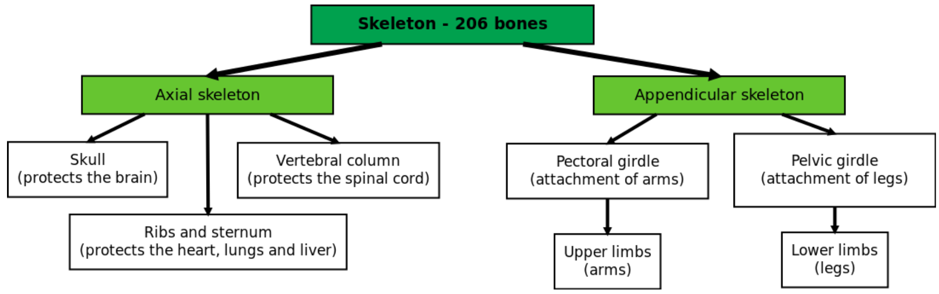


Figure 7.11: There are 206 bones in the adult human skeleton, which can be 'grouped' into different categories.

Axial skeleton ESG88

The axial skeleton forms the central axis of the body and consists of the skull, vertebral column and rib cage and sternum.

The Skull

The skull consists of the **cranium** and **facial bones**.

The **cranium** consists of eight flat bones joined together by immovable joints called sutures. The cranium surrounds and protects the brain. There is a large opening at the base of the skull called the **foramen magnum** through which the spinal cord passes. On either side of the foramen magnum is a projection which articulates with the first vertebra (called the **atlas**) to allow for the nodding movement of the head.

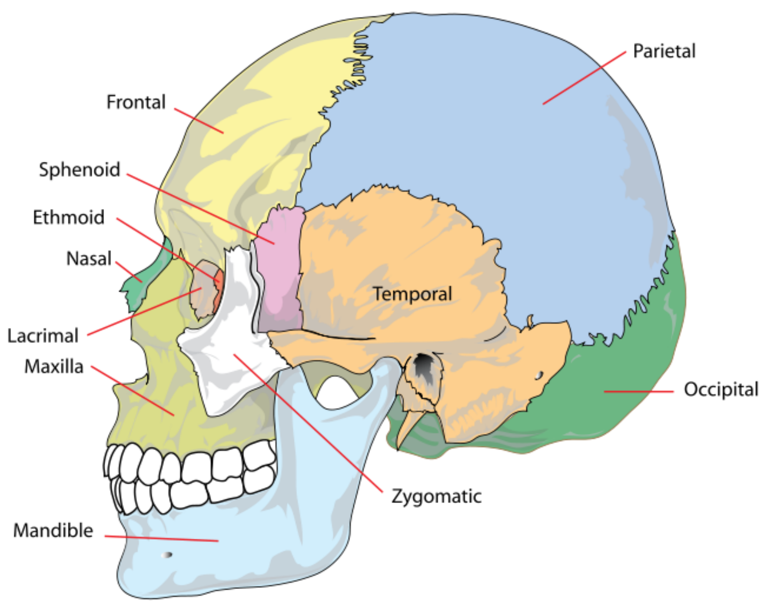


Figure 7.12: The cranium.

There are 15 **facial bones**. These are irregular bones that include the cheek bones, nasal bones, temples, upper jaw bone (maxilla)) and lower jaw bones (mandible). The only movable bone is the lower jaw.

The upper and lower jaws bear the sockets for the 32 permanent teeth. The number, type and arrangement of the teeth in an animal is indicated by a **dental formula**. The human dental formula is: 2.1.2.3/2.1.2.3.

This formula represents the numbers of each type of teeth in half of the upper jaw and half of the lower jaw. This formula tells us that in both the upper and lower halves there are 2 incisors, 1 canine, 2 premolars and 3 molars.

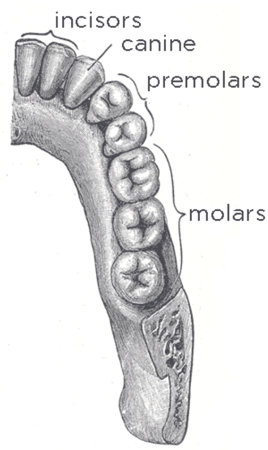


Figure 7.13: Dental formula in a human adult.

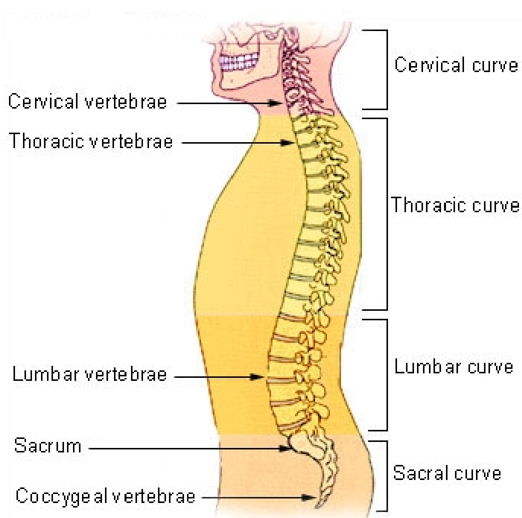
FACT

A few interesting facts about the human skeleton:

- Humans have seven neck bones - the same as giraffes.
- The strongest and longest bone is the thigh bone (the femur).
- One out of 20 people have an extra rib.

The human vertebral column

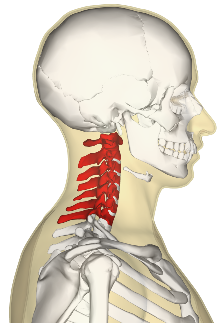
The vertebral column typically consists of 24 articulating vertebrae and 9 fused vertebrae in the sacrum and the coccyx. Between the vertebrae are **discs of fibrocartilage**, which prevent friction between vertebrae, and act as shock absorbers during walking, running and jumping. **Spinal nerves** are able to enter and leave the spinal cord through gaps between adjacent vertebrae. **Strong ligaments and muscles** around the spine stabilise the vertebrae and help to control movement. The vertebrae join up to each other in such a way that there is a continuous **spinal canal** which runs from the base of the skull to the pelvic girdle. This canal contains the **spinal cord**. The entire vertebral canal can be divided into five regions.



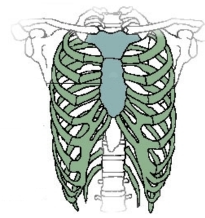
- Cervical region
- Thoracic region
- Lumbar region
- Sacral region
- Coccyx

FACT
In a newborn baby the entire vertebral column curves backwards probably because of the confines of the uterus. Initially a baby cannot support the weight of its head. When after about 3 months it is able to support its head, the **cervical forward curve is complete**. The **lumbar forward curve** is complete when the baby is able to stand on its own and ready to learn to walk.

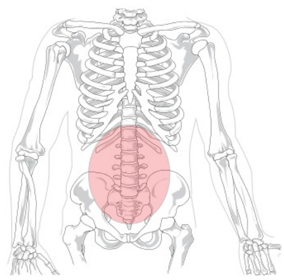
The **cervical** (neck) region consists of seven vertebrae. The first cervical vertebra, called the **atlas**, supports the skull and allows for the nodding movement of the head. The second vertebra, called the **axis**, has a projection on which the atlas pivots to give the side to side movement of the head.



The **thoracic region** (chest) consists of 12 vertebrae, which each bear a pair of ribs.



The **lumbar region** (lower back) consists of five vertebrae. This region has the largest vertebrae as it carries the weight of the body.



The **sacral region** consists of five fused vertebrae, forming a bone called the **sacrum**. the sacrum forms part of the pelvic girdle which provides surfaces for the attachment of muscles and the legs.

The **coccyx** is made up of four fused bones. These bones form the tail in those mammals that have tails.

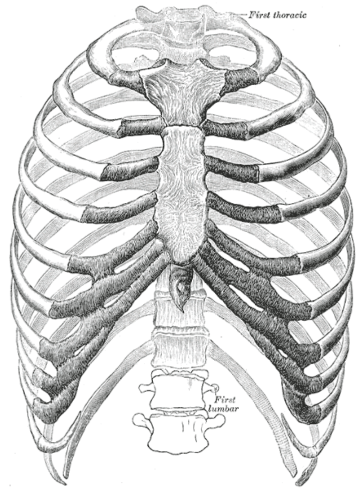
Functions of the vertebral column

- Supports the skull
- Surrounds and protects the spinal cord
- Provides attachment for ribs, girdles, and back muscles
- Separate vertebrae and S-shaped curvature provide flexibility allowing humans to bend backwards, forwards and sideways
- Fibrocartilage discs between the vertebrae act as shock absorbers

The rib cage and sternum

The rib cage is a bony and cartilaginous structure. A typical rib cage consists of 24 ribs (12 pairs), the sternum (an inverted T-shaped structure connecting the rib bones), costal cartilages and the 12 thoracic vertebrae shown in the diagram on the following page.

The first seven pairs of ribs connect directly to the sternum and are referred to as *true ribs*. The remaining five pairs of ribs do not connect directly to the sternum and are referred to as *false ribs*. The rib cage aids in the protection of the heart and lungs. With the help of the diaphragm and the intercostal muscles, they increase and decrease the volume of the thoracic cavity thereby allowing inhalation and exhalation to take place.



Appendicular skeleton ESG89

The appendicular skeleton consists of the **pectoral girdle** with the **arms** and the **pelvic girdle** with the **legs**. The pectoral girdle and arms and pelvic girdle and legs will be explored in greater detail in the following section.

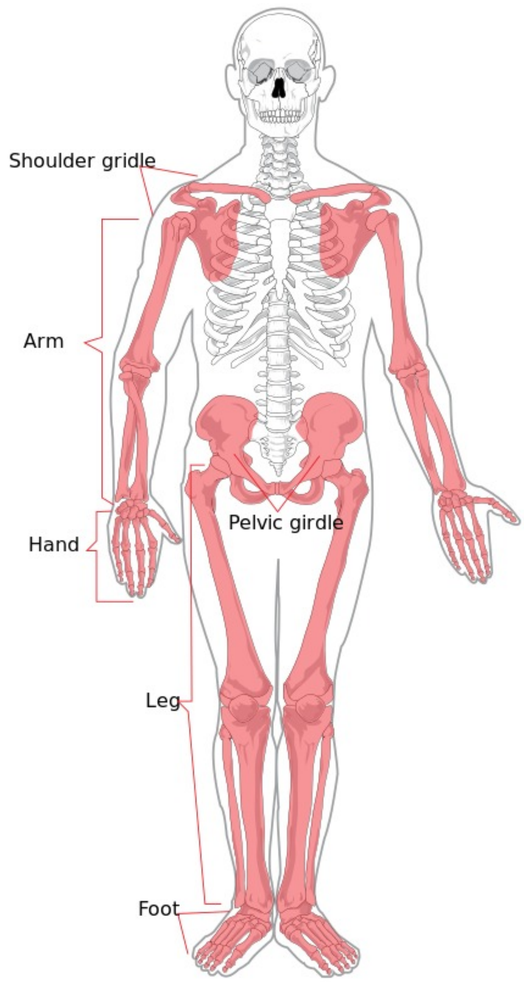


Figure 7.14: The appendicular skeleton is shaded.

The pectoral girdle and arms

The pectoral girdle consists of two **clavicles** (collar bones) and two **scapulae** (shoulder blades). Each clavicle is attached to the sternum in the front and the scapulae at the sides and they help to support the shoulders. The clavicle is the most frequently broken bone in the body as it often takes the full impact of falls on outstretched arms or of blows to the shoulder. The pectoral girdle is connected by muscles to the back of the thorax to enable it to have a supporting structure as well as giving the shoulders greater freedom of movement which in turn allows greater mobility of the arms. Any limit to movement is provided by the clavicle.

Each upper **arm** has a single bone called the **humerus** which fits into the **Glenoid cavity** on the **scapula** to form a ball and socket joint. This cavity is very shallow which allows the arms to move in almost any direction. The fore-arm consists of two bones namely the **ulna** in line with the little finger and the **radius in line with** the thumb. The joint at the elbow is a hinge joint. The wrist consists of eight small **carpal bones** arranged in two rows of four. The palm of the hand consists of five **metacarpal** bones. There are 14 digits (short bones) or **phalanges** in each hand, two in each thumb and three in each of the fingers.

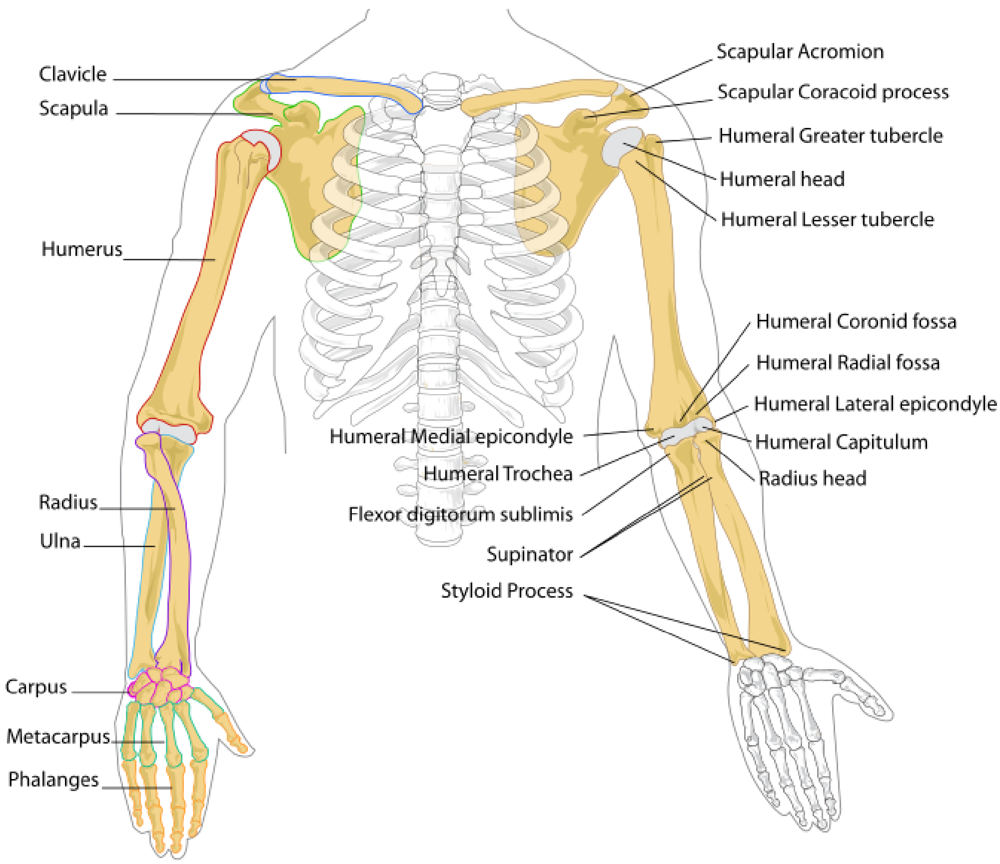


Figure 7.15: Skeletal framework of the arm and shoulder region.

Functions of pectoral girdle

- Forms a strong support structure for the attachments of the arms.
- Provides large area of bone for the attachment of muscles.
- Forms ball-and-socket joints with the arms which allows the arms to move freely.

FACT
The female pelvic girdle is wider and lighter than the male. This is an adaptation to allow for pregnancy and childbirth.

Pelvic girdle and the legs

The pelvic girdle consists of hip bones joined at the front by cartilage called the **pubic symphysis** and they are attached to the **sacrum** at the back. Each hip bone consists of three fused bones (ilium, ischium and pubis). Portions of all three bones contribute to the formation of the **acetabulum,** a deep socket into which the head of the femur (thigh bone) joins to form the hip joint.

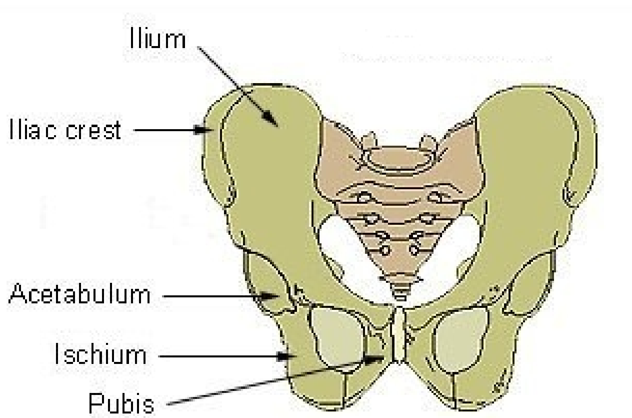


Figure 7.16: Skeletal framework of pelvic girdle.

The **femur** in the **leg** is the largest and strongest bone in the body. The upper end forms a ball and socket joint with the hip bone while the lower end articulates with the **tibia** to form the hinge joint of the knee. The **patella** or kneecap is a flat triangular bone which is embedded in the tendon of the thigh muscle and attached by a ligament to the tibia.

There are two bones in the lower leg: the **tibia** (shin bone) which is the larger of the two and supports most of the mass. The upper end articulates with the femur while the lower end articulates with one of the tarsal bones to form the ankle joint. The **fibula** (calf bone) is thinner than the tibia and serves mainly for the attachment of muscles. It is attached to the femur and is articulated to the top and bottom of the tibia.

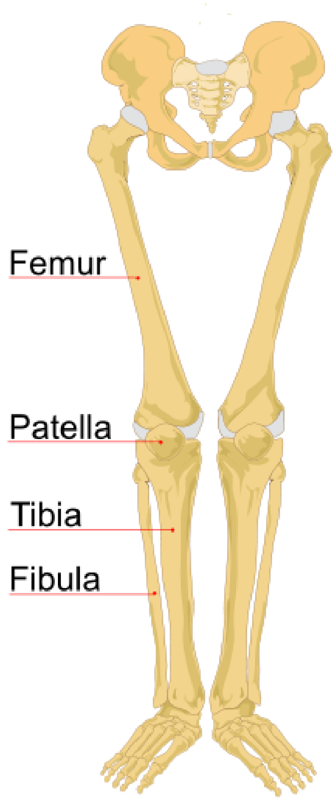


Figure 7.17: Skeletal framework of pelvic girdle and legs.

The structure of the foot is similar to that of the hand. However, the foot supports the weight of the body, so it is stronger and less mobile than the hand. There are seven **tarsals** or ankle bones, only one of which, the talus, articulates with the tibia. The talus us also know as the **ankle bone**.

The **heel bone** (calcaneum) is the largest of the tarsal bones and is the bone to which the calf muscle is attached. The heel bone presses firmly on the ground when one stands, walks or runs.

There are five **metatarsal bones** which form the ball and arch of the foot. The 14 **phalanges** of the toes are the counterparts of those in the fingers, with the big toe having two phalanges and the other four having three phalanges each. Together these structures consist of the bones form the **lower limb** shown in Figure 7.18.

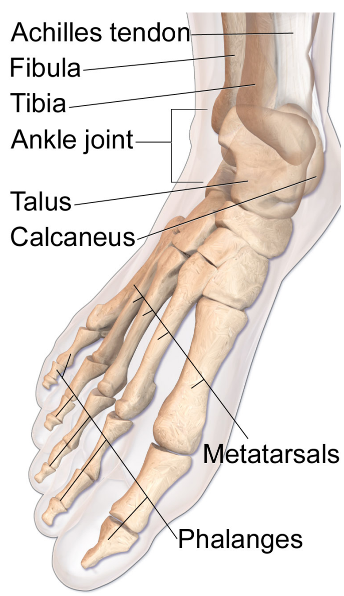


Figure 7.18: Bones of lower extremity.

Functions of skeleton ESG8B

The human skeleton is living and performs many functions in the body. Some important functions are summarised below:

1. **Movement:** Muscles attach to the bones of the skeleton, enabling movement.
2. **Protection:** The skull protects the brain, the ribcage protects the heart and lungs, and the pelvic bones protect the digestive tract and reproductive organs.
3. **Support:** Provides shape and support to the body.
4. **Storage of minerals:** Bones store minerals such as calcium and phosphate ions.
5. **Hearing:** Bones in the middle ear, called the hammer, anvil and stirrup, amplify sound waves and assist in the hearing process.
6. **Red blood cell production:** Long bones and flat bones contain red bone marrow to produce red blood cells.

Structure of long bone ESG8C

Although there are many different types of bones in the skeleton, we will discuss the different parts of a specific type of bone: the **long bone**. The femur, tibia and fibula in the leg, and the humerus, radius and ulna in the arm are all examples of long bones.

- **Epiphysis:** The head of each end of a long bone consists largely of spongy bone and is covered with hyaline cartilage.
- **Spongy bone**: Found in the epiphysis of long bones and contains red marrow.
- **Red bone marrow:** Found in the spaces between the trabeculae in spongy bone. This is where the red blood cells are made at the rate of 2 -3 million per second. White blood cell types are also produced here.
- **Trabeculae:** The struts in the network of irregular bony plates in the epiphysis of bones which transfer stresses from the epiphysis to the diaphysis which has a much thicker layer of compact bone and resists stress better.
- **Diaphysis:** Cylindrical shaft of a long bone composed of hard compact bone on the outside.
- **Periosteum:** The membrane of dense fibrous connective tissue which surrounds the outside surface of the shaft of a long bone. It has blood vessels which enables it to nourish the bone and repair injuries. It also provides a surface for the attachment of muscles by means of tendons and ligaments.
- **Endosteum:** The delicate connective tissue layer lining the inside surface of compact bone.
- **Marrow cavity:** This is filled with yellow marrow which consists largely of fat.

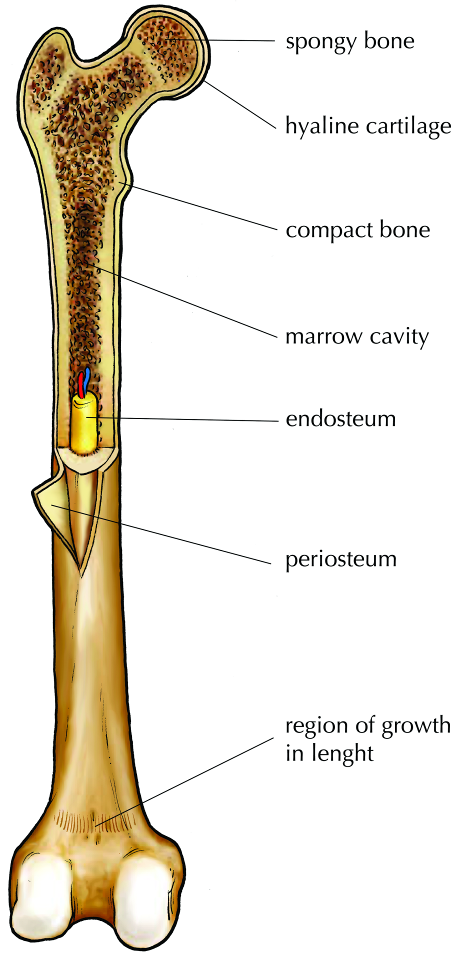


Figure 7.19: Longitudinal section showing parts of a long bone.

Activity: Draw and label a longitudinal section of a long bone

In this activity you need to draw and label the parts of a long bone.

Instructions:

Make sure that you follow all the guidelines for biological drawings:

1. Give your diagram a caption or heading
2. Your diagram must take up at least half a page
3. Your drawing should be in pencil
4. Label lines should be drawn with a ruler
5. Label lines should not cross

Investigation: Optional Investigation: Investigating organic and inorganic components of bones

Aim:

Experiment A: Remove the inorganic component of bone in order to investigate the organic component

Experiment B: Remove the organic component of bone in order to observe the properties of the inorganic component

WARNING!

Bunsen burner and methylated spirits: Wear safety goggles and no loose fitting clothes. Do not wear synthetic clothes that easily catch fire (cotton and wool clothes are preferable).

Hydrochloric acid: Wear closed shoes, safety goggles, a lab coat and gloves.

Apparatus:

Experiment A

- two small chicken bones
- two test tubes
- dilute hydrochloric acid/white vinegar

Experiment B

- towel
- one small chicken bone
- pipe clay triangle or wire gauze on a tripod stand
- bunsen burner or Methylated spirits burner

Method:

Experiment A

1. Label two test tubes with your initials and A and B. Put a bone in each test tube.
2. Cover Bone A with water and Bone B with dilute hydrochloric acid. Leave for a few days. The acid will dissolve out the mineral component of the bone leaving behind the organic part.
3. Take out Bone A and dry it.
4. Use tweezers to take Bone B out of the acid. Rinse it under the tap and dry it.
5. Compare the two bones and write down how they appear and whether they are soft or hard, flexible or brittle.

Experiment B

1. Place the chicken bone (Bone C) on a pipe triangle or wire gauze on a tripod stand.
2. Roast the bone strongly for 10 minutes. Roasting will burn off the organic component of bone (mainly the protein collagen) leaving behind the mineral part.
3. Allow the bone to cool down completely before you touch it.
4. Describe the appearance of Bone C stating whether it is soft or hard, flexible or brittle.

Observations:

Note down your observations in your lab notebook.

Conclusions:

What can you conclude about the different organic and inorganic components of bones?

Questions:

1. What are the main inorganic components of bone?
2. What changes have occurred in Bone A?
3. What properties have been removed from Bone B with the loss of its inorganic components?
4. Which deficiency disease can have similar effects on bones in children?
5. What is the role of Bone B in this experiment?
6. What protein makes up the main organic component of bone?
7. What changes took place in Bone C during the roasting process?
8. What properties have been removed from Bone C with the loss of its organic component?

7.4 Musculoskeletal tissues ESG8D

The tissues which provide structure to the body and enable movement are part of the **musculoskeletal** system. The tissues in the this system include the bones, cartilage, joint, tendons, ligaments and muscles. In this section we will examine each of these types of tissues, so that in the next section on locomotion, we can understand how these structures work together to bring about movement.

- **Bone**: hard mineralized tissue that determines the structure of the body and provides attachments for muscles.
- **Cartilage**: flexible connective tissue that is usually found in many areas of the body including the joints between bones.
- **Joints**: region where bones meet, a variety of joint types allow for a range of movements in a number of different planes.
- **Ligament**: tissue that connects bones to other bones.
- **Tendons**: fibrous connective tissue that connects muscle to bone and transfers the force generated by the muscles into skeletal movement.
- **Muscles**: made up of fibres that are capable of contraction and therefore capable of bringing about movement.

Bones ESG8F

Bones provide the framework and internal core structure for the attachment of muscles. Bone is a living rigid tissue which forms the support structures for the rest of the body. The process of bone formation is called ossification. The matrix of bone contains a dense arrangement of collagen fibres together with mineral salts of calcium, magnesium and phosphates. The calcium salts give bone its hardness and rigidity while collagen fibres give bones its flexibility and strength.

Microscopic structure of a long bone

Bones are made up of numerous hollow tunnels called **Haversian canals**. Haversian canals occur within the matrix of bone tissue and run **parallel** to the length of the bone. Each Haversian canal consists of a **nerve** to carry impulses, **blood vessels** to transport gases, food and wastes and a **lymph duct** to drain tissue fluid. Under the microscope they appear as black circles against a lighter background.

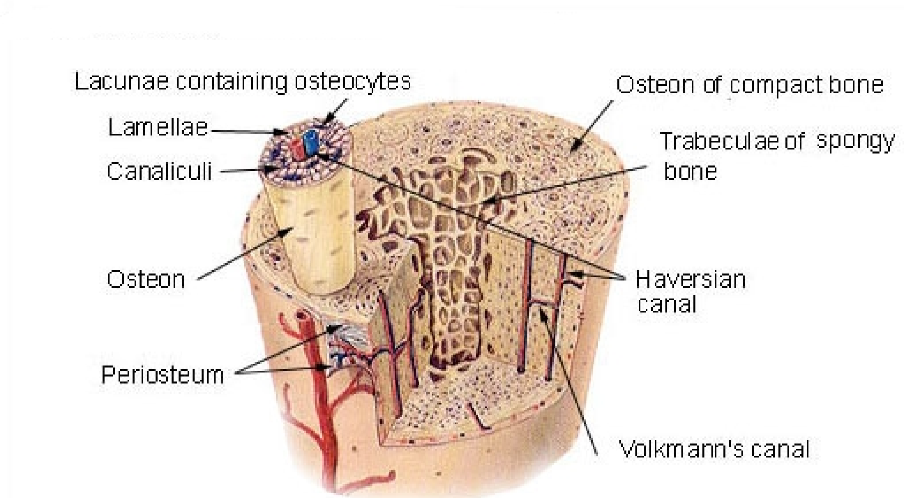


Figure 7.20: A diagram of a section of compact bone showing Haversian canals.

FACT
Apart from osteocytes which are embedded in the lacunae of bone there are two other types of bone cells.
Osteoblasts: Bone forming cells. These cells allow the bone to change and remodel its shape as the organism grows and responds to stresses. If a bone is broken or if strengthening is needed, bone cells lay down new tissue and repair damaged tissue
Osteoclasts: Special bone cells for destroying and reabsorbing bone tissue.

Each Haversian canal is surrounded by concentric rings of compact bone called **lamellae**. Each of these layers contains a ring of fluid-filled cavities called **lacunae**. Each of these lacuna will contain a number of bone cells called **osteocytes**. The lacunae are linked to each other and to the Haversian canal by a system of very tiny interconnecting canals called **canaliculi**. Strands of cytoplasm extend through these canals which supply the osteocytes with oxygen and nutrients and remove waste products. The Haversian canals, lacunae, osteocytes and canaliculi together form a unit called an Haversian System and a number of these systems make up compact bones.

Functions of bone

- To serve as a firm support framework for the whole body.
- To protect such delicate structures as the brain and spinal cord.
- To serve as levers, working with attached muscles to produce movement.
- To serve as a storehouse for calcium salts, which may be reabsorbed into the blood if there is not enough calcium in the diet.
- To produce blood cells in the red marrow.

Cartilage ESG8G

Cartilage is a tough semi-transparent flexible tissue that consists of a tough matrix or jelly-like substance. The matrix is made up of collagen (a protein) and proteins with special carbohydrate chains called proteoglycans. Cartilage is enclosed by a fibrous capsule called the perichondrium. It consists of living cells called chondrocytes which secrete a rubbery protein matrix called chondrin. Chondrocytes occur in small fluid-filled spaces called lacunae which are scattered throughout the matrix. There are no blood vessels or nerves in the matrix.

Cartilage	Appearance	Location	Function
Hyaline cartilage	glass-like, bluish-white, few fibres	at ends of bones, forms c-shaped structures in Trachea, joins ribs to sternum, larynx and tip of nose, temporary cartilage in bones	reduces friction at joints, allows movement of ribs during breathing, forms permanent structures, allows bones to increase in length
Fibrocartilage	many white collagen fibres	discs between the vertebrae, in the rim of ball and socket joints, between pubic bones	acts as shock absorbers, makes the socket deeper while still allowing movement
Elastic	many yellow fibres in matrix	in the pinna of the ear, in the epiglottis	maintains the shape of the ear, strengthens the epiglottis

Table 7.1: Appearance, location and function of different types of cartilage.

Cartilage and bone

Infant and young children do not have bones like those of adults. Their bones are made mostly of cartilage - a firm, elastic, fibrous material. As the individual grows and matures, the cartilage is gradually replaced by bone cells which deposit crystals of calcium carbonate and calcium phosphate. This process called **ossification** greatly increases the strength of the bone.

Joints ESG8H

A joint is a point at which two bones make contact. It allows movement in many planes.

1. **Fibrous joints**: Joins bones where no movement is allowed. An example of this includes the bones of your cranium (the skull).
2. **Cartilaginous joints**: These allow slight, restricted movement. An example is the discs between the vertebrae of the spine.
3. **Synovial joints**: These allow free movement in one or more directions. Examples include the joints of the pelvic and pectoral girdles. They also facilitate movements like standing, sitting, walking and running.

Another way of categorising joints is **movable** and **immovable** joints. Most joints in the skeleton are movable joints. Movable joints are also known as **synovial joints**. Synovial joints are characterised by the existence of capsules, which contain synovial fluid. The synovial fluid helps to prevent friction during movement.

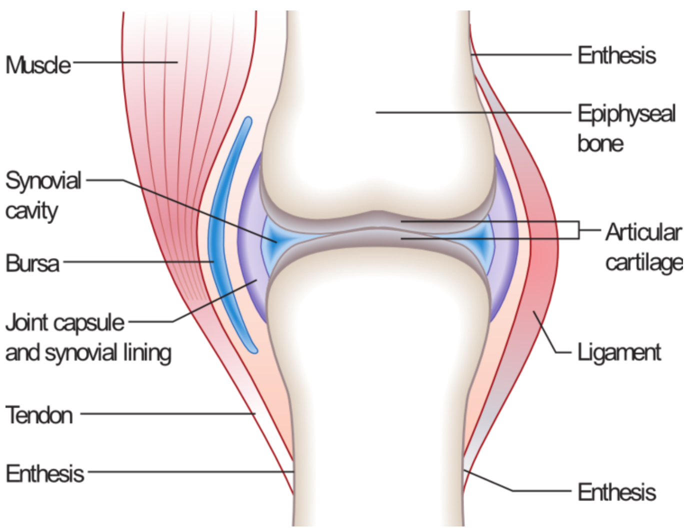


Figure 7.21: Example of a synovial joint.

There are a number of different types of synovial joints. The four main types of synovial joints include:

1. **Ball and socket joint**: Found in structures such as the shoulder. It allows forwards/backwards, up/down and roundabout movement.
2. **Hinge joint**: Found in structures such as the elbow. It allows the forearm to move up and down and acts like the hinge of a door.
3. **Pivot joint**: Allows turning of the head in a rotational movement from side to side.
4. **Gliding joint**: Found in the wrist and foot. It allows bones to slide over one another.

Activity: Movement at joints

Joints occur where two bones meet. Different types of joints allow for different types of movements. In this activity you will need to identify the different joint types, identify where they are located in the body and describe their motion.

Instructions:

For each of the following joints, you need to:

- give an example of their location in the body
- describe their motion

1. Fibrous joints
2. Ball and socket joints
3. Gliding joints
4. Hinge joints
5. Pivot joints

Tendons and ligaments ESG8J

Tendon and ligaments are dense bands of dense connective tissue. **Ligaments** join bone to bone, and **tendons** join muscles to bone. An example of a ligament is the anterior cruciate ligament (ACL) of the knee, and an example of a tendon is the Achilles tendon, which attaches your calf muscle to your heel. Tendons and ligaments are similar structures, but they have some important differences, which are summarised in Table 7.2.

Comparison of ligaments and tendons

Ligaments	Tendons
join bone to bone	attach muscles to bones
consist of white collagen fibres and a network of yellow elastic fibres	consist of non elastic collagen fibres which give tendons a white shiny appearance
strong collagen fibres prevent dislocation at joints, and yellow elastic fibres allow flexibility at the joint	parallel arrangement of strong collagen fibres in order to efficiently convert muscle contraction into movement of the skeleton

Table 7.2: Table comparing ligaments and tendons

Antagonistic muscles ESG8K

Voluntary muscles are normally connected to at least two bones. The point of attachment to the movable bone is called the point of **insertion** and the point of attachment of a muscle to the immovable bone is called the **origin**. Most muscles work in pairs and when a muscle works it needs to have an **agonist** and an **antagonist**.

An agonist is a muscle that acts to move a limb out of a particular position (contraction). An antagonist is a muscle that acts in opposition to the specific movement generated by the agonist and is responsible for returning the limb back to its original position (relaxation). Antagonistic pairs of muscles are necessary because each muscle can only exert a pulling force. A muscle cannot push itself back to its starting position. Therefore another muscle is required to pull in the opposite direction in order to return the agonist muscle back to its starting position. An example of this can be found in the contraction and relaxation of the biceps and triceps muscles when moving your forearm.

Example: Biceps and triceps

In the case of the biceps the two bones involved are the scapula (origin) and the humerus (insertion). The biceps muscle gets its name from having two tendons attached to the scapula. The tendons join to form a single muscle body, and then splits again into two tendons, one of which inserts at the radius, and the other of which inserts at the ulna. When the biceps muscle contracts, the forearm is lifted or bent, decreasing the angle between the forearm and humerus and flexing your arm. This ability of the biceps to decrease the angle between the joints results in it being called a **flexor** muscle.

FACT
The *biceps brachii* muscle gets its name from being a two-headed muscle, attaching to the scapula at two points. Although it is commonly referred to as a 'bicep', biceps is the correct form even in the singular. Similarly, the *triceps brachii* muscle joins at three points, and should be referred to as the triceps, whether you are talking about one or both arms.

FACT
The mechanics of the antagonism within the biceps and triceps.
See video: 2CT5

FACT
Learn more about antagonistic muscles: `http://www.botany.uwc.ac.za/Sci_Ed/grade10/manphys/skel_mus.htm`

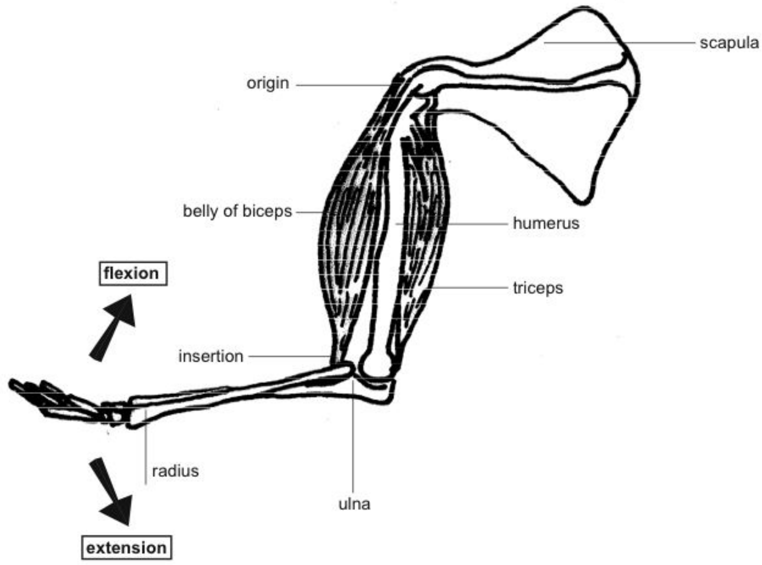


Figure 7.22: Illustration of the triceps (extensor) and biceps (flexor) muscles.

Straightening of the forearm

When the arm is bent the biceps cannot contract since it is already in a contracted state. Muscles can only cause movement by **pulling as they contract**, not by pushing when they relax. Therefore, the straightening of the arm is brought about by the contraction of the **triceps muscle** (an **extensor** muscle) as it increases the angle between forearm and humerus. The triceps has three points of origin, two on the humerus and one on the scapula, and a single point of insertion on the ulna.

Activity: Dissection of animal tissue

Aim:

The aim of this dissection is for you to revise the theory behind tissues and apply your knowledge to actual tissues.

Instructions:

You will be working in pairs. Instructions for this activity will be bulleted and written in *italics*. Questions for you to answer are numbered.

At the end of the practical you should:

1. Know and be able to use disse cting instruments correctly, especially insertion and removal of blades.
2. Be able to recognise and use ether responsibly.
3. Be familiar with apparatus.

4. Use a scale: zero (calibrate) and record mass.
5. Perform simple mathematical calculations such as percentage.
6. Be able to read a vernier calliper.
7. Clean and dry thoroughly and appropriately.

Materials:

- one piece filter paper
- scissors
- forceps
- threader
- pointer
- scalpel
- blade
- dissecting tray
- petri dish
- chicken wing
- 1 ml ether
- cloths
- roller towel

Method:

1. Skin

- *Before you begin, look at the external appearance of the chicken wing.*
- *Weigh the entire wing and record its mass in the table on the last page.*
- *Insert the scalpel blade onto the handle.*
- *Lie the wing upside down on the dissecting board.*
- *Cut with scissors from the severed end towards the wingtip along the midline of the wing.*
- *Remove as much of the skin as you can by freeing it from the underlying tissue with a blunt instrument or pulling with your fingers.*
- *Carefully observe the tissue that you are breaking.*

1. Is skin a tissue or an organ?
2. Why is there a 'web' of skin between the joints?
3. What are the 'bumps' on the skin?
4. How easily does the skin come off between the joints?
5. Where is the skin most firmly attached?
6. Record the mass of the skin in a table as shown on the last page.

2. Connective tissue

The skin is held to the underlying pink tissue by a type of connective tissue.

1. Name this particular type of connective tissue.
2. Give two adjectives that accurately describe it.

3. Fatty tissue

- *Look at the underside of the skin you have removed. You should see clumps of yellow material. This is fat, or* ***adipose tissue****. It is also a type of connective tissue.*
- *Take a small amount of this fatty tissue and squash it gently in a small beaker with some ether.*
- *Pour some of this solution onto a piece of filter paper.*
- *Dry the filter paper by waving it in the air.*
- *This oily stain is known as a* ***translucent*** *stain.*
- *From now on collect all the fatty material you find, as you will need it later (place in a separate beaker).*

1. What do you think the function of connective tissue is here?
2. What do you notice? There is an oily stain on the paper after the ether has evaporated.

4. Muscle

Muscle is the pinky-orange tissue you can see under the skin. The muscles were most likely severed when the chicken was dismembered in the butchery. Muscles are all arranged in 'antagonistic pairs' where the action of one muscle (e.g. flexion) causes the opposite action to occur in it's partner (e.g. contraction).

- *Hold the wing in your left hand.*
- *Grip the end of one of the muscles with forceps. Pull it.*
- *Describe what happens and name the type of action it caused.*
- *Let go and pull various other muscles.*
- *Can you get one to cause the opposite movement?*
- *Carefully dissect out a single muscle in FULL. Remove it from the wing completely.*

1. What type of tissue lies between the muscles?
2. Draw the wing muscle.
3. You need to follow the convention of drawing diagrams by:
   a) providing a heading or title.
   b) adding labels (tendon, muscle, epimysium, fat tissue).

c) labelling on the right hand side of the diagram.
d) providing a scale bar.

5. Blood vessels

The smallest **vessels** you will be able to see are small **arteries** (**arterioles**) and small **veins** (**venules**). **Capillaries** are the very smallest blood vessels — so narrow in fact that erythrocytes can only fit through in single file. It is only between these vessels and the surrounding tissues where **diffusion** of substances occurs. Capillaries will not be visible to the naked eye.

- *As you work, look out for blood vessels.*
- *The darker vessels are venules; the redder ones are arterioles.*
- *In the cut end of thicker vessels you may be able to see the* ***lumen*** *and vessel wall.*
- *If you find one, work the blunt end of the threader into it and down the vessel and see where it leads.*

1. Name two substances that will diffuse into the tissues and out of the tissues in this wing.

6. Nerves

Nerves are bundles of neurons enclosed in a membrane rather like a piece of electrical flex. They tend to be deep in the tissues for protection.

- *Keep a look out for nerves.*
- *Nerves are hard to see but when soaked in ethanol they become white (If possible check with your teacher if he or she can do this for you).*

7. Tendons

Muscles are attached to bones by means of tendons. Tendons are made of a type of connective tissue that contains lots of white fibres made of collagen. It is this collagen that gives the connective tissue its properties.

- *Your task now is to remove all the muscles neatly from the bones.*
- *As you do so, try and pull one or two off the bone using your fingers or forceps; remove the rest using scissors or the scalpel.*
- *Look carefully at how the tendon joins the muscle.*
- *If necessary dissect into the muscle tissue.*
- *Collect ALL the muscles you remove.*
- *You should now have a pile of fat and a pile of muscle.*
- *Weigh and record the mass of subcutaneous fat and muscle in the table where you recorded the mass of the wing.*

1. How firmly are the muscles attached to bones?
2. Approximately how many muscles did you remove?
3. Describe how the tendon and muscle join.
4. Write down four adjectives to describe collagen from what you can observe.

8. Bone

- *You should now be left with some bones joined together with skin, muscles and 'proper' connective tissue removed.*
- *Use the miniature hacksaw to cut a bone in half.*

1. Describe what you see after sawing the bone in half.
2. Use the vernier calliper to measure the thickness of the bone wall.
3. The bones of most birds are hollow. Why are hollow bones an advantage for a bird?

9. Ligaments

Ligaments look similar to tendons and have a very similar histology with lots of collagen fibres. Ligaments join bone to bone, and also form protective capsular ligaments around synovial joints by for instance, keeping in the lubricating synovial fluid.

- *Cut through and carefully remove the capsular ligament of a large joint using your scissors.*

1. Can you see internal ligaments?
2. Write down three observable characteristics of the ligament you cut.

10. Cartilage

- *Look at the end of a bone and find the cartilage (it is pearly white in colour).*
- *Try to remove it from the bone. Then try to scratch it first with your nail and, then with something very hard and sharp.*

1. Describe what you observe.
2. What type of cartilage is this?
3. What do you think the function of cartilage is?
4. What common, man-made material is closest in its properties to cartilage?

Questions:

Data (show all working)

Tissue	Mass, correct to 1 decimal place (g)
Entire wing	
Skin	
Muscle	
Subcutaneous Fat	

1. Muscle is eaten for its protein. Muscle is made of protein. What percentage of this wing is muscle?
2. What total percentage of this wing was made up of fat?
3. Calculate the total fat-to-muscle ratio as a percentage.
4. Look at the price per kilo for these wings. Assuming the wings have the same mass, and there are 6 per pack, how much does one wing cost?
5. You are paying the above price only to really eat the muscle (protein), what is the actual price per kilo you are paying for the meat (protein) in this case?

Cleaning:

Tidy and clean the work station thoroughly after each session. Wash instruments in hot soapy water with a sponge/scourer, rinse in the cold sink (NOT under running water) and dry with a cloth. Replace apparatus in the correct containers. Scalpel blades are to be removed, cleaned, dabbed dry with roller-towel and returned to their envelopes.

7.5 Human locomotion ESG8M

Locomotion refers to the ability to move. Specifically, it refers to the way in which organisms travel from one place to another. Examples of types of locomotion include running, swimming, jumping or flying. Human locomotion is achieved by the use of our limbs. Below we discuss the major organs and structures that bring about movement in humans.

FACT
Watch this video and learn about the amazing ways that human bones, muscles and tendons have adapted for long-distance running.
See video: 2CT6

FACT
How muscles work: the sliding filament model
See video: 2CT7

Figure 7.23: A marathon event in progress: this locomotion is facilitated by the skeletal framework described in this section.

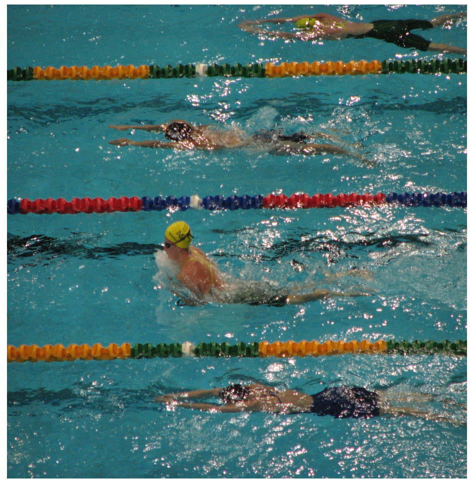


Figure 7.24: Swimmers taking part in a gala.

The structures used during locomotion include:

1. **Bones** provide the body's supporting structure. They provide the framework that help maintain the body's shape and provide a surface for the attachment of muscles.
2. **Joints** are points of contact between individual bones. They allow bones to move against and past each other to enable movement.
3. **Ligaments** connect bones the ends of bones together in order to form a joint. Most ligaments limit dislocation, or prevent certain movements that could form breaks. They hold bones in place so that they work in a coordinated manner.
4. **Tendons** connect muscle to bone. They transfer the force generated by muscle contraction into movement of the skeleton.
5. **Muscles** work in antagonist pairs to cause bones to move. Muscles are attached to bone via the tendon. Therefore as the muscle contracts, the bone moves.

7.6 Muscle structure and function ESG8N

You learnt about three types of muscle tissue (skeletal, smooth and cardiac) in Chapter 4. In this chapter, we will look at **striated** or **skeletal muscle**. Skeletal muscle is voluntary muscle which means it can be controlled by will.They are the muscles that you use to enable you to run, skip, walk etc.

The basic units of a muscle are called myofibrils. Myofibrils make up the muscle fibre (muscle cell). Numerous muscle fibres are found in bundles. These bundles are surrounded by perimysium. Several of these together make up the fasciculus. Numerous fasciculi are surrounded by epimysium. These structures combine to form a muscle.

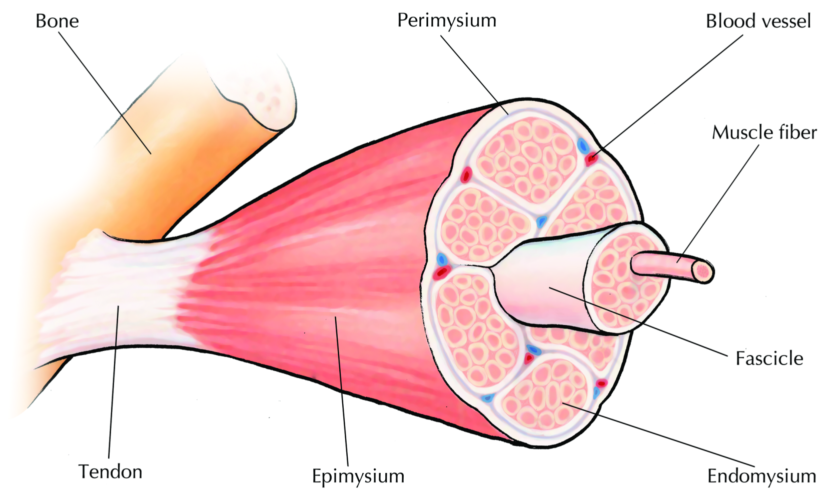


Figure 7.25: Different structural components of the voluntary muscle.

FACT
Watch a video about the anatomy of a muscle cell:
See video: 2CT8
Learn more about myosin and actin:
See video: 2CT9
Learn about the role of sarcoplasmic reticulum in muscle cell:
See video: 2CTB

FACT
ATP stands for adenosine triphosphate. It is the energy reserve of the body.

Muscle contraction

Each muscle cell (muscle fibre) is made up of many **myofibrils**. Myofibrils are responsible for the muscle contraction. Each myofibril consists of units called **sarcomeres**. There are many sarcomeres joined end to end in each myofibril. Sarcomeres consist of **thin actin** filaments and **thick myosin** filaments.

When muscle fibres contract these filaments slide across each other. The actin filaments shorten, but the length of the myosin filaments do not change. This causes the sarcomeres to shorten, resulting in the shortening of the whole muscle. The contraction of the muscle fibres requires energy in the form of ATP. The energy is supplied by the process of cellular respiration.

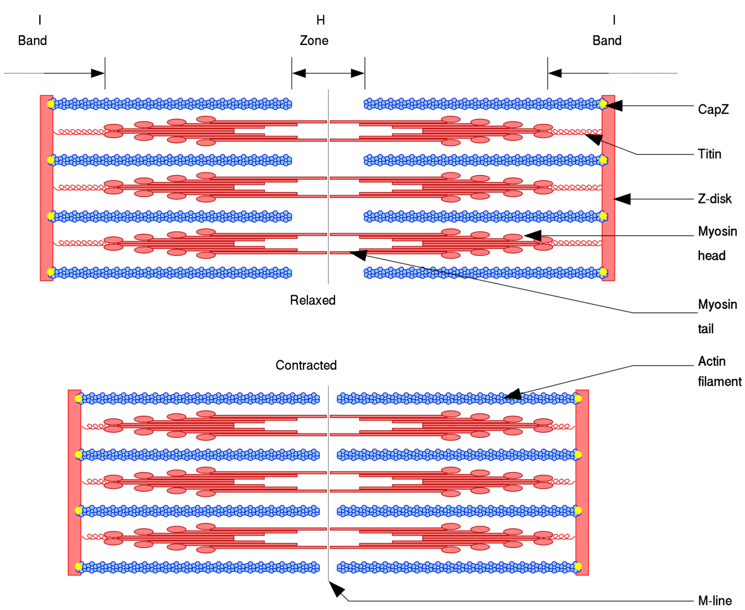


Figure 7.26: Diagram showing a sarcomere made up up thick and thin filament that slide past each other to enable muscle contraction.

FACT
Summary of the workings of the muscle:
See video: 2CTC
See video: 2CTD

FACT
Osteoporosis is derived from the Greek words for bone (*ostoun*), and pore (*poros*). It is common in older people, especially women.

FACT
Osteoporosis is common in older women whose oestrogen levels drop after menopause. Oestrogen usually suppresses osteoclast activity (bone resorption). When oestogen levels drop, the activity of osteoclasts is no longer inhibited and bone breakdown exceeds bone formation. This results in an overall loss of bone mass.

7.7 Diseases ESG8P

As a result of wear-and-tear over time and due to lack of proper nutrition, individuals can develop bone problems. Common bone problems include rickets, osteoporosis and arthritis.

Rickets ESG8Q

Rickets is a disease that is most commonly caused by a lack of vitamin D, however it can also be caused by deficiencies in phosphorous or calcium. Deficiencies in these key nutrients results in a softening of the bone tissue, leading to fractures and bone deformities in children. Rickets is a widespread childhood disease in many developing countries.

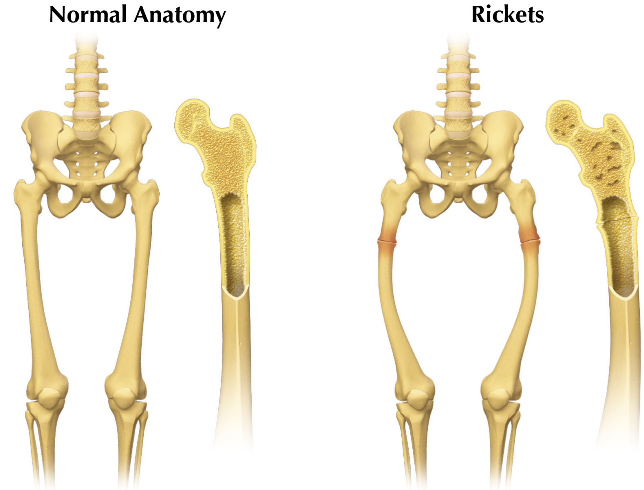


Figure 7.27: The diagram shows the difference between a normal patient and a rickets patient.

Osteoporosis ESG8R

Bones are constantly being broken down by osteoclasts and built up by osteoblasts. When the process of breakdown and deposition are evenly matched bone mass is maintained. However, when there is a shortage of calcium in the body or when a bone is inactive (e.g leg in plaster or immobilised), calcium is withdrawn from the bone for use in other parts of the body. This results in an increased breakdown of bone tissue without an increase in deposit of new bone by **osteoblasts**. Excessive breakdown without new bone deposition results in the development of holes/pores in the bone (hence the name of the disease). A decrease in bone density makes the bone weak and prone to fractures. The most typical fractures are of the spine, wrist and hip.

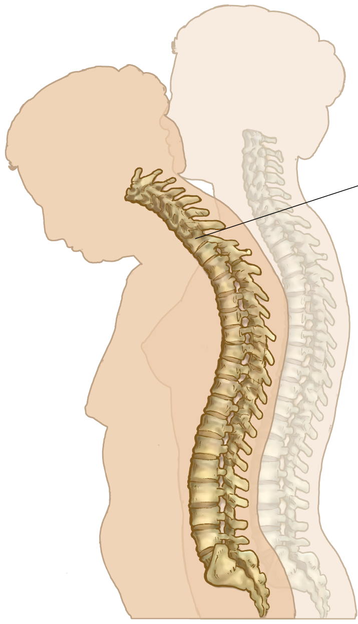


Figure 7.28: Pictures illustrating the onset of osteoporosis.

FACT
Visualise osteoarthritis
See video: 2CTF

Arthritis ESG8S

Arthritis is a diseases caused by disorders of joints or inflammation of them. There are several types of arthritis. The hand of an individual affected by a particular form of arthritis called rheumatoid arthritis can be seen in Figure 7.29. It is caused by an individual's cells being attacked by their own immune system and is known as an **auto-immune disorder**. The immune system attacks the body tissues and most damage occurs in the cartilage found between joints.

Figure 7.29: The hands shown have been affected by arthritis.

Arthritis can also be caused by the daily wear-and-tear of a joint, when bones constantly rub against each other. It can affect the hands, the knee, feet, hip and back. It usually affects the elderly but can also result from an injury. The disease can also result from a lifestyle characterised by lack of exercise. Arthritis cannot be cured. However, in rare cases joint replacement is available.

7.8 Summary ESG8T

- There are three types of skeletons:
  1. Hydrostatic skeleton
  2. Endoskeleton
  3. Exoskeleton
- When animals moved from water to land, there was a need for the development of strong limbs and a skeleton to provide support to the bodies, which had previously been provided by water.
- Humans have an endoskeleton consisting of:
  1. Axial skeleton (cranium, facial bones, foramen magnum, palate and jaws, vertebral column, rib cage and breastbone/sternum)
  2. Appendicular skeleton (pectoral girdle with arms and pelvic girdle with legs)
- Functions of the human skeleton are:
  1. Movement
  2. Protection
  3. Support
  4. Storage of minerals
  5. Hearing
- The tissues associated with the human skeleton are bone, cartilage, tendons and ligaments.
- Joints

  A joint is formed when two or more bones come into contact.

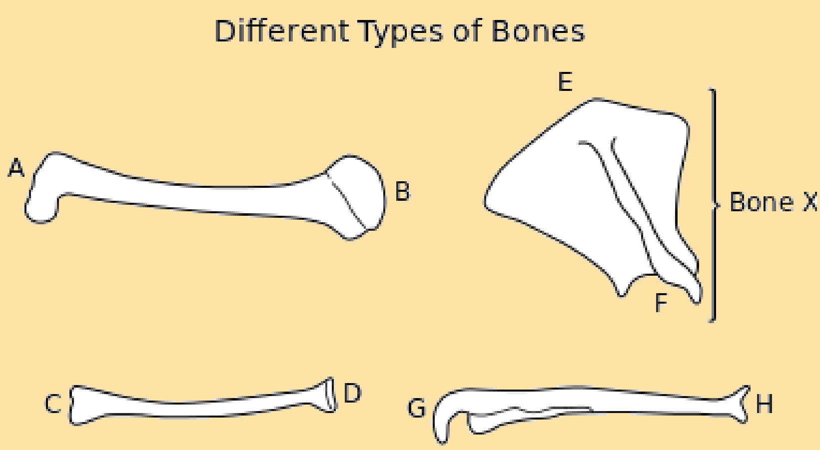
  There are three types of joints:
  1. Immovable joints
  2. Partly movable joints
  3. Synovial joints (Hinge joints, ball and socket joints, pivot joints, gliding joints)
- Human locomotion requires the use and coordination of bones, joints, ligaments, tendons and antagonistic muscles.
- Muscles

  There are three types of muscle tissue:
  1. Smooth/involuntary
  2. Skeletal/voluntary
  3. Cardiac muscle

  Myofibrils are responsible for muscle contraction.
- There are many diseases that affect the skeleton, such as rickets, osteoporosis and arthritis.

Exercise 7 – 1: End of chapter exercises

1. Draw a table showing the three types of skeletons and provide one advantage and one disadvantage of each.
2. State where the Haversian canal is located and state its function.
3. State four functions of bone tissue.
4. Tabulate two differences between tendons and ligaments.
5. Supply the biological term for each of these bones:
    a) thigh bone
    b) knee cap
    c) shin bone
    d) ankle bone
    e) heel bone
    f) upper arm bone
    g) wrist bones
    h) breast bone
6. State **four** functions of the human skeleton.
7. State the number of:
    a) bones in the human vertebral column
    b) pairs of true ribs
    c) lumbar vertebrae
8. Study the following diagrams showing the main bones of the pectoral girdle and the human arm (forelimb) and answer the questions that follow:



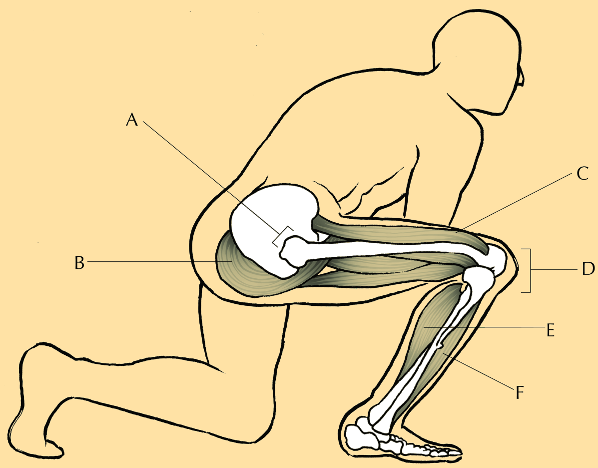
    a) Identify bone X.
    b) Parts of some of these bones meet at certain joints. By using the letters (A–H) only, state which parts of the bones form the shoulder joint.
    c) Name the type of synovial joint that is located at the following parts of the body:

i. At the elbow

ii. Where the lower limb joins the pelvis

iii. In the wrist

9. The diagram below shows the legs of an athlete while he is waiting for a race to start. The letters A to F show some of the muscles as well as joints that will be used during the race.



a) When the Starter's gun is fired, the athlete's right leg will straighten, pushing the athlete upwards and forwards. Which of the letters (A to F) indicate muscles that will:

i. relax

ii. contract

b) The leg shown in the diagram has different types of joints. Which of the following letters (A to F) indicates:

i. a hinge joint

ii. a ball and socket joint

10. During the race, the above athlete suffered an injury to his right knee that resulted in torn ligaments. As a consequence, he was not allowed to participate in competitions for six weeks, and was only paid one third of his monthly income during this time.

a) What are ligaments?

b) Do you think that athletes who are unable to take part in competitions due to injury should be entitled to their full income? Give a reason for your answer.

c) After six weeks the athlete found out that the knee injury was permanent. He had surgery to fit in an artificial knee, which could perform better than his original knee. Suggest why he should **not** be allowed to participate in the competitions he took part in previously.

11. Skeleton and Movement – True or False? If it is false provide a reason for why you think the statement is false.

a) The skeleton's role is to provide support, protection and capacity for movement.
b) The skeleton is divided into the axial and appendicular skeleton.
c) The axial skeleton consists of the pectoral and pelvic girdles and their attached limbs.
d) Carpals are found in the ankles and tarsals in the wrists.
e) The biceps muscle raises the arm while the triceps lowers it in an antagonistic pair.
f) Synovial liquid lubricates joints and keeps them friction free.
g) Bone joints in the cranium are examples of fibrous joints.
h) The neck contains 7 lumbar vertebrae.
i) Tendons join muscles to bone and are elastic while ligaments join bone to bone and are non-elastic.
j) Bone is composed of flexible minerals such as Calcium and Phosphate with rigid fibres of Collagen.
k) Osteocyte is another word for bone cell.

12. Compare the biceps and triceps muscles with respect to:
    a) Point of origin
    b) Point of insertion
    c) Function

Check answers online with the exercise code below or click on 'show me the answer'.

1. 2CTG 2. 2CTH 3. 2CTJ 4. 2CTK 5. 2CTM 6. 2CTN
7. 2CTP 8. 2CTQ 9. 2CTR 10. 2CTS 11. 2CTT 12. 2CTV

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CHAPTER 8

Transport systems in animals

8.1 Overview ESG8V

Introduction ESG8W

All living organisms require oxygen and nutrients, and a method of removing carbon dioxide and waste products. However, the circulatory system is not limited to the delivery of nutrients, gas exchange, and waste removal. Hormones, too, rely on the circulatory system to reach target organs, and the immune system depends on the transport of white blood cells and antibodies. This chapter discusses transport systems found in mammalian systems, with a focus on transport systems found in humans.

Key concepts

- There are open and closed circulatory systems. In an open circulatory system blood enters a cavity, in a closed circulatory system blood remains in vessels.
- A double closed circulation system consists of the pulmonary and systemic circulatory systems.
- The direction of blood flow is significant. In the systemic circulatory system oxygenated blood is transported to the body and deoxygenated returns to the heart. In the pulmonary circulatory system, deoxygenated blood is sent to the lungs, and oxygenated blood is returned to the heart.
- Specialised cells (sinoatrial node) send signals to the atrioventricular node to cause the atria and ventricles to contact and control the cardiac cycle and heart rate.
- The structure of blood vessels such as arteries, veins and capillaries are suited to their function.
- The lymphatic system transports lymph around the body and returns fluid to the blood circulatory system.
- The lymphatic system also plays an important role in immunity.
- Conditions and diseases of the heart and circulatory system include high and low blood pressure, heart attacks and strokes. Treatments include stents, valve replacements, bypass surgery, pacemakers, and heart transplants.

8.2 Circulatory systems in animals ESG8X

Transport systems are crucial to survival. Unicellular organisms rely on simple **diffusion** for transport of nutrients and removal of waste. Multicellular organisms have developed more complex **circulatory** systems.

Open and closed circulation systems ESG8Y

There are two types of circulatory systems found in animals: **open** and **closed** circulatory systems.

Open circulatory systems

In an open circulatory system, blood vessels transport all fluids into a cavity. When the animal moves, the blood inside the cavity moves freely around the body in all directions. The blood bathes the organs directly, thus supplying oxygen and removing waste from the organs. Blood flows at a very slow speed due to the absence of smooth muscles, which, as you learnt previously, are responsible for contraction of blood vessels. Most invertebrates (crabs, insects, snails etc.) have an open circulatory system. Figure 8.1 shows a schematic of an open circulatory system delivering blood directly to tissues.

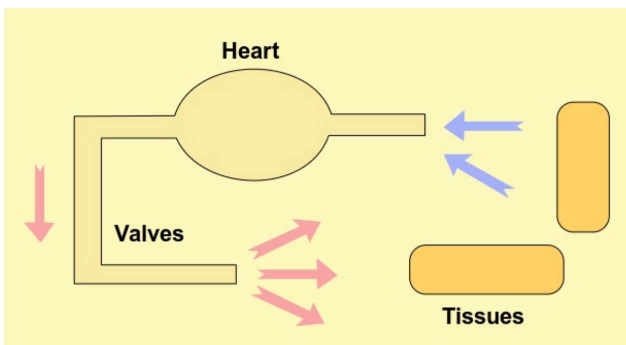


Figure 8.1: Open circulatory system.

Closed circulatory systems

Closed circulatory systems are different to open circulatory systems because blood never leaves the blood vessels. Instead, it is transferred from one blood vessel to another continuously without entering a cavity. Blood is transported in a single direction, delivering oxygen and nutrients to cells and removing waste products. Closed circulatory systems can be further divided into **single** circulatory systems and **double** circulatory systems.

Single and double circulation systems ESG8Z

The circulatory system is a broad term that encompasses the **cardiovascular** and **lymphatic** systems. The lymphatic system will be discussed later in this chapter. The cardiovascular system consists of the heart (cardio) and the vessels required for transport of blood (vascular). The vascular system consists of arteries, veins and capillaries. Vertebrates (animals with backbones like fish, birds, reptiles, etc.), including most mammals, have closed cardiovascular systems. The two main circulation pathways in invertebrates are the **single** and **double** circulation pathways.

Single circulatory pathways

Single circulatory pathways as shown in the diagram below consist of a double chambered heart with an atrium and ventricle (the heart structure will be described in detail later in this chapter). Fish possess single circulation pathways. The heart pumps deoxygenated blood to the gills where it gets oxygenated. Oxygenated blood is then supplied to the entire fish body, with deoxygenated blood returned to the heart.

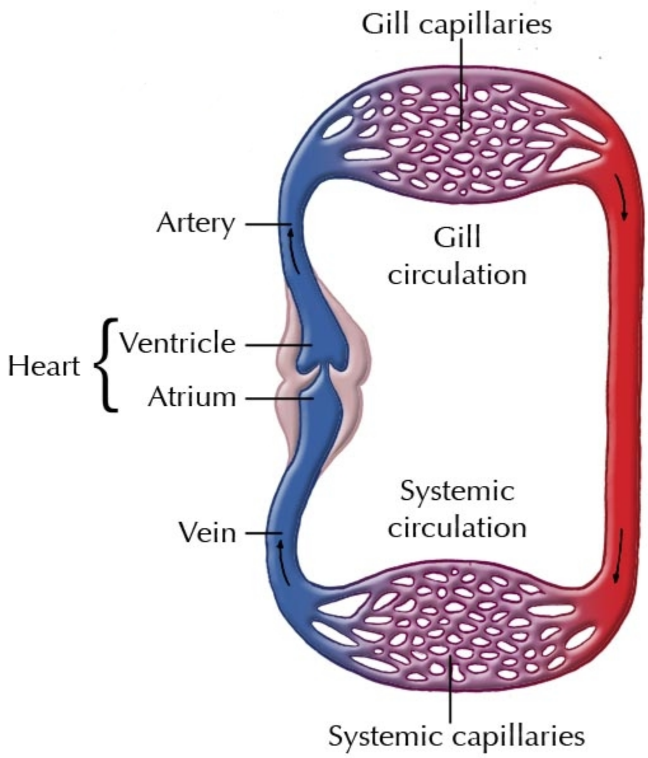


Figure 8.2: Single circulation system as found in a typical fish species. The red represents oxygen-rich or oxygenated blood, the blue represents oxygen-deficient or deoxygenated blood.

Double circulatory systems

Double circulation pathways are found in birds and mammals. Animals with this type of circulatory system have a four-chambered heart.

FACT
Humans, birds, and mammals have a four-chambered heart. Fish have a two-chambered heart, one atrium and one ventricle. Amphibians have a three-chambered heart with two atria and one ventricle. The advantage of a four chambered heart is that there is no mixture of the oxygenated and deoxygenated blood.

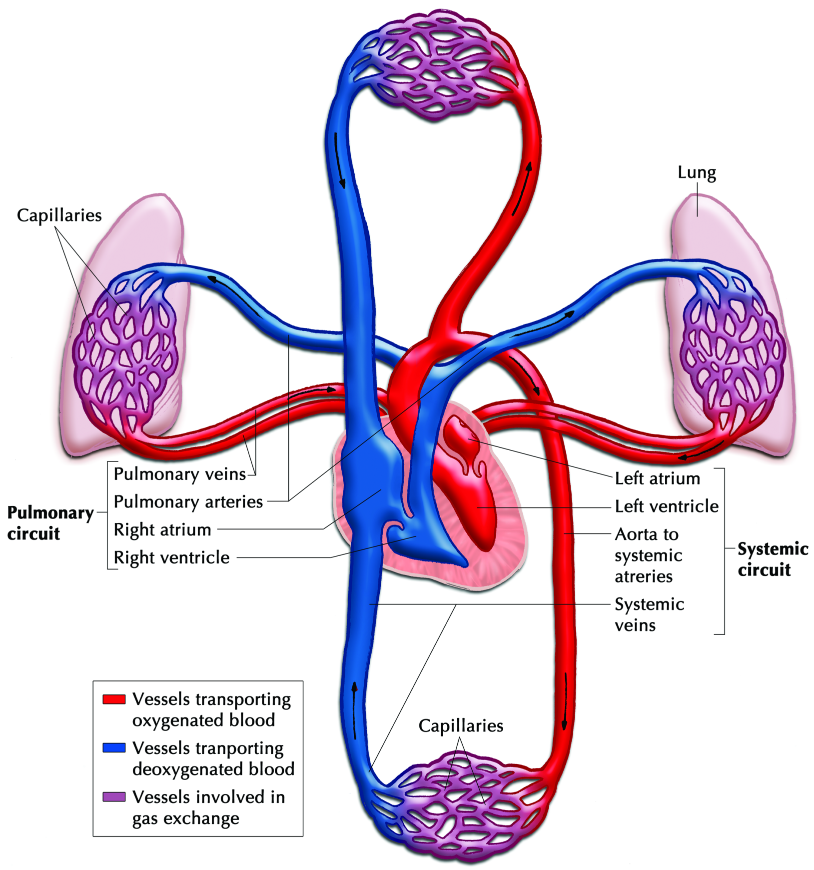


Figure 8.3: Double circulation system showing pulmonary and systemic circuits.

The right atrium receives deoxygenated from the body and the right ventricle sends it to the lungs to be oxygenated. The left atrium receives oxygenated blood from the lungs and the left ventricle sends it to the rest of the body. Most mammals, including humans, have this type of circulatory system. These circulatory systems are called 'double' circulatory systems because they are made up of two circuits, referred to as the **pulmonary** and **systemic** circulatory systems.

Human circulatory systems ESG92

The human circulatory system involves the **pulmonary** and **systemic** circulatory systems. The **pulmonary circulatory system** consists of blood vessels that transport deoxygenated blood from the heart to the lungs and return oxygenated blood from the lungs to the heart. In the **systemic circulatory system**, blood vessels transport oxygenated blood from the heart to various organs in the body and return deoxygenated blood to the heart.

FACT
A simulation that shows how the human circulatory system is divided into two circuits: the systemic and the pulmonary circulatory systems: http://www.biologyinmotion.com/cardio/index.html

Pulmonary circulation system

In the pulmonary circulation system, deoxygenated blood leaves the heart through the right ventricle and is transported to the lungs via the **pulmonary artery**. The pulmonary artery is the only artery that carries deoxygenated blood. It carries blood to the capillaries where carbon dioxide diffuses out of the blood into the **alveoli** (lung cells) and then into the lungs, where it is exhaled. At the same time, oxygen diffuses into the alveoli, and then enters the blood and is returned to the left atrium of the heart via the **pulmonary vein**.

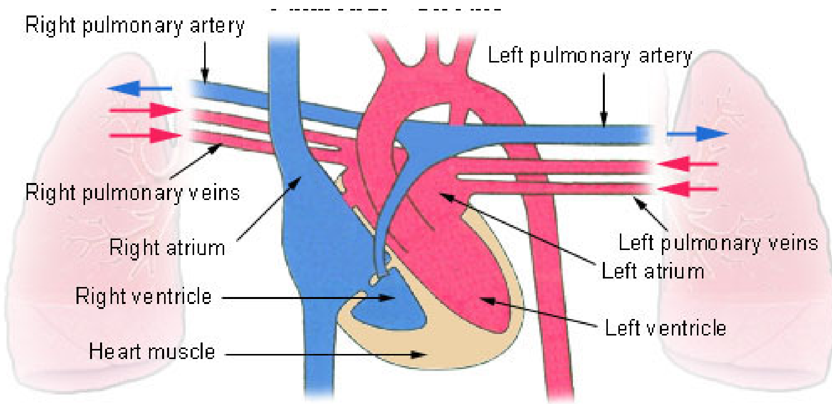


Figure 8.4: Pulmonary circulation system. Oxygen rich blood is shown in red; oxygen-depleted blood is shown in blue.

Systemic circulation

Systemic circulation refers to the part of the circulation system that leaves the heart, carrying oxygenated blood to the body's cells, and returning deoxygenated blood to the heart. Blood leaves through the left ventricle into the **aorta**, the body's largest artery. The aorta leads to smaller arteries that supply all organs of the body. These arteries finally branch into capillaries. In the capillaries, oxygen diffuses from the blood into the cells, and waste and carbon dioxide diffuse out of cells and into blood. Deoxygenated blood in capillaries then moves into venules that merge into veins, and the blood is transported back to the heart. These veins merge into two major veins, namely the **superior vena cava** and the **inferior vena cava** (Figure 8.9). The movement of blood is indicated by arrows on the diagram. The deoxygenated blood enters the right atrium via the the superior vena cava. Major arteries supply blood to the brain, small intestine, liver and kidneys. However, systemic circulation also reaches the other organs, including the muscles and skin. The following diagram (Figure 8.5) shows the circulatory system in humans.

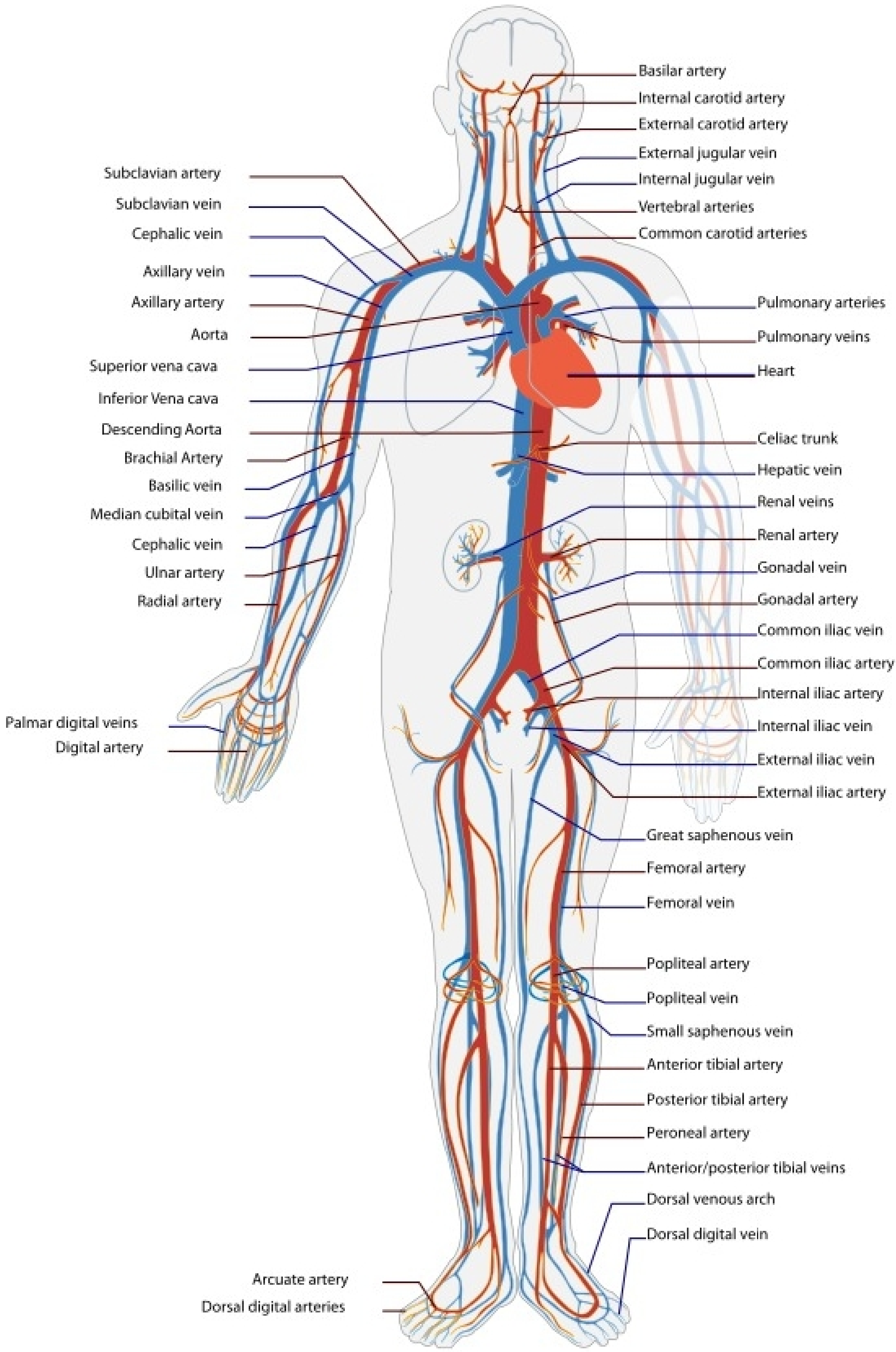


Figure 8.5: The systemic circulatory system supplies blood to the entire body.

FACT
Clench your fist - the size of your fist is more or less the size of your heart.

The heart and associated blood vessels ESG93

External structure of the heart

The heart is a large muscle, about the size of your clenched fist, that pumps blood through repeated rhythmic contractions. The heart is situated in your thorax, just behind your breastbone, in a space called the **pericardial cavity**. The heart is enclosed by a double protective membrane, called the **pericardium**. The region between the two pericardium layers is filled with **pericardial fluid** which protects the heart from shock and enables the heart to contract without friction.

The heart is a muscle (**myocardium**) and consists of four chambers. The upper two chambers of the heart are called **atria** (singular = atrium). The two atria are separated by the inter-atrial septum. The lower two chambers of the heart are known as **ventricles** and are separated from each other by the interventricular septum. The ventricles have more muscular walls than the atria, and the walls of the right ventricle, which supplies blood to the lungs is less muscular than the walls of the left ventricle, which must pump blood to the whole body.

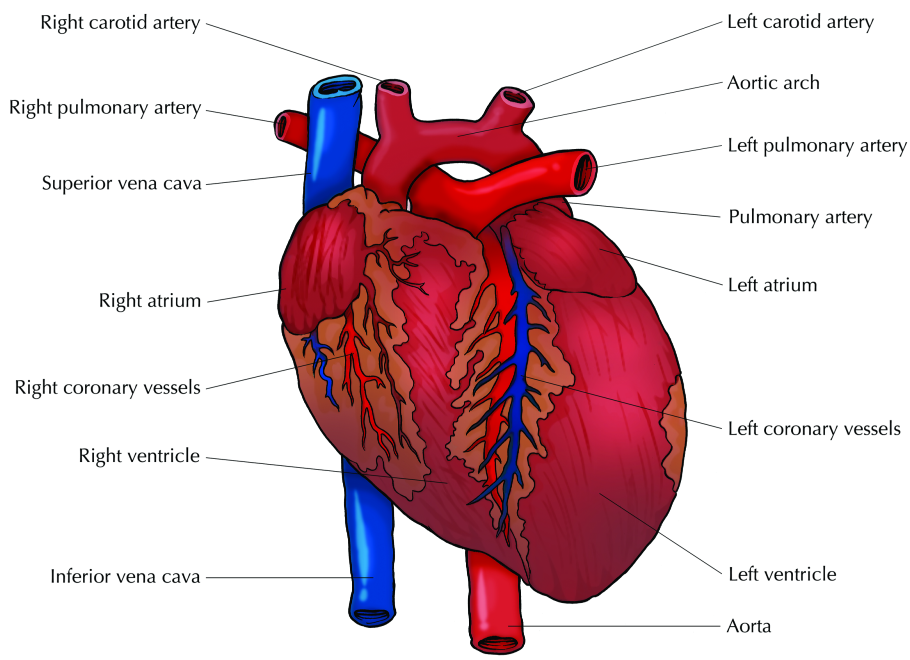


Figure 8.6: The external structure of the heart: the major part of the heart consists of muscles and is known as the myocardium. The region in which the heart is found is known as the pericardial cavity, which is enclosed by the pericardium.

In addition, there are a number of large blood vessels that carry blood towards and away from the heart. The terms 'artery' and 'vein' are not determined by what the vessel transports (oxygenated blood or deoxygenated) but by whether the vessel flows to or from the heart.

Arteries take blood away from the heart and generally carry oxygenated blood, with the exception of the pulmonary artery. **Veins** transport blood towards the heart and generally carry deoxygenated blood, except the pulmonary vein. On the right side of the heart, the **superior vena cava** transports deoxygenated blood from the head and arms and the inferior vena cava transports deoxygenated blood from the lower part of the body back to the heart, where it enters the right atrium. The **pulmonary artery** carries deoxygenated blood away from the right ventricle of the heart towards the lungs to be oxygenated.

FACT
In humans, the left lung is smaller than the right lung to make room in the chest cavity for the heart.

On the left side of the heart, the **pulmonary vein** brings oxygenated blood from the lungs towards the left atrium of the heart and the oxygenated blood exits the left ventricle via the **aorta** and is transported to all parts of the body.

Since the heart is a muscle, and therefore requires oxygen and nutrients itself to keep beating, it receives blood from the **coronary arteries**, and returns deoxygenated blood via the **coronary veins**.

Internal structure of the heart

As previously mentioned, the heart is made up of **four chambers**. There are **two atria** at the top of the heart which receive blood and **two ventricles** at the bottom of the heart which pump blood out of the heart. The **septum** divides the left and right sides of the heart.

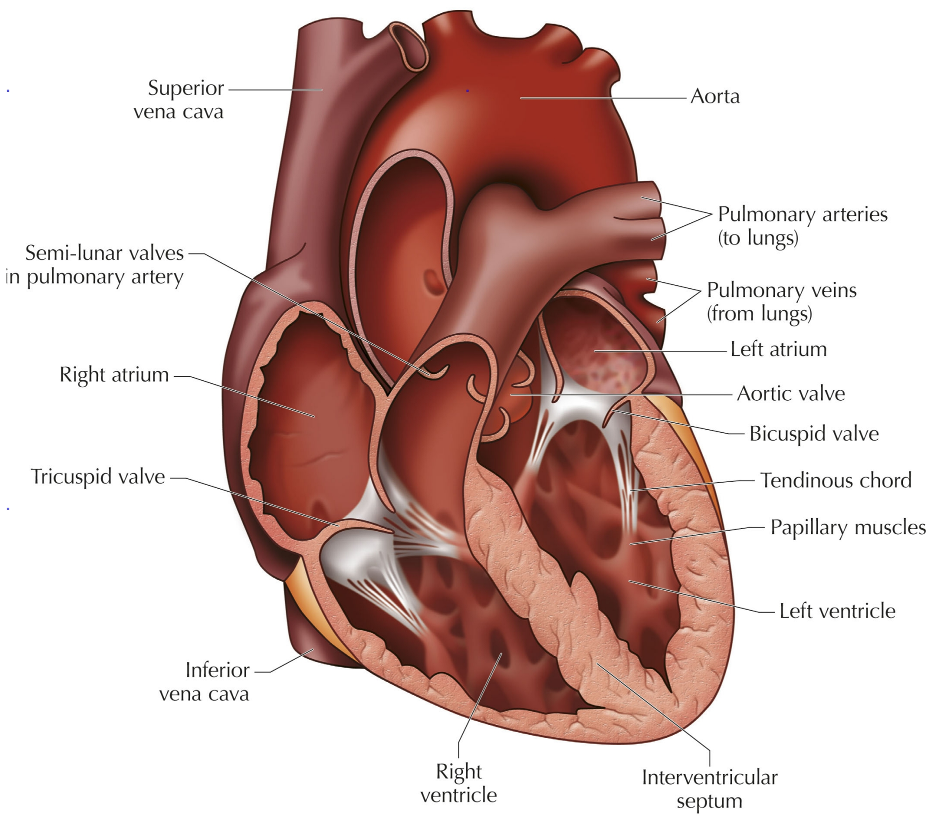


Figure 8.7: The internal structure of the mammalian heart.

FACT
This video shows the passage of blood through the heart and around the body.
See video: 2CTW

FACT
Memory trick: the t**RI** cuspid valve is found on the **RI**ght side of the heart.

In order to make sure that blood flows in only one direction (forward), and to prevent backflow of blood, there are valves between the atria and ventricles (atrioventricular valves). These valves only open in one direction, to let blood into the ventricles, and are flapped shut by the pressure of the blood when the ventricles contract.

The **tricuspid valve** is situated between the right atrium and the right ventricle while the **bicuspid/ mitral valve** is found between the left atrium and the left ventricle. Strong tendinous cords (*chordae tendineae*) attached to valves prevent them from turning inside out when they close. The **semi-lunar valves** are located at the bottom of the aorta and pulmonary artery, and prevent blood from re-entering the ventricles after it has been pumped out of the heart.

In the previous sections we have discussed pulmonary and systemic circulation, and we have described the four chamber structure of the heart as well as some of the major arteries and veins that transport blood towards and away from the heart. In order to summarise all this information, study the flow diagram below which describes the passage of deoxygenated blood through one full cycle.

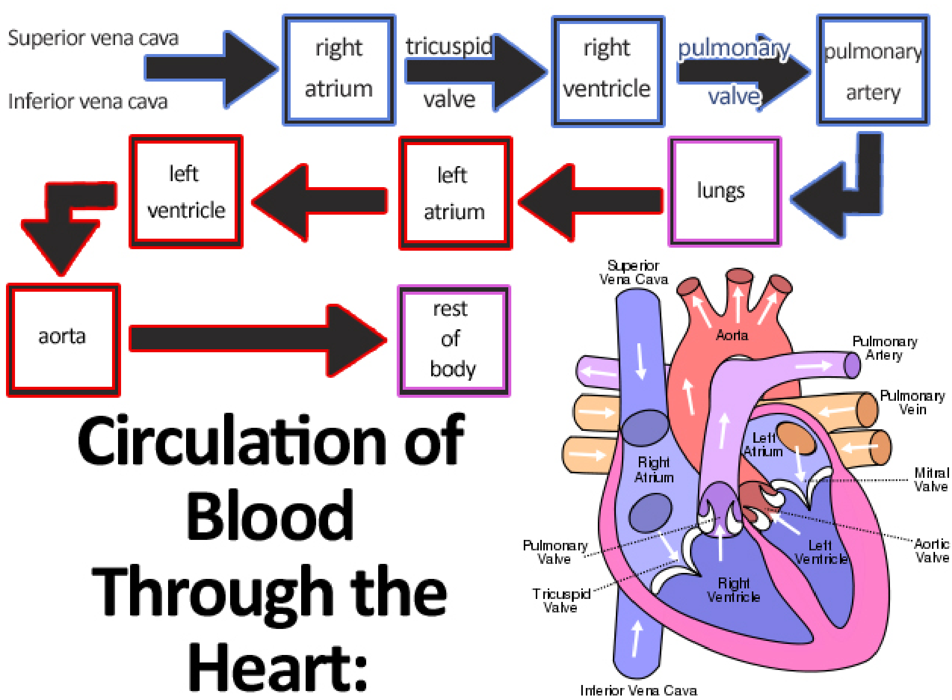


Figure 8.8: Flow diagram depicting movement of blood from the heart through the circulatory system. The blue boxes represent deoxygenated blood, the purple boxes represent capillary networks where gaseous exchange occurs and the red boxes represent stages at which the blood is oxygenated.

Major organs and systemic circulation ESG94

All the organs of the body are supplied with blood. This is necessary so that the cells can obtain oxygen, which is required for cellular respiration, as well as essential nutrients. Each organ has an artery that supplies it with blood from the heart. Metabolic wastes, including carbon dioxide, need to be removed from cells and returned to the heart. These move into the capillaries which enter into veins that eventually enters either the superior or inferior vena cava which then enters the right atrium.

Arteries and veins have been named according to the organ to which they supply blood. The **liver** receives oxygenated blood from the heart via the hepatic artery. This artery runs alongside the **hepatic portal vein**. The hepatic portal vein contains nutrients that have been absorbed by the digestive system. This nutrient-rich blood must first pass through the liver, so that the nutrient composition of the blood can be controlled. Blood passes from the liver to the heart through the **hepatic** vein. Metabolic waste is circulated in the blood, and if allowed to accumulate, would eventually reach toxic levels. The **kidneys** are supplied with blood (which contain waste) via the **renal** arteries. The kidneys filter metabolic waste from the blood, passing it to urine to be excreted safely. Blood leaves the kidney via the renal vein.

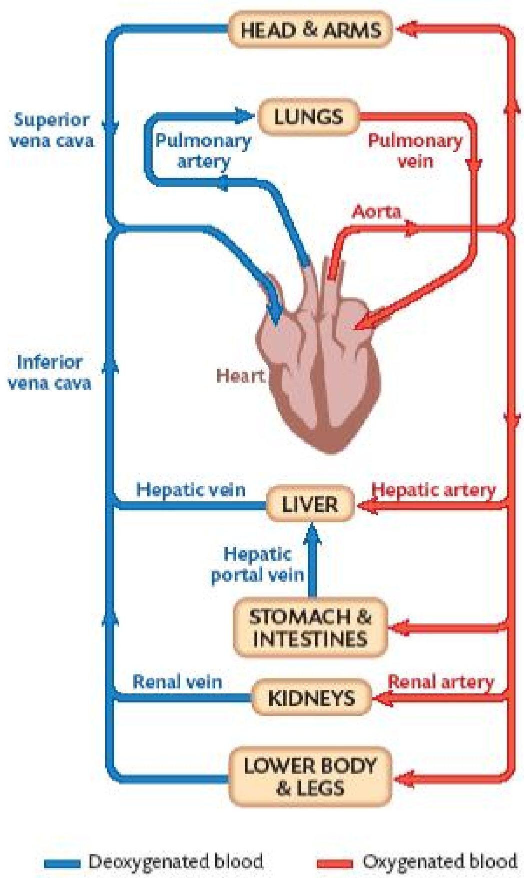


Figure 8.9: Major blood vessels of the circulatory system.

The **brain** is supplied with blood via the **carotid** arteries and the vertebral arteries. The blood from the brain is drained via the **jugular** veins. The brain is supplied with 15% of the total amount of blood pumped by the heart. The heart is also a muscle (myocardium) that requires blood flow to work. Blood is supplied to the heart via two **coronary arteries**, and leaves the heart via four **cardiac veins**.

Investigation: Dissecting a mammalian heart

Aim:

To dissect a mammalian heart (sheep or ox heart).

Apparatus:

- your teacher will give each group a heart to dissect
- a scalpel handle with a blade or a sharp non-serrated knife
- a sharp pair of scissors
- a pair of forceps
- gloves
- paper towel
- pictures of the external and internal views of the heart

Method:

1. Work in groups of four.
2. Place the heart on the dissecting board with the atria at the top and the ventricles facing downwards.
3. Carefully examine the external view of the heart. Try identify the vertical and horizontal groves on the heart. This is the position of the internal walls between the chambers of the heart.
4. Examine and note the difference in the walls of the ventricles and atria. Also note the difference in appearance between the walls of the ventricles and atria.
5. With the scalpel or sharp knife carefully cut the heart open across the left atrium.
6. Compare the thickness and the size of the right ventricle and atrium.
7. Identify the valves and examine the tendinous cords which are attached to the valves.
8. Identify the semi-lunar valves at the bottom of the pulmonary artery.
9. Now cut through the left side of the heart in the same way as you did the right side of the heart.
10. Carefully cut through the septum of the heart so that you have two halves.

Questions:

1. What is the smooth outer layer of the heart called?
2. Did you notice any fat around the heart?
3. Did you notice a difference between the atria and ventricles externally?
4. Name the blood vessels visible on the outside of the heart.
5. Compare the thickness of the walls of the atria and ventricles. Explain why they are different.
6. Explain the difference between the left and right ventricular walls.

The cardiac cycle ESG95

A cardiac cycle refers to the sequence of events that happens in the heart from the start of one heartbeat to the start of the subsequent heartbeat. During a cardiac cycle the atria and the ventricles work separately. The sinoatrial node (pacemaker) is located in the right atrium and regulates the contraction and relaxing of the atria.

- At rest, each heartbeat takes approximately 0,8 seconds.
- The normal heart rate at rest is approximately 72 beats per minute.
- During **systole** the heart muscle contracts.
- During **diastole** the heart muscle relaxes.

The phases of the cardiac cycle will be broken down and explained in the following section:

Phase 1: Atrial systole (Atrium contracts)

- Blood from the superior and inferior vena cava flows into the right atrium.
- Blood from the pulmonary veins flows into the left atrium.
- The atria contract at the same time.
- This contraction lasts for about 0,1 seconds.
- Blood is forced through the tricuspid and bicuspid valves into the ventricles.

Phase 2: Ventricular systole (Ventricle contracts)

- Ventricles relax and fill with blood.
- The ventricles contract for 0,3 seconds.
- Blood is forced upwards, closing the bicuspid and tricuspid valves (lubb sound).
- The blood travels up into the pulmonary artery (on the right) and the aorta (on the left).
- The atria are relaxed during ventricular systole.

Phase 3: General diastole: (General relaxation of the heart)

- The ventricles relax, thus decreasing the flow from the ventricles.
- Once there is no pressure the blood flow closes the semi-lunar valves in the aorta and the pulmonary artery (dubb sound).
- General diastole lasts for about 0,4 seconds.

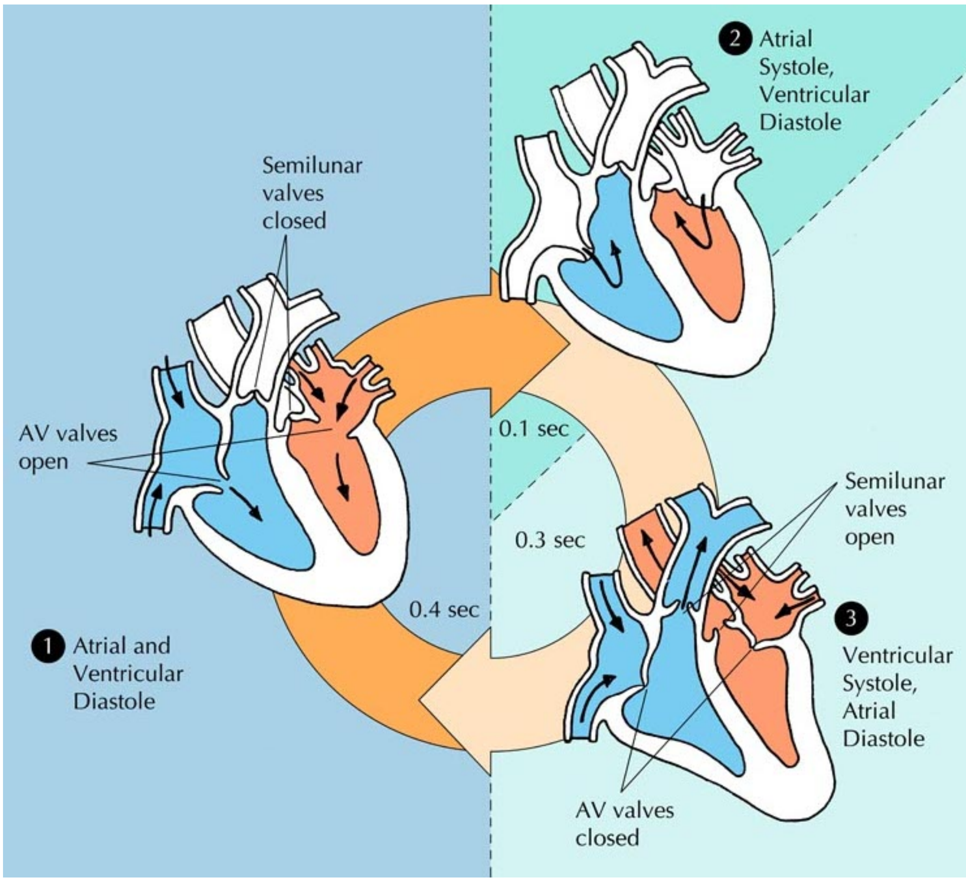


Figure 8.10: The cardiac cycle of contraction and relaxation of heart muscles during pumping of blood throughout the body.

The sound the heart makes

The heart makes two beating sounds. One is loud and one is soft. We call this the **lubb dubb** sound. The **lubb** sound is caused by the pressure of the ventricles contracting, forcing the atrioventricular valves shut. The **dubb** sound is caused by the lack of pressure in the ventricles which causes the blood to flow back and close the semi-lunar valves in the pulmonary artery and aorta. A doctor uses a **stethoscope** to listen to the heartbeats. Alternatively, a person's pulse can be measured by pressing a finger (other than the thumb which already has a pulse) against the brachial artery in the wrist or the carotid artery next to the trachea. The pulse of the heart allows us to measure the heart rate which is the number of heartbeats per unit time.

Mechanisms for controlling cardiac cycle and heart rate (pulse)

The cardiac cycle is controlled by nerve fibres extending from nodes of nerve bundles through the heart muscle. There are two nodes, namely the **sinoatrial node (SA node)** and the **atrioventricular node (AV node)**. The SA node is located within the wall of the right atrium while the AV node is located between the atria and the ventricles. Electrical impulses generated in the SA node cause the right and left atria to contract first, initiating the cardiac cycle. The electrical signal reaches the AV node, where the signal pauses, before spreading through conductive tissues called the bundles of His and Purkinje fibres. These fibres branch into pathways which supply the right and left ventricles, causing the ventricles to contract. The SA node is the pacemaker of the heart since electrical signals are normally generated there - without any stimulation from the nervous system **(automaticity)**. However, although the heart rate is automatic, it changes during exercise or when experiencing intense emotions like fear, anger and excitement. This is as a result of added stimulation from the nervous system and hormones, such as adrenaline.

FACT
Simple simulation of how electrical activity spreads over the heart. http://en.wikipedia.org/wiki/File:ECG_Principle_fast.gif

Electrical activity

The electrical activity in the heart is so strong that it can be measured from the surface of the body as an **electrocardiogram** (ECG). A normal heart has a very regular rhythm. **Arrhythmia** is a condition where the heart has an abnormal rhythm, as shown in the figures. **Tachycardia** is when the *resting* heart rate is too fast (more than 100 beats per minute), and **bradycardia** is when the heart rate is too slow (less than 60 beats per minute).

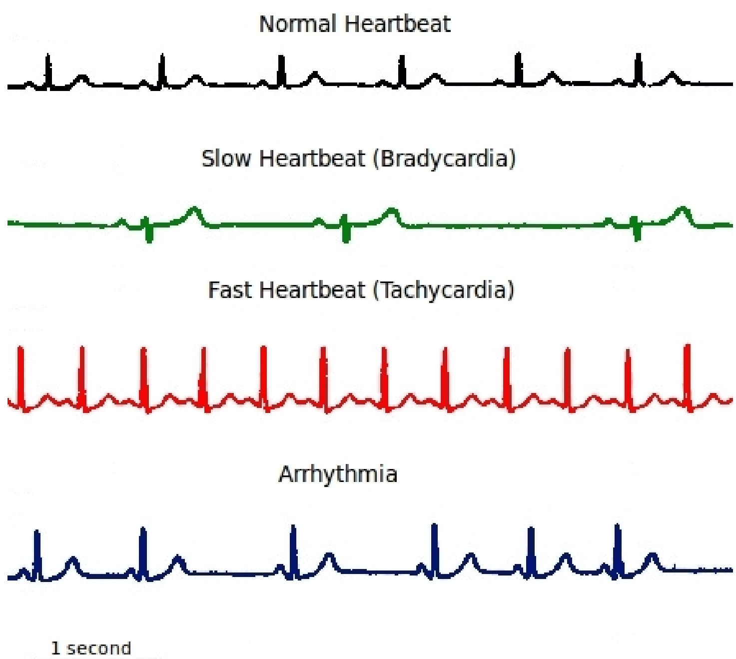


Figure 8.11: Electrocardiogram depicting different heart rhythms.

Investigation: Investigating heart rates before, during and after strenuous exercise

Aim:

To investigate your heart rate before, during and after strenuous exercise.

Apparatus:

- stopwatch
- pen and paper for recording

Method:

1. Work in pairs on the field and ensure you have a stop watch.
2. One partner performs the experiment and the other records the results. Partners then swap roles.
3. Take the resting pulse rate before exercising.
4. One partner runs quickly around the field twice.
5. Immediately after the run take his/her pulse.
6. Continue to take his pulse every minute for 5 minutes.
7. Record the results and plot a graph using the data pertaining to you.

Results:

Record your results here:

Time	Heart rate (beats/minute)
Before exercise (resting)	
0 min(immediately after exercise)	
1 min (after exercise)	
2 min	
3 min	
4 min	
5 min	

Draw a line graph to illustrate your results. Show the resting pulse rate as a separate dotted line on the axis.

Conclusions:

Write your conclusion.

Questions:

1. Write a hypothesis for this investigation.
2. Write down the independent variable.
3. Write down the dependent variable.
4. Name ONE factor that must be kept constant during this investigation.
5. Write down two ways in which the accuracy of this investigation can be improved.
6. What conclusions can be made about your cardiovascular fitness?
7. Explain why the heart rate increases during exercise.

FACT
Cardiac output is the volume of blood that is pumped by the heart in one-minute. Cardiac output is equal to the stroke volume (SV) multiplied by the heart rate (HR).

Stroke Volume

The stroke volume is the amount of blood pumped through the heart during each cardiac cycle. The stroke volume can change depending on the needs of the body. During exercise, muscles need more oxygen and glucose in order to produce energy in the form of ATP. Therefore the heart increases its stroke volume and stroke rate to meet this demand. This is a temporary change to maintain homeostasis, and after exercise the heart rate and stroke volume return to normal.

When a person exercises regularly, and is fit, the heart undergoes certain long-term adaptations. The heart muscle gets stronger, and expels more blood with each contraction. There is therefore a greater stroke volume with each heart-beat. Since the heart expels more blood with each stroke, the heart has to beat less often in order to maintain the same volume of blood flow. Therefore, fit people often have lower resting heart rates.

Blood Pressure

Blood pressure refers to the force that the blood exerts on the blood vessel walls. Blood pressure is determined by the size of the blood vessels and ensures that blood flows to all the parts of the body. Normal blood pressure is 120/80 (120 over 80) measured in units of mercury (mm Hg). The 120 represents the systolic pressure, which is when the ventricles contract. The 80 represents the diastolic pressure, which is when general diastole occurs.

Blood pressure can be increased by smoking, stress, adrenalin surges, water retention, high cholesterol, obesity and lack of exercise. High blood pressure **(hypertension)** is dangerous and increases the risk of an aneurysm, stroke or heart attack. Low blood pressure **(hypotension)** can lead to light-headedness and fainting because of insufficient blood supply to the brain.

FACT
Laughing is good exercise for your heart. Whenever you laugh, the blood vessels dilate (open up), causing the blood flow to increase, thus keeping your heart healthy.

Blood vessels ESG96

We will now examine the structure and function of arteries, capillaries, veins and valves.

Arteries

Arteries carry blood **A**way from the heart. The pressure created by the pumping heart forces blood through the arteries.

Arteries have three layers. They have an outside layer made up of connective tissue; a middle layer made up of smooth muscle, to allow contraction of the arteries in order to regulate the pressure of blood flow, and an inside layer of tightly connected simple squamous endothelial cells. The large arteries close to the heart branch into smaller arterioles (smaller arteries) and eventually branch into capillaries.

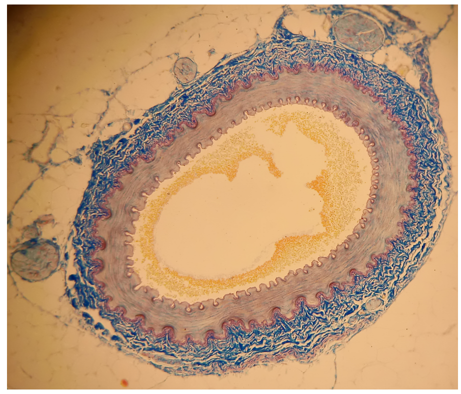


Figure 8.12: Micrograph of artery.

Capillaries

Capillaries are little more than a single layer of endothelial cells. Capillaries form intricate networks throughout the tissues. They allow water, nutrients and gases to diffuse out of the blood and waste materials to diffuse into the blood. This exchange occurs between the blood and the tissue fluid. The tissue fluid is the fluid surrounding the cells. The blood cells never come into contact with the cells. The blood and tissue fluid exchange material, and the tissue fluid then exchanges material with the cells.

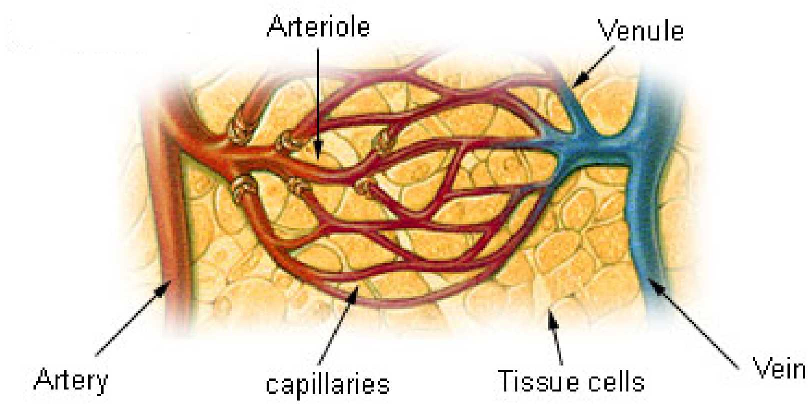


Figure 8.13: Diagram representing the branching of an artery into arterioles. These subsequently form the capillary bed which empties into several venules, leading to the vein.

Veins

The intricate networks formed by the capillaries eventually converge to form venules, (small veins). The venules then converge to form veins which return the blood to the heart. Vein walls only consist of two layers. The outer layer is made up of connective tissue whereas the inner layer is made up of endothelial cells.

Valves

Once the blood has passed through the capillaries very little blood pressure remains to return blood to the heart.Instead of pressure from the heart veins use a series of valves to force blood to return to the heart. Contraction of the muscles squeezes the veins, pushing the blood through them. The valves cause the blood to flow in only one direction, back to the heart.

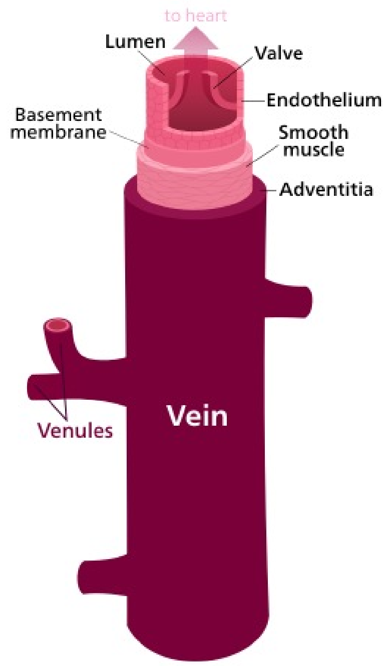


Figure 8.14: Schematic diagram of a vein.

Comparison between arteries, veins and capillaries ESG97

The figure and table below summarise the differences between arteries, capillaries and veins.

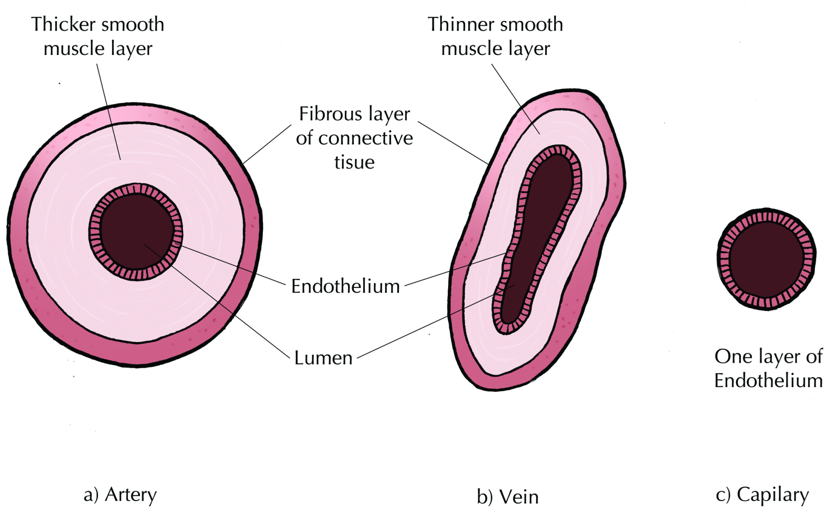


Figure 8.15: Cross-section showing the differences between a) arteries, b) veins and c) capillaries.

FACT
The average adult heart beats:

- 72 times a minute
- 100 000 times a day
- 3 600 000 times a year
- A billion times during a lifetime.

Arteries	Capillaries	Veins
blood moves **away** from the heart	blood supply at tissue level	blood **returned** to the heart
thick middle layer of involuntary muscle to increase or decrease diameter	one layer of endothelium with very small diameter	thin middle layer as pressure is reduced
inner layer of endothelium which reduces friction	only endothelium layer present	larger diameter of inner cavity, lined with endothelium to reduce friction
situated deeper in the tissue to maintain body temperature	situated at tissue level only	situated near the surface of the skin to release heat
no valves except in the base of the aorta and the pulmonary arteries	no valves present	semi-lunar valves are present at intervals, to prevent back flow of blood
blood always under high pressure	blood is under high pressure where red blood cells are forced to flow through in single file	blood is under low pressure
a pulse can be felt as blood flows	no pulse	no pulse can be detected

Table 8.1: Table comparing arteries, capillaries, and veins

8.3 Lymphatic circulatory system ESG98

The lymphatic system is part of the circulatory system, comprising a network of inter-connected tubes known as **lymphatic vessels** that carry a clear fluid called **lymph** towards the heart.

The lymphatic organs play an important part in the immune system. The lymphatic system transports the white blood cells which are important in the immune response against pathogens.

Composition of the lymphatic system ESG99

The lymphatic system is composed of lymph vessels, lymph ducts, lymph nodes and organs. The organs associated with the lymphatic system are the **spleen** and **thymus**. The spleen is the boundary between the blood and the lymphatic system. Knots of lymphatic tissue in the spleen add lymphocytes to the blood.

The spleen also acts as a filter for the blood, and helps to destroy worn out red-blood cells. In the event of damage to the spleen, it can be removed and its functions will be carried out by the liver, the bone marrow and the lymph nodes.

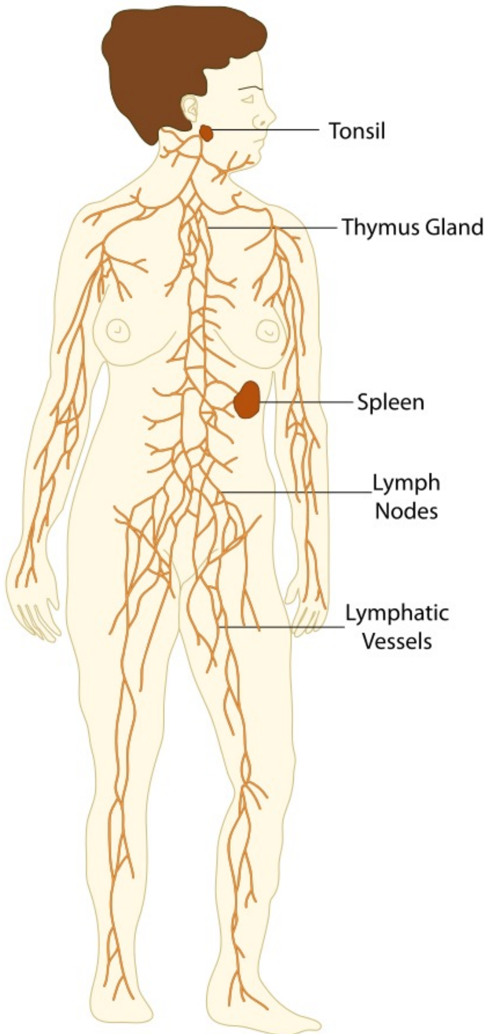


Figure 8.16: Diagram of human lymphatic system.

Lymph vessels are located as a network throughout all tissues in the body. Lymph vessels assist the circulatory system and all the cells of the body by removing wastes, germs and excess water from the tissue fluid. Lymph vessels carry lymph fluid from the bottom of the body up towards the heart and also drains from the head and shoulders as well as the arms.

Muscle contractions help push the lymph fluid upwards, and **valves** prevent the lymph fluid from flowing backwards. Many lymph vessels eventually merge into two large lymphatic vessels, called **lymphatic ducts** which empty into veins in the neck. The **thoracic duct** collects from the left side of the body and the lower right side of the body and empties into the left subclavian vein. The right thoracic duct collects from the right arm, thorax, neck and head, and drains into the right subclavian vein.

Most of the disease-fighting function of the adult mammal is carried out by the **lymph nodes** which occur along the lymph ducts. Lymph nodes are small, irregularly-shaped masses through which lymph vessels flow. Clusters of nodes occur in the armpits, groin, and neck. Cells of the immune system line channels through the nodes and attack bacteria and viruses travelling in the lymph, so they basically act as tiny filters.

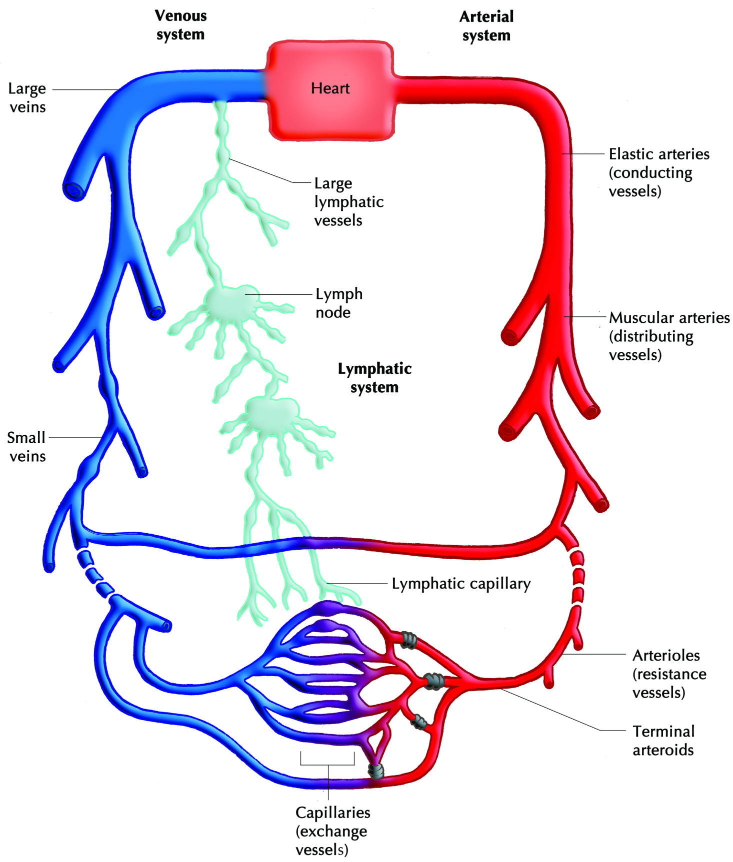


Figure 8.17: Interaction between lymphatic and cardiovascular circulatory systems.

Functions of lymphatic system ESG9B

The main functions of the lymphatic system are as follows:

- The main function of the lymphatic system is to **collect and transport tissue fluids** from the intercellular spaces in all the tissues of the body, back to the veins in the blood system.
- Lymph plays an important role in **returning plasma proteins to the bloodstream**.
- **Digested fats are absorbed** and then transported from the villi in the small intestine to the bloodstream via the lymph vessels.
- **Lymphocytes are manufactured in the lymph nodes**
- Antibodies manufactured in the lymph nodes assist the body to build up an effective **immunity** to infectious diseases.

- Lymph nodes **play an important role in the defence mechanism of the body**. They filter out micro-organisms (such as bacteria) and foreign substances such as toxins.
- Lymph transports large molecular compounds (such as enzymes and hormones) from their manufactured sites to the bloodstream.

FACT
Watch this video on lymph.
See video: 2CTY

NOTE:

Elephantiasis is a disease characterised by thickening of the skin and underlying tissues, especially in the legs and genitals. It occurs when the body becomes infected by parasitic infections, which target the lymphatic system.

Figure 8.18: An Ethiopian farmer affected by elephantiasis after being infected by a worm that settled in the lymphatic system .

A comparison of the cardiovascular and lymphatic systems

Table 8.2 provides a comparison of the cardiovascular and lymphatic systems.

Cardiovascular System	Lymphatic System
Blood is responsible for collecting and distributing oxygen, nutrients and hormones to the tissues of entire body.	*Lymph* is responsible for collecting and removing waste products left behind in the tissues.
Blood flows in the arteries, capillaries, and veins.	*Lymph flows* in an open circuit from the tissues into lymphatic vessels.
Blood flows towards the heart and away from the heart.	*Lymph* flows in one direction only (towards the heart).
Blood is pumped by the heart to all parts of the body.	*Lymph is not pumped*. It passively flows from the tissues into the lymph capillaries.
Blood consists of the liquid plasma that transports the red and white blood cells and platelets.	*Lymph* that has been filtered and is ready to return to the cardiovascular system is a clear or milky white fluid.
Blood is visible and damage to blood vessels causes obvious signs such as bleeding or bruising.	*Lymph is colourless or translucent* and damage to the lymphatic system is difficult to detect until swelling occurs.
Blood is filtered by the kidneys.	*Lymph is filtered* by lymph nodes located throughout the body.

Table 8.2: Comparison between the cardiovascular system and the lymphatic system

8.4 Cardiovascular diseases ESG9C

Cardiovascular diseases affect the heart or blood vessels (arteries, veins and capillaries). Cardiovascular diseases are the biggest cause of deaths worldwide, and the incidence of these diseases is rising rapidly in countries like South Africa. Cardiovascular diseases can be avoided through improvements in eating habits and through regular exercise. In this section we will study the causes of heart attacks and strokes as well as how these may be treated. We will also study the causes of high and low blood pressure and how these have an effect on our well-being. We will finally discuss the types of treatments that are available such as stents, valve replacements, bypass surgery, pacemakers and heart transplants.

Heart attack ESG9D

This is also referred to as a **myocardial infarction**. Heart muscles are provided with oxygenated blood by a system of coronary arteries. Blocked flow of blood can cause the death of cardiac muscle due to lack of oxygen. Arteries get blocked as a result of the gradual build-up of lipids and cholesterol, which form a **plaque**. This condition of plaque build up in the arteries is referred to as **atherosclerosis**. When a plaque bursts, it causes blood to clot at the site of the rupture and obstructs the artery (see diagram in Figure 8.20). Often there are no symptoms of atherosclerosis. However, some people who have narrowed coronary arteries experience chest pain, (**angina**), when blood flow to the heart is insufficient.

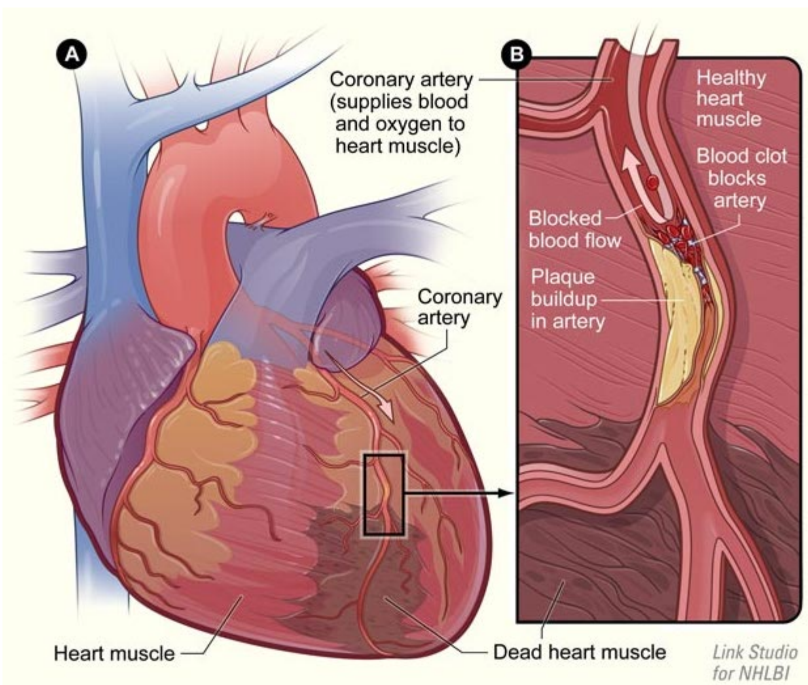


Figure 8.19: Heart attack: the blood clot blocks the coronary arteries and cardiac muscle dies from lack of oxygen.

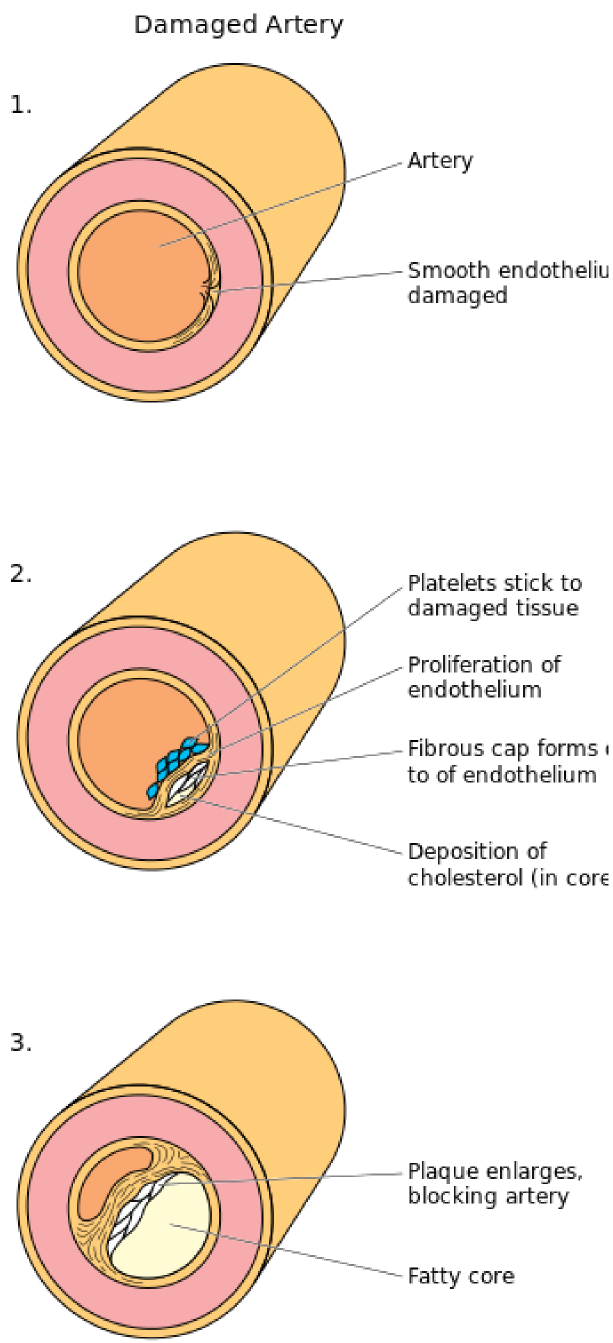


Figure 8.20: 1. Normal arteries have a wide diameter through which blood can easily flow. 2. Plaque forms on the walls of the artery, narrowing the lumen. 3. When the plaques bursts, platelets form a blood clot at the site of rupture, which can obstruct the artery.

See video: 2CTZ

See video: 2CV2

See video: 2CV3

Hypertension ESG9F

As previously mentioned blood pressure is the pressure exerted by the blood against the walls of the blood vessels, especially the arteries. Normal blood pressure at rest is within the range of 100–140 mm Hg systolic (top reading) and 60–90 mm Hg (bottom reading). High blood pressure (hypertension) is said to be present if it is persistently at or above 140/90 mm Hg. Hypertension is a major risk factor for strokes, heart attacks and bursting of blood vessels (aneurysms). Hypertension is essentially caused by a resistance to blood flow in blood vessels.

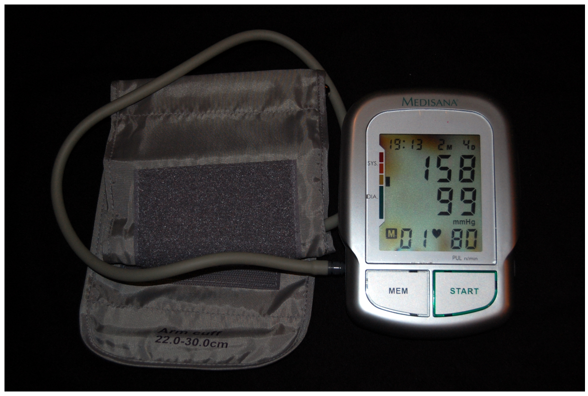


Figure 8.21: The instrument used to measure blood pressure is a **sphygmomanometer**. This figure shows an automated arm blood pressure meter showing arterial hypertension. From the top reading systolic pressure is 158 mm Hg and diastolic reading is 99 mm Hg and the heart rate is 80 beats per minute.

Hypotension ESG9G

Hypotension refers to abnormally **low** blood pressure, especially in the arteries of the systemic circulation. A patient is considered hypotensive if he/she has a systolic blood pressure less than 90 millimetres of mercury (mm Hg) or diastolic pressure being less than 60 mm Hg. However, in practice, blood pressure is considered too low only if noticeable symptoms are present, such as feeling light-headed. If the blood pressure is sufficiently low, fainting and often seizures will occur. Severely low blood pressure can deprive the brain and other vital organs of oxygen and nutrients, leading to a life-threatening condition called **shock**.

Stroke ESG9H

A stroke results when a clot, burst artery or blood vessel interrupts flow of blood to the brain, resulting in glucose and oxygen not reaching the brain. This causes impairment in speech, movement and memory. Larger strokes can result in paralysis or death.

See video: 2CV4

Aneurysm ESG9J

An aneurysm is a localised blood-filled bubble in an artery wall. These bubbles form due to a weakness in the blood vessel wall and can grow quite large. Aneurysms can occur in many places in the body, including the brain, abdomen or aorta. When aneurysms burst, they result in massive internal blood loss and death.

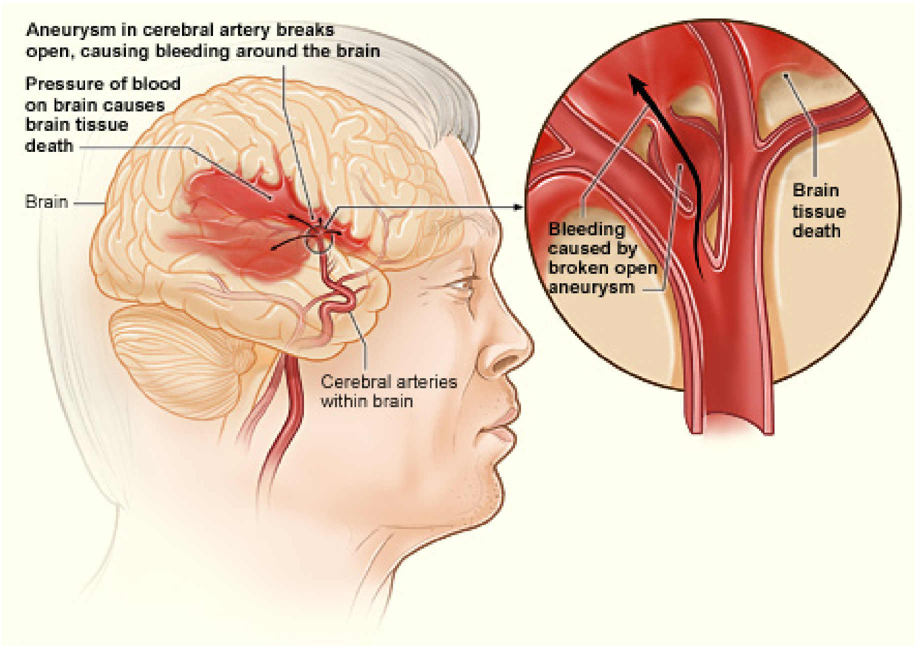


Figure 8.22: A hemorrhagic stroke caused by a burst aneurysm in the brain.

8.5 Treatment of heart diseases ESG9K

We will now examine some of the treatment of cardiovascular diseases.

Stents ESG9M

In some cases, a small wire mesh tube is inserted into a blocked or narrowed artery to keep it open. This is called a percutaneous coronary intervention. To perform this procedure, doctors insert a needle into the femoral artery, and then thread a very thin wire through the arteries until it reaches the heart and the area of blockage. A thin catheter with a small wire coil (stent) and in inflatable balloon is then threaded over the thin wire and inserted into the coronary artery at the site of the blockage. Once in position, the balloon is gently inflated to open the artery and remove the blockage. The stent is left in the artery so that the artery does not block again, and the catheter is removed.

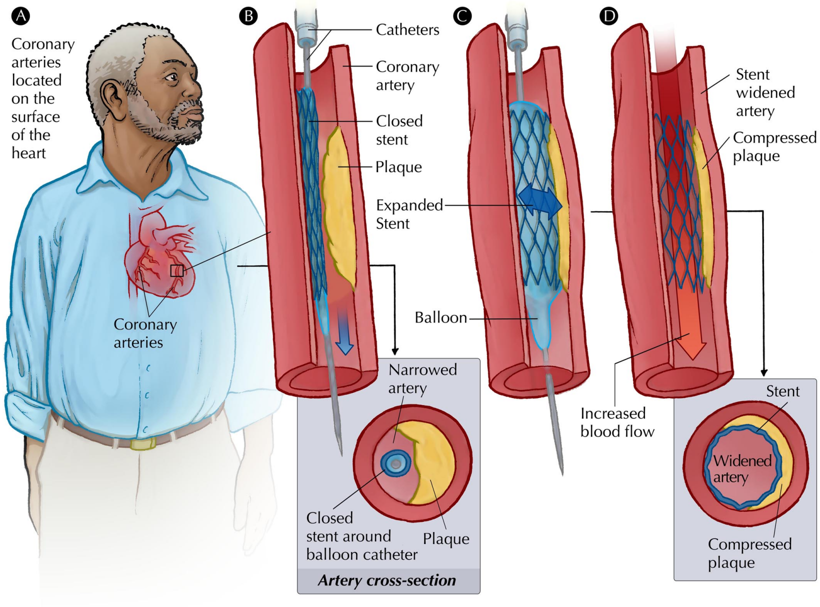


Figure 8.23: Stent replacement in heart patients.

See video: 2CV5

Pacemaker ESG9N

Pacemakers are small electrical devices that get implanted into the chest or abdomen of patients in order to help control arrhythmias (abnormal heart rhythms). Modern devices are quite advanced and can learn a patient's normal heart-beat patterns and detect when the heart enters an abnormal rhythm (e.g. skips a beat). The device will then send out a little electrical pulse to stimulate the heart to beat and restore a normal heart beat.

Valve replacement ESG9P

Valve replacement surgery is the replacement of one or more of the heart valves with an artificial valve. There are two types of valves presently being used: **Biological valves** are manufactured from animal or human tissue. These valves have a life span of approximately 12 to 15 years. If biological valves are used the patient generally does not require additional blood thinning medication. **Mechanical valves** are manufactured from synthetic materials. These valves, because they are made of synthetic materials last longer, but the patient needs to take anti-coagulant medication for the rest of their lives.

Coronary Bypass Surgery ESG9Q

This is the most common type of surgery used for the treatment of coronary heart disease. The surgeon removes a section of a vein from the patient's leg and then carefully grafts the removed vein (attaches) onto the aorta to bypass the blocked part of the artery.

See video: 2CV6

Heart Transplant ESG9R

A heart transplant is the surgical removal of a person's diseased heart and replacement with a healthy heart from a donor. Heart failure is a condition in which the heart is damaged or weak. As a result, it cannot pump enough blood to meet the body's needs. Heart transplants are done as a life-saving measure for end-stage heart failure. Donor hearts are in short supply, therefore patients who need heart transplants go through a very careful selection process. They must be sick enough to need a new heart, yet healthy enough to receive it. Survival rates for people receiving heart transplants have improved, especially in the first year after the transplant.

Figure 8.24: Heart transplant by Dr Christiaan Barnard.

FACT
The survival after heart transplant surgery is about 88% after the first year, 75% after 5 years and 56% after 10 years.

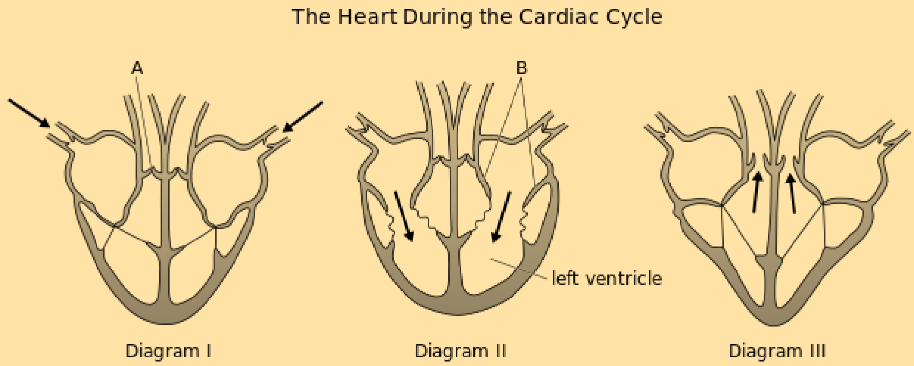
FACT
The first human heart transplant was performed on the 3rd December 1967 by Professor Christiaan Barnard, a **South African** heart surgeon. The patient, Mr Louis Washkansky, unfortunately only survived for 18 days after the surgery. However the cause of death was pneumonia, and not his new heart, which beat strongly till his death.

8.6 Summary ESG9S

- Nutrients and oxygen are required by cells for cellular respiration. These are transported by blood to the various cells.
- Carbon dioxide and other waste products need to be transported from the cells to the exterior. This is also transported via blood.
- There are open and closed circulatory systems. In an open circulatory system blood enters a cavity, in a closed circulatory system blood remains in vessels.
- A double closed circulation system consists of the pulmonary and systemic circulatory systems.
- Blood is pumped through the heart under high pressure to the various parts of the body.
- The right side of the heart receives deoxygenated blood from the body via veins and sends it to the lungs to be oxygenated.
- The left side of the heart receives oxygenated blood from the lungs and sends it via arteries to all parts of the body.
- Specialised cells (sinoatrial node) send signals to the atrioventricular node to cause the atria and ventricles to contact and control the cardiac cycle and heart rate.
- The lymphatic system is composed of lymph vessels, lymph nodes, and organs.
- Lymph vessels assist the circulatory system and all the cells of the body by removing wastes, germs and excess water from the tissue fluid.
- There are many diseases that affect the heart and circulatory system and many treatments are available.

Exercise 8 – 1: End of chapter exercises

1. The following diagrams show the heart during the cardiac cycle. The arrows represent the flow of blood. Study the diagrams and answer the questions that follow:



   a) Identify the structures labelled A and B respectively.
   b) Name and explain what happens in each of the phases of the cardiac cycle represented in:
      i. Diagram I
      ii. Diagram II
      iii. Diagram III

2. Loss of a lot of blood, vomiting and diarrhoea often causes a decrease in blood volume. As a result, blood cannot move normally around the body, as blood vessels are not completely full. The tissues do not get enough blood, leading to possible death of cells and hence damage to organs.
   a) Explain why severe vomiting and diarrhoea would cause a decrease in the blood volume.
   b) What is the relationship between blood volume and blood pressure?

3. Read the passage below and then answer the questions based on it.

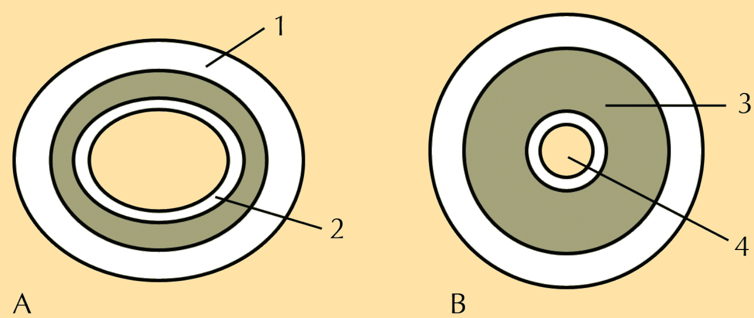
When the ventricles of the heart pump blood into the arteries, the pressure of the blood in the arteries is high. This is called systolic pressure (average 120 mm Hg). When the heart muscle relaxes, the pressure in the arteries is much less. This is called diastolic pressure (average 80 mm Hg). The average blood pressure of a healthy person is 120 over 80.

It is normal for a person's blood pressure to differ slightly from the average. If blood pressure is too high or too low there is medication that can be used to control this. High blood pressure is called 'hypertension' and low blood pressure is called 'hypotension'. There are several contributing factors to heart disease, namely hypertension, strokes, lack of exercise, smoking, rich fatty diets, obesity and diabetes.

Research has shown that 25% of the South African population suffer from hypertension and that this is on the increase. The treatment for hypertension is expensive and has a great impact on the health system and on the economy.

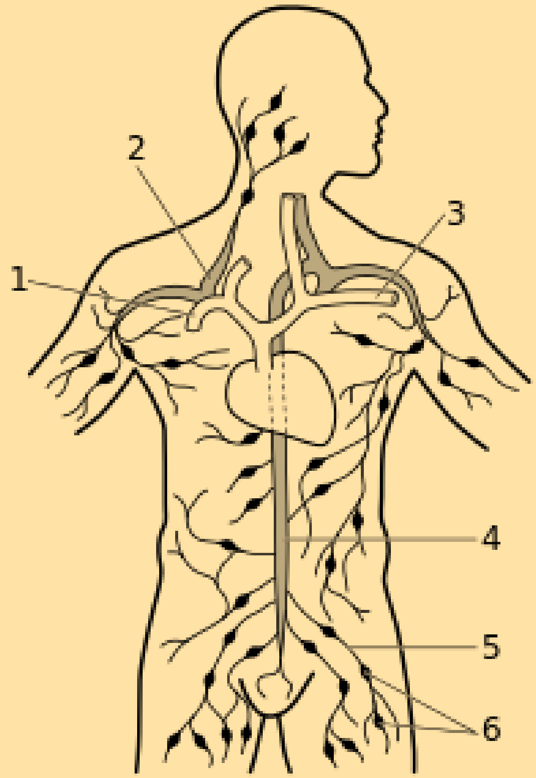
a) Explain what causes the pressure in the arteries to rise and fall.
b) Why is it essential that blood pressure in the capillary vessels be much lower than that in the artery?
c) List **three** reasons why heart disease is on the increase in South Africa.
d) Suggest **one** way in which the government could reduce the number of people with heart disease.

4. Study the diagrams which show two cross-sections of mammalian blood vessels and answer the questions that follow:



a) Which vessel, A or B is the artery?
b) Provide **two** reasons for your answer to the previous question.
c) Which vessel carries blood at low pressure?
d) Provide an explanation for your answer to the previous question.
e) Identify the parts numbered 1 to 4.
f) How do capillaries differ from larger blood vessels?
g) In which vessel, A or B would you expect to find valves?
h) What is the function of the valves in the previous question?
i) Name the blood vessel that:
   i. carries deoxygenated blood from the heart to the lungs
   ii. carries oxygenated blood from the heart for systemic circulation
   iii. carries blood from the digestive system to the liver

5. Study the diagram of the lymphatic system and answer the questions that follow:



a) Name the components of the lymphatic system.
b) Identify the:
   i. blood vessel numbered 3
   ii. duct numbered 4
   iii. structure numbered 6
c) Name **two** factors that assist movement of the lymph fluid.
d) State **four** functions of lymph in the human body.

6. Multiple-choice questions
   a) The left side of the heart:
      i. transports deoxygenated blood to the lungs
      ii. is more muscular than the right-hand side
      iii. has a built in pacemaker
      iv. is a mixture of oxygenated and deoxygenated blood
   b) Angina is:
      i. a panic attack caused by the release of too much adrenalin
      ii. a fatal heart attack
      iii. a serious heart cramp caused by a lack of oxygen in the cardiac muscles
      iv. the result of a clot in the blood vessels going to the brain

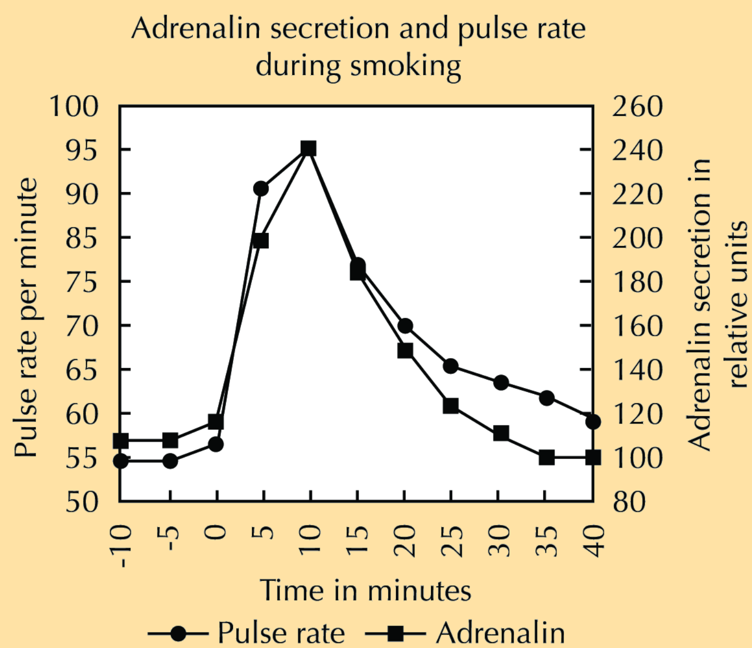
c) The stage in the cardiac cycle when the blood is pumped into the aorta and the pulmonary artery is:

i. atrial systole
ii. ventricular diastole
iii. general diastole
iv. ventricular systole

d) The valve between the left ventricle and the left atrium of the heart is called the:

i. mitral valve
ii. tricuspid valve
iii. aortic semi-lunar valve
iv. pulmonary semi-lunar valve

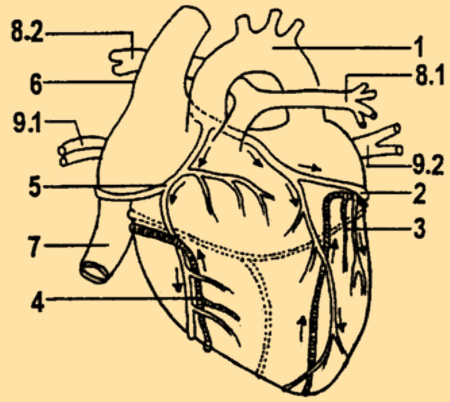
e) The accompanying graph indicates that changes in adrenalin secretion and the pulse rate, before, during (0 to 10 minutes) and after a cigarette was smoked. Use the given graph to indicate which one of the following deduction is a valid interpretation of the graph.



i. Smoking directly causes an increase in the basal metabolic rate.
ii. The cardiac muscles relax during smoking.
iii. Smoking directly stimulates the pulse rate.
iv. There is a no relationship between adrenalin secretion and pulse rate.

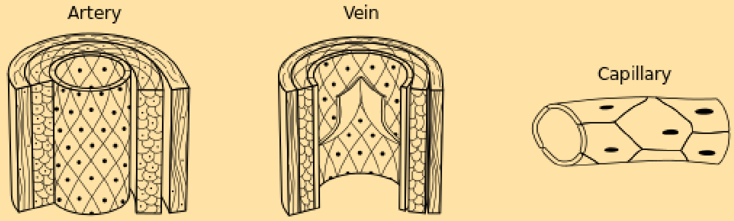
f) Explain why there is a relationships between smoking and adrenalin secretion.

7. Study the accompanying diagram of the ventral view of the external structure of the heart and answer the questions that follow.

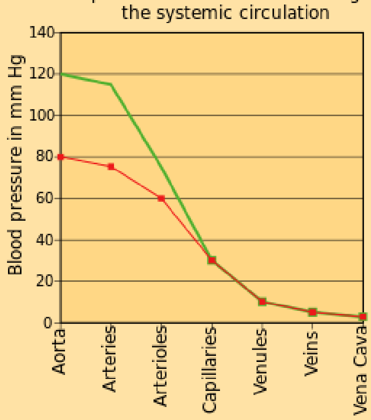


   a) Label parts numbered 1, 2, 7, 8.2 and 9.2
   b) What type of blood (oxygenated or deoxygenated) is transported by blood vessels 1, 3 and 6?
   c) What possible danger to human health exists if the lumen of structure 4 is obstructed with a thick layer of cholesterol?
   d) Discuss what happens during ventricular systole in the cardiac cycle.

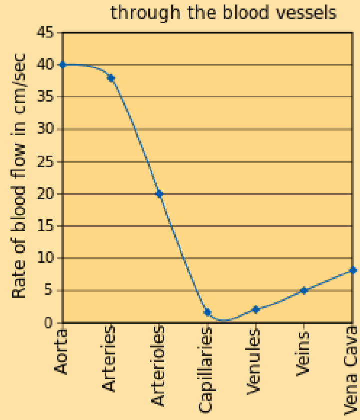
8. Study the diagrams below illustrating the structure of different types of blood vessels. Graph A shows the average blood pressure in different blood vessels in the human body, while graph B indicates the rate of blood flow in the different blood vessels.



Graph A: The changes in blood pressure as blood flows through the systemic circulation



Graph B: The average rate of blood flow through the blood vessels

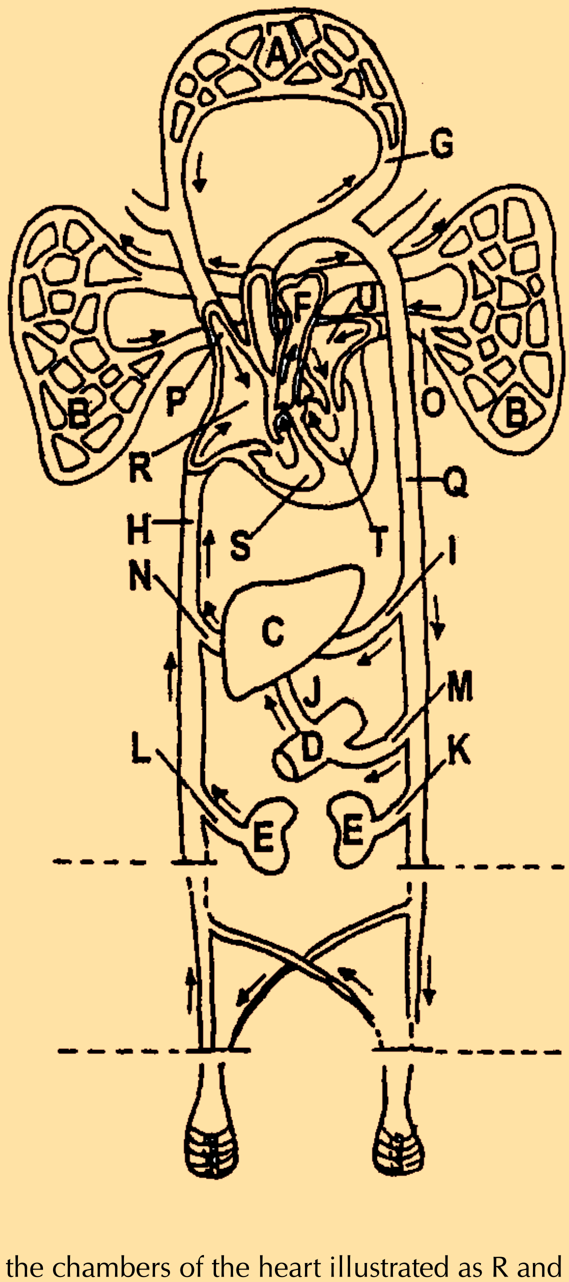


a) Tabulate three **structural** differences between an artery and a vein.

b) Study graph B and give a reason why the rate of blood flow in the capillaries is very low.

c) What is the systolic and diastolic pressure in the aorta? (graph A)

9. The accompanying diagram represents the basic human blood circulation. Study the diagram and answer the questions.



a) Name the chambers of the heart illustrated as R and T.

b) Name the arteries indicated as I and K. (organ C is the liver and organ E is the kidney)

c) Name the vein indicated as J.

10. Answer the following questions with a word or phrase that corresponds to the description given.

    a) The membrane surrounding the heart.
    b) The valve situated between the left atrium and left ventricle.
    c) The phase in the cardiac cycle when the atria contract.
    d) The name of the artery taking deoxygenated blood to the lungs.
    e) The blood circulatory system that supplies the heart muscle with oxygenated blood.
    f) The disorder / condition that results from a blockage in a blood vessel in the brain.
    g) The instrument used to measure blood pressure.
    h) The blood system that supplies oxygen to body cells.
    i) The structure that separates the left and right sides of the heart.
    j) The ability of the heart to contract at its own inherent rhythm.
    k) The layer found on the inside of veins.
    l) The blood vessel connecting the stomach and intestine to the liver.
    m) Veins that have lost their elasticity and form small sacs of blood.
    n) The smallest blood vessels in the body.
    o) The pacemaker of the heart.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 2CV7 2. 2CV8 3. 2CV9 4. 2CVB 5. 2CVC 6a. 2CVD
6b. 2CVF 6c. 2CVG 6d. 2CVH 6e. 2CVJ 6f. 2CVK 7. 2CVM
8. 2CVN 9. 2CVP 10. 2CVQ

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CHAPTER 9

Biospheres to ecosystems

9 Biospheres to ecosystems

9.1 Overview ESG9T

Introduction ESG9V

In this chapter we will study the way the biosphere interacts with the atmosphere, lithosphere and hydrosphere. This will be followed by a description of the major aquatic and terrestrial biomes in South Africa. We will then learn about the abiotic and biotic factors that make up an ecosystem and examine how these factors interact. This will be followed by a discussion on energy flow and the different trophic levels in an ecosystem that can be represented by either a chain, pyramid or web. We will next look at how all the important nutrients are cycled through the environment. We will conclude this chapter with a discussion of ecotourism in South Africa.

Key concepts

- The biosphere consists of all the living organisms on Earth.
- The biosphere interacts with the hydrosphere, the lithosphere and the atmosphere.
- Biomes are natural habitats for flora and fauna that extend to both aquatic and terrestrial regions.
- The location of biomes across southern Africa, and in South Africa itself, is governed by climate, soils and vegetation.
- The environment consists of living (biotic) and non-living (abiotic) components which interact.
- The ecosystem brings together the various interactions between living organisms.
- Abiotic factors affect the nature of an ecosystem. Such factors include physiographic factors, soil quality, light, temperature, water, atmospheric gases and wind.
- Biotic factors that affect the ecosystem include producers, consumers and decomposers.
- Energy flows through the trophic levels of an ecosystem tracing the relationships that exist in an ecosystem.
- Oxygen, carbon, nitrogen and water also cycle through the ecosystem. item Ecotourism presents both opportunities and challenges for the preservation of our ecosystems.

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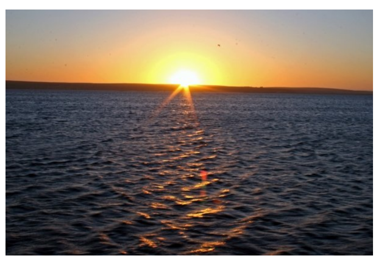
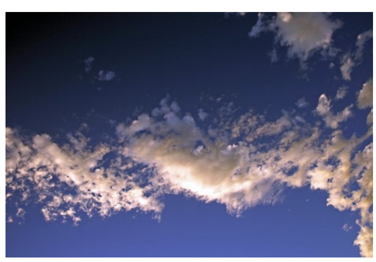
atom →molecule→cell→tissue→organ→system→organism→**ecosystem**

9.2 Biosphere

ESG9W

The biosphere refers to all living organisms on Earth and is often called the global ecosystem. The biosphere interacts with other spheres, such as the lithosphere, atmosphere and hydrosphere. Each of these spheres is discussed briefly below:

- **Biosphere**: is the sphere that includes all living organisms, from plants to bacteria to multicellular organisms.
- **Hydrosphere**: is the combined mass of water found on, under and above the surface of the earth. The hydrosphere is made up of oceans, seas, lakes, rivers and springs. The water in these bodies can be freshwater or salt water. The hydrosphere is home to a wide diversity of aquatic plant and animal life.
- **Lithosphere**: refers to the outermost surface of the Earth, the Earth's crust. The *oceanic lithosphere* is associated with the oceanic crust and exists in oceanic basins. *Continental lithosphere* is associated with continental crust which covers the Earth's landmass. The lithosphere shields living organisms from the heat of the Earth's core and contains ionic compounds which allow plant and animal life to exist.
- **Atmosphere**: is the layer of gases surrounding the earth. The gases in the atmosphere allow organisms to respire and regulates the temperature of the planet. The atmosphere's ability to absorb the ultraviolet rays of the sun is what allows life on earth to survive.

Spheres on Earth	
Biosphere	Hydrosphere
	
Lithosphere	Atmosphere
	

The connections between spheres imply that disturbances in one sphere affect the other spheres. For example, excessive deforestation (biosphere) results in increased erosion of soil (the upper layer of the lithosphere- *pedosphere*) into rivers (hydrosphere). Deforestation also results in an increase in atmospheric carbon dioxide (atmosphere). Deforestation therefore is an example of how disturbances in one sphere produces effects in the hydrosphere, upper-lithosphere and atmosphere.

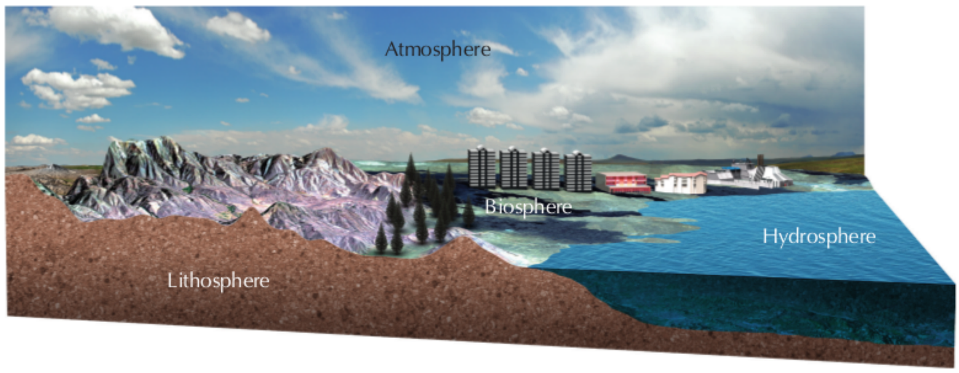


Figure 9.1: The various spheres within the biosphere are connected.

9.3 Biomes ESG9X

The biosphere is divided up into a number of **biomes**. Biomes are regions with similar climate and geography. The key factors determining climate are average annual precipitation (rainfall) and temperature. These factors, in turn, depend on the geography of the region, such as the latitude and altitude of the region, and mountainous barriers. The specific conditions of biomes determine the plant and animal life found within them. The communities of plants, animals and soil organisms in a particular biome are collectively referred to as an **ecosystem**. Biomes can be **aquatic** or **terrestrial**.

Aquatic biomes ESG9Y

Water covers a major portion of the Earth's surface, so aquatic biomes contain a rich diversity of plants and animals. Aquatic biomes are divided into two main groups depending on the amount of salt present in the water: freshwater and marine biomes.

1. Freshwater

Freshwater biomes are defined by their low salt concentration, which is usually less than 1%. Examples include: ponds, lakes, streams, rivers and wetlands.

2. Marine biomes

Marine bodies are salty, having approximately 35 grams of dissolved salt per litre of water (3,5%). Marine biomes are divided into oceans, coral reefs and estuaries. The vegetation of the marine biomes consists of the different types of algae, which is one of the major sources of oxygen in the world. Green algae also play a role in the removal of carbon dioxide from the atmosphere.

Oceans: are very large marine bodies that dominate the Earth's surface and hold the largest ecosystems. The open ocean or sea covers nearly three-quarters of the earth's surface and contains a rich diversity of living organisms. Examples of animals in the ocean biome include whales, sharks, octopuses, perlemoen, crabs and crayfish. Figure 9.2 shows a typical ocean ecosystem.

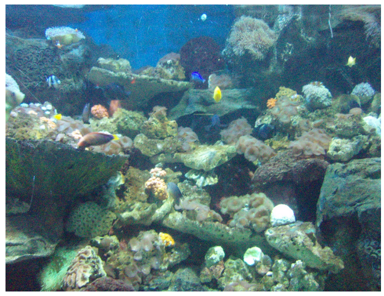


Figure 9.2: Ocean ecosystem.

Coral reefs: are found in the warm, clear, shallow waters of tropical oceans around islands or along continental coastlines. Coral reefs are mostly formed underwater from calcium carbonate produced by living coral. Reefs provide food and shelter for other organisms and protect shorelines from erosion. South Africa has only one coral reef in the subtropical ocean waters north of Lake St. Lucia in northern KwaZulu Natal. Figure 9.3 shows a typical coral reef system.

Figure 9.3: Coral reef.

Estuaries: are partially enclosed areas of fresh water and silt from streams or rivers, which mix with salty ocean water. Estuaries represent a transition from land to sea and from freshwater to saltwater. Estuaries are biologically very productive areas and provide homes for a wide variety of plants, birds and animals. Figure 9.4 shows an example of an estuary system.

Figure 9.4: Knysna Estuary.

Marine biomes of South Africa

South Africa's long coastline stretches for over 3000 kilometres, from Namibia in the West to Mozambique in the East. There are a few key features to note about South Africa's coastline and marine biomes. South Africa's coastline is rugged, as rocky shores are exposed to high wave energy and the coastline generally experiences high wind for most of the year.

There are up to 343 estuaries found along the coast, two thirds of which are found on East Coast between Cape Padrone in the Eastern Cape Province and Mtunzini in KwaZulu-Natal. The Eastern coastline receives the highest rainfall, mostly during summer.

South Africa's East Coast has relatively warm waters (20-25 degrees C), the West Coast receives colder Atlantic waters (9-14 degrees C), and the South Coast experiences intermediate water temperatures (16-21 degrees C). The cold Benguela Upwelling System on the South-West coast supports large numbers of marine animals. The warm Agulhas current off the East Coast has a smaller quantity of fish but a greater diversity of species. Abundant opportunities exist for tourism, recreation, food, export and associated economic development.

Terrestrial biomes ESG9Z

Terrestrial biomes occur on land and can be of many types. Examples include: thicket, tundra, forest, grassland and desert. Terrestrial biomes are usually classified based on the dominant vegetation, climate or geographic location. The location and characteristics of the various biomes is mostly influenced by climatic conditions such as rainfall and temperature.

South African Biomes ESGB2

The most recent classification of the terrestrial biomes in South Africa divides the region into the following eight biomes (Figure 9.5):

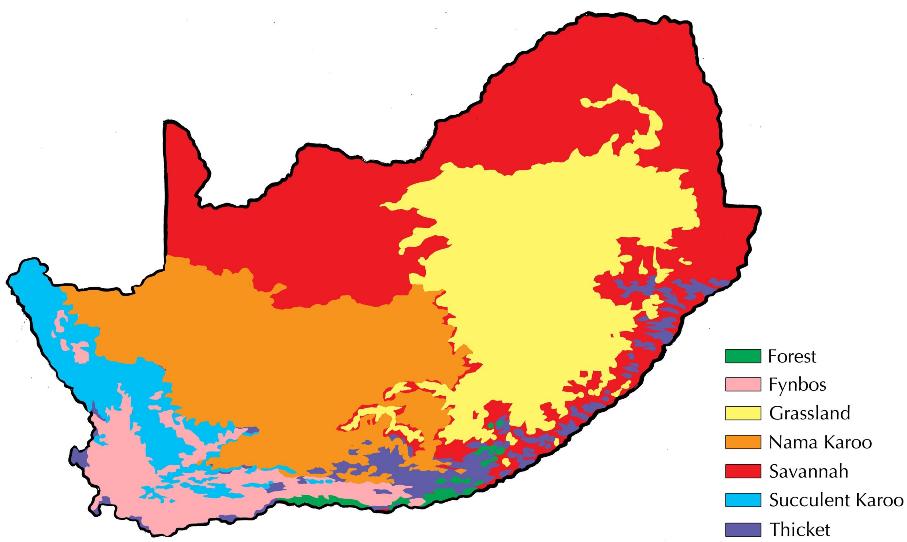


Figure 9.5: Biomes of South Africa.

We will now examine the following eight South African biomes:

1. Grassland
2. Savannah
3. Succulent Karoo
4. Nama Karoo
5. Forest
6. Fynbos
7. Desert
8. Thicket

1. Grassland Biome

- **Location**: grasslands are found on the Highveld.
- **Climate**: they typically have summer rainfall of 400 mm to 2000 mm. Winters are cold, and frost can occur.
- **Soil and geography**: in grasslands, the soil is red/yellow/grey or red/black clay. Grassland soil has rich fertile upper layers.
- **Flora**: vegetation is mainly grass, but trees can grow on the hills and along river beds.
- **Fauna**: many types of grass-eating herbivores can be found in this habitat, such as black wildebeest, blesbok and eland. Rodents are also common in grasslands which makes this biome an ideal hunting ground for birds of prey. The diverse plant species also support many plant-eating insects such as butterflies, grasshoppers, crickets and ants.

Figure 9.6: Grasslands are regions where the vegetation is dominated by grasses.

Figure 9.7: Grasslands are regions where the vegetation is dominated by grasses.

Activity: Burning of grassland

Aim:

Compare and analyse the advantages and disadvantages of burning grassland.

Materials:

- Internet
- articles
- books

Instructions:

1. Using these resources, tabulate the advantages and disadvantages of burning grassland.
2. Remember to cite your references correctly.

2. Savannah biome

- **Location**: the Savannah biome is the largest biome in Southern Africa. It is found mainly in the western parts of Limpopo, the northern parts of the Northern Cape and Free State, the North West Province and KwaZulu Natal.
- **Climate**: summers are hot and wet and the winters are cool with little or no rain. Frost occurs in winter.
- **Soil and geography**: the soil consists of red/black clay or red/ yellow/ grey soil and is often sandy.
- **Flora**: this biome is also known as the bushveld, where grasses are mainly found and regular fires prevent the trees from dominating. Herbaceous plants and woody plants can be found in different areas. Plants are able to withstand fire.
- **Fauna**: big game species such as kudu and Springbok, lion, buffalo and elephant are found in the Savannah Biome. This is also a malaria-prone area.

Figure 9.8: Savanna biome in Mpumalanga.

Figure 9.9: Savanna biome.

3. Succulent Karoo biome

- **Location**: the Succulent Karoo biome can be found along the west coast of the Northern Cape Province and the northern parts of the Western Cape Province.
- **Climate**: this biome is hot in summer and cold in winter and the rainfall in this area is very low. Fog is common, and frost is seldom severe enough to cause damage.
- **Soil and geography**: lime-rich, weakly developed soils, rocks and sand that is easily eroded.
- **Flora**: forty percent of plant species found here are endemic to this biome. The Namaqualand region of this biome is famous for its colourful wild flowers. Succulent plants are able to live through dry seasons by using water stored in their leaves or stems.
- **Fauna**: insects are common and the plants provide grazing for sheep and goats.

FACT
'Karoo' comes from the Khoi word *Karusa*, which means dry, barren, thirstland. Karoo is an apt description for this arid region.

Figure 9.10: Succulent Karoo biome.

Figure 9.11: Nama Karoo found in the Northern Cape province.

4. Nama Karoo

- **Location**: the Nama Karoo is the second largest biome in South Africa. It forms the major part of the Northern Cape Province and the Free State.
- **Climate**: it is regarded as a semi-desert area receiving very little rain. The summers are very hot and the winters are very cold and frost often occurs.
- **Soil and geography**: soil occurring on rocks is weakly developed. The area is also characterised by sands and rocky and red clay, making erosion occur easily.
- **Flora**: it is characterised by grassy dwarf shrub land.
- **Fauna**: the flora provides good grazing for sheep and goats.

FACT
Trees are not only producers, but as a result of their size they also create a **habitat** for other species. The leaf cover of trees provides **shelter** for animals, while the bark and fissures in the trees also provide a habitat for insects. The leaf cover also creates a shady environment in which shade-loving, low-growing plants can flourish.

FACT
When leaves or fruit fall from the trees and collect at the feet of the trees, another series of organisms can appear. By breaking down organic material, decomposers such as microorganisms return the organic nutrients to the soil. Humus is formed in this way. Humus is dead organic material. Other creatures that live off decayed organic material, namely the detritivores, also promote this process of decomposition by breaking up dead plant matter into its component nutrients.

5. Forest Biome

- **Location**: the forest biome in South Africa occurs in patches, in areas such as Knysna of the Western Cape as well as KwaZulu Natal, the Eastern Cape, Limpopo and Mpumalanga.
- **Climate**: some of these forests experience rain only in winter, while others get rainfall throughout the year.
- **Soil and geography**: forests range in altitude from sea level to above 2000 metres, soil is drained and virtually all soil types are present.
- **Flora**: forests are dominated by trees of which the Yellowwood is the largest. There are many herbaceous and bulbous plants that also occur.
- **Fauna**: numerous insect species, birds ans small mammals such as bushpig, bushbuck and monkeys. The canopy is a perfect habitat for birds such as the Knysna Loeries, pigeons and eagle.

Figure 9.12: Forest biome.

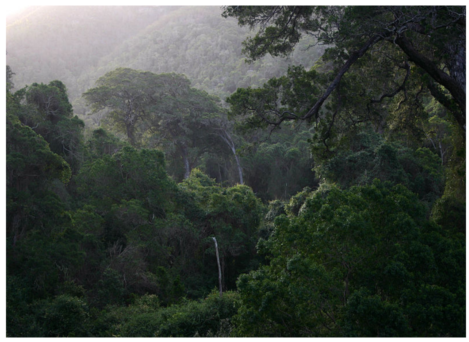


Figure 9.13: Knysna Forest.

Project: Poster project to illustrate the role players in a forest ecosystem

Instructions:

1. Bring pictures of animals, trees and other plants to class.
2. The teacher will divide the class into groups.
3. Each group will prepare a poster to illustrate the mutual dependence of the trees, other plants and animals.
4. Each group must present their poster to the rest of the class.
5. Answer the following questions / follow the instructions arising from the class discussion:

Questions:

1. Supposing the tree on your poster was to fall over.
   a) Which organisms would die?
   b) Which organisms would move away?
   c) Which organisms would increase in number?

2. Describe the role played by trees in an ecosystem.
3. Ecologically speaking, why is it bad practice to rake up leaves under trees?
4. Name three more examples where humans harm ecosystems.
5. Identify components of the ecosystem, including each trophic level. Represent this in the form of a diagram.

FACT
The Fynbos contains approximately 75% of South Africa's rare and threatened plants.

6. Fynbos

- **Location**: fynbos is the natural shrub found in the Western Cape of South Africa.
- **Climate**: characterised by cold, wet winters and hot, dry summers (Mediterranean climate conditions).
- **Soil and geography**: poor, acid and coarse-grained soil.
- **Flora**: fynbos is widely known for its widespread biodiversity. Important plant types found in the fynbos include proteas, 'silver trees' and 'pincushions'. Plants growing here do not lose their leaves. Proteas have striking flowers. It has the highest fynbos variety in the world, with over 9000 species of fynbos found here.
- **Fauna**: fynbos is home to many bird species, insects and small mammals.

Figure 9.14: Mountain Fynbos found in Hermanus, Western Cape.

Figure 9.15: Fynbos in Cape Peninsula.

The flora of the fynbos has a high degree of **endemism**. This is the ecological state of being specific to a geographic location such as an island, country or in this case, a defined biome such as the fynbos.

Fire is a necessary stage in the life-cycle of nearly all fynbos plants, and is common during the dry summer months. Many of the seeds germinate only after the intense heat of a fire. As proteas 'prepare' for the fire, they retain their seeds on the bush for at least a year, a habit known as **serotiny**.

The lowlands of the fynbos have been developed for agriculture and wine farming. Due to this, various species of fynbos have been threatened. For this reason, the fynbos region must be protected and preserved. It is a major tourist destination.

Project: Discovering fynbos in South Africa

The astonishing richness and diversity of the Western Cape's natural resources is matched only by the resourcefulness and diversity of its many people. Historical patterns of unsustainable use of resources have led to the Cape Floristic Region (CFR) being listed as one of the world's threatened bioregions, and the scars are deeply etched in the land and its people.

Western Cape residents are exploring new and sustainable ways to value and benefit from these globally important assets.

South Africa's Cape Floristic region is legendary, and the unique nature of the **fynbos** biome has been celebrated by biologists, conservationists, development experts, and ecologist worldwide.

(Adapted from speech by Tasneem Essop the Western Cape Provincial Minister for Environment, Planning and Economic Development)

Instructions

Write an essay on the **fynbos biome** and discuss the following aspects:

1. What is the meaning of the term "fynbos"?
2. Identify features of families/ indicator species that make up this vegetation type.
3. Describe its ecological role in the environment.
4. Describe the environmental impacts of destroying this type of vegetation.
5. Describe the economical importance of fynbos for the people of the Western Cape.
6. Describe management strategies involved in protecting it.

7. Thicket

- **Location**: the thicket biome occurs along the coasts of KwaZulu Natal and the Eastern Cape.
- **Climate**: thickets develop in areas where the rainfall is fairly high; however, there may be dry periods that prevent the vegetation from developing into forests.
- **Soil and geography**: most thickets occur in river valleys.
- **Flora**: the vegetation of this biome includes short trees, low intertwining shrubs and vines. There are no distinct layers of trees and shrubs, with many large open spaces found in the thicket biome. Thickets in the Eastern Cape are comprised of dense impenetrable vegetation dominated by spiny, often succulent trees and shrubs.
- **Fauna**: examples of fauna found in thicket include kudu, monkey, bushbuck and elephant.

Figure 9.16: Thicket Biome, Umdloti

Figure 9.17: Kalahari desert.

FACT
Did you know that most of the animals in the desert can live without water for a long time? They have adapted in many ways to do this. For instance, they can store water internally, take water out of their prey, or peck at succulents and suck out the water stored inside them.

8. Desert Biome

- **Location**: the Desert Biome is found largely in the Namib Desert along the coast of Namibia. The transition regions between deserts and grasslands are sometimes called semi-arid deserts.
- **Climate**: deserts are dry areas where evaporation usually exceeds precipitation. Rainfall is low, less than 25 centimetres per year, and can be highly variable and seasonal. The low humidity results in temperature extremes between day and night. Deserts can be hot or cold. Hot deserts (e.g. the Namib and Kalahari) are very hot in the summer and have relatively high temperatures throughout the year and have seasonal rainfall. This combination of low rainfall and high temperatures keeps the air very dry, increasing its evaporating power.
- **Soil and geography**: the soil consists mostly of sand, gravel or rocks.
- **Flora**: deserts have relatively little vegetation.
- **Fauna**: many insects and reptiles (lizards and snakes) occur in the desert biome.

Activity: Biomes Advertisement

Aim:

Getting to know the biomes of South Africa.

Materials:

- posters
- maps
- reference books
- adverts
- brochures
- Internet

Instructions:

You work for an Advertising Agency that is bidding for the account of a top travel agency. The bid includes designing a full page advert (A4) for the *Get-away* Magazine. Presentation, appeal and accuracy will therefore be of top priority. Study some advertisements for ideas.

The travel agency has specified that they would like the following to be included in the ad, which is geared towards people looking for a different and fascinating holiday in a **specific biome**:

1. A region in the biome of your choice, including cities and/or towns worth a visit
2. Climate (of interest to tourists)
3. Well-known geographical features in the region
4. Mention of some interesting wildlife (i.e. birds, animals, plants) that may be seen
5. Pictures
6. Tour dates
7. The name of the travel agency, with contact information

Project: Biome Poster

The following activity is to be done in groups of **four**

Instructions

1. Brainstorm a suitable set of criteria for assessment for poster and verbal report
2. Select **one** biome from the list given and do the following:
3. Use suitable references to obtain as much information as possible on the plants and animals found in your selected biome.
4. Make notes about the climate, landscape, flora and fauna, stating how some of these are adapted to their environment.
5. **Design** an attractive poster to illustrate the landscape as well as the dominant plants and animals that make up a food chain.
6. **Display** your poster on the classroom wall and each person of the group is to give a verbal presentation on an aspect of the biome you studied.

9.4 Environment ESGB3

The environment refers to everything that surrounds us, including the place where we live. We usually use the term 'environment' to refer to the physical aspects of our surroundings, which may be living (biotic) or non-living (abiotic). This means that if you live in a city, the environment consists of the buildings, roads and other infrastructure, while if you live on a farm, your environment consists of you pastures, farm house etc.

Although an environment consists of non-living and living things, the term 'environment' really just describes one's surroundings, but does not really define the relationships, connectedness or dynamic nature of those surroundings. To study how the living and non-living parts of the environment depend on and are influenced on each other, we need to understand a different concept- the ecosystem.

FACT
Ecology- rules for living on Earth
See video: 2CVR

FACT
Learn more about biotic and abiotic components:
See video: 2CVS

9.5 Ecosystems ESGB4

An ecosystem is a complex system that consists of all the living organisms in a particular area, as well as the environment with which the organisms interact. The living organisms and non-living components of the ecosystem interact in such a way as to maintain balance. Ecosystems are divided into **biotic** (living) and **abiotic** (non-living) components respectively. Each component is discussed in detail below.

Biotic components ESGB5

Biotic components are living things that shape the ecosystem. Each biotic factor needs energy to do work and for proper growth. To get this energy, organisms either need to produce their own energy using abiotic factors, or interact with other organisms by consuming them. Biotic components typically include:

- **Producers**: also known as **autotrophs** include all green plants. Producers make their own food using chemicals and energy sources from their environment. The producers include land and aquatic plants, algae and microscopic phytoplankton in the ocean. **Plants** use photosynthesis to manufacture sugar (glucose) from carbon dioxide and water. Using this sugar and other nutrients (e.g. nitrogen, phosphorus) taken up by their roots, plants produce a variety of organic materials. These materials include starches,lipids, proteins and nucleic acids.
- **Consumers**: are also known as **heterotrophs**. They eat other organisms, living or dead, and cannot produce their own food. Consumers are classed into different groups depending on the source of their food.

Herbivores (e.g. buck) feed on plants and are known as *primary consumers*. **Carnivores** (e.g. lions, hawks, killer whales) feed on other consumers and can be classified as *secondary* consumers. They feed on primary consumers. *Tertiary consumers* feed on other carnivores. Some organisms known as **omnivores** (e.g.crocodiles, rats and humans) feed on both plants and animals. Organisms that feed on dead animals are called **scavengers** (e.g., vultures, ants and flies). **Detritivores** (detritus feeders, e.g. earthworms, termites, crabs) feed on organic wastes or fragments of dead organisms.

- **Decomposers**: (e.g. bacteria, fungi) also feed on organic waste and dead organisms, but they can digest the materials outside their bodies. The decomposers play a crucial role in recycling nutrients, as they reduce complex organic matter into inorganic nutrients that can be used by producers. If an organic substance can be broken down by decomposers, it is called *biodegradable*.

Abiotic components ESGB6

Abiotic components are the non-living chemical and physical factors in the environment that affect ecosystems. Abiotic components play a crucial role in all of biology. Abiotic factors are broadly grouped into **physiographic**, **edaphic** and **climactic** factors and **atmospheric gases**.

1. Physiographic factors

Physiographic factors are those associated with the physical nature of the area. The main physiographic factors we will look at are slopes, aspect and altitude.

- **Slope**: is the gradient or steepness of a particular surface of the Earth. The slope affects the rate of water run-off. A steep slope encourages fast run-off of water and can cause soil erosion. The soil tends to be shallow and infertile with reduced plant growth. Plants are small and few animals are present. A gentle slope favours slower flow of surface water, reduces erosion, and increases availability of water to plants. The direction and steepness of a slope also influences the surface temperature of the soil.
- **Altitude**: is the *height* of the land above sea level. At high altitudes the temperature is lower, the wind speed is greater, and the rainfall less. Environments at higher altitudes are also more likely to experience snow conditions. Altitude plays a role in vegetation zones. At high altitudes, less plant and animal species are found. Plants growing at mid-altitudes experience more stunted growth. Plants at sea-level are abundant.
- **Aspect**: refers to the position of an area in relation to the sun or wind or wave action. It is the direction that the slope faces i.e. North, East, West. In South Africa rain fall is more common on the south-eastern slopes, therefore these tend to be forested or rich in vegetation. The slopes facing the other way (north west) tend to be drier.

2. Edaphic factors

Edaphic factors are those factors related to the soil. The qualities that may characterise the soil include drainage, texture, or chemical properties such as pH. Edaphic factors affect the organisms (bacteria, plant life etc.) that define certain types of ecosystems. There are certain plant and animal types that are specific to areas of a particular soil type. The particular factors we will consider include the pH of the soil and soil structure.

- **pH of soil** is a measure of how acid or alkaline soil is and can be measured by using the pH scale. The pH scale ranges from 0 to 14. Neutral solutions have a pH value of 7. Acid solutions have a pH value of less than 7 and alkaline solutions have a pH value greater than 7. Litmus paper or universal indicator can be used to determine whether a solution is acid or alkaline.

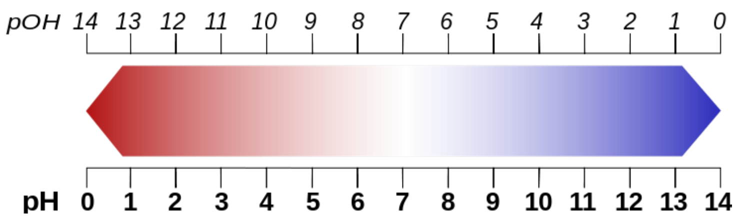


Figure 9.18: pH scale for soil.

NOTE:
Did you know that some species of Hydrangea flowers are natural pH indicators? The flowers of the *Hydrangea macrophylla* and *Hydrangea serrata* cultivars, can changes colour depending on the relative acidity of the soil in which they are planted. In an acidic soil with a pH below 7, the flowers will usually be blue. However in an alkaline soil with a pH above 7, the flowers will be more pink. Moving the plant from one soil to another results in a change in flower colour if the pH of the soil is different (see Figure 9.19).

Figure 9.19: Hydrangeas.

- **Soil Structure**: the decomposed organic matter, called humus gives top-soil its dark colour. It supplies plants with nutrients and helps the soil retain water. Soils rich in humus are fertile soils. The specific soil type is determined by the size of particles e.g sand has very large sized particles, clay has very small sized particles and loam has a mixture of particle sizes. If you roll moist soil between your fingers, clay soil feels sticky, sandy soil feels gritty and loam soil feels soapy. The water retention capacity of soils is the ability of soil to retain different amounts of water. Clay soil retains a large amount of water. Sandy soil retains very little water. Loam soil retains a moderate amount of water.

Investigation: Investigating the water-retaining properties of soil

Aim:

To investigate the water retaining properties of three soil types.

Apparatus:

- loam, sand and clay soil samples
- filter funnels and filter paper
- measuring cylinders
- water
- stop watches

Method:

1. Set up the three different 100 ml measuring cylinders, each with a funnel lined with filter paper.
2. Label each of the measuring cylinders either loam, sand or clay.
3. Add the same amount (e.g 50 gm) of each specific soil sample to the corresponding labelled funnel with filter paper.
4. Carefully pour the same amount (50 ml) of water into each funnel.
5. Immediately start the stopwatch.
6. Allow the water to pass through the soil sample.
7. Wait until the water is no longer dripping into the cylinder before you record the time for each soil type.
8. Record how much water there is in the measuring cylinder.

Results:

1. Write down your results in a table:
   a) The time taken for the water to pass through the soil.
   b) The amount of water in the measuring cylinder.
2. Draw a bar graph to represent your results.

Observations:

1. Which sample of water retained the most water?
2. Which sample of water retained the least water?
3. Is the speed at which the water drains related to the amount of water that gets retained? Describe the relationship using your results.

Conclusions:

Explain your observations. Try to describe three properties that result in the different water-retaining capacities of different soil types. Use your experimental results to recommend which soil would you use for your pot plants.

3. Climatic factors

- **Sunlight**: is essential for the process of photosynthesis. Producers, such as plants, rely directly on the sun. Heterotrophs, such as animals, use light from the sun indirectly by consuming plants or other heterotrophs. All organisms receive the energy required for survival through the break down of sugars and other molecular components that are produced by the autotrophs. These sugars are then broken to release the energy stored in them, by the process of cellular respiration.
- **Temperature**: varies greatly across different parts of the Earth and throughout the year. Temperature affects the rate of evaporation and transpiration and causes seasonal changes in weather. Seasonal variation in vegetation also occurs as the germination of seeds requires warm temperatures. Plants and animals have special adaptations that make them suited to the temperature of their specific environment. Temperature affects the rate at which photosynthesis, cellular respiration and decomposition take place. As you learnt in the earlier section on enzymes, this is linked to the optimal temperature profile for enzymes. The rate of reaction increases with increasing temperature and decreases at lower temperatures.
- **Water**: is one of the most important factors in the ecosystem. It is the main component of living cells and is essential for all living organisms. About 80% of the human body and 90% of the plant body consists of water. Water is not evenly distributed over the Earth. It is abundant in aquatic ecosystems and least abundant in deserts. Plants are adapted to the available amount of water in the following ways:
  - **Xerophytes** are plants that are able to live in dry habitats, or in regions with low annual rainfall. These plants are resistant to drought, have to cope with a shortage of water, high temperatures and light intensities and dry warm winds. We discussed in detail the adaptations developed by xerophytes in order to avoid water loss in the earlier chapter on plant structure.

FACT
Endothermic animals are able to regulate their body temperature so they are not affected by extreme temperatures, and are able to live in habitats over a wide range of temperatures. In cold regions, animals have developed a layer of insulating fat, or hibernate during the colder months. In very hot regions, animals have adapted by becoming nocturnal in their habitats. Ectothermic animals are unable to regulate their body temperature, and therefore the change in environmental temperature will affect their distribution and activities.

FACT
In Northern Hemisphere countries where the day length is substantially longer in the summer, the rate of growth of plants is very high.

- **Mesophytes** are plants that need an average, regular supply of water.
- **Hydrophytes** are plants that are able to live entirely or partially submerged in water or in very wet soil. These plants have to cope with a water surplus.

4. Air/gases

- **Wind**: speeds up evaporation and assists in pollination of plants and the dispersal of their seeds.
- **Air**: is composed of 78% nitrogen, 21% oxygen, 4% carbon dioxide and water vapour. Look ahead to the section on nutrient cycles to read more detail. Oxygen is used in cellular respiration and combustion and is returned to the environment by the process of photosynthesis. Carbon dioxide is a product of cellular respiration and decayed organic matter. It is removed from the atmosphere by plants during the process of photosynthesis. Nitrogen is needed by all living organisms for the synthesis of proteins. The amount of water vapour found in the air remains constant on average, however, it can vary greatly from one place to another. Some parts of the earth are prone to high humidity levels, while other locations have very dry air. Much of what we consider weather is caused by water vapour. The clouds in the sky are largely made up of it, and it is the condensation of this vapour into droplets that creates rain and snow.

Project: Studying a terrestrial ecosystem

Aim and background information

You are required to choose **one** ecosystem within a local biome for special study. The study will be conducted over two terms and will involve a number of investigations. You may work in groups. Each group will have to plan, collect, record, present, analyse and evaluate the data.

1. Soil

The type of soil found in your ecosystem will have an influence on the types of plant that will grow in that ecosystem. It is important to identify the types of soil found in your ecosystem by doing the following soil tests.

1.1 How to identify soil texture

1. Roll some wet soil into a ball.
2. Then try to roll the ball into a sausage shape.
3. Bend the sausage into a ring.

How to interpret your observations:

- if the sausage breaks as you bend it, the soil is sandy.
- if the sausage bend slightly, and then breaks, the soil is loamy.
- if the sausage bends easily the soil contains a lot of clay.

1.2 How to measure pH

You will need the following materials:

- spoon
- water
- jar with a lid
- plastic teaspoon
- soil sample
- red and blue litmus paper or universal litmus paper

1. Collect a small sample of soil to test.
2. Place a teaspoon of soil into the jar, stir it to loosen all the particles.
3. Carefully add water to fill the jar approximately half way.
4. Screw the lid onto the jar and shake the jar gently.
5. Stand the jar on a flat surface and wait until the soil settles and the water becomes clear. This may take a few days.
6. Unscrew the cap and using the plastic spoon, carefully remove some water from the jar.
7. Test the pH of the water by using the litmus paper.

How to interpret litmus paper observations:

- blue litmus paper will turn red when placed in an acid solution.
- red litmus paper will turn blue when placed in an alkaline solution.
- if using universal litmus paper read the pH of the pH scale.

1.3 Measure the water-holding capacity of your soil sample/samples

You will need the following apparatus:

- filter paper
- water
- soil sample (preferably dry)
- a two litre plastic cool drink bottle with the top of the bottle cut off (the top will act as your funnel and the bottom will act as a water-collecting vessel)

1. Remove the bottle cap from the top part of the bottle (funnel).
2. Place the 'funnel' inside the bottom half of the bottle.
3. Measure out your soil sample to be tested (measure by mass or volume).
4. Place the piece of filter paper into the neck of the bottle.
5. Add the soil sample into the 'funnel'.
6. NOTE: If testing more than one soil sample, the same amount of soil and water must be added to each bottle top.
7. Very slowly add water to the bottle.
8. Observe how much water runs through the soil into the bottom of the bottle.
9. Once the soil has drained of the water, measure the amount of water that was filtered using a measuring cylinder.

2. Temperature

You will need the following apparatus:

- thermometer

1. Measure the air temperature using a thermometer. Record the temperature in your ecosystem at two different times of day.
2. Try and record the temperature at the same time on every day for one week in the third term and repeat the process for one week in the fourth term.
3. A table similar to the table below needs to be completed for your temperature recordings.

Date	Time	Temperature

4. Use the information in the table to draw a line graph of the temperature over the study period.
5. Discuss whether there are any differences or general patterns in the daily temperature between the third and fourth terms.

3. Light

You will need the following apparatus:

- watch or clock

1. To measure the photoperiod of your ecosystem, you are required to keep a record of the times of sunrise and sunset.

2. Record the times of sunrise and sunset for one week in the third term, and for one week in the fourth term.
3. Record the effects of the photoperiod on the behaviour of plants. An example is: daisies open during the day and close at night. Record what happens to your plants. Complete a table similar to the table below.

Date	Time Flower Opens	Time Flower Closes

4. Draw two line graphs showing the times the flowers open and the time the flowers close.
5. Also record the times of sunrise and sunset.
6. From your graph discuss if the opening and closing of the flowers are related to sunrise and sunset.
7. Discuss whether you found any differences between the third and fourth terms.

4. Physiographic Factors

You will need:

- compass

1. If your ecosystem is on a slope, record the direction of the slope.

5. Studying biotic factors

If the ecosystem you are studying covers a large area, it may be difficult to observe all the living organisms. If this is the case, you can get some idea of the plant and animal diversity in the ecosystem you are studying by choosing a smaller sample area to study.

You will need:

- pencil
- wooden sticks
- string
- metre stick or measuring tape or string
- field guide to plants and animals in your ecosystem (if necessary)

1. Mark out an area of 4 square metres in your ecosystem.
2. Choose an area you think will contain the most plants and animals.

3. Wind the string around the wooden sticks so that you create a grid to study within your ecosystem.
4. Make a list of all the plants and animals found in your ecosystem.
5. Try and name the plants and animals. Use a reference book or the Internet to identify the plants and animals in your ecosystem.
6. Draw a distribution map showing where the different organisms were found in the ecosystem.
7. Give each organism you found a code.
8. Use the codes to make a map by showing where in the grid each organism was found.
9. Record how many different plants and animals were found in your ecosystem.
10. Which parts of your grid recorded the most plants and animals?
11. Briefly discuss which abiotic factors influenced your ecosystem.
12. Investigate what the animals in your ecosystem eat and then draw a food web for the ecosystem.
13. Why do the organisms you found in your ecosystem live in this habitat?
14. Write a short paragraph describing the ecological niche of one of the organisms you observed.

6. The effect of humans on the ecosystem

Determine if humans have had any effect on the ecosystem. These effects may be positive, negative, or a combination of both.

1. Write a short paragraph of 200 words on the effect of humans on your ecosystem.

Write a scientific report on the ecosystem you have studied.

Your report should include the following:

- A title
- Introduction
- Equipment or materials used
- Results (including tables)
- Observations
- Discussion
- Conclusion
- References
- You can use drawings and photographs to illustrate your report.

9.6 Energy flow ESGB7

FACT
A catchy song about food chains to help you remember:
See video: 2CVT

In ecology, energy flow refers to the flow of energy through a food chain. In an ecosystem, we attempt to establish the feeding relationships between organisms living together. Each organism belongs to a 'trophic level' which refers to the position occupied by an organism in the food chain. Energy is passed on from every trophic level to the next and each time about 90% of the energy is lost with some being lost as heat into the environment and some being incompletely digested food. So primary consumers get about 10% of the energy produced by autotrophs while secondary consumers get 1% and tertiary consumers get 0,1%. A general energy flow scenario is as follows:

- **Autotrophs**: solar energy is fixed by autotrophs (also called producers, such as green plants) into energy in the form of carbohydrates. This is done by photosynthesis.
- **Primary consumers**: part of the food made available by plants is consumed by primary consumers known as herbivores. The energy gained is converted to body heat or used to grow, reproduce, etc. Energy loss also occurs in the expulsion of undigested food by egestion.
- **Secondary consumers**: carnivores and omnivores consume the primary consumers, and use the energy obtained to grow, move, respire etc.
- **Tertiary consumers**: may be the major predators of an ecosystem, and feed on the primary and secondary consumers with some energy passed on and some lost as with other levels of the food chain.
- **Decomposers**: A final link in any food chain are the decomposers which break down the organic matter of the tertiary consumers and release the nutrients into the soil. They also break down plants, herbivores and other dead organic matter. Examples of decomposers are bacteria and fungi.

The flow of energy in an ecosystem can be explained in the form of a chain, web or pyramid.

Food chain ESGB8

A food chain is a series of nutrient and energy changes that moves through a chain of organisms. It always begins with a producer and terminates with decomposers. Below is an example of a simple food chain in a grassland ecosystem. The **arrows** show the movement of energy from one organism to another.

green plant → **impala** → **leopard** → **bacteria**

producer → primary consumer → secondary consumer → decomposer

Activity: Understanding Food Chains

Activity 1:

Trace a **food chain** of the vegetables, fruit, cheese, eggs or meat that you had for breakfast or will have for dinner.

Activity 2:

1. In the food chain shown in the text which of the three organisms is the
   a) herbivore
   b) carnivore
   c) producer
2. Draw in the decomposers in the above food chain. Ensure that the direction of the arrows is correct.
3. What organism(s) will feed on the leopard?
4. Construct a new food chain showing at least four organisms.
5. Producers use sunlight to manufacture their own food. Write a word equation to depict this process. [Hint: think of the requirements and outcomes of the process of photosynthesis]

Food pyramid ESGB9

A food pyramid is another way of representing the relationships between organisms in an ecosystem.

Trophic levels and the food pyramid

- **Producers**: Plants are on the first level, or bottom of the pyramid, because they produce their own organic food using energy from the sun and therefore have a lot of energy to pass on.
- **Primary Consumers**: Herbivores are on the second level because they feed on plants. Herbivores consume plants; therefore, to maintain balance, there are far fewer herbivores than plants.
- **Secondary Consumers**: Carnivores feed on herbivores. Consequently, to maintain balance, there are fewer carnivores than herbivores. Carnivores get their energy from plants indirectly and are on the third level.

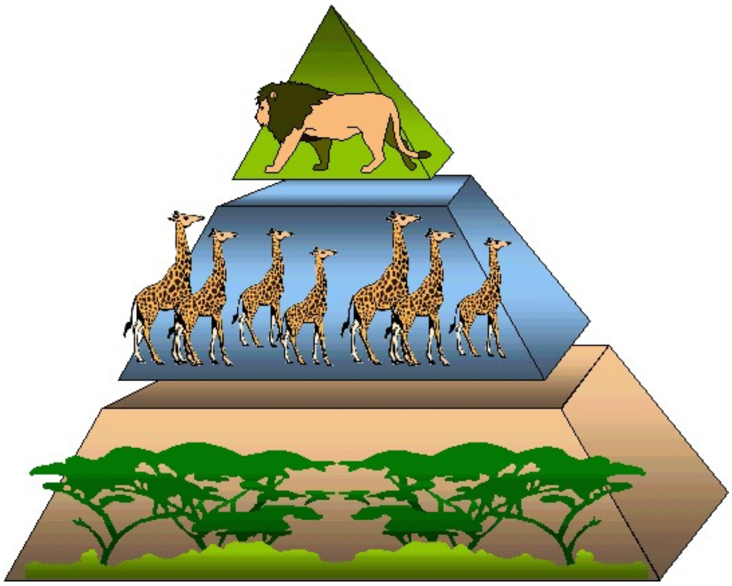


Figure 9.20: Food pyramid.

Trophic levels can be drawn as one of the following:

- **pyramid of numbers:** which shows the total number of organisms in each trophic level.
- **pyramid of biomass:** which shows the total amount of biomass (living matter) at each trophic level.
- **pyramid of energy:** which shows the total amount of energy contents in the biomass of each trophic level.

Most pyramids are drawn as **energy** pyramids, and are always triangular, whereas number pyramids are not.

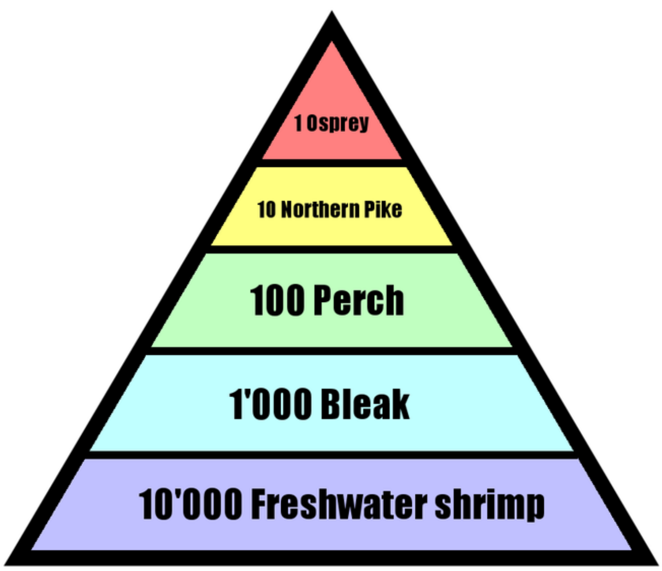


Figure 9.21: Pyramid of numbers.

Food web ESGBB

A food web is made up of a number of food chains. It represents the different feeding relationships in an ecosystem or a biome. It is usually more complicated than a food chain because organisms can get their energy or food from more than one source. The presence of a number of food sources makes the system more stable. If one organism is removed, the whole system will not collapse, unlike in a single food chain. A food web in a typical Savannah environment is shown in Figure 9.22.

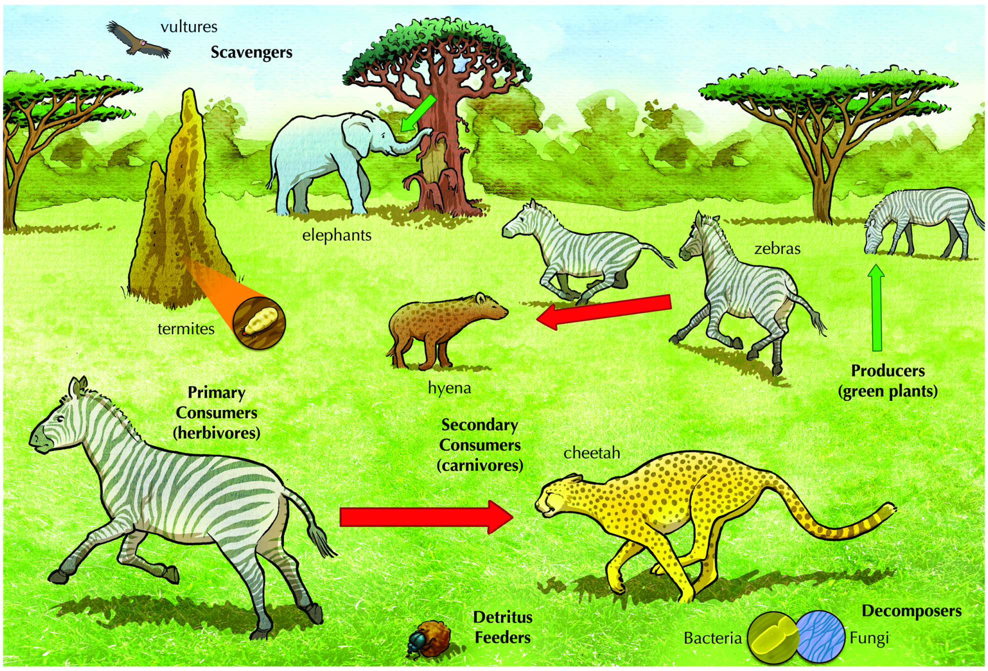


Figure 9.22: The figure shows a food web in a typical Savannah environment.

Activity: Understanding food chains and food pyramids

Aim:

Gain conceptual understanding of food chains and food pyramids

Materials:

- textbook
- resources provided by teacher

Instructions:

1. Look at any of the food webs or food chains in this chapter, or use a food chain or food web provided by your teacher.

Questions:

1. Identify a food chain that has three trophic levels.
2. Identify a food chain that has four trophic levels.
3. Name two:
   a) producers
   b) primary consumers
   c) secondary consumers
   d) tertiary consumers
4. There are very few tertiary consumers compared to the primary consumers. Why?
5. What will happen if the hyena is removed from the food web?

FACT
Bill Nye the science guy talks about the food web:
See video: 2CVV

FACT
A simple video explaining nutrient cycling:
See video: 2CVW

9.7 Nutrient cycles ESGBC

A nutrient cycle refers to the movement and exchange of organic and inorganic matter back into the production of living matter. The process is regulated by the food web pathways previously presented, which decompose organic matter into inorganic nutrients. Nutrient cycles occur within ecosystems. Nutrient cycles that we will examine in this section include water, carbon, oxygen and nitrogen cycles.

Water cycle ESGBD

Over two thirds of the Earth's surface is covered by water. It forms an important component of most life forms, with up to 70% of plants and animals being composed of water. Vast quantities of water cycle through Earth's atmosphere, oceans, land and biosphere. This cycling of water is called the **water** or **hydrological** cycle. The cycling of water is important in determining our weather and climate, supports plant growth and makes life possible.

- **Evaporation**: Most water evaporates from the oceans, where water is found in highest abundance. However some evaporation also occurs from lakes, rivers, streams and following rain.

- **Transpiration**: Is the water loss from the surface area (particularly the stomata) of plants. Transpiration accounts for a massive 50% of land-based evaporation, and 10% of total evaporation.
- **Evapotranspiration**: The processes of evaporation and transpiration are often collectively referred to as evapotranspiration.
- **Condensation**: The process by which water vapour is converted back into liquid is called condensation. You may have observed a similar process occurring when dew drops form on a blade of grass or on cold glass. Water in the atmosphere condenses to form clouds.
- **Precipitation**: Water returns to Earth through precipitation in the form of rain, sleet, snow or ice (hail). When rain occurs due to precipitation, most of it runs off into lakes and rivers while a significant portion of it sinks into the ground.
- **Infiltration**: The process through which water sinks into the ground is known as infiltration and is determined by the soil or rock type through which water moves. During the process of sinking into the Earth's surface, water is filtered and purified. Depending on the soil type and the depth to which the water has sunk, the ground water becomes increasingly purified: the deeper the water, the cleaner it becomes.
- **Melting and freezing**: Some water freezes and is 'locked up' in ice, such as in glaciers and ice sheets. Similarly, water sometimes melts and is returned to oceans and seas.

The processes involved in the water cycle are shown in Figure 9.23.

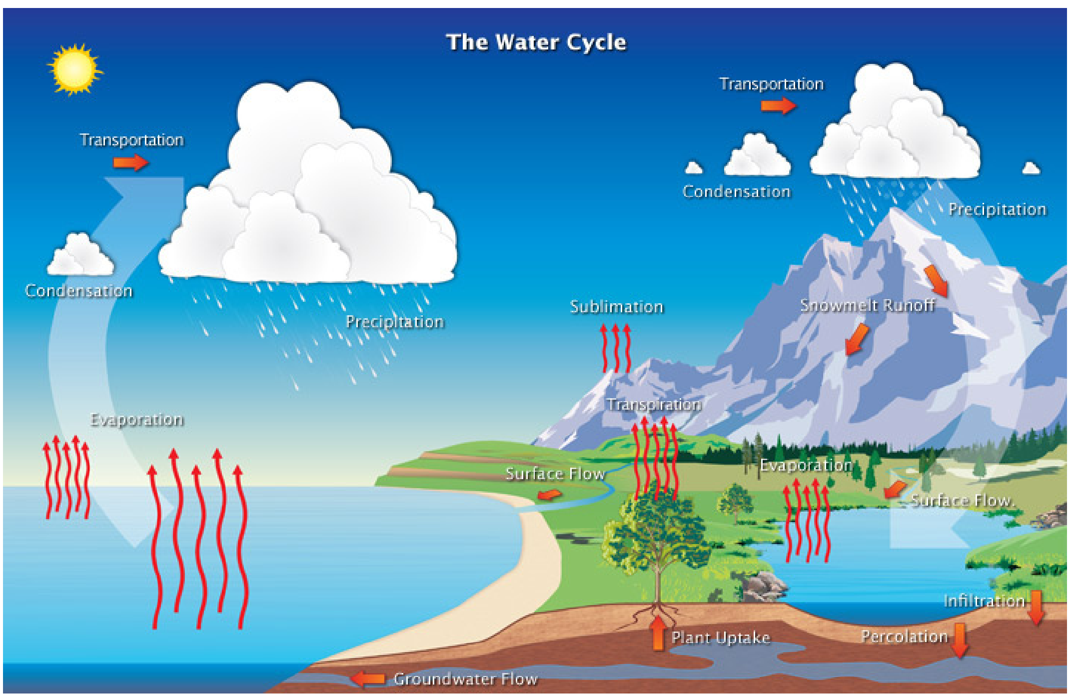


Figure 9.23: The water cycle.

Oxygen cycle ESGBF

FACT
A video about the oxygen cycle. Focus on the first part of the video clip and the summary at the end.
See video: 2CVX

Oxygen is one of the main gases found in the air, along with nitrogen. Oxygen is re-cycled between the air and living organisms in the following ways:

- **Breathing and respiration**: organisms such as animals and plants take in oxygen from the air during breathing and gaseous exchange processes. The oxygen is used for cellular respiration to release energy from organic nutrients such as glucose.
- **Photosynthesis**: during photosynthesis, plants absorb carbon dioxide from the air to synthesise sugars, and release oxygen.
- There is a **complementary** relationship between photosynthesis and cellular respiration in that the former produces oxygen and the latter consumes oxygen.

The oxygen cycle is shown in Figure 9.24.

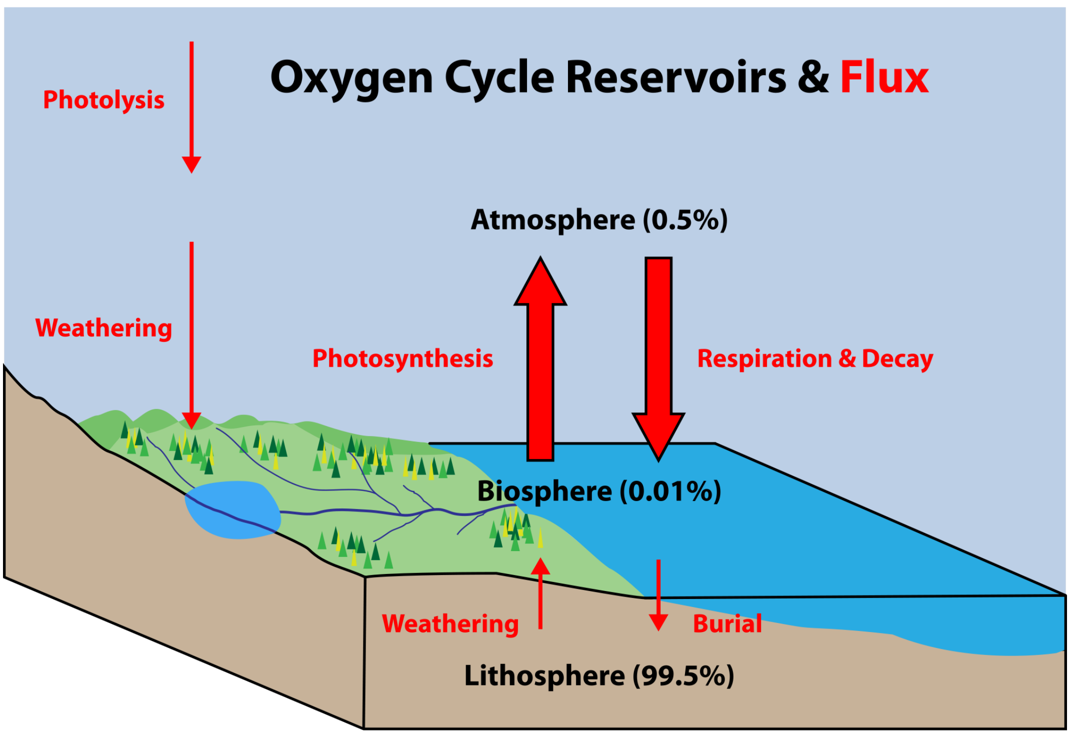


Figure 9.24: Oxygen cycle.

FACT
Learn more about the carbon cycle in this video:
See video: 2CVY

Carbon cycle ESGBG

Carbon is the basic building block of all **organic** materials, and therefore, of living organisms. Most of the carbon on earth can be found in the crust. Other reservoirs of carbon include the oceans and atmosphere. Carbon moves from one reservoir to another by these processes:

- **Combustion**: Burning of wood and fossil fuels by factory and auto emissions transfers carbon to the atmosphere as carbon dioxide.
- **Photosynthesis**: Carbon dioxide is taken up by plants during photosynthesis and is converted into energy rich organic molecules, such as glucose, which contains carbon.
- **Metabolism**: Autotrophs convert carbon into *organic* molecules like fats, carbohydrates and proteins, which animals can eat.
- **Cellular respiration**: Animals eat plants for food, taking up the organic carbon (carbohydrates). Plants and animals break down these organic molecules during the process of cellular respiration and release energy, water and carbon dioxide. Carbon dioxide is returned to the atmosphere during gaseous exchange.
- **Precipitate**: Carbon dioxide in the atmosphere can also **precipitate** as carbonate in ocean sediments.
- **Decay**: Carbon dioxide gas is also released into the atmosphere during the decay of all organisms.

Photosynthesis and **gaseous exchange** are the main carbon cycling processes involving living organisms. Figure 9.25 depicts the carbon cycle.

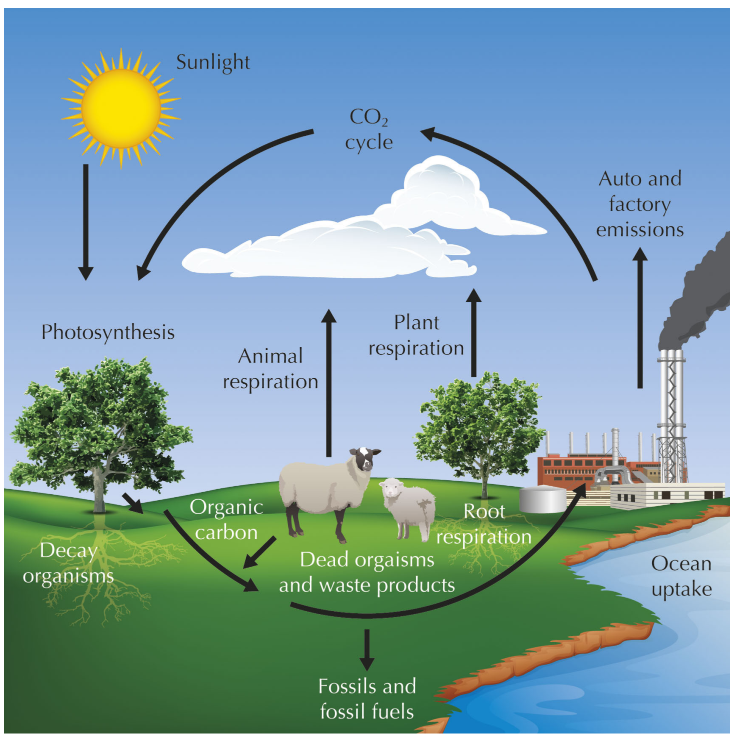


Figure 9.25: The carbon cycle.

Nitrogen cycle ESGBH

FACT
This video summarises the nitrogen cycle.
See video: 2CVZ

Nitrogen (N_2) makes up most of the gas in the atmosphere (about 78%). Nitrogen is important to living organisms and is used in the production of amino acids, proteins and nucleic acids (DNA, RNA).

- Nitrogen gas present in the air is **not** available to organisms and thus has to be made available in a form absorbable by plants and animals.
- Only a few single-cell organisms, like bacteria can use nitrogen from the atmosphere directly.
- For plants, nitrogen has to be changed into other forms, eg. nitrates or ammonia. This process is known as nitrogen fixation.

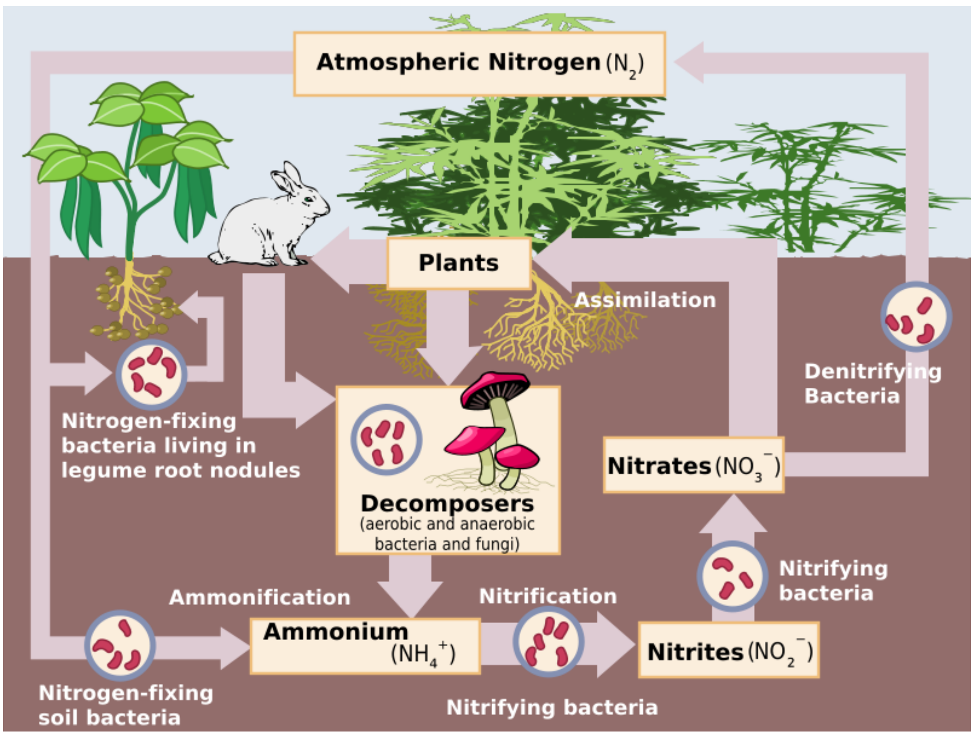


Figure 9.26: The nitrogen cycle.

The nitrogen cycle involves the following steps:

- **Lightning**: Nitrogen can be changed to nitrates directly by lightning. The rapid growth of algae after thunderstorms is because of this process, which increases the amount of nitrates that fall onto the earth in rain water, acting as fertiliser.
- **Absorption**: Ammonia and nitrates are absorbed by plants through their roots.
- **Ingestion**: Humans and animals get their nitrogen supplies by eating plants or plant-eating animals.

FACT
South Africa is home to: The largest bird— ostrich.

- **Decomposition**: During decomposition, bacteria and fungi break down proteins and amino acids from plants and animals.
- **Ammonification**: The nitrogenous breakdown products of amino acids are converted into ammonia (NH_3) by these decomposing bacteria.
- **Nitrification**: Is the conversion of the ammonia to nitrates (NO_3^-) by nitrifying bacteria.
- **Denitrification**: In a process called denitrification, bacteria convert ammonia and nitrate into nitrogen and nitrous oxide (N_2O). Nitrogen is returned to the atmosphere to start the cycle over again.

9.8 Ecotourism ESGBJ

The attractions of touring South Africa ESGBK

South Africa is a beautiful country that boasts great diversity in its flora and fauna. There are many interesting cultural, historical and environmental places that people from South Africa and other countries want to visit.

From what you learnt about the different biomes, you can see that South Africa has a range of ecosystems from desert, mountain, forest and marine systems to our own unique fynbos biome.

South Africa is one of the most biodiverse countries in the world. Although it only encompasses about 1,200,000 km^2, it is home to 10% of all plant species on earth. South Africa is considered mega diverse, along with 17 other countries, which means that together these countries contain 70% of the planet's biodiversity. South Africa's ability to support such a diverse population of plants and animals is due in large part to its unique geography. The combination of geography and wildlife makes South Africa an important travel destination to many.

Ecotourism is thought to be the idea of bringing tourism into a country while supporting the biodiversity.

Economic benefits of ecotourism

- Tourism is one of the fastest growing sectors of South Africa's economy and is estimated to bring in up to R62 billion/ year
- Reinvesting some of the earnings from eco-tourism into the communities living near tourist destinations might be a means of alleviating poverty.
- Tourism provides jobs: e.g park operators, sellers of local crafts, guides, etc.
- Eco-tourism has the potential to create infrastructural development for communities that live around major tourist destinations. This is especially useful where major tourist locations are found in remote areas.

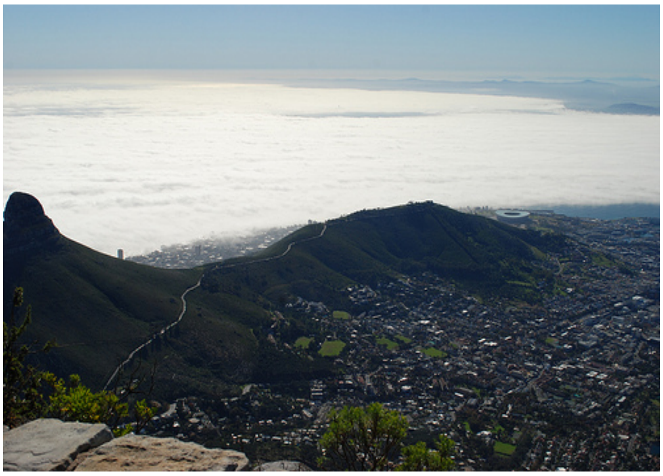


Figure 9.27: Cape Town, South Africa is a world-renowned tourist destination.

Figure 9.28: A baby impala in the Kruger National Park.

Ethical issues

While tourism has great economic potential and gives people access to unique places and cultures, it can have a negative impact. Sensitive ecosystems, such as wetlands and coasts, need to be protected so that the balance of organisms can be maintained. Too many visitors, and visitors who are not informed about their impact on the environment, can have a harmful effect. In the same way tourists need to be sensitive to the cultures and people that they visit.

To protect the plants and animals in the unique ecosystems of South Africa, many areas have been declared National Parks and have strict rules about how to behave.

In the same way, places that are historically or culturally important have been declared national heritage sites that are protected and maintained. South Africa is also proud to have eight UNESCO (The United Nations Educational, Scientific and Cultural Organisation) sites:

- **Cultural**
  - Fossil Hominid Sites of Sterkfontein, Swartkrans, Kromdraai, and Environs (1999)
  - Mapungubwe Cultural Landscape (2003)
  - Robben Island (1999)
  - Richtersveld Cultural and Botanical Landscape (2007)
- **Mixed**
  - UKhahlamba / Drakensberg Park (2000)
- **Natural**
  - Cape Floral Region Protected Areas (2004)
  - Greater St. Lucia Wetland Park (1999)
  - Vredefort Dome (2005)

How to be a responsible ecotourist ESGBM

Many areas of South Africa are protected. When travelling to these areas, you need to respect the area and the people that you are visiting. These are a few tips:

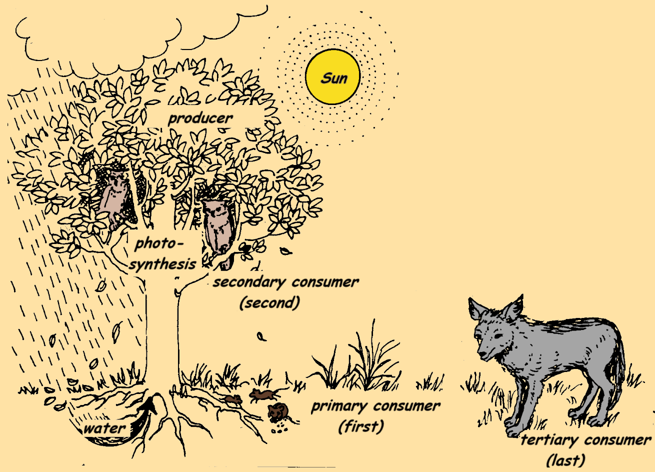
- Learn a little about the place you are visiting before you go in order to be aware of the do's and don'ts. For example, littering is not allowed in any National Park in South Africa.
- South Africa is rich in cultural diversity, which means that people from different areas have different ways of doing things. Learn about the culture of local people so that you can make sure not to offend anyone by your behaviour.
- When you are in a protected area, do not damage plants or animals or buildings. For example, writing graffiti on historical buildings or sites. Remember the saying: take only pictures, leave only footprints.

9.9 Summary ESGBN

- The biosphere is the sphere in which all ecosystems on Earth exist. It interacts with the atmosphere, lithosphere and hydrosphere.
- Biomes contained within the biosphere are regions with similar climatic and geographic conditions. Broadly, biomes are either aquatic or terrestrial.
- South Africa's major aquatic biomes include freshwater and marine biomes, based on their salt concentrations. Terrestrial biomes of South Africa include Grassland, Savannah, Succulent and Nama Karoo, Forest, Fynbos, Desert and Thicket Biomes. Each is located differently across South Africa and has its own distinctive plant and animal life.
- Ecosystems refer to environments that consist of abiotic factors and biotic factors (organisms) that interact to maintain a balance.
- Abiotic factors including physiographic (slope, altitude and aspect) and edaphic (soil pH, texture, humus content) factors.
- Energy flows through ecosystems from the sun through to producers (plants), primary consumers (typically herbivores), secondary consumers (carnivores), ultimately terminating at decomposers.
- The food chain describes the relationships linking producers, consumers and decomposers. Food pyramids can also be used to represent this relationship. Pyramids of biomass, energy and numbers of organisms can also be used to describe the biotic relationships in ecosystems.
- Nutrient cycles describe the flow of particular nutrients (C, O, N and water) through the ecosystem.
- Ecotourism produces widespread benefits to South Africa, creating jobs, preserving its natural beauty and improving infrastructure. There are ethical considerations involved in ensuring that the ecological and cultural diversity of South Africa's ecosystems is preserved.

Exercise 9 – 1: End of chapter exercises

1. Study the sketch of the forest ecosystem below:



   a) Name the:
      i. producer
      ii. primary consumer
      iii. secondary consumer
      iv. tertiary consumer
   b) The ecosystem consists of living organisms together with the _

2. Read the article below and answer the questions that follow:

ANTARCTIC: ALGAE CREATE 100-KM LONG BLOOM FROM IRON IN SNOW

SYDNEY — Snow blown into the Antarctic Ocean from the frozen continent has triggered an algal bloom so large and so vividly green it can be seen from space, media reports said yesterday.

The bloom, captured by Australian scientists monitoring a NASA satellite 650 kilometres above the earth, is about 100 kilometres north-to-south and 200 kilometres wide.

The snow contains minute quantities of iron that stimulates the growth of nutrients.

University of Tasmania glaciologist Mark Curran said the monster bloom had sparked a food chain starting with krill and plankton and going all the way up to seals and whales.

The bloom is thought to be phaeocystis algae, a single-cell photosynthetic algae sometimes called the "foam algae" that is present in all the world's oceans.

Curran told Australia's AAP news agency that the bloom had lasted 20 days so far and would eventually dissipate.

"They die off, things like bacteria comes through there and feeds on the material and then the material eventually will sink to the bottom of the ocean — anything that hasn't been consumed by predators higher up the food chain," he said.

Researchers from the Australian Antarctic Division aboard the Aurora Australia research vessel hope to pass through the bloom en route to Australia's Mawson Station.

— Sapa-DPA.

a) Describe what you understand by the term algal bloom.

b) With reference to above article, name the abiotic factor that is responsible for the bloom and how the factor reached the Antarctic Ocean.

c) Discuss the role decomposers could play in this ecosystem.

3. Earthworms will burrow into the soil if they are on the surface and it is daylight. We can explain this behaviour by saying that they are either repelled by light or because they are attracted to the soil.

   Describe an experiment that you could do to determine which explanation is correct. When designing your experiment, bear in mind that earthworms are living organisms.

   Set out your design under the following headings:

   a) Hypothesis

   b) Aim

   c) Apparatus and Materials

   d) Method

4. Read the following information taken from UWC Enviro Fact sheet on the Fynbos and answer the questions that follow:

> Fynbos is the major vegetation type of the small botanical region known as the Cape Floral Kingdom. The Cape Floral Kingdom is both the smallest and the richest floral kingdom, with the highest known concentration of plant species: 1 300 per 10 000 km^2. The nearest rival, the South American rain forest has a concentration of only 400 per 10 000 km^2. Conservation of the Cape Floral Kingdom, with its distinctive fynbos vegetation, is a national conservation priority demanding urgent action.
>
> Over 7 700 plant species are found in fynbos, an astonishing number for such a small area. Of these roughly 70% are endemic to the area. Many of these are threatened with extinction. The richness of the fynbos is well demonstrated by its ericas or heaths, of which there are over 600 different species. There are just 26 in the rest of the world. Although the most striking features of the composition of fynbos are the presence of many conspicuous members of protea, erica and reed family that fill the niche usually occupied by grasses, the largest family in number of species is Asteraceae (daisy family), with just under 1000 species of which more than 600 are endemic. Furthermore, fynbos is very rich in geophytes (bulbous plants) and many species from the family Iridaceae have become household names, freesia, gladiolus, iris, and watsonia. Another remarkable feature of fynbos is the number of species found within small areas. For example, the total world range of some species consists areas smaller than half a soccer or rugby field!.

Fynbos cannot support herds of large mammals since the nutrient poor soils on which it grows do not provide enough nitrogen for the protein requirements of large mammals. However, smaller mammals common to fynbos are baboons, grysbok, dassies, and the striped mouse. Fynbos does not support high numbers of birds. Fynbos also supports large numbers of butterfly species. Many are however at risk. The early stages (larvae) of many of these butterfly species are entirely carnivorous and live on a diet of ant brood. The butterfly larvae actually live inside the nest of their host ant. Although fynbos is not particularly rich in reptiles and amphibians, many of the species living there are both endemic and threatened. The very rare geometric tortoise is found in only a few surviving fynbos areas and is regarded as the world's second rarest tortoise.

The Cape has more than half of South Africa's frog species. Fynbos also has a high concentration of threatened fish species, particularly in the Olifants River system. With the widespread occurrence of alien vegetation which use up more water than indigenous fynbos plants, many habitats are becoming restricted leading to local extinction of certain species of fish because isolated tributaries are drying up.

http://www.bcb.uwc.ac.za/envfacts/fynbos/

a) The fynbos is said to be a very bio diverse habitat. List any three pieces of evidence from the text that show the idea of a rich biodiversity.
b) Give three distinctive abiotic characteristics (excluding edaphic factors) of this biome.
c) Define the following terms mentioned in the text:
   i. endemic
   ii. alien species
   iii. indigenous
   iv. extinct
d) Construct a possible food chain of at least four organisms that would be found in this biome, use some organisms mentioned in the text. Label the levels of the organisms mentioned.
e) Discuss the characteristics of the soil found in the fynbos and the implications for animals in the area.

5. Which of the following are biotic components in an ecosystem?
   a) air and water
   b) plants and animals
   c) light and temperature
   d) rocks, soil and climate

6. Which combination of the following processes takes place in the nitrogen cycle?

   - i) Herbivores consume plant protein.
   - ii) Decomposers break down dead organisms.
   - iii) Bacteria change nitrites to nitrates.
   - iv) Plants absorb nitrates from the soil.

   a) i, ii and iii
   b) i, ii, iii and iv
   c) i and iv
   d) i, ii and iv

7. A soil has the following characteristics: large particles, large air spaces, holds little water, feels gritty. The type of soil is:

   a) clay
   b) sand
   c) loam
   d) silt

8. Plants that are suited to live in areas with little water are called:

   a) terrestrial
   b) fynbos
   c) xerophytes
   d) hydrophytes

9. In a food chain, energy flows in the following direction:

   a) producers → primary consumers → secondary consumers → decomposers
   b) decomposers → producers → primary consumers → secondary consumers
   c) primary consumers → secondary consumers → producers → decomposers
   d) producers → secondary consumers → primary consumers → decomposers.

10. In a stable ecosystem, a wide variety of:

    a) producers depend on plants for shelter and camouflage.
    b) micro-organisms depend on plants for carbon dioxide and nitrogen.
    c) animals depend on plants for food and oxygen.
    d) plants depend on micro-organisms for pollination and seed dispersal.

11. When a jackal kills and eats a rabbit, the jackal is the:

    a) producer
    b) prey
    c) predator
    d) saprophyte

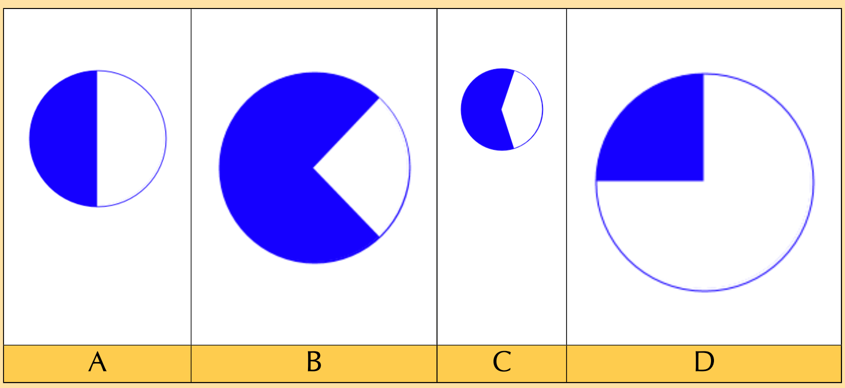
12. Which of the following refers to an organism's whole way of life and the use to which it puts the available environmental resources?

    a) niche
    b) habitat
    c) community
    d) ecosystem

13. Organisms that live in water are called:

    a) terrestrial
    b) xerophytes
    c) buoyant
    d) aquatic

14. A giant oil tanker was wrecked at sea. The shallow waters of the coastline provided a rich source of edible crabs. Oil does not kill the crabs but harm their flesh, making them inedible and they cannot be sold. Samples of crabs were collected at sites A to D. The number of crabs is indicated by the size of the circle. The extent of the shaded part at each site represents the proportion of crabs with diseased flesh after the disaster.



    a) Which sample site (A to D) had the highest number of crabs?
    b) In which sample site was the crabs only rarely found?
    c) Name the agent of pollution that affected the crabs.
    d) In which sample site was the most crabs affected compared to the population size?
    e) Explain your answer to the question above.
    f) List two strategies that could reduce the effects of oil pollution at sea.

Check answers online with the exercise code below or click on 'show me the answer'.

1ai. 2CW2	1aii. 2CW3	1aiii. 2CW4	1aiv. 2CW5	1b. 2CW6	2a. 2CW7
2b. 2CW8	2c. 2CW9	3a. 2CWB	3b. 2CWC	3c. 2CWD	3d. 2CWF
4a. 2CWG	4b. 2CWH	4ci. 2CWJ	4cii. 2CWK	4ciii. 2CWM	4civ. 2CWN
4d. 2CWP	4e. 2CWQ	4fi. 2CWR	4fii. 2CWS	4fiii. 2CWT	5. 2CWV
6. 2CWW	7. 2CWX	8. 2CWY	9. 2CWZ	10. 2CX2	11. 2CX3
12. 2CX4	13. 2CX5	14a. 2CX6	14b. 2CX7	14c. 2CX8	14d. 2CX9
14e. 2CXB	14f. 2CXC				

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CHAPTER 10

Biodiversity and classification

10.1 Overview ESGBP

Introduction ESGBQ

'Biodiversity is the greatest treasure we have. Its diminishing is to be prevented at all costs'. — Thomas Eisner, US environmental scientist, who has made interesting findings into how organisms produce chemicals to fight off predation.

The diversity of life on Earth has fascinated scientists for generations. The earliest scientists attempted to understand life by categorising it according to a range of common traits. Over time these classification systems have changed based on the new evidence gathered. In this unit you will study the history of the system of classifying organisms, starting with Aristotle and progressing to the current five-kingdom system devised by Whittaker. You will also be introduced to the scientific convention of referring to organisms in Latin using two names - referred to as binomial nomenclature. It is important to try and draw connections between this section and the previous one in which you studied the plant and animal life common to each biome.

Key concepts

- There is enormous biodiversity on Earth, consisting of different ecosystems, containing a variety of species, which each have genetic differences.
- South Africa is a 'hotspot' of diversity and has a large diversity of species endemic to the region.
- Classification schemes are a way of categorising biodiversity based on common characteristics.
- The history of classification began with Aristotle.
- Currently, the most widely used classification system is the five-kingdom scheme consisting of the kingdoms: Animalia, Plantae, Fungi, Protista and Monera (or Bacteria).
- In Science we name living organisms using a naming system called binomial nomenclature, which is written in the form: *Genus, species*
- Based on cell structure, there are key differences between prokaryotes and eukaryotes.
- The main groupings of living organisms are bacteria, protists, fungi, plants and animals. Each of these categories of organisms have distinctive features that differentiate them.

10.2 Biodiversity ESGBR

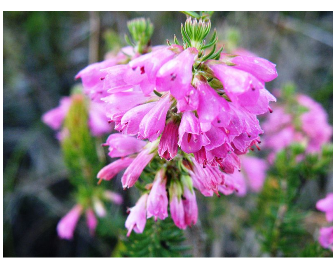
Biodiversity is the term we use to refer to the variation in life forms in an ecosystem, biome or the entire planet. The term also describes the genetic wealth within each species, the inter-relationships between them and the natural areas in which they occur.

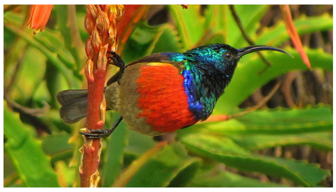
In this chapter we will focus on understanding the existing biodiversity and how scientists attempt to describe it. Biodiversity varies widely across the Earth, depending on temperature, rainfall, soils, geography and the presence of other species.

Scientists have described over 1,7 million of the world's species of animals, plants and algae. A rich species diversity is found in South Africa. With a land surface of approximately 148 000 square kilometres, representing approximately 1% of the Earth's total surface, South Africa contains10% of the world's total known bird, fish and plant species, and 6% of the world's mammal and reptile species.

This natural wealth is threatened by the expansion of the human population and the increasing demand this places on the environment. South Africa as a country is a 'hotspot' of biodiversity, a term given to an area with a large biodiversity of plants and animals. The Karoo and the Cape are biodiversity hotspots in South Africa. South Africa has a wide range of climatic conditions and many variations in landscape as you learnt in the previous chapter. These various landscapes give rise to the biomes which allow a wide variety of life to survive. In the table below are listed some of the major plant, mammal, bird, reptile and amphibian, fish and insect species found in South Africa. You are not expected to know any of the numbers but they are given to you in order to illustrate the extent of biodiversity that exists in South Africa.

FACT
Biodiversity varies greatly across different regions of the Earth. In addition, biodiversity has also varied greatly across **time**. You will learn more about how biodiversity has changed over Earth's history in the following chapter: **'The History of Life on Earth'**.

Life form	Diversity and threatened species
Plants 	More than 20 300 species of flowering plants occur in South Africa. One of the six most important areas of plant growth in the world is in the Western Cape. Most of the 2000 threatened species of plants are found in the fynbos in South-West Cape.

Life form	Diversity and threatened species
Mammals 	243 mammals found in the region. Among the 17 threatened species in South Africa are the black rhino, pangolin, giant golden mole. The blue antelope and quagga have become extinct.
Birds 	Of more than 800 bird species, 26 are threatened, including the penguin, Cape vulture, martial eagle and Cape parrot.
Reptiles and Amphibians 	In total 370 reptiles and amphibians occur in the region of which 21 are threatened. Six of these are endangered.
Fish 	220 freshwater fishes occur of which 21 are threatened. There are more than 2000 marine fish species.
Insects 	80 000 insects are known to occur. There are many insect species that are unidentified.

Most of the diverse species found in South Africa are **endemic** or **indigenous** to the country.

- **Indigenous** means that these species originate or occur naturally in South Africa.
- **Endemic** means that these species occur **only** in South Africa and nowhere else.

10.3 Classification schemes ESGBS

Classification ESGBT

The practice of classifying organisms is referred to as **taxonomy**. Classification is usually a hierarchical process. One begins with general and broad differences, and then one systematically introduces more and more detailed and specific criteria.

We have prepared an activity in order to show why we try and classify living organisms, what sort of mental process it entails, and how it is done. The activity below is not Life Sciences related, but conveys the process of classification. Try and think of the problems that arise while classifying the items below. Can BBC news be entertaining too? If so, should it not be under entertainment? Do you think that the final level of classification is the most definitive?

Activity: Classification

Aim:

To understand how classification systems work.

Materials:

Pen and paper **Instructions:**

1. Listed below are different TV programmes:
   - Carte-Blanche
   - Rocky
   - Isidingo
   - Rambo
   - Hitler's Bodyguards
   - Generations
   - Vietnam: Lost Films
   - BBC news

2. Divide these TV programmes above into 2 groups, under the headings: Entertainment and Documentary.
3. Now further subdivide the Entertainment group into Action and Soapies groups.
4. Do the same for Documentary using the headings: News/Current Affairs and History.

You have just drawn an example of a dichotomous branching diagram/ tree. All objects can be divided in this way. We call this a classification system.

Classification can be a tricky business. Problems arise when something can be classified to greater detail, or when an object or organism could belong to more than one category. Biologists have faced these classification conundrums for centuries when trying to classify organisms in one category or another.

Artificial classification systems, such as the grouping of vehicles into those that provide transport on land, water or air, are based on arbitrary groupings and have little meaning. The biological classification system, however, is based on research in anatomy, physiology, chemistry, genetics and many other branches of science. It is a scientific method of classification that groups organisms that share common features.

This classification is not random, but rather it describes evolutionary relationships. As a consequence, it is always necessarily hierarchical, where the important features inherited from a common ancestor determine the group in which the organisms are placed. For example, humans and whales both feed their young on milk, which is a characteristic inherited from a common ancestor. This similarity places them under the same class, **mammals**, even though their habitats are completely different.

Each organism is grouped into one of five large groups or **kingdoms**, which are subdivided into smaller groups called **phyla** (singular: phylum) and then smaller and smaller groups with other names.

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

When trying to identify animals, it is this hierarchy or ranking scheme that we follow. We start by identifying the kingdom to which an organism belongs, then its phylum, class, family, order, and so on.

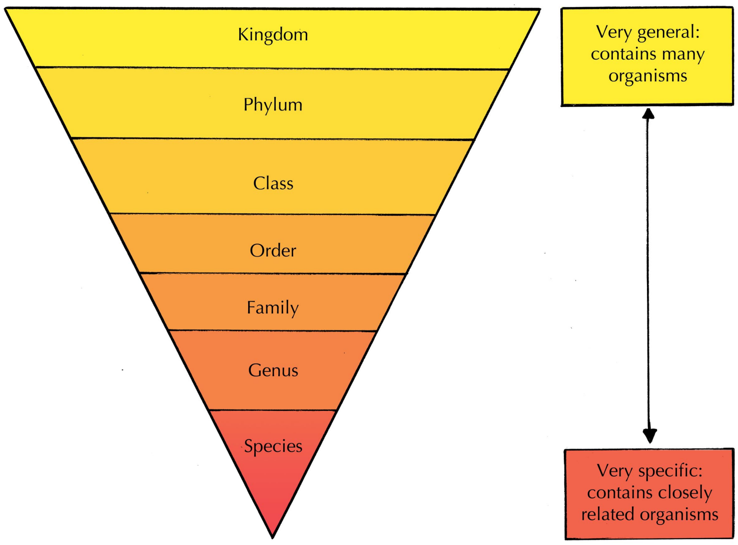


Figure 10.1: Schematic diagram showing hierarchy or ranking scheme used by taxonomists.

FACT
Watch a video about taxonomy: life's filing system
See video: 2CXD

This is similar to explaining how to find your house to a being from another planet. You would have to say Earth first, then Africa, then South Africa, then KZN, then Durban, then the suburb, then the road name and finally the house number. He would have to start searching in a big place and gradually work down to smaller places (or groupings).

A way to remember it is "**K**waito **P**eople **C**ome **O**ut **F**rom **G**auteng **S**inging". By learning this mnemonic you are going to remember the sequence in the classification system:

- Kingdom - Kwaito
- Phylum - People
- Class - Come
- Order - Out
- Family - From
- Genus - Gauteng
- Species - Singing

Activity: Constructing a mnemonic to remember the sequence of the classification system

Instructions:

Make an easy to remember memory aid to remember the sequence of levels of the classification system.

History of classification ESGBV

Aristotle (384-322 BC) was a 4th century Greek philosopher. He divided organisms into two main groups, namely plants and animals. His system was used into the 1600's. People who wrote about animals and plants either used their common names in various languages or adopted more-or-less standardised descriptions.

Caspar Bauhin (1560–1624) took some important steps towards the binomial system currently used by modifying many of the Latin descriptions to two words.

Figure 10.2: Aristotle (384–322 BC) devised one of the earliest classification schemes.

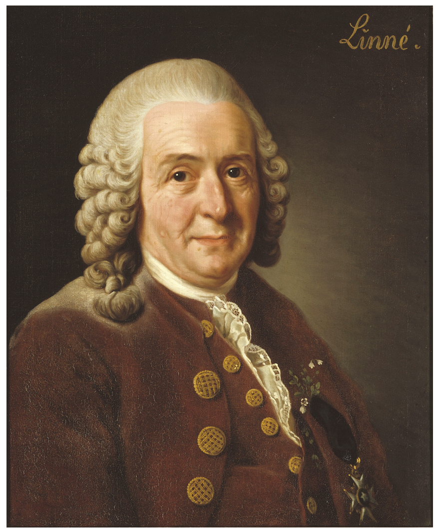


Figure 10.3: Carl Linnaeus developed a more advanced classification scheme and the system of naming organisms called binomial nomenclature.

Carolus Linnaeus (Carl Von Linne) (1707–1778) was an 18th century Swedish botanist and physician. He classified plants and animals according to similarities in form and divided living things into two main kingdoms namely — plant and animal kingdoms. He named the plants and animals in Latin or used latinised names in his books *Species Plantarum* (1753) and *Systema Naturae* (1758). The two-kingdom classification system devised by Linnaeus is not used today. As scientists discovered more and more about different organisms, they expanded the system to include many more kingdoms and groupings. However, one of Linnaeus more enduring systems was the system of naming organisms- called **binomial nomenclature**. We will learn more about binomial nomenclature in the next section.

Ernst Haeckel (1834-1919) was able to observe microscopic single-celled organisms and he proposed a third kingdom of life, the Protista, in 1866. Protista were single celled organisms that were neither plant nor animal, but could have characteristics of either.

Herbert Faulkner Copeland (1902–1968) recognised the important difference between the single-celled eukaryotes and single-celled prokaryotes. He proposed a four-kingdom classification, and placed the bacteria and blue-green algae (prokaryotes) in a fourth kingdom- Monera.

Robert Harding Whittaker (1920-1980) devised a five kingdom system in 1969. He recognised that fungi belonged to their own kingdom. However, even today the five-kingdom system is under dispute. It is the nature of science that as more discoveries come to light, theories will continue to be improved upon and revised.

Binomial Nomenclature ESGBW

One of Linnaeus' greatest contributions was that he designed a scientific system of naming organisms called **binomial nomenclature** (bi - 'two', nomial - 'names'). He gave each organism a two part scientific name - **genus** (plural - 'genera') and **species** (plural - 'species') names. The genus and species names would be similar to your first name and surname. **Genus name** is always written with a capital letter whereas **species name** is written with a small letter. The scientific name must always be either written underlined or printed in italics.

Since Latin was once the universal language of science among western scholars in medieval Europe, these names were typically in Latin.

For example the scientific name of the African elephant is *Loxodonta africana*.
Genus: *Loxodonta* **Species:** *africana*

Figure 10.4: Elephant (*Loxodonta africana*).

Figure 10.5: Blue crane, South Africa's national bird.

An organism will always have only one scientific name even though they might have more than one common name. For example Blue crane, indwe (for amaXhosa) and mogolori (for Batswana) are all common names for South Africa's national bird (shown below). However, it has got only one scientific name which is *Anthropoides paradiseus*.

The scientific name of our human race is *Homo sapiens sapiens*. We are the only surviving members of the genus *Homo* — other more ancient or ancestral types such as *Homo ergaster* and *Homo neanderthalensis have all become extinct.*

Figure 10.6: *Homo neanderthalensis*

Figure 10.7: *Homo sapiens*

Prokaryotes and eukaryotes ESGBX

Prokaryotes are uni- or multicellular organisms made up of cells that do not have a nuclear envelope (pro - before, karyon - nucleus). The genetic material is not bound in a nucleus. They also lack cell organelles such as an endoplasmic reticulum, a Golgi apparatus, lysosomes, and mitochondria. Prokaryotes are divided into two main groups namely the Bacteria and the Archaea (ancient bacteria).

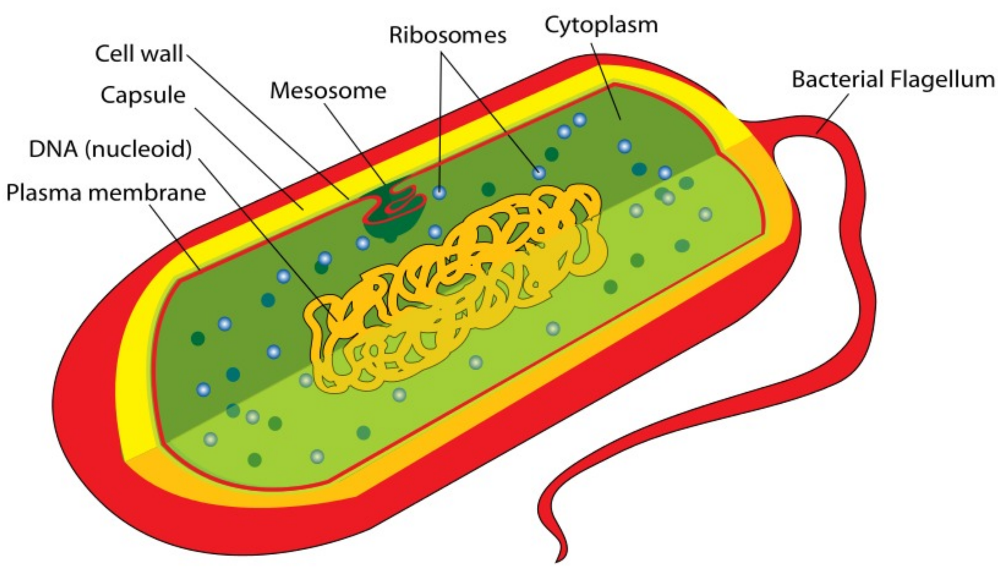


Figure 10.8: A prokaryote cell

Eukaryotes are organisms that possess a membrane-bound nucleus that holds genetic material (eu - true, karyon - nucleus). Eukaryotes may contain other membrane-bound cell organelles, such as mitochondria and chloroplasts. Eukaryotic organisms can be unicellular or multicellular. Eukaryotes include organisms such as plants, animals, fungi, and protists.

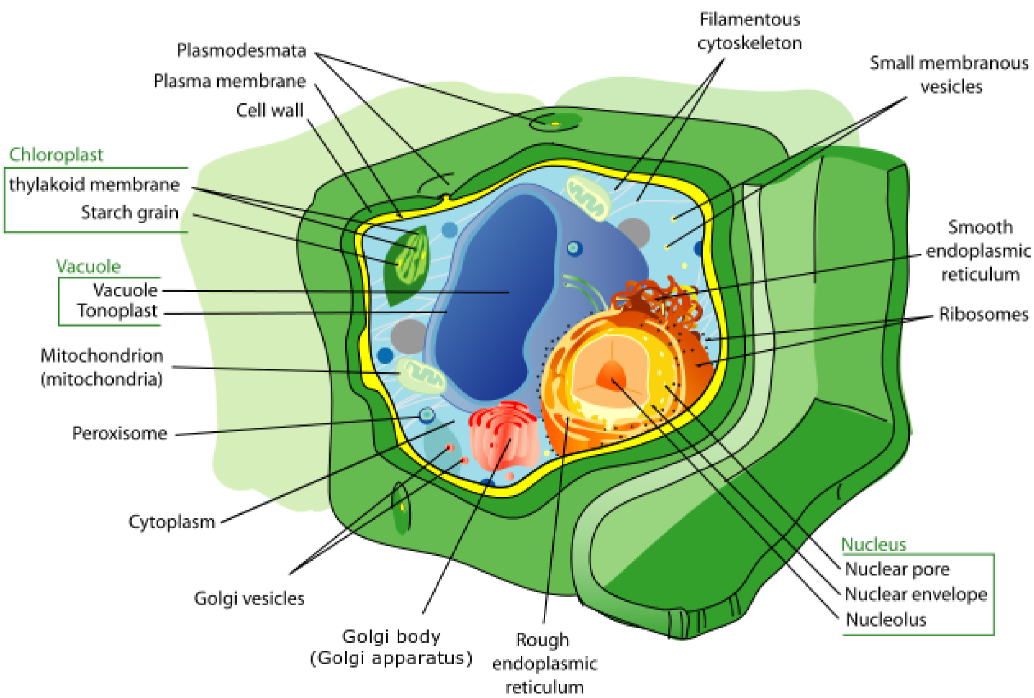


Figure 10.9: A eukaryote cell

Table: Differences between prokaryotes and eukaryotes.

Prokaryotes	Eukaryotes
Small cells	Large cells
Unicellular or multicellular	Often (but not always) multicellular
Genetic material is not contained within a nucleus	Genetic material is contained in a membrane-bound nucleus
Cells have a simple membrane internal system but no organelles Example: no chloroplast, no mitochondria	Cells have a distinct membrane system with organelles Examples: Chloroplast, mitochondria, golgi bodies

FACT

A video showing a brief summary of the five kingdoms

See video: 2CXG

FACT

Bacteria are found everywhere and are the most numerous organisms on Earth. In a single gram of soil, there are about 40 million bacterial cells. The human body also contains 10 times as many bacterial cells as human cells!

10.4 Five kingdom system ESGBY

The five kingdom system is the most common way of grouping living things based on simple distinctive characteristics. Classification systems are always changing as new information is made available. Modern technologies such as Genetics makes it possible to unravel evolutionary relationships to greater and greater detail. The five-kingdom system was developed by Robert H. Whittaker in 1969 and was built on the work of previous biologists such as Carolus Linnaeus.

Living things can be classified into five major kingdoms:

- Kingdom Animalia
- Kingdom Plantae
- Kingdom Fungi
- Kingdom Protista
- Kingdom Monera (Bacteria)

We will now identify the main distinctive features of each kingdom:

Kingdom Monera ESGBZ

The Kingdom Monera consists of prokaryotic, unicellular organisms. No nuclear membrane or membrane-bound organelles such as chloroplasts, Golgi complex, mitochondria or endoplasmic reticulum are present. Monera have a cell wall of protein plus polysaccharide compound, but not cellulose. They reproduce asexually by binary fission. Important examples of Monera include Archaea and Bacteria.

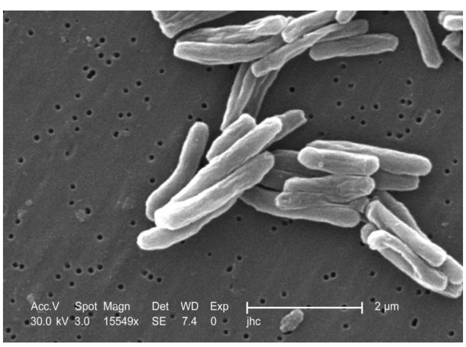


Figure 10.10: *Mycobacterium* bacteria that causes Tuberculosis.

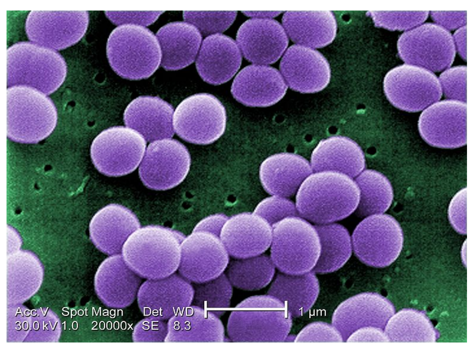


Figure 10.11: *Staphylococcus aureus* bacteria can cause skin infections, sinusitis and food poisoning.

Kingdom Protista ESGC2

Protista are eukaryotic and can be unicellular or simple multicellular. They reproduce sexually or asexually. Important examples of protists include the organism known as *Plasmodium* (which causes malaria), *Amoeba* and *Euglena*. There are two major groups of protists which include the Protozoans, whose cells are similar to animal cells in that they do not have cell walls and the plant-like cells which do have cell walls and are similar to algae.

Figure 10.12: *Euglena* an example of a protist.

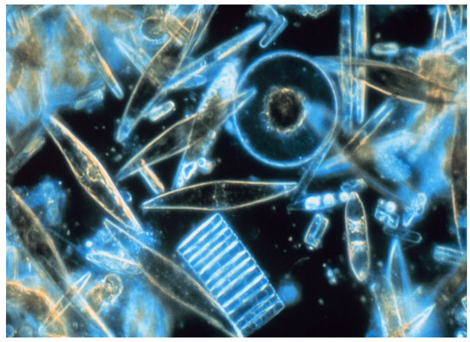


Figure 10.13: Diatoms from Antarctic sea ice.

Kingdom Fungi ESGC3

Fungi are eukaryotic organisms that can be multicellular or unicellular. Mushrooms and moulds are examples of multicellular fungi and yeast is an example of a unicellular fungi. All fungi have a cell wall made of chitin. They are non-motile (not capable of movement) and consist of threads called hyphae. Fungi are heterotrophic organisms which means they require organic compounds of carbon and nitrogen for nourishment. They are important as decomposers (saprophytes) and can be parasitic. They store carbon as glycogen, not in the form of starch. Fungi reproduce sexually and asexually by spore formation. An important example of a useful fungus is *Penicillium* (a fungus which was used to make penicillin, one of the most powerful antibiotics ever created).

Figure 10.14: Examples of fungi.

Figure 10.15: Mushrooms are examples of fungi.

FACT

A TED video on the many uses of Fungi

See video: 2CXH

FACT

Sir Alexander Fleming discovered the first antibiotics in 1928, after observing that colonies of *Staphylococcus aureus* bacteria could be destroyed by the fungi *Penicillium notatum*. This observation that certain substances were deadly to microbial life lead to the discovery and development of medicines that could kill many types of disease-causing bacteria in the body.

Kingdom Plantae ESGC4

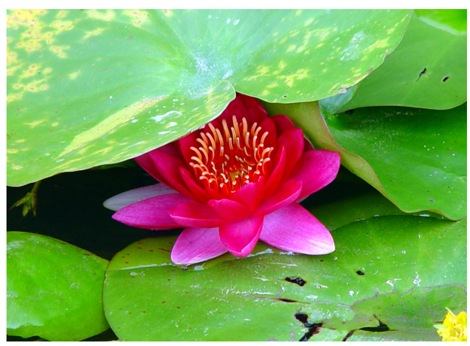
Organisms belonging to the plant kingdom are eukaryotic and multicellular organisms. They have a distinct cell wall made of cellulose. Cells are organised into true plant tissues. Plants contain plastids and photosynthetic pigments such as chlorophyll. They are non-motile. Plants make their own food by photosynthesis and are therefore said to be autotrophic. Plants undergo both sexual and asexual reproduction. They store food as starch. Important examples of plants are mosses, ferns, conifers and flowering plants.

Examples of plant variety:







Kingdom Animalia ESGC5

Members of the animal kingdom are eukaryotic and multicellular but have no cell wall or photosynthetic pigments. They are mostly motile and they are heterotrophic, which means they must feed on other organisms and cannot make their own food. They reproduce sexually or asexually. Animals store carbon as glycogen and fat.

Important examples of this kingdom include: Porifera (sponges), Cnidaria (jellyfish), Nematoda (nematode worms), Platyhelminthes (flatworms), Annelidas (segmented worms), Mollusca (Snails and Squid), Echinodermata (starfish), Arthropoda (Insects and Crustaceans), Chordata (includes all the vertebrates: fish, amphibians, reptiles, birds, mammals).

Examples of animal variety:

Animal Phyla

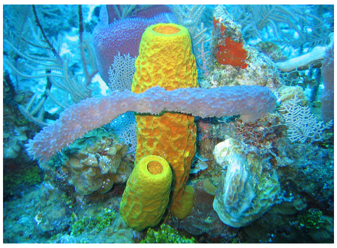


Figure 10.16: **Porifera**

Figure 10.17: **Cnidaria**

Figure 10.18: **Platyhelminths**

Figure 10.19: **Mollusca**

Figure 10.20: **Echinodermata**

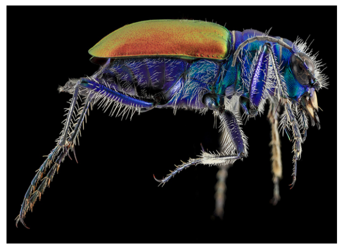


Figure 10.21: **Arthropoda**

Classes of vertebrates

Figure 10.22: Fish

Figure 10.23: Amphibians

Figure 10.24: Reptiles

Figure 10.25: Birds

Figure 10.26: Mammals

Activity: Investigate examples of life forms from each kingdom

Aim:

To investigate examples from each kingdom.

Instructions::

1. Research one beneficial and one harmful application of one member from each kingdom, with examples from their use in South Africa. Students can be grouped into smaller groups and each one is given one kingdom to research. (Use www.arkive.org as a research tool for your favourite animal or plant or http://bugscope.becnkman.uiuc.edu/ for nice pictures of insects). Results can be presented in the form of a poster.
2. Go to your nearest supermarket or garden and find one representative organism for each kingdom. Present this information by drawing a diagram.

Dichotomous Key ESGC6

A **dichotomous key** is a tool that taxonomists often use to classify organisms correctly. It is a form of hierarchical grouping that involves making decisions in a series of steps, from general differences to very specific differences. It is called a **di**chotomous key because there are always **two** choices. There is a very specific way to set up a dichotomous key. For instance, one must always move from the general to the specific, and one must always ensure that the two choices in the decision tree are **mutually exclusive** and **jointly exhaustive**. Mutually exclusive means that there cannot be overlap between the two options, as this would result in wanting to place an organism in two groups. Jointly exhaustive means that your two options must cover all possibilities, otherwise you won't be able to place an organism in either of the groups.

Activity: Identifying arthropods using a dichotomous naming key

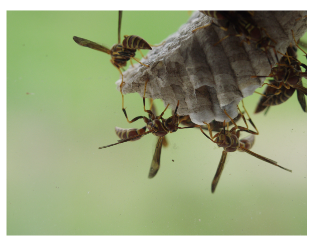
Aim:

To use a dichotomous key to identify arthropods.

Instructions:

1. Study the organisms in the table of specimens provided to you.
2. Use the dichotomous key to find out to which taxonomic group each of these arthropods belong.
3. Write the letter corresponding to the arthropod, and then your answer.

Table of specimens

		
A	B	C
		
D	E	F
		
G	H	I
		
J	K	L

	Characteristic	Instruction
1a 1b	Arthropod has eight legs Arthropod does not have 8 legs	go 2 (Arachnids) go 4
2a 2b	Arachnid has pedipalp with pincers Arachnid does not have pedipalp with pincers	**SCORPION** Go 3
3a 3b	Arachnid drinks blood Arachnid does not drink blood	**TICK** **SPIDER**
4a 4b	Arthropod has more than 16 legs Arthropod does not have more than 16 legs	Go 9 (Myriapoda) Go 5
5a 5b	Arthropod has 3 pairs of legs Arthropod does not 3 pairs of legs	Go 6 (Insects) **CRUSTACEAN**
6a 6b	Insect has hardened fore-wings Insect does not have hardened fore-wings	**COLEOPTERA** Go 7
7a 7b	Insects are social and/ or live in a hive Insects are not social, do not live in a hive	**HYMENOPTERA** Go 8
8a 8b	Insects does not have a sponge-like proboscis Insects have a sponge-like proboscis	**LEPIDOPTERA** **DIPTERA**
9a 9b	Myriapod with one pair of legs per segment Myriapod with two pairs of legs per segment	**CENTIPEDE** **MILLIPEDE**

10.5 Summary ESGC7

By the end of this chapter you should know the following:

- The definition of the biological classification system and hierarchical manner of grouping of living organisms based on similarities and differences.
- A brief history of major developments in the classification of organisms.
- The scientific method of naming of organisms using the binomial nomenclature. All organisms have only **one** scientific name but many common names.
- The division of organisms into prokaryotes (simple, unicellular) and eukaryotes (mostly multicellular) and the major differences between the two.
- The classification of living organisms into five major kingdoms: Monera, Protista, Fungi, Plantae and Animalia and the unique characteristics of each kingdom.

Exercise 10 – 1: End of chapter exercises

1. Which of the following in a classification system is the smallest?
    a) Kingdoms
    b) Species
    c) Family
    d) Class
2. Which Swedish botanist and physician named plants and animals in Latin?
    a) Casper Bauhin
    b) Aristotle
    c) Robert Whittaker
    d) Carolus Linnaeus
3. The five kingdom classification system was suggested by:
    a) Whittaker
    b) Linnaeus
    c) Darwin
    d) Pasteur
4. The following example is the scientific name of a lion: *Panthera leo*. The first part of the scientific name represent the...
    a) Genus name
    b) Kingdom name
    c) Species name
    d) Family name
5. Write down the correct biological term for the following descriptions.
    a) Type of system by modifying many of the Latin descriptions to two words.
    b) Group of organisms which are able to interbreed and produce fertile offspring.
    c) The scientific name of our human race.
    d) The type of asexual reproduction in the Kingdom Monera.
    e) Highest grouping in a classification system.
6. Give the definition of the term **Biodiversity**.
7. Tabulate **three** differences between prokaryotes and eukaryotes.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 2CXJ 2. 2CXK 3. 2CXM 4. 2CXN 5a. 2CXP 5b. 2CXQ
5c. 2CXR 5d. 2CXS 5e. 2CXT 6. 2CXV 7. 2CXW

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CHAPTER 11

History of life on Earth

11 History of life on Earth

11.1 Overview ESGC8

Introduction ESGC9

In this chapter we will learn about the history of life on Earth. We will first talk about tools (fossil dating) and theories, (continental drift) that help us understand our past. Next we will look at the geological time-scale and discuss three major eras: the Paleozoic, Mesozoic and Cenozoic. We will talk about the Cambrian explosion, which was a major explosion in the diversity of life, and we will discuss mass extinctions, which were mass losses in the diversity of life forms. We will also look at the evolution of humans in the last 4 million years. Throughout the chapter will look at fossil evidence from Southern Africa that originates from key periods in Earth's history.

Key concepts

- Scientists use deductive reasoning to understand fossils and the history of life on Earth.
- Geological events often caused changes in climate, which in turn influence the emergence and disappearance of species.
- It takes special circumstances for fossils to form, and fossils can be dated by radiometric, radiocarbon or relative dating.
- Climate and geography helped shape the evolution of life on Earth.
- Geological timescales are divided into eons, eras and periods.
- The Cambrian explosion was a rapid explosion in the diversity of life-forms. All animal groups have their origin in the Cambrian explosion.
- Mass extinctions are massive losses in life, and there have been five mass extinction events in history.
- In the last 4 million years significant changes have occurred in species occurring in Africa, including the evolution of humans.
- Humans have a massive effect on biodiversity and the natural environment and are partially responsible for the '6th mass extinction'. item South Africa is rich in many fossils from diverse time periods.
- Fossil tourism is a source of income and employment in fossil localities.

11.2 Representations of life's history ESGCB

Scientists have divided the history of life into different time periods using the **geological timescale**. In this section we will present the key evidence scientists have used to construct this time scale. We will discuss the **continental drift** theory which explains how the continents were formed. We will also briefly touch on the theory of natural selection which explains how one life form can evolve into another over many years by adapting to its changing environment. We will then present the methods by which we are able to determine evolution of life forms over time through examining the **fossil record**.

Geological timescale ESGCC

The geological timescale is a 'calendar' of events in the Earth's history. It shows major geological and climactic events, and how these events affected the emergence and disappearance of species over time. In order to help us make sense of this vast amount of time, scientists divided it into smaller units of time. In descending order, these units are: eons, eras and periods.

- **An Eon**: is defined as a unit of time equal to a billion years.
- **An era**: is a division of time within an eon but does not have a fixed number of years. The Mesozoic era for example lasted from 252 million years to 66 million years ago.
- **A period**: typically refers to a subdivision of an era and its length is determined by a system of dating based on examining fossil evidence belonging to a particular era.

Table 11.1 below shows one method of representing the geological timescale:

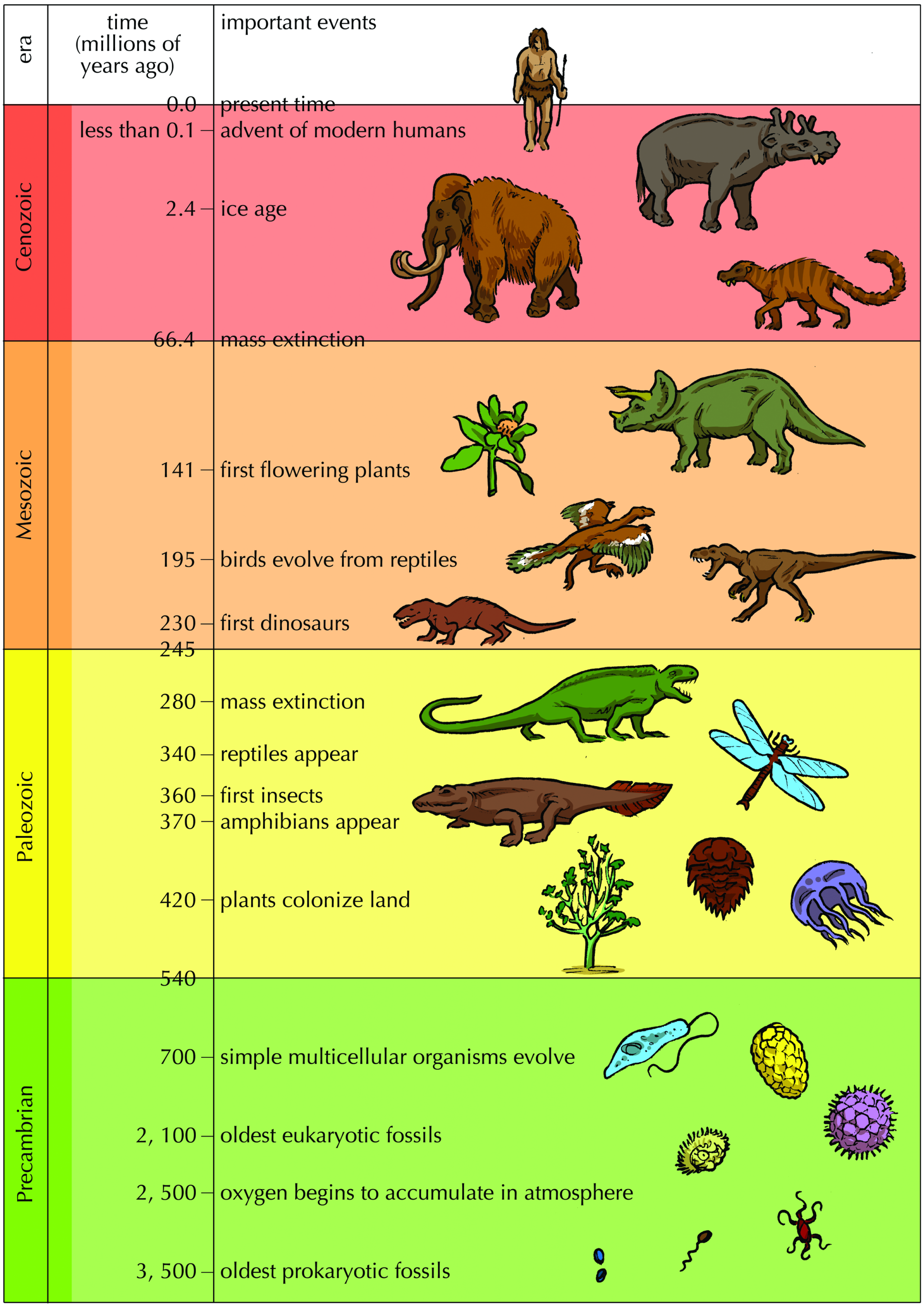


Figure 11.1: Geological timescale with key events and characteristics shown.

While you will not be expected to remember the names of specific periods, you will be expected to understand the eras and their particular characteristics.

Another visually powerful way of representing Earth's history is via the use of the geological 'clock' (Figure 11.2). Human history occupies just 2 million of the 4500 million year long history of the Earth. On this clock, human existence constitutes less than a minute of the evolutionary history of life on Earth.

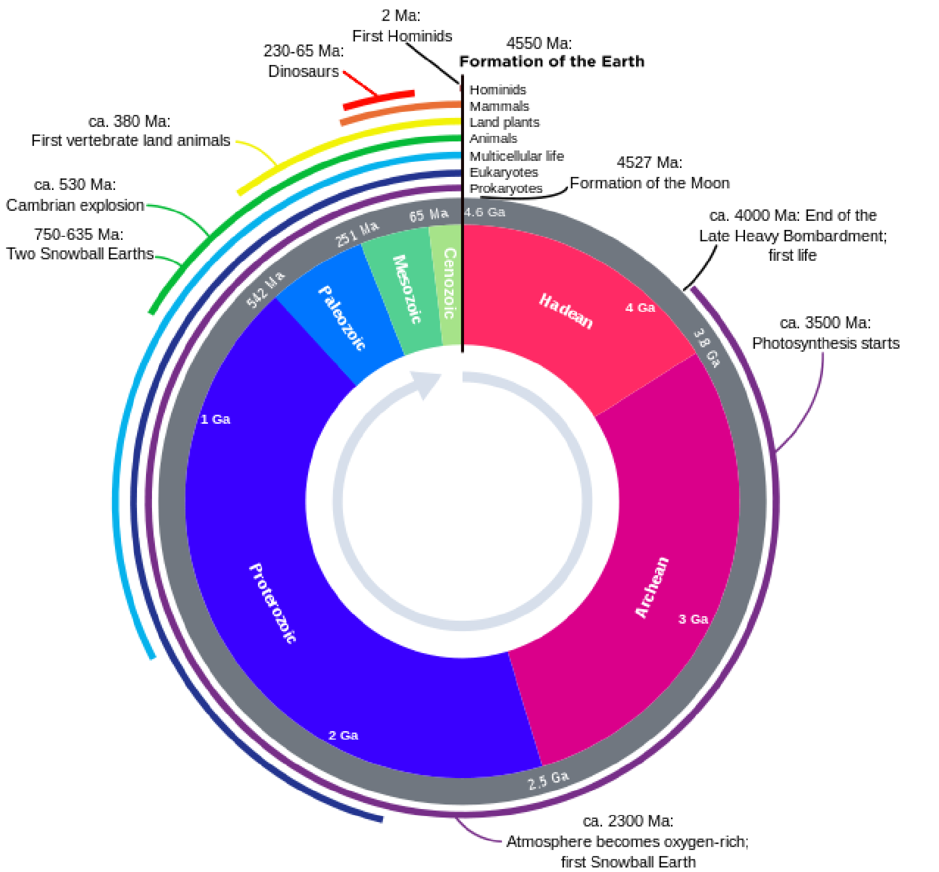


Figure 11.2: "Human history on Earth is a mere second on the clock". In this representation, the two million years' of human history constitute an effect too small to be visible on the timescale.

FACT
http://deeptime.info/
This website has an 'infographic' showing geological time on a clock. Each hour on the clock corresponds to a period of the Earth's history, and shows the characteristics of each period and the key events within them.

Activity: Construct a timeline of the key events in the history of life on Earth (Essential CAPS)

Aim:

In this exercise you will learn to combine all the information given on the history of life and depict it on a simple geological timescale of your own.

Materials:

- exercise book or cardboard
- coloured pens and pencils
- pictures and information from the Internet and books

Instructions:

Draw a timescale that stretches from '0 years ago' to 530 million years ago.

Depict the history of life on this timescale. On your timeline, show:

- Mesozoic, Paleozoic and Cenozoic eras
- Two major climate changes characteristic of each era
- Major changes to plant and animal life that took place during this time

Continental Drift ESGCD

Continental drift is the breakup and movement of the Earth's continents relative to each other by drifting across the Earth's surface. Since the initial continental drift hypothesis was proposed, the study of plate tectonics has helped us understand why continents move.

Plate tectonics is the study of the folding and faulting of the Earth's crust (lithosphere).

Biogeography is the branch of biology focusing on the geographical distribution of plants and animals. It has been instrumental in developing our understanding of the evidence for continental drift.

Evidence for continental drift

There is considerable evidence for the theory of continental drift that draws upon fossil evidence, plate tectonics theory and studies of glacier sediments. For example:

- Similar plant and animal fossils have been found on different continents' shores, suggesting that these were once joined. For example:
  - The *Mesosaurus* found in Brazil and South Africa.
  - The *Lystrosaurus* from rocks of the same age found in South Africa, South America, India, Australia and Antarctica
  - Earthworms found in South America and Africa suggest that these existed in a common habitat on a single continent.
- The complementary shapes of South America and Africa have enabled scientists to propose how these continents pulled apart due to various plate tectonic forces.
- The study of glaciers left over from the ice ages has provided an important line of evidence for continental drift. Glacial sediments from South America, Africa, India, Madagascar, Arabia, India, Antarctica and Australia showed evidence of having once been joined together, suggesting the existence of the supercontinent Gondwana.

Using this evidence, scientists have inferred that in the past the Earth existed as a super-continent known as Pangea until the early Mesozoic era. There were three major phases in the break-up of Pangea:

- **First phase**: about 175 million years ago, Pangea began to rift, giving rise to the supercontinents Laurasia and Gondwana.
- **Second phase**: began in the early Cretaceous period (150–140 million years ago) when Gondwana broke and separated into multiple continents: Africa, South America, India, Antarctica and Australia.
- **Third phase**: occurred in the early Cenozoic era. During this phase, Laurasia split when North America/Greenland split from Eurasia resulting in the expansion of the Atlantic and Indian Oceans.

FACT
Natural selection is a process you will learn about in more detail in Grades 11 and 12.

FACT
This video explains how natural selection takes place!
See video: 2CXX

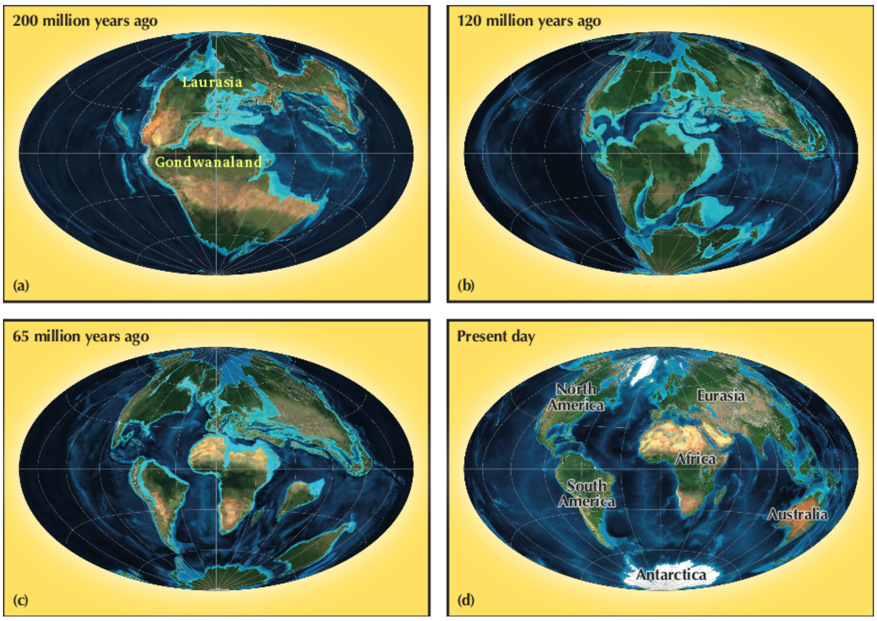


Figure 11.3: Diagram showing continental drift.

Natural selection ESGCF

Through a process known as **natural selection**, adaptations that allow one organism to survive better than another and produce more off-spring, results in future generations of organisms who have acquired those traits. For Grade 10, you are required to understand the following key features of evolution by natural selection:

- Individuals in a species show a wide range of variation: .e.g. the many different types of dogs you see.
- The variation is caused by genetic differences.
- Individuals that are well-adapted to the environment in which they live are more likely to survive and produce more offspring.
- The genes that allowed the individuals to be successful are **passed on to the offspring** in the next generation.
- Over many hundreds (and thousands) of generations this results in changes in the physical appearance and habits of organisms.

Fossil formation ESGCG

The **fossil record** is a key source of evidence that helps scientists understand life's history. Fossils are the remains, impressions or traces of animals and plants from the remote past. Fossils usually take the form of a mold or a cast in rock. Generally, a preserved specimen is regarded as a fossil if it is older than approximately 10 000 years (although this is not a strict definition).

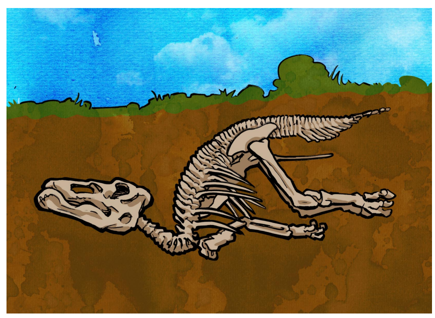
Examples of common fossils are skeletons or parts of skeletons, shells or teeth. Sometimes plants or animals can leave imprints that get preserved as fossils.

The study of fossils across geological time, how they are formed, and how ancient organisms have evolved in relation to other phylogenetic groups, is called **palaeontology**.

How fossils are formed:

1. For fossilisation to occur, a plant or animal must first die. Soft tissues decay quite quickly, therefore animals that have hard exoskeletons and woody plants tend to fossilise better than soft-bodied organisms.

2. The organism (plant or animal) must be buried beneath mud and or soil shortly after death. Although decay still takes place, the lack of oxygen slows it down. As more and more layers of mud and soil are added, the sediments become compressed.

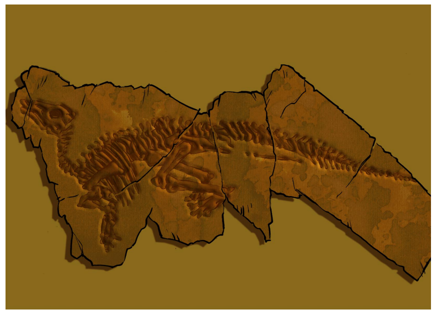


3. Eventually, this compression turns the sediment into rock, which forms a mould around the shape of the original skeleton. Sometimes the original bone or shell softens and dissolves completely, sometimes the bone or shell remains. Water that is rich in dissolved minerals trickles in through the layers of sediment into the mould.

4. The mineral-rich water enters the hollow and crystallises to create a natural cast of the original organism. Otherwise, the minerals slowly seep into the skeleton, changing its chemical composition and making it capable of surviving for a long time.

FACT
If the rocks surrounding a fossil are distorted and squeezed by geological forces, it will result in distortion of the fossils within them.

5. Over many millions of years, rock that was once buried rises again to the surface and is eroded away, exposing the fossils.



Fossilisation is very rare and only happens when a plant or animal dies in exactly the right circumstances. Usually animal corpses are eaten by other animals or decomposed by bacteria before fossilisation can occur. Even hard parts, like bones and shells, are eventually destroyed through erosion and corrosion.

Methods of dating fossils ESGCH

We have learnt how fossils are formed over geologic timescales. In this section we will learn how we determine the age of a fossil. There are two methods of dating fossils:

1. Radiometric dating
2. Relative Dating

1. Radiometric Dating

In order to understand radiometric dating, it is necessary to revise our understanding of the atom. The nucleus of an atom is made up of **protons** and **neutrons**. The number of protons in the nucleus define what type of element it is. However, the number of neutrons of an element may vary. Atoms with the same number of protons, but different numbers of neutrons are called **isotopes**.

Some isotopes are stable, while others are unstable. Unstable isotopes undergo a process called **radioactive decay**, whereby they spontaneously change to elements of a different type. We can never predict when a specific atom will undergo radioactive decay. However, when considering many atoms, we observe that the decay occurs at an **exponential decay rate**. Exponential decay means that over a certain period of time, called a **half life**, half of the unstable isotopes in a sample will undergo radioactive decay.

FACT
Learn more about how radiocarbon dating works.
See video: 2CXY

One of the most useful radiometric dating methods is radiocarbon dating.

Radiocarbon dating

- The carbon atom exists as three different isotopes. These are carbon-12 (C-12), carbon-13 (C-13) and carbon-14 (C-14).
- All living organisms maintain an equilibrium of carbon-14 with the atmospheric carbon-14.
- After an organism dies, it no longer incorporates new carbon into its body.
- The carbon-14 present within them undergoes radioactive decay to nitrogen-14, and decreases from the original equilibrium with carbon-12.
- The half-life of carbon-14 is 5730 years. This means that if we start out with say 10 units of carbon-14, in 5730 years' time only 5 units will remain. In another 5730 years' time only 2.5 units will remain and so on.
- Thus, using radiocarbon dating, scientists can determine how much carbon-14 remains within a particular fossil, and thereby infer the age of the fossil.

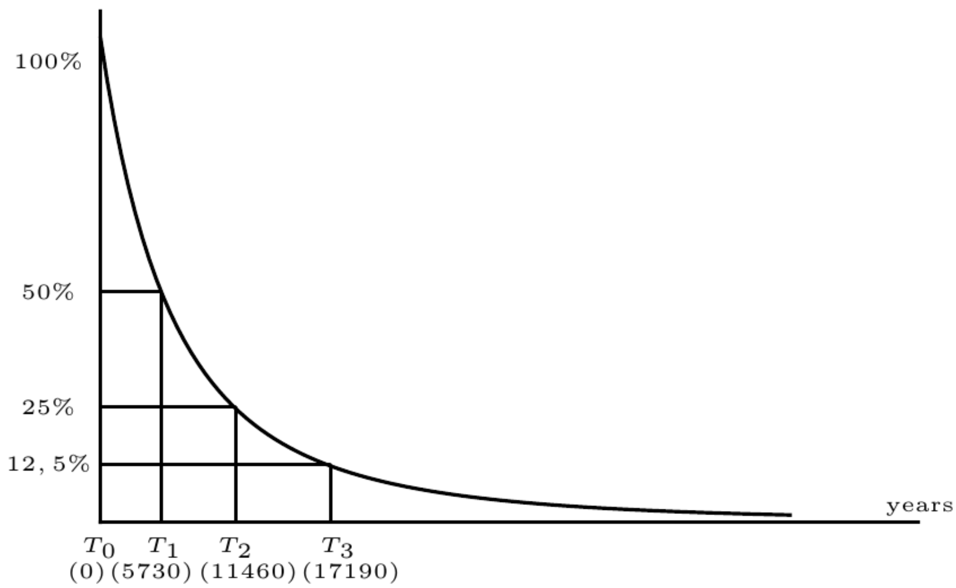


Figure 11.4: **Radiometric dating:** Graph showing the half-life of C-14. The amount of carbon-14 halves every 5730 years.

The isotopes of different elements undergo decay at different rates; some decay much more rapidly than others. This makes radiometric dating a useful tool as scientists can use different elements to date longer and shorter time-scales. Carbon has a relatively short half-life, and therefore it is not of much use when dating fossils that are millions of years old.

Uranium-lead and potassium-argon dating

In order to date older fossils, scientists use **uranium-lead dating** and **potassium-argon dating**. The half-life of uranium-235 is 700 million years, and the half-life of potassium-40 is 1.3 billion years. In order to estimate the age of incredibly old fossils, scientists date the age of the igneous (volcanic) rock in which the fossils are buried. This provides them with an estimate of the age of the fossils contained within them.

FACT
A video about discovering fossil evidence.
See video: 2CXZ

2. Relative Dating

- Relative dating is the method of determining the order of events from the fossil record.
- By studying the order in which fossils occur in the fossil record, geologists can determine the order of events as they occurred but not when exactly they occurred.
- Fossils found at the lowest layer of rock would be the oldest, as these would have been buried for the longest time, whereas fossils found closer to the surface would be buried more recently and therefore be younger.
- The geological time-scale you studied earlier was almost entirely developed by relative dating methods. It is a useful method of dating when fossil materials lack radioactive isotopes.

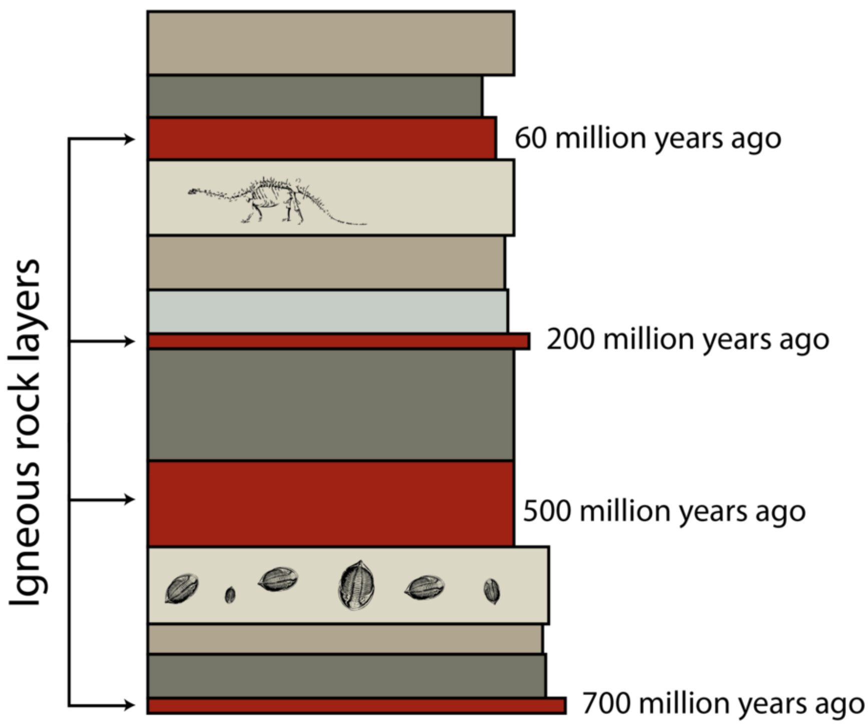


Figure 11.5: In relative dating, fossils are dated relative to layers of igneous (volcanic) rocks that they are near. Older layers are deeper in the Earth, younger layers are closer to the surface.

Deductive reasoning to understand the past ESGCJ

Deductive reasoning combines the use of evidence and theories to make deductions about the past. Therefore scientists use their understanding of continental drift and natural selection theories, together with evidence of climate changes and extinct organisms from the fossil record, to piece together Earth's history.

- Scientists use the fossil record to make conclusions about the history of life through a process of **deductive reasoning**.
- Deductive reasoning involves combining our understanding of known principles to make conclusions about new evidence that we have uncovered.
- Our knowledge of the history of life is not based on radiometric dating methods alone. Rather, our understanding of the changes in Earth's climate and biogeography allow us to make conclusions about newly discovered fossil evidence.
- For example, from our knowledge of the changes to the Earth's early atmosphere, we know that the formation of the ozone layer blocked off the damaging rays of the sun's UV rays. This led to the growth of plant species which gradually made terrestrial existence possible.
- A transitional fossil is any fossilised remains that is common to an ancestral life form as well as to the group that is derived from it.
- Transitional fossils give us information about how an ancestral species evolved to form the existing species.
- An example of a transitional fossil is the *Archaeopteryx*. It is thought to belong to the genus of Theropod dinosaur which is closely related to the birds.

The exercise below requires you to understand the similarities between the *Archaeopteryx* and the modern bird.

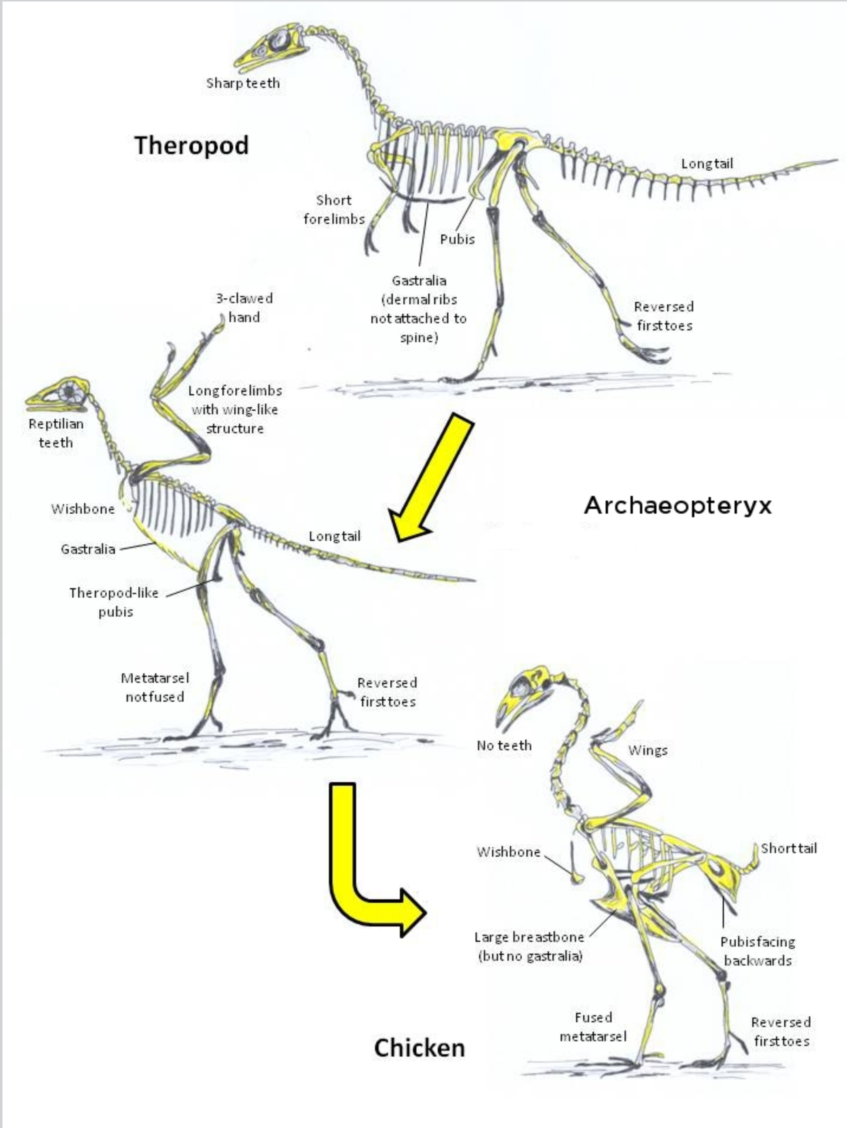
Activity: Comparing the skeleton of a modern bird to the Archaeopteryx

Aim:

To compare the skeletons of a modern bird (chicken) and Archaeopteryx

Instructions:

1. Use the pictures below to compare the skeletons of a dinosaur (Theropod), *Archaeopteryx* and a chicken (modern bird). Give four differences and four similarities between *Archaeopteryx* and dinosaurs, and between *Archaeopteryx* and modern birds.



11.3 Life's History ESGCK

Pre-Cambrian ESGCM

Hadean: the Earth we live on is approximately 4,6 billion years old. The conditions that allowed for the emergence of life lasted approximately 500 million years. It was an environment in which the Earth's crust cooled and the oceans and atmosphere began to form. In this environment, a variety of complex chemical reactions occurred, resulting in the production of the earliest molecules capable of making copies of themselves.

FACT
Approximately 850–630 million years ago, a 'global glaciation' event is thought to have occurred, also known as an 'Snowball Earth'. At this time temperatures dropped dramatically and large parts of the Earth's surface were covered in ice. During this period it is thought that any life forms dependent on light would have gone extinct.

Archean: when life in the form of uni-cellular organisms first developed, the Earth's early atmosphere consisted entirely of volcanic gases, and there was no free oxygen. **Prokaryotes** evolved, with photosynthesising bacteria (known as **cyanobacteria**) emerging approximately 3 billion years ago. The presence of photosynthesising cyanobacteria resulted in the release of oxygen into the atmosphere.

The early single-celled organisms (bacteria and cyanobacteria) lived together in aquatic colonies. These colonies were formed by trapping sediments and minerals floating in water and by producing a mucus which bound everything together. As the colony of bacteria, minerals and sediments grew, so did the structure that they made, and layer upon layer built up. In order to capture as much sunlight as possible, the shape of the top of this sedimented algal mat was curved. These curved and multi-layered structures, called **stromatolites**, were preserved and exist as fossils. Some stromatolites survive to this day, in scattered locations around the globe (Figure 11.6).

Figure 11.6: Stromatolites have been found at Wondergat, Northwest Province, South Africa.

Figure 11.7: Stromatolites in Shark Bay, Australia.

Proterozoic: over the next 800 million years, the earliest forms of sexual reproduction developed, thus greatly increasing the diversity of organisms. The first multicellular organisms consisting of cells specialised to perform specific functions began to evolve. The soft-bodied organisms, known as *Swartpuntia*, first appeared approximately 600 million years ago and went extinct by the start of the Cambrian, 543 million years ago. *Swartpuntia* fossils were discovered in Namibia and are some of the oldest fossils known to exist from before the Cambrian period.

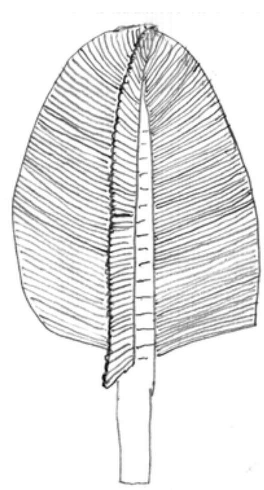


Figure 11.8: Earliest soft-bodied animals found in Namibia. A simplified reconstruction of *Swartpuntia*.

Cambrian explosion ESGCN

From approximately 580–500 million years ago, a large diversity of creatures appeared. This event is called the **Cambrian Explosion**, and almost all of the animals alive today can trace their beginnings to this rapid expansion of diversity. The Cambrian Explosion was the relatively rapid appearance over millions of years of most of the main animal groups found in the fossil record.

In Cambrian times there was no life on land and little or none in freshwater — the sea was still very much the centre of living activity. From 580–540 million years ago, oxygen began to accumulate in the atmosphere, allowing for the formation of the ozone layer which blocked the damaging rays of the ultraviolet light from the sun, permitting the colonisation of land.

The Cambrian explosion was just the first period of the **Paleozoic era**. It is famous because of the sudden explosion in diverse morphologies, and the fact that is "sowed the seeds" for the continued evolution that occurred throughout the Paleozoic.

FACT
Watch this fascinating video about some of the interesting organisms that lived after the Cambrian Explosion and left beautiful fossil remains.
See video: 2CY2

FACT
Watch a video about trilobites.
See video: 2CY3

FACT
Hard shells fossilise more readily than soft bodied organisms, as they are better at resisting decay, take significantly longer to break down, and have a greater chance of surviving burial under layers of sediment. For this reason, hard-shelled organisms such as trilobites dominate the fossil record. Sometimes by pure luck, geologists find beautiful fossils of soft bodied creatures. A good place for discovering softer bodied organisms is the Burgess Shale site.

Paleozoic era (542 to 251 million years ago) ESGCP

The massive supercontinent Pangaea formed during the Paleozoic, and this era also saw the diversification and evolution of many of the animal phyla that are still present today. During the Paleozoic:

- The first fish (chordates) appeared more than 500 million years ago, and it is from this common ancestor that vertebrates, including mammals (and humans) are ultimately descended. Fish developed bony spines and jaws with teeth which increased the size and diversity of the prey they could capture.
- Animals with shells and exoskeletons (e.g the trilobites) were in abundance early in the Paleozoic, but declined towards the end of the era.
- The earliest plants colonised land approximately 430 million years ago, having evolved from the nearby algae growing along lakes and other coastal areas.
- Forests of primitive plants covered the Earth's surface, resulting in increased oxygen levels and decreased carbon dioxide levels in the earth's atmosphere.
- The first insects appeared, and later on some species developed wings.
- Later in the Paleozoic amphibians became common and diverse and started moving onto land.
- Early reptiles (synapsids) colonised land.
- Towards the end of the Paleozoic gymnosperms (seed-bearing plants) replaced much of the earlier plant-types.

FACT
Cycads occur across much of the subtropical and tropical parts of the world including here in South Africa where their evolutionary importance has made them a 'protected species'.

The end of this period was marked by a mass extinction event (called the Permian-Triassic extinction event) which eliminated almost all marine life but had a less devastating impact on terrestrial species.

South African fossil record: fossils of early land plants such as clubmosses, lycopods, ancestral gymnosperms and algae were found near Grahamstown and Port Alfred. Fossils of plants belonging to the *Glossopteris* flora are found in the Karoo. This plant flourished throughout the ancient landmass of Gondwanaland. However, by the end of the Permian period this crop had become extinct. The fossilised remains of these plants are found in silts and in rocks throughout the country, where coal deposits can be found (Figure 11.9). Among the organisms that moved on to land at this time were the ammonoids, which are marine invertebrate animals with spiral-shaped shells, the fossils of which are found in the Makhatini flats in KwaZulu Natal.

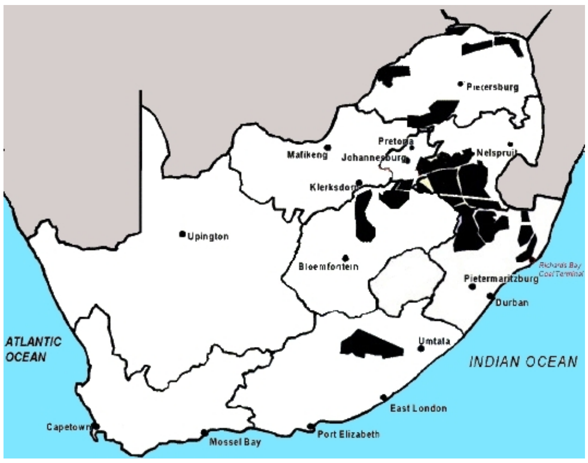


Figure 11.9: Map of coal deposits in SA: often these deposits are the sites of plant and animal fossils as they are created by the same process.

"Living fossils" in South Africa: Cycads have been in existence for over 280 million years. There are several rare species of cycads found exclusively within South Africa. They grow very slowly and live for up to a 1000 years. Because they are such a rare species, there are several restrictions on what can be done to them. In South Africa, unless required for conservation purposes, it is illegal to collect, pluck, destroy, export or possess cycads without a special permit.

Figure 11.10: Cycads have been in existence for over 280 million years.

Mesozoic (251-72 million years ago) ESGCQ

The Mesozoic Era is often referred to as the 'age of reptiles' because throughout the marine and terrestrial habitats, reptiles (especially dinosaurs) were dominant. This era is divided into three major periods: Triassic, Jurassic and Cretaceous.

The major events of this era included significant changes in the **climate**, **evolutionary activity** and **land mass** of Earth.

- The climate of the Mesozoic fluctuated dramatically between cooling and warming periods.
- Until this point, the Earth existed as one giant land mass called Pangaea. During the Mesozoic era, this land mass broke up, and by the end of the era, the continents as we know them today drifted into their current positions.
- The extinction of nearly all animal species in the former Paleozoic era led to rapid evolution of many new life forms.
- Dinosaurs appeared on land, becoming the major terrestrial vertebrates for nearly 135 million years.
- Pterosaurs (flying reptiles) dominated the skies and aquatic reptiles such as ichthyosaurs were found in the oceans.
- During the Triassic, *Archaeopteryx*, a link between reptiles and birds was thought to evolve.
- The earliest birds appeared during the Jurassic period having evolved from an order of dinosaur called theropods.
- Dinosaurs became extinct around 65 million years ago, at the end of the Cretaceous period.
- The dominant land plant species of the time were the seed-producing plants known as the **gymnosperms**. These include the cycads and conifers.

FACT
The existing sequoia trees found mainly in the United States were also thought to have evolved in the Mesozoic.

Figure 11.11: Sequoia trees in California, USA.

South African fossil examples: The mammal-like reptile, *Lystrosaurus* was by far the most dominant terrestrial vertebrate during the Early Triassic period.

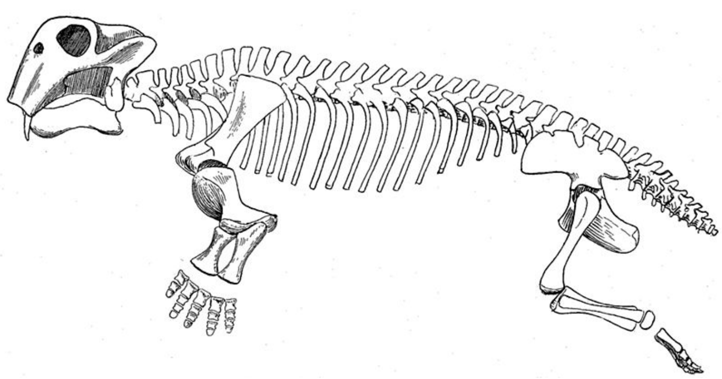


Figure 11.12: *Lystrosaurus* skeletal diagram.

FACT
When the coelacanth was initially discovered by an East London fisherman in 1938, and identified as such by Professor JLB Smith, this surprised scientists because they thought it had become extinct. Soon there were other such discoveries of the coelacanth off the coast of KwaZulu-Natal as well as Northern Madagascar. Coelacanths represent a link between fish and amphibians.

Specimens of the *Lystrosaurus* were unearthed in the Balfour and Katburg formations in the Karoo. The discovery of *Lystrosaurus* in the Coalsack Bluff in the Transantarctic Mountains helped confirm the theory that the continents of the Earth were once joined, as *Lystrosaurus* had already been found in the Early Triassic fossil record of Southern Africa, India and China.

"Living fossils" in South Africa:
Coelacanths were thought to have gone extinct towards the end of the Cretaceous period but were re-discovered in 1938 off the northern coast of South Africa in KwaZulu-Natal. The coelacanth is thought to have evolved into its current form over 400 million years ago and is nicknamed a 'living fossil' because knowledge of the species was previously based on fossils, as it was thought to have gone extinct.

Figure 11.13: Coelacanths, which represent a link between fish and amphibians, were though to have gone extinct at the end of the Cretaceous period.

Coelacanths and amphibians share a common ancestor- the lobe-finned fish. Lobe-finned fish have fleshy fins unlike fins in other fish which are joined to the body by a single bone. Pectoral and pelvic fins have articulations resembling those of tetrapod limbs. These fins evolved into legs in the earliest tetrapod land vertebrates which were amphibians. Living lobe-finned organisms include the coelacanths and lungfish.

Activity: Is the Coelacanth the missing link between fish and amphibians?

Aim:

This activity is designed to help you to understand whether coelacanths represent a link between fish and amphibians.

Instructions:

1. Use resources such as the Internet, encyclopaedias and magazines.
2. Find out what structural features lead scientists to suggest that coelacanths represent a link between fish and amphibians.
3. Once you have completed their research, have a class discussion.

Cenozoic era (65 million years ago to present) ESGCR

If the Mesozoic was the "age of dinosaurs", then the Cenozoic has been the "age of mammals". The Cretaceous-Paleogene extinction event occurred towards the end of the Mesozoic era and half the animal species on Earth, including the dinosaurs were wiped out. As a result mammals diversified to fill ecological niches.

- The continents moved into their existing locations, with Australia-New Guinea which split from Gondwana during early Cretaceous, drifting north and eventually colliding with Southeast Asia. Antarctica moved into its current position over the South Pole and the Atlantic Ocean widened and South America became attached to North America.
- 54–33 million years ago, Africa was an island, not yet joined to the Middle East and Europe.
- The climate warmed significantly until 55 million years ago, followed by long-term cooling since 49 million years ago.
- Many species of grass evolved from flowering plants between 33 and 24 million years ago.
- As the Earth cooled, grasslands began to expand and forests shrank.
- Animals evolved to fit the new, open landscape and many fast-running prey and predator species arose as a result.

It is during the Cenozoic Era that our species, *Homo sapiens* evolved into the anatomically modern humans we are today.

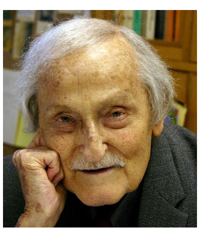
FACT
In Grade 12 you will study the course of human evolution in great detail to gain a firm understanding of how we evolved. For Grade 10, we will learn some of the significant changes that have occurred in our species in Africa over the last four million years.

The evolution of *Homo sapiens*: evidence from Africa ESGCS

Humans are thought to have evolved from their ape-like ancestor over the last 6 million years. Human evolution has involved changes in **physical appearance** and **behavioural traits**. Some important physical developments include bipedalism, and a larger, more complex brain. **Bipedalism** is the ability to stand upright on two legs; it was an important adaptation as it freed the hands to be used in other tasks. Developments in behavioural characteristics include the ability to use fire, the ability to make and use tools, and the ability to communicate by means of language.

The most widely accepted theory of how anatomically modern humans evolved, suggests that *Homo sapiens* evolved in Africa approximately 200 000 to 150 000 years ago in what has now become known as the "Out of Africa" theory. Some of the evidence for the key events as found in Africa is shown in the table below.

FACT
Philip Tobias (October 1925–June 2012) was a South African palaeoanthropologist at the University of Witwatersrand, whose work has contributed enormously to our understanding of how humans evolved. He is best known for his work with fellow palaeoanthropologist Louis Leakey. He identified the ancestral species of human beings known as *Homo habilis*. His work at the Sterkfontein caves in Gauteng has led to it becoming a World Heritage site. He was also famous for his opposition to apartheid and gave speeches condemning apartheid at protest rallies and also to academic audiences.



Human ancestors evolved and migrated out of Africa in a series of 'waves'.

Event in human evolutionary history	Evidence of event from Africa
Hominins and chimpanzees diverge from a common ancestor.	The earliest known human ancestor after the chimpanzee/ human separation is *Orrorin tugenensis* (Millenium Man, Kenya, around 6 million years ago).
Evidence of development of bipedalism in humans in *Australopithecus afarensis*.	Human-like footprints discovered on volcanic ash in Laetoli, Tanzania from 3,9–2,9 million years ago.
Bipedal *austrolopithecines* lose body hair 3–2 million years ago.	Loss of body hair occurs in parallel with the development of bipedalism.
Homo habilis is able to make and use tools 2,3–1,4 million years ago.	Fossil tools discovered in Olduvai Gorge, Tanzania and at Lake Turkana, Kenya.
Approximately 200 000 years ago, anatomically modern humans evolved.	The earliest fossil evidence found is near Omo river in Ethiopia.

Fossil sites from South Africa providing evidence for pre-humans and humans

South Africa has been the site of various fossil discoveries and has been home to some of the world's leading paleoanthropologists such as Robert Broom, Raymond Dart and Phillip Tobias. Fossils of pre-humans and humans found across the country have contributed significantly to our understanding of human history on Earth. The table below shows some of the evidence and where it is located in South Africa.

Figure 11.14: The 'Taung Child'.

Fossil Evidence and Age	Location in South Africa	Importance
Australopithecus africanus (the "Taung Child") (approximately 2,5 million years ago)	North West Province	Most direct ancestor of modern humans
Australopithecus sediba (approximately 2 million years ago)	Malapa Nature Reserve, Cradle of Humankind	First evidence of transition to tool-making in humans
Homo sapiens (approximately 75 000 years ago)	Klasies River Caves, Eastern Cape	Discovery of earliest anatomically modern humans

11.4 Mass extinctions ESGCT

A mass extinction is a sharp decrease in the amount of plant and animal life. There have been five major mass extinction events in Earth's history. These are shown in the table given, along with the major events that characterised each.

Major mass extinction event	Date of occurrence	Major events
Cretaceous-Paleogene extinction event	65 million years ago	Approximately 75% of all species became extinct. Mammals and birds emerged as the dominant land vertebrates.
Triassic-Jurassic event	205 million years ago	Most non-dinosaur species were eliminated, leaving land dinosaurs with no competition.
Permian-Triassic event	250 million years ago	This was Earth's largest extinction event. It resulted in the loss of 96% of marine species and 70% of land species. The event had great evolutionary significance because it allowed the vacant habitats and ecosystems to be filled by new species through natural selection.
Late Devonian extinction	375–360 million years ago	This was a prolonged period of extinction lasting up to 20 million years. During this period up to 70% of living species were eliminated.
Ordovician-Silurian extinction event	450–440 million years ago	Over 50% of all genera were eliminated during this period and is ranked as the second largest mass extinction in Earth's history

FACT
Learn about the five major mass extinctions that occurred in Earth's history.
See video: 2CY4

FACT
Earth's sixth mass extinction?
See video: 2CY5

Ongoing sixth mass extinction ESGCV

- We are currently living through the 'sixth' mass extinction according to many scientists. The present rate of extinction is thought to be 140 000 species per year. This rapid extinction rate started in approximately 10 000 BC and has continued into the 21st century.

- The extinction includes disappearance of large mammals such as the woolly mammoth.
- The sixth extinction event is thought to be occurring at a rapidly increasing rate.
- The two major causes for the sixth extinction are thought to be human hunting and the rapid rise in human population. You will learn more about the impact of human activity on the environment in Grades 11 and 12.

FACT
The Golden Toad of Costa Rica has been extinct since around 1989. Its disappearance has been attributed to a confluence of several factors, including global warming event known as El Nino, fungus, and the introduction of new species that out-competed it for habitat and food.

Causes of mass extinctions ESGCW

There is still a lot of debate among scientists as to what caused the mass extinctions. To be a valid theory to explain what caused mass extinctions, the theory must:

- explain all the losses of species at a particular mass extinction event (not just specific losses e.g. dinosaurs).
- explain why some organisms died and others survived.
- be based on natural events and processes that are shown to have occurred around the time of extinction.

FACT
Watch a video about the debate about what really killed the dinosaurs.
See video: 2CY6

Two of the hypotheses put forward are:

- the impact theory of extinction
- massive volcanic activity

FACT
Watch a video about the meteor impact that may have caused the extinction of the dinosaurs.
See video: 2CY7
See video: 2CY8

Impact event

Scientists believe that an asteroid was responsible for the mass extinction that occurred 65 million years ago. The meteorite that hit Earth was most likely 10 km in diameter, and upon impact it would have released an amount of energy that was 2 million times more powerful than the most powerful man-made device ever created. The massive impact caused earthquakes and volcanic eruptions that produced toxic gases, and ejected dust, soot and debris into the air, blocking out sunlight and preventing photosynthesis. The impact also resulted in the production of sulfur rich acid rain and caused forest fires and mega-tsunamis. The impact of an asteroid smashing into Earth may have caused food chains to collapse both on land and at sea. They believe this impact produced the 180 km wide Chicxulub crater found in the Gulf of Mexico.

Volcanic activity

Some scientists believe that volcanic eruptions may have caused the mass extinction event at the end of the Cretaceous period that led to the extinction of among others, the dinosaurs. The researchers, through examining a trail of dead particles floating in the sea, spanning half a million years, developed a timeline that links mass extinction to large-scale eruptions of the Deccan Traps, an ancient volcanic range in Western India.

Evidence suggests that the massive volcanic eruptions pumped out massive quantities of carbon dioxide and sulphur dioxide into the air, thus altering the climate and contributing to the mass extinction event at the end of the Cretaceous period.

Figure 11.15: Illustration of an impact event.

Figure 11.16: Deccan traps, Mahabaleshwar, India.

Activity: What caused the mass extinctions?

Aim:

To use understanding of fossil evidence and scientific method to demonstrate how each of the hypotheses for mass extinction arrives at its conclusion.

Instructions:

- What are the key requirements of a theory that attempts to explain the mass extinctions?
- Choose one of the two hypotheses discussed and describe it in your own words. List the evidence that supports the theory.
- Through your research on the Internet and by reading books in the library, list any other evidence that you found in support of your chosen hypothesis.

Activity: Understanding evolutionary history based on evidence from South Africa

Aim:

We want to locate where the key events in the history of life occurred in South Africa, based on our earlier discussion of fossil evidence found in South Africa.

Instructions:

1. The table below lists evidence from South Africa on the history of life.
2. Draw a map of South Africa.
3. On your map, show where each piece of evidence listed in the table is located.
4. Also show what this evidence indicates about the history of life.
5. In the third column of the table, write down the era from which these fossils are likely to have emerged. The first part has been done for you.

Evidence	Location	Era
Stromatolites	False Bay, Cape Town	Paleozoic, Pre-Cambrian
Soft-bodied animals	Northern Cape	
Early land plants	Grahamstown	
Primitive plants e.g *Glossopteris*	Mooi River, Estcourt	
Coelacanth	Northern KZN Coast	
Mammal-like reptiles e.g. *Lystrosaurus, Thrinadoxon*	Karoo	
Dinosaurs *Euskylosaurus*	Drakensberg and Maluti mountains, Ladybrand, Free State	
First mammals	Lesotho, Eastern Cape	
Humans and pre-humans	Gauteng, North West, Free State, KwaZulu-Natal, Limpopo	

Activity: Observing fossils

Aim:

Examine fossils at a museum or fossil site or look at photographs of fossils.
Materials:

Some fossil sites have already been described.

- These websites provide a list of museums that contain fossils:
  http://www.southafrica.info/travel/cultural/museums.htm
  http://www.museumsonline.co.za/
- A list of fossil sites around the world is given below. Identify the ones that are within South Africa:
  http://en.wikipedia.org/wiki/List_of_fossil_sites.

- If you are unable to visit the fossil sites or museums, the following website gives photographs and explanations of the major fossils that have shaped our understanding of the history of life: http://english.fossiel.net/determinatie/identification.php.

Instructions:

Travel to your nearest museum, fossil site or the website listed and observe any fossils on display. Find out how they have been preserved, describe the key features of each fossil, how they were dated and what they tell us about our past.

11.5 Impact of humans on biodiversity and the environment ESGCX

Humans have impacted the biodiversity and environment in several crucial ways. The broad term used to describe this effect is known as the **anthropogenic effect** which refers to effects created by human activity and normally refers to environmental pollution.

A number of activities that humans are involved in contribute to the changes in the environment. The table below lists some of these activities and their effects on the environment.

Human activity	Environmental Impact
Agriculture	Climate change as a result of rising carbon dioxide; deforestation and desertification as well as use of fossil fuels.
Fishing	Use of dynamite for fishing results in destruction of habitats; Overfishing results in extinction of fish species.
Irrigation	Results in changes to the quality of the soil and underground water. It also uses up the water supply in the local rivers and lake areas.
Meat production	This is one of the largest contributors to environmental degradation worldwide. Current methods of animal raising contribute to water pollution, land degradation, climate change and loss of biodiversity.
Oil industry	The degradation of land, air pollution and the environmentally toxic process of oil extraction and processing results in loss of biodiversity and destruction of the environment.

FACT
You may have heard of the controversy surrounding "fracking". This is also known as 'hydraulic fracturing' and is the process by which rocks are broken up ('fractured') in order to release natural gas or petroleum. There is an estimated 485 trillion cubic feet of gas in the Karoo in South Africa, making it the fifth largest source of natural gas in the world. By using this gas, South Africa would be able to reduce its dependence on coal. However the use of fracking to obtain this gas would result in a destruction of the fossil record present beneath the Earth's surface in this area of South Africa.

Human activity	Environmental Impact
Mining	Mining results in erosion of soil, contamination of the groundwater and surface water by chemicals from mining processes. It also results in deforestation near mining sites. Mining processes are highly toxic and contamination resulting from mining can affect the health of the population.
Transport	The environmental impact of transport is mainly due to its use of petroleum, which creates air pollution. Air pollution contributes to global warming through emissions of carbon dioxide.

Group discussion: How do we manage the impact of humans on the planet?

The table above presents the various human activities that have impacted on the environment and on biodiversity. In groups, discuss possible methods by which the impacts listed above could be reduced. How can we reduce the impact humans have on the environment? After your discussion, re-draw the table and add a third column to the right listing these different ways you have discussed among yourselves.

11.6 Fossil tourism ESGCY

Given the intense interest humans have in their origins and the deep knowledge of our past with which fossils provide us, fossil tourism is an important source of income and employment in areas in which fossils are located.

South Africa has a number of sites rich in fossils, which attract tourists. The **Cradle of Humankind** in the Krugersdorp area of Gauteng (i.e. Sterkfontein, Swartkrans, Kromdraai and surrounding area) has been declared a World Heritage Site, since it has yielded so many significant fossils, such as Mrs Ples, Little Foot and the recently discovered Karabo Child (2008). There is a tourist centre at Maropeng near this site ("Maropeng" is the Tswana word for "origins").

Many other areas in South Africa also attract tourists due to their rich fossil deposits, such as Langebaan, Border Cave and the Karoo area.

Many South Africans can find jobs in such tourist areas. They can work as tour guides, hotel staff, game rangers, drivers, curio sellers and the like. It is important also that the local people see the tourist site as a potential source of income and employment, not merely as something academic that has nothing to do with them.

Figure 11.17: Fossil therapsid skeleton in Karoo National Park, South Africa.

Figure 11.18: Fossil therapsid skull in Karoo National Park, South Africa.

FACT
A brief video about Maropeng and what you can do there. We can rightly be proud of this world class centre!
See video: 2CY9

11.7 Summary ESGCZ

- Scientists use deductive reasoning to understand fossils and the history of life on Earth.
- Geological events often caused changes in climate, which in turn influence the emergence and disappearance of species.
- It takes special circumstances for fossils to form, and fossils can be dated by radiometric or relative dating.
- Climate and geography helped shape the evolution of life on Earth.
- Geological timescales are divided into eons, eras and periods.
- The Cambrian explosion was a rapid explosion in the diversity of life-forms. All animal groups have their origin in the Cambrian explosion.
- During the Paleozoic the first fish, animals with shells and insects evolved and plants first colonised land.
- The Mesozoic was the ‘age of dinosaurs’, later in the era birds evolved, and gymnosperms evolved.
- The Cenozoic is the most recent era and was the ‘age of mammals’.
- Mass extinctions are massive losses in life, and there have been five mass extinction events in history.
- In the last 4 million years significant changes have occurred in species occurring in Africa, including the evolution of humans.
- Humans have a massive effect on biodiversity and the natural environment and are partially responsible for the ’6th mass extinction’.
- South Africa is rich in many fossils from diverse time periods.
- Fossil tourism is a source of income and employment in fossil localities.

Exercise 11 – 1: End of chapter exercises

1. In each of the following cases write down the letter of the most correct alternative.

   a) Which of the fossils have been found in Namibia?

      i. Mammal-like reptiles
      ii. *Glassopteris* leaves
      iii. Soft-bodied animals
      iv. Early mammals

   b) A problem in the accuracy of radiocarbon dating is that:

      i. scientists are not sure that radioactive decay actually occurs
      ii. the decay rate of minerals can change without warning
      iii. the rocks that contain the fossils can't be dated
      iv. the half-life of carbon-14 is relatively short, and most fossils are millions of years old

2. Study the table below that shows the decay of carbon-14 over time and then answer the questions that follow:

Decay of carbon-14								
Years from present	0	5730	11460	17190	22920	**X**	34380	40110
Number of half-lives elapsed	0	1	2	3	4	5	6	7
Percentage of original carbon-14 remaining	100	50	25	12,5	6,25	**Z**	1,56	0,78

   a) State two types of methods used to determine the age of fossils.
   b) Calculate the value of:

      i. X
      ii. Z

   Explain why it would not be possible to date the fossil of an organism that existed 80 million years ago using the decay of carbon-14.

   d) Give two reasons why there are gaps in the fossil record.

3. Study the graph on the following page which shows the major extinction events answer the questions that follow.

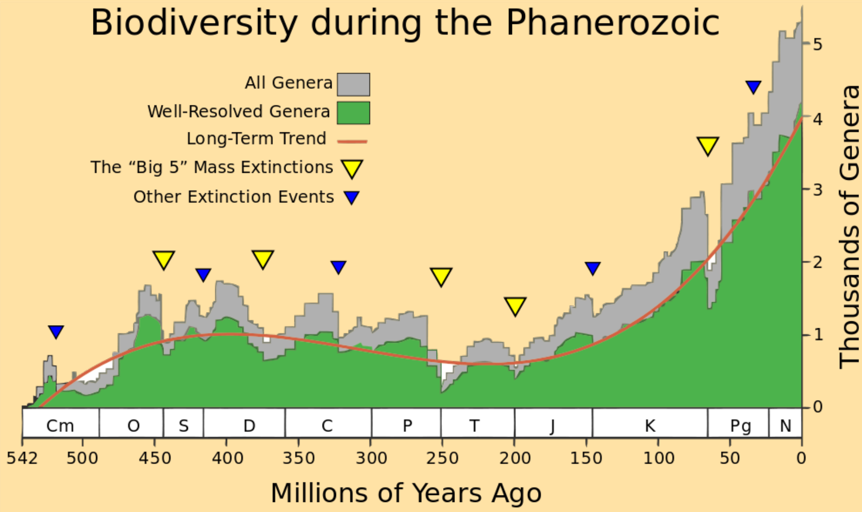


Figure 11.19: Graph of mass extinctions

a) When did the Cenozoic era begin?
b) Which mass extinction took place towards the end of the Paleozoic era?
c) Approximately how many genera of species went extinct at the end of the Paleozoic era? Show ALL working.
d) Explain why the number of genera of organisms increased rapidly after each mass extinction.

4. The following questions are about the extinction of dinosaurs on Earth.

a) What evidence do scientists use to show that dinosaurs once existed on Earth?
b) How long ago did the dinosaurs become extinct?
c) Describe a hypothesis that has been proposed for the extinction of many species, including the dinosaurs during the extinction event at the end of the mesozoic.

Check answers online with the exercise code below or click on 'show me the answer'. 1a. 2CYB 1b. 2CYC 2. 2CYD 3. 2CYF 4. 2CYG

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Solutions to exercises

List of Definitions