LIFE SCIENCES

Grade 12 Textbook

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

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Contributors

Dr Arnold Johannes, Mr Peter Weisswange (editors), Ms Angie Weisswange (illustrator), Ms Tiffany Bell, Ms Margaret Elferink, Mr Jason Field, Ms Michelle Tracy Hagemann, Ms Kathryn Lamarque, Ms Jessica Marais, Ms Alydia Monteith, Ms Danielle Stander, Mr Peter Weisswange (all authors), Ms Helena Oosthuizen, Ms Delia Stander, Ms Kerstin Stoltsz.

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Quality Assurance

by Life Sciences Subject Advisors,
under the direction of Mr Kanthan Naidoo (CES):

Ms Phumzile Dlamini (EC), Mr Gonasagaren Pillay (KZN), Ms Zimasa Sanda (EC), Ms Jennifer Titus (NC)

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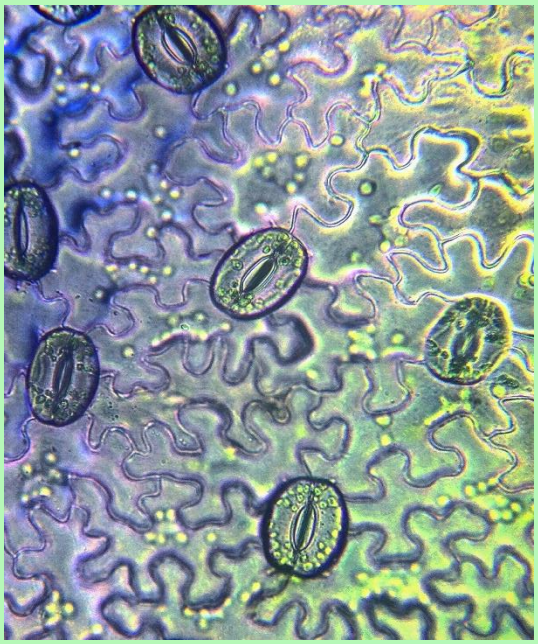
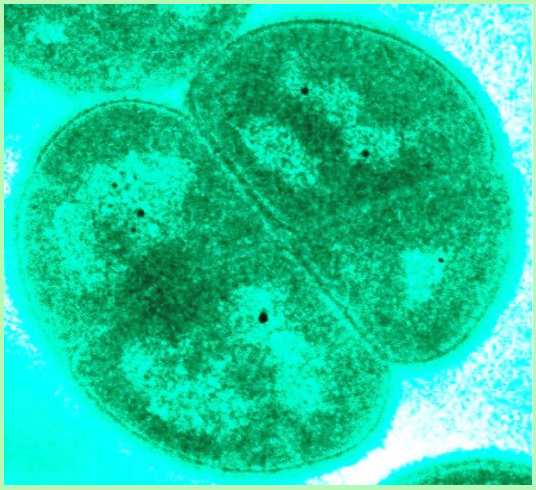
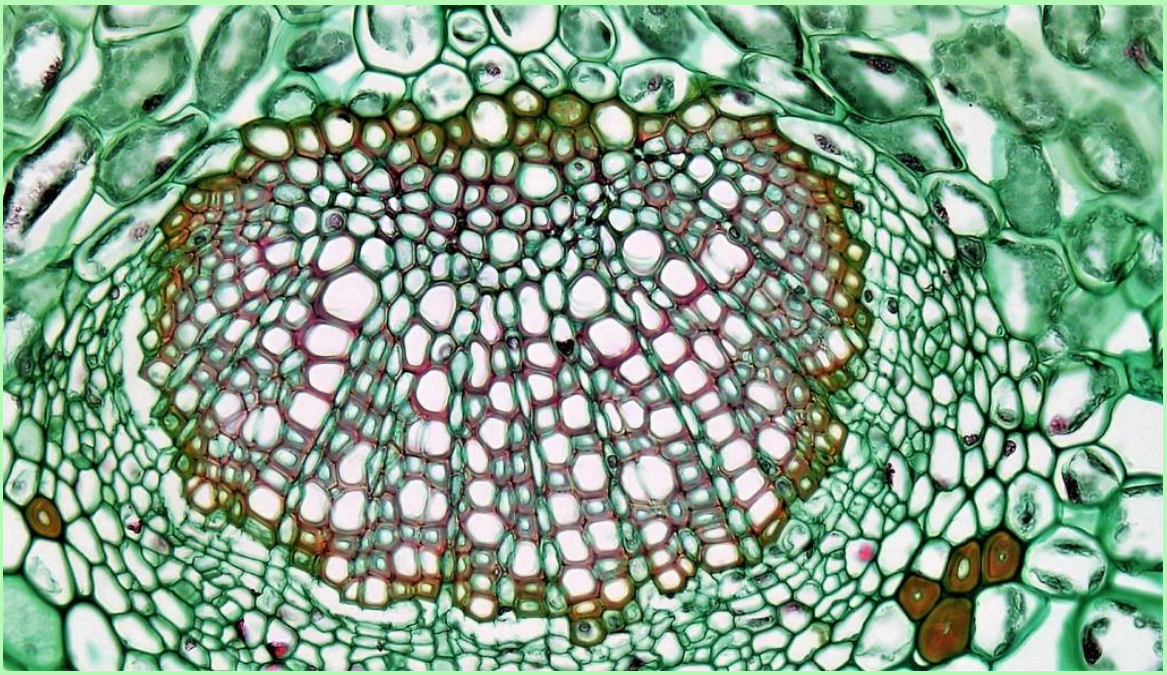






INTRODUCING LIFE SCIENCES

The aim of this textbook is to allow you, the learner, to be an active partner in your learning experience. The text has been designed to cover all the content you need for Grade 12, and to provide it in a readable manner that communicates all concepts simply, clearly and in the necessary amount of detail.

The next few pages will provide you with a broad overview of Life Sciences and hopefully show you its value as a choice for a school subject.

Studying Life Sciences also offers you broader benefits: it will encourage your ability to **think critically**, to **solve problems** and seek to **understand the world around you**.

What are the Life Sciences?

The term 'Life Sciences' indicates clearly the two ideas held together in this subject:

- **Life** refers to all living things – from the most basic of molecules through to the interactions of organisms with one another and their environments.
- **Science** indicates it is necessary to use certain methods in our study of the subject. The two broad aims of any science are to increase existing knowledge and discover new things.

We approach this using careful methods that can be copied by others. These include:

- proposing hypotheses (the predicted outcome of an investigation) and
- carrying out investigations and experiments to test these hypotheses.

Scientific knowledge changes over time as more is discovered and understood about our world; as such, Life Sciences is a constantly growing subject.

Why choose Life Sciences as a subject?

- **First**, to give you knowledge and skills that are helpful in everyday life, even if you do not pursue Life Sciences after school.
- **Secondly**, to expose you to the wide variety of sub-fields within the subject that could encourage or interest you to pursue a career in the sciences.

If you choose to study Life Sciences at school you will be able to study any Life Science specialisations after school - such as microbiology, genetics, environmental studies or biotechnology.

What skills will Life Sciences equip you with?

This subject will teach you important biological concepts, processes, systems and theories, and provide you with the skills to think, read and write about them. Life Sciences will:

- give you the ability to evaluate and discuss scientific issues and processes
- provide an awareness of the ways biotechnology and a knowledge of Life Sciences have benefited humankind
- show you the ways in which humans have impacted negatively on the environment and organisms within it, and show you how to be a responsible citizen in terms of the environment and conservation
- build an appreciation of the unique contribution of South Africa to Life Sciences - both the diversity of the unique biomes within Southern Africa and the contributions of South Africans to the scientific landscape.

Life Sciences Strands for Grade 12

Everything you study this year will fit into one of these three broad strands. These knowledge pathways grow over your three years of FET.

Within each knowledge strand, ideas should not be studied separately; rather seek to discover the links between related topics so that you grow in your understanding of the inter-connectedness of life. As you study each section or chapter, look for the broad strokes that place it under one of these strands:

- Knowledge **Strand 1**: Life at a Molecular, Cellular and Tissue Level
- Knowledge **Strand 2**: Life Processes in Plants and Animals
- Knowledge **Strand 3**: Diversity, Change and Continuity

The Purpose of studying Life Sciences

There are three broad purposes, which will expand as we continue:

- **Aim 1** - knowing the content (theory);
- **Aim 2** - doing practical work and investigations;
- **Aim 3** - understanding the applications of Life Sciences in society - both present society (indigenous and western) and within the context of history.

Aim 1: Knowing the content of Life Sciences

Learning content involves understanding and making meaning of scientific ideas, and then connecting these ideas. Theory is not just recalling facts; it is being able to *select important ideas*, *use different sources to learn*, and *describe concepts,*

processes and theories important to Life Sciences.

Within this you will learn to *write summaries*, develop your *own diagrams* and *reorganise data* you are given into something meaningful. Additionally, you will learn to *interpret the data* you are working with and *link it to theory* you have studied.

Aim 2: Doing practical work and investigations

Life Science is a fascinating subject and one of the best ways to understand it is for you to see it in action. Therefore, it is important for you to know how to do practical investigations. Within this, you will learn many useful skills like how to *follow instructions* in a safe manner and how to *name*, *recognise* and *handle laboratory equipment*.

During a practical investigation it is important for you to be able to *make observations*. There are many ways this can be done - by making drawings, describing what you see, taking measurements, and comparing materials before and after a certain treatment. After making these observations it is important for you to be able to *measure* and *record them* in a useful way. From here you will *interpret your data* - you will look for the value in what you gathered and discuss the changes, trends, and applications of what you have shown.

Finally, you will learn how to design your own investigations and experiments. An investigation is more straightforward; for example, it could involve observing soil profiles or counting animal populations.

Planning an experiment would begin with identifying a problem, and then hypothesising a solution. In planning, you would identify variables and consider ways to control them, select apparatus and materials to assist you, and then plan an experiment that could be repeated by someone else. It is also important to consider ways of capturing and interpreting your data.

Aim 3: Understanding the history, importance and modern applications of Life sciences

The third aim of Life Sciences is to show you that school science can be relevant to your life and that studying provides enrichment to you, even if you do not pursue it past school level.

As you study you will be exposed to the history of science and indigenous knowledge systems from other times and other cultures. As you learn a certain section of work, you will be introduced to how that knowledge was developed by various scientists across the ages as they pursued a deeper understanding of the world around them.

Our search of knowledge is shaped by our world view. Therefore, an important concept to be aware of is that modern science (and technology) and traditional, indigenous knowledge systems will sometimes differ in their approach to science.

These seemingly opposite views can be held together as both bring a certain dynamic; they should not be seen as opposing forces.

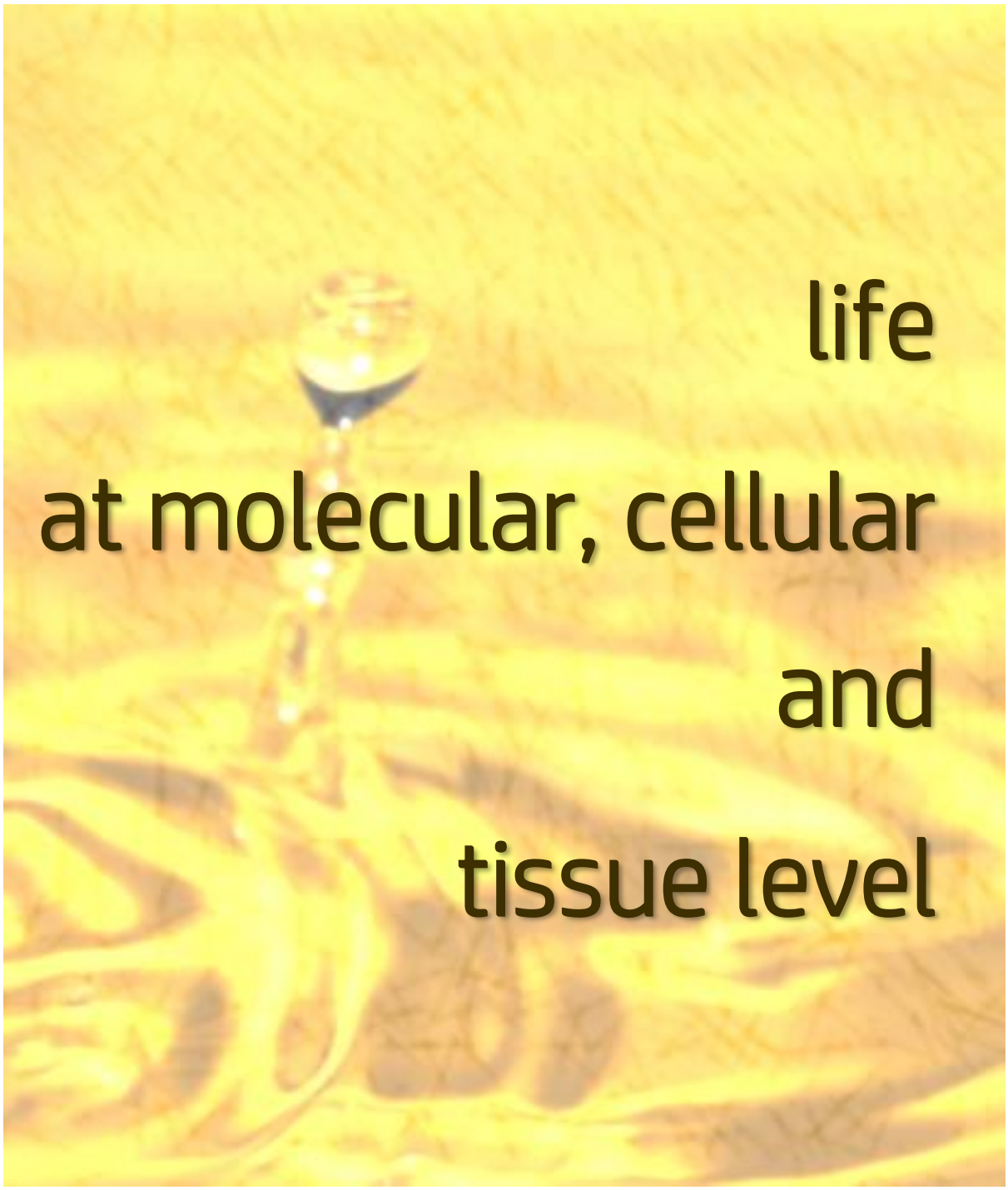
Finally, there are many possible career fields branching out of Life Sciences and, as you learn, some of these will be shown through examples. Different sections would open up different careers choices- *in the past* (for example palaeontology), *the present* (like horticulture, game ranch management and preservation) and *the future* (such as biotechnology and genetic engineering).

A final word on using this textbook

The best way to use this textbook to increase your understanding and thereby results would be as follows:

- Remember, good learning begins in the classroom so always pay careful attention as your teacher works through it with you
- Take note of sections you do not understand and revisit them
- Ask questions to make sure you understand
- Consider the end-of-chapter summaries and build on them to create your own point-form summary note
- Practice re-sketching the given diagrams
- Work through all the given questions and answers at the end of the chapter

Strand



1: DNA – the code of life

CHAPTER 1: DNA – THE CODE OF LIFE

Introduction

- All living organisms contain both DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) – we focus on their location, structure and function.
- We explore the discovery of DNA, its role in the human body and how it replicates.
- Protein synthesis is vital for life – we examine how proteins are formed by both DNA and RNA.

Revision of cellular structure

It is important to know the location and functions of certain organelles, illustrated in Figure 1 below.

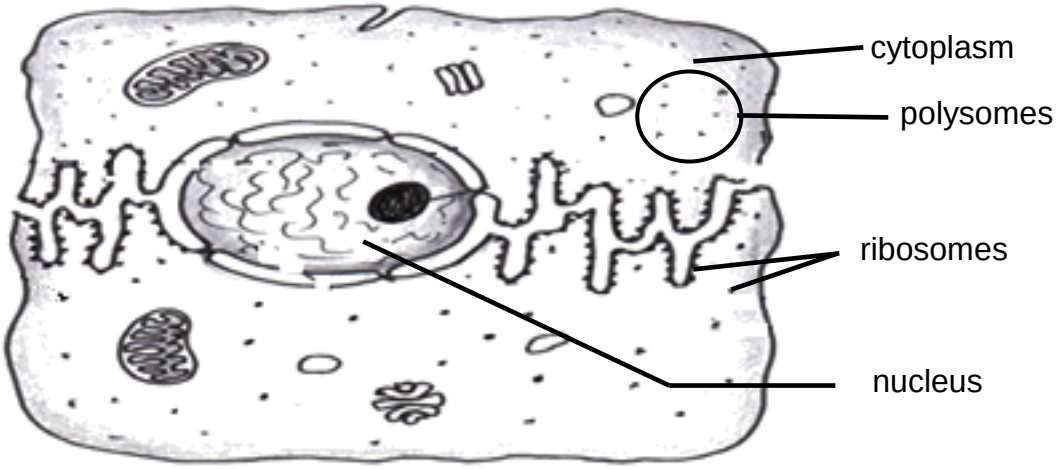


Figure 1: Structure of a cell

Cytoplasm is the base substance in which the organelles of the cell are suspended. It is a watery substance and allows for metabolic reactions to take place.

Ribosomes are small, round organelles which are mainly found attached to the endoplasmic reticulum or are free-floating in the cytoplasm. Ribosomes can also be found inside other organelles such as the chloroplast and mitochondria but in smaller numbers. They are the site of protein synthesis and consist of RNA and protein.

The **nucleus** controls all of the cell's activities.

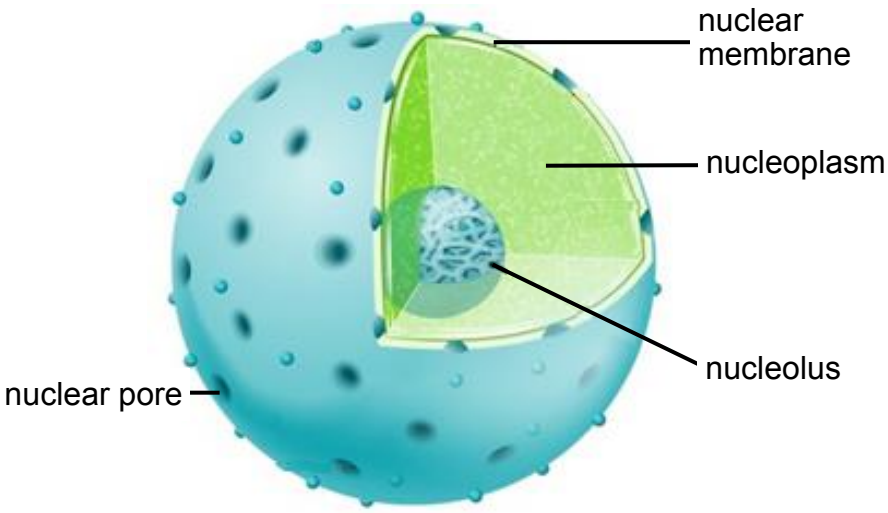


Figure 2: Parts of the nucleus

A nucleus has four main parts:

- the double **nuclear membrane** – it encloses the nucleus and contains small pores to allow for the passage of substances in and out of the nucleus
- the **nucleoplasm** – this is a jelly-like fluid within the nucleus
- the **nucleolus** – a dark body suspended in the nucleoplasm which contains free nucleotide bases and produces ribosomes
- the **chromatin network** – found in the nucleoplasm: contains the DNA which forms the chromosomes containing the genetic code of a person / organism

The structure of nucleic acids

Key terminology

nucleic acid	a type of organic compound
monomer	a building block
nucleotide	the monomer which forms DNA and RNA

There are two types of nucleic acids in the human body – DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Together these form the basis of all life of earth. They consist of monomers (building blocks) called nucleotides.

The basic structure of a nucleotide is illustrated in Figure 3 below. Each nucleic acid is composed of a phosphate (P), a sugar molecule (S) and a nitrogenous base (NB).

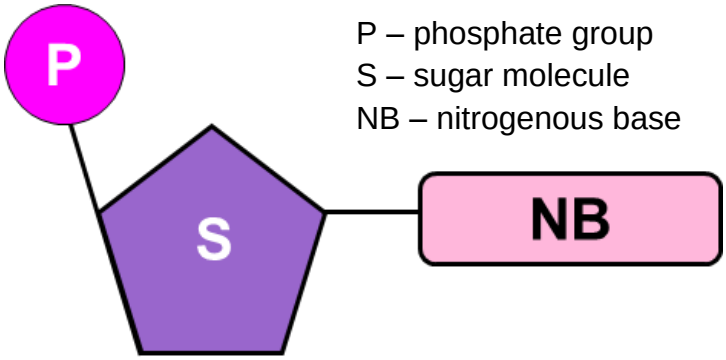


Figure 3: A nucleotide

DNA – deoxyribonucleic acid

Key terminology

DNA	• deoxyribonucleic acid is made up of nucleotides • nitrogenous bases adenine, thymine, guanine and cytosine • carries the genetic code for protein synthesis
nuclear DNA	DNA found in the nucleus
extra- nuclear DNA	DNA found outside of the nucleus: mitochondrial and chloroplastic DNA.
double helix	the shape of DNA consists of two strands joined together and twisted spirally
hereditary	genetic information passed on from parent to offspring

A brief history of the discovery of DNA

- 1952 – Rosalind Franklin and her assistant Maurice Wilkins researched the structure of DNA using X-ray diffraction images.
- Watson and Crick did independent research on DNA. Upon seeing Franklin's images, they proposed a 3-D double helix model for DNA in 1953.
- 1962 – Watson and Crick received the Nobel Prize for the discovery of the structure of DNA, and Wilkins received an award for his X-ray photography. Franklin had died of cancer.

Rosalind Franklin – background: https://www.youtube.com/watch?v=BIP0lYrdirI

The location of DNA

DNA is found in **two locations** in a cell:

- Mostly in the nucleus of a cell – this is referred to as **nuclear DNA**
- a small amount is found outside the nucleus – it is referred to as **extra-nuclear DNA**. There are two types of extra-nuclear DNA:
    - chloroplastic DNA – found in the chloroplasts of plant cells
    - mitochondrial DNA – found in the mitochondria (useful for tracing ancestry)

The structure of DNA

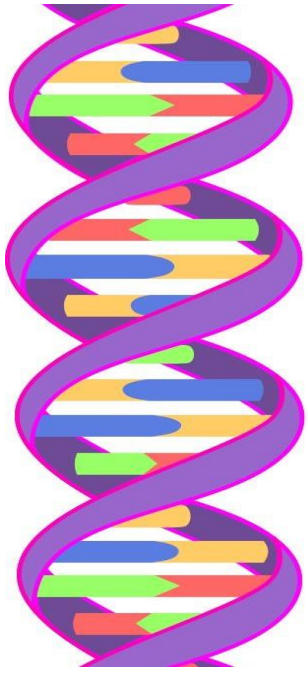


Figure 4A: DNA double helix

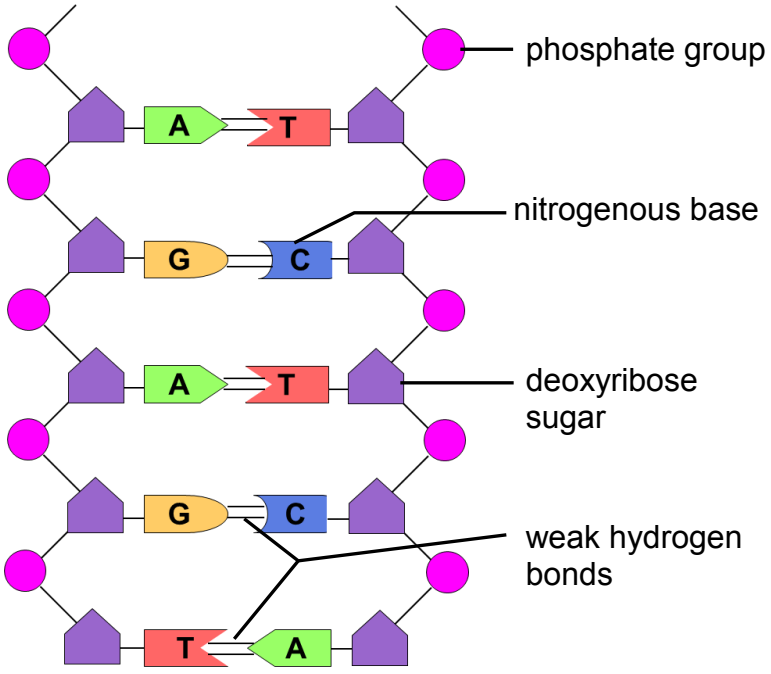


Figure 4B: DNA – simplified structure

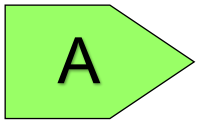
DNA has a double helix structure (Figure 4A), consisting of monomers called nucleotides which link to form long chains, called polymers. The sugar in DNA is deoxyribose sugar and is attached to a nitrogenous base. The phosphate and sugar molecules are attached to one another by strong bonds alternately to form the long chains (Figure 4B).

There are four types of nitrogenous bases in DNA:

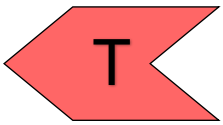
adenine (A)	cytosine (C)
thymine (T)	guanine (G)

Nitrogenous bases are complementary, and always join together in a specific order:

- adenine always links to thymine (Figure 5A)
- guanine always links with cytosine (Figure 5B)

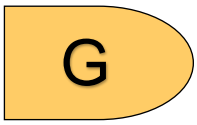


adenine

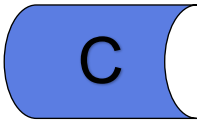


thymine

Figure 5A: adenine with thymine



guanine



cytosine

Figure 5B: guanine with cytosine

This pairing of bases means that two strands of DNA are joined together, forming a long ladder-like structure. The nitrogenous bases are held together by weak hydrogen bonds. The ladder-like structure becomes coiled and is known as a **double helix structure**. The DNA strands wind around proteins which are known as histones.

The role of DNA

DNA carries hereditary information in the form of genes. Genes are short sections of DNA which code for a specific trait, and determine the physical characteristics (e.g. blood grouping, a gene linked to breast cancer) and behaviour of an organism (e.g. whether an organism can be tamed and domesticated).

Most of the DNA strands do not code for anything and are known as non-coding DNA. Scientists are still researching the importance of the non-coding DNA.

The main functions of DNA include:

- Controls the functioning of cells
- Regulate the functioning of genes
- Passes on hereditary characteristics

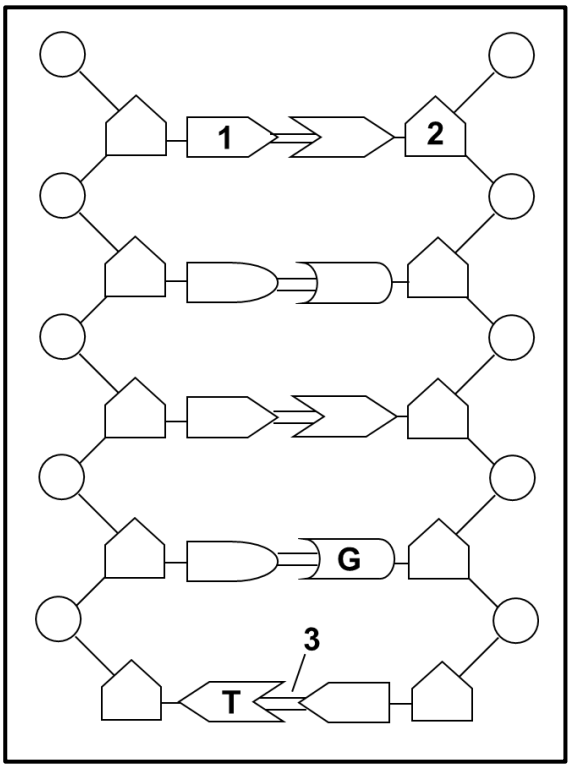
The structure of DNA: https://www.youtube.com/watch?v=C1CRrtkWwu0

Activity 1: DNA

The diagram on the next page shows part of a DNA molecule.

1. Label parts 1, 2 and 3 (3)
2. Give the number of nucleotides shown in the diagram (1)
3. Name two places in an animal cell where this nucleic acid may be found. (2)
4. What is the natural shape of this molecule? (1)
5. Draw a nucleotide with the nitrogenous base adenine. (4)

(11)



RNA – ribonucleic acid

Key terminology

RNA	RNA consists of nucleotides. Nitrogenous bases found in RNA are adenine, uracil, guanine and cytosine
messenger RNA	mRNA carries the code for protein synthesis from DNA to the ribosome
ribosomal RNA	rRNA forms ribosomes which are the site of protein synthesis
transfer RNA	tRNA brings amino acids to the ribosome to form the protein

There are three types of RNA (ribonucleic acid), all formed in the nucleus by DNA. They perform different functions in different places in a cell. The types are:

- messenger RNA (mRNA)
- ribosomal RNA (rRNA)
- transfer RNA (tRNA)

The location of RNA

- **Messenger RNA** (mRNA) is formed in the nucleus but then enters the cytoplasm where it attaches to ribosomes.
- **Ribosomal RNA** (rRNA) is found in the ribosomes in the cytoplasm of the cell.
- **Transfer RNA** (tRNA) is found freely in the cytoplasm of the cell.

The structure of RNA

Like DNA, RNA also consists of monomers (nucleotides) which link to form longer chains (polymers).

However, RNA is a **single-stranded structure** which is not coiled. The sugar in RNA is ribose and is attached to a nitrogenous base. The phosphate and sugar molecules are attached to one another alternately to form the chains.

The structure of RNA is illustrated in Figure 6 below.

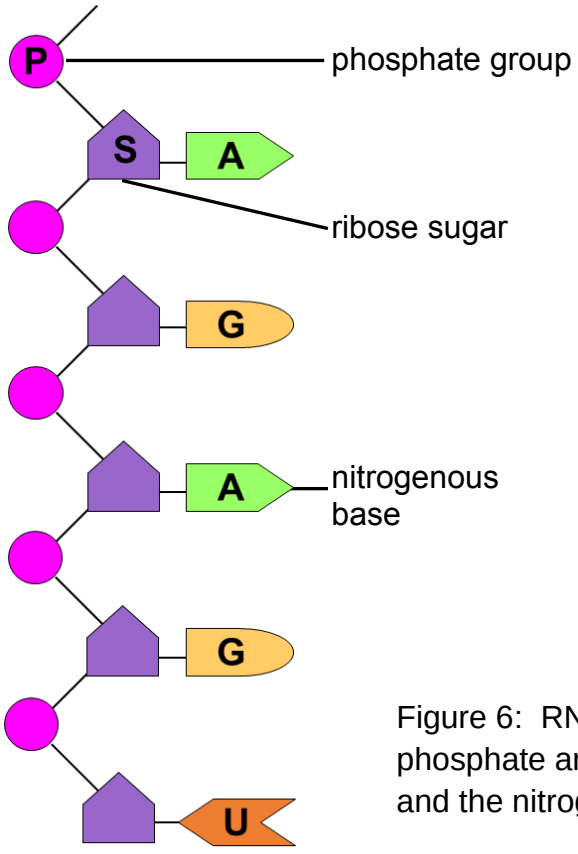


Figure 6: RNA – note the chain formed by the phosphate and sugar molecules on the left, and the nitrogenous bases on the right.

There are four types of nitrogenous bases in RNA:

adenine (A)

uracil (U) – *not thymine as in DNA*

cytosine (C)

guanine (G)

The role of RNA

The three types of RNA are very important to the process of protein synthesis, with each type playing a unique role.

Comparison between DNA and RNA

DNA and RNA are **similar** in some respects. They both …

- contain sugar alternating with phosphate
- contain the nitrogenous bases adenine, guanine and cytosine
- play a role in protein synthesis

DNA and RNA also have **significant differences**, tabulated in Table 1 below.

Table 1: The **main differences** between DNA and RNA.

DNA	RNA
contains deoxyribose sugar	contains ribose sugar
double helix and coiled	single stranded
contains the nitrogenous base thymine	contains the nitrogenous base uracil
found in the nucleus only	found in the nucleus, ribosomes and cytoplasm of cells

A comparison DNA and RNA. It is very important to know the differences.
https://www.youtube.com/watch?v=0Elo-zX1k8M

DNA replication

DNA replication is the process through which DNA makes an identical copy of itself. This occurs during interphase of the cell cycle in the nucleus. In Figures 7A to 7E, a small portion of DNA is shown undergoing replication.

1. The **DNA double helix** unwinds (Figure 7A)

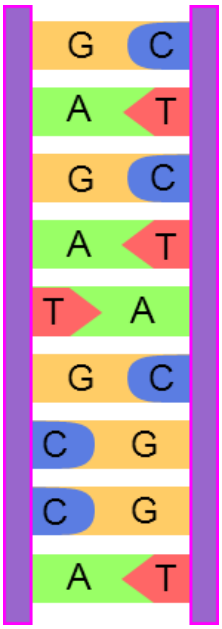


Figure 7A

2. The weak hydrogen bonds between the nitrogenous bases are broken. The DNA strands separate (they **unzip**)(Figure 7B)

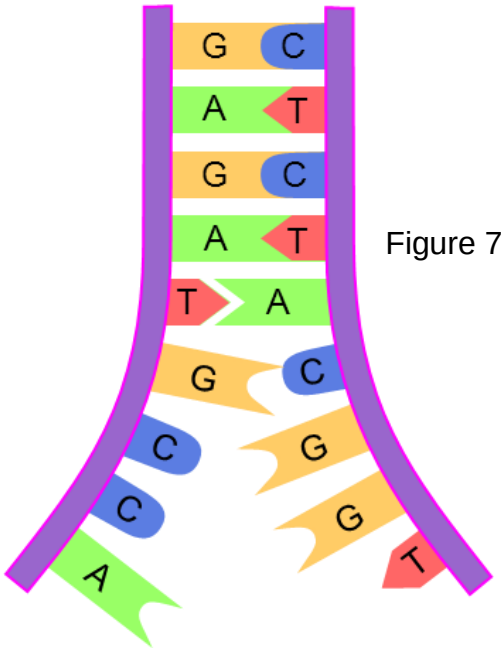


Figure 7B

3. Each original DNA strand serves as a **template** on which its complement is built (Figure 7C)

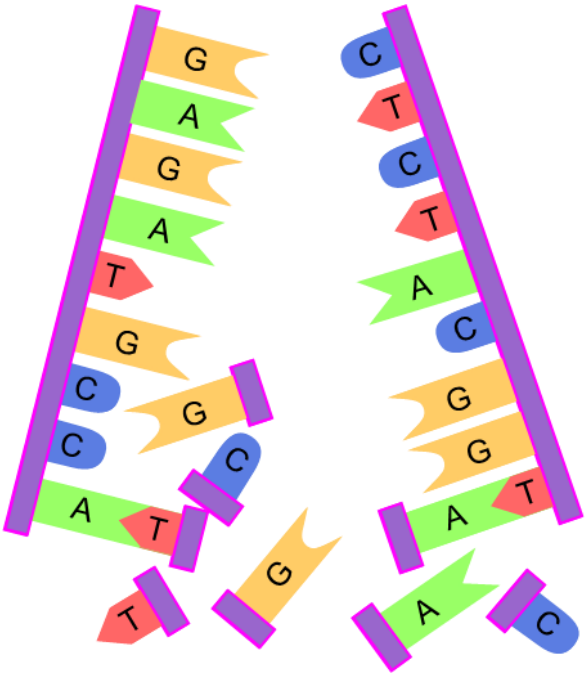


Figure 7C

4. Free nucleotides build a DNA strand onto each of the original DNA strands, attaching their **complementary nitrogenous bases** (A to T and C to G) (Figure 7D)

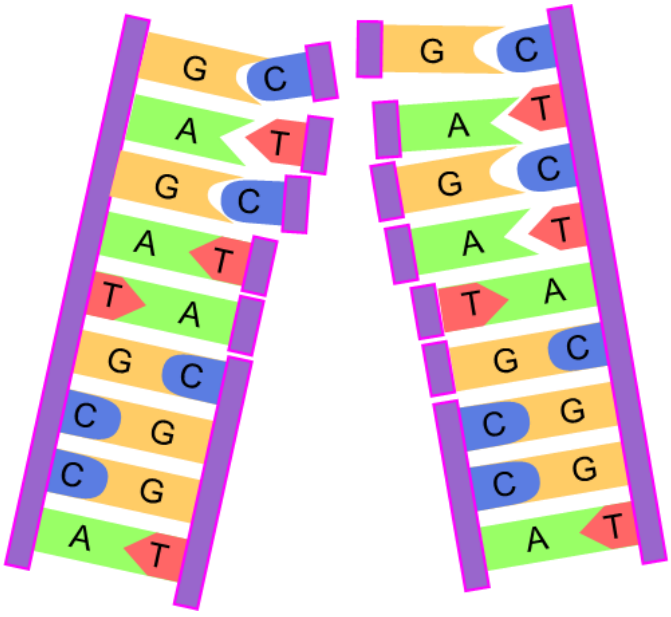


Figure 7D

5. This results in **two identical DNA molecules.** Each molecule consists of one original strand and one new strand (Figure 7E).

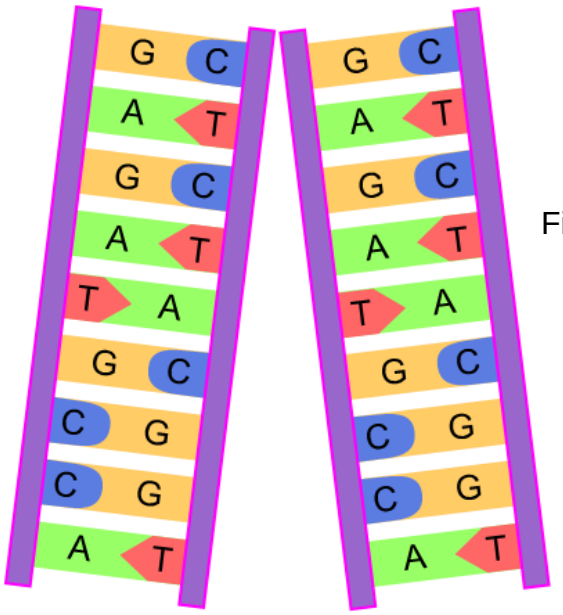


Figure 7E

Figure 7A – 7E: The process of DNA replication

DNA replication is important for cell division, particularly mitosis. It allows each chromosome to be copied so that each new identical daughter cell produced contains the same number and type of chromosomes.

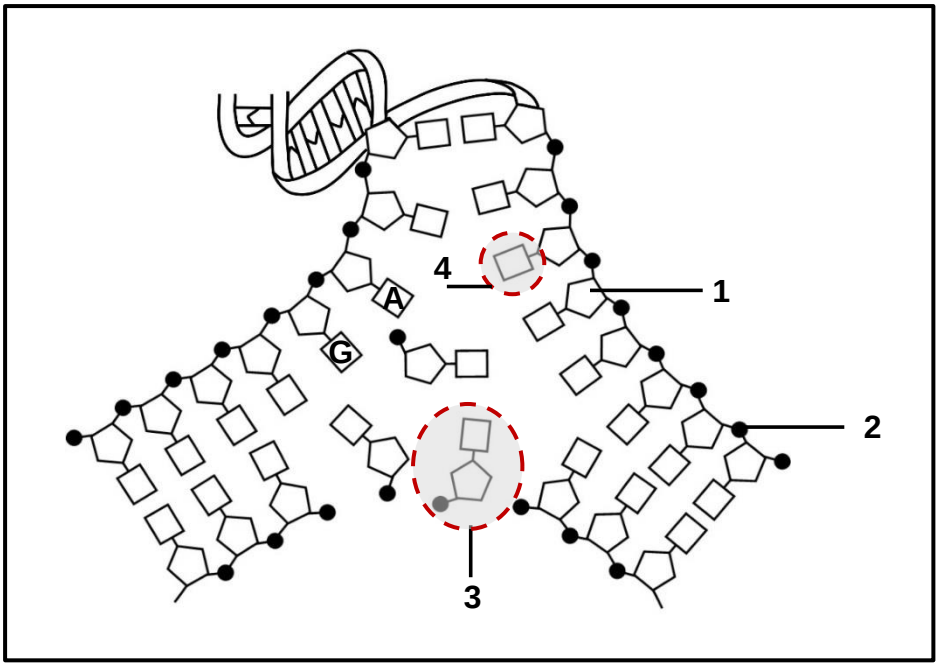
Errors that occur during DNA replication

- Errors that occur during DNA replication may sometimes lead to mutations (a change in the nitrogenous base sequence)
- If the incorrect nitrogen base attaches to the original strand and a nitrogen base is added or deleted …
    - the sequence or order of the bases changes on the new DNA molecule …
    - resulting in a change in the gene structure

DNA replication: Understand the process.
https://www.youtube.com/watch?v=Qqe4thU-os8

Activity 2: DNA replication

Study the diagram below and answer the questions that follow.



1. Name the process illustrated in the diagram above. (1)
2. State the significance of the process mentioned in question 1. (1)
3. Identify the parts labelled as 1, 2, 3 and 4. (4)
4. Describe how this process takes place. (6)
5. Give one location of extra-nuclear DNA. (1)

(13)

DNA profiling

A DNA profile is a pattern produced on X-ray film. This pattern consists of lines which are of different lengths and thicknesses and in different positions, as shown in Figure 8. All individuals, except identical twins, have a unique DNA profile.

Figure 8: DNA profiles for three different individuals.

DNA profiles are used to:

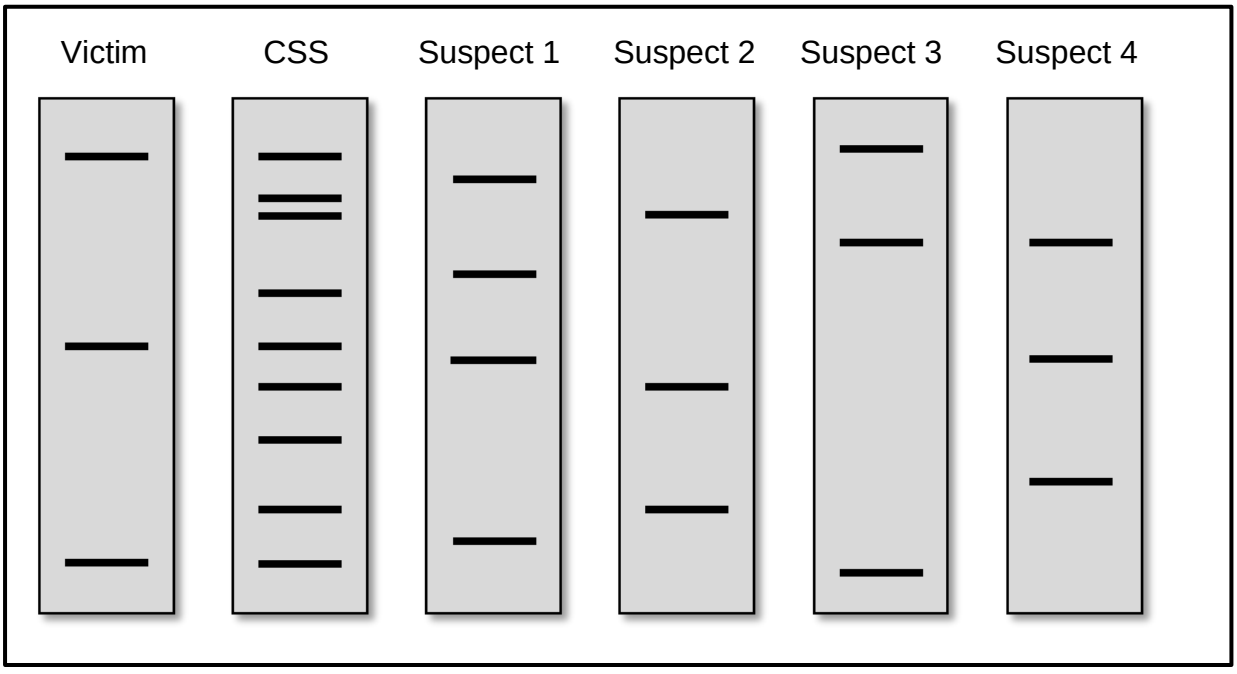
- identify crime suspects in forensic investigations
- prove paternity (father) and maternity (mother) (biological parents)
- determine the probability or causes of genetic defects
- establish the compatibility of tissue types for organ transplants
- identify relatives

DNA profiling is generally accepted as being extremely reliable. The interpretation and comparison of profiles should however be approached with caution, for the following reasons:

- Humans interpret the results which means mistakes could be made
- The method of profiling may be different in different laboratories producing inconsistencies
- Only a small piece of DNA is used in profiling, so the profile might not be 100% unique to a particular individual
- DNA profiling is expensive and therefore not readily accessible to those who cannot afford it, particularly in criminal cases
- DNA profiles may reveal information about a person which could be used against them in a prejudicial way. For example: being HIV positive or having genetic abnormalities may lead to insurance companies not covering a person or prejudice in the court room

Activity 3: DNA profiling

DNA profiles from a crime scene.



In a fight involving a number of people, one person was seriously injured. Police took blood samples from the victim, the crime scene (CSS – crime scene sample) and four suspects. The DNA was then extracted from each sample. The results of these tests are shown in the diagram above.

1. Which suspect probably injured the victim? (1)
2. Give a reason for your answer to the previous question. (1)
3. List one application of DNA profiling other than for solving crime. (1)
4. Give two reasons why DNA profiling may sometimes be challenged. (2)

(5)

Protein synthesis

Key terminology

amino acids	monomers of proteins
base triplet	three nitrogenous bases one after the other on DNA
transcription	1st stage of protein synthesis – mRNA formed from DNA carrying code for the protein to be made
translation	2nd stage of protein synthesis – amino acids combine to form a protein
codon	three nitrogenous bases one after the other on mRNA – these are complementary to the triplet on DNA
anti-codon	three nitrogenous bases one after the other on tRNA – these are complementary to the codon on mRNA

The process in which proteins are made is called protein synthesis. Proteins are made by linking various amino acids that are present in the cytoplasm of cells. There are 20 different amino acids, and they combine in a large variety of combinations. The number of amino acids and the sequence of the amino acids determine the type of protein that is formed.

Figure 9 illustrates a protein with different amino acids represented by the different shapes and colour. The bond between the amino acids is known as a peptide bond.

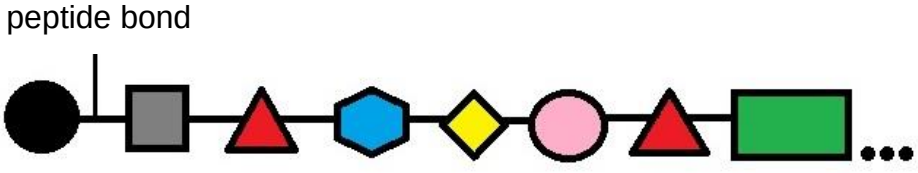


Figure 9: Amino acids linked by peptide bonds

The genes found in DNA contain the code which determines which type of protein that will be formed.

- The smallest protein contains 50 amino acids linked together
- Proteins generally contain 300 or more amino acids.

Three consecutive nitrogenous bases on the DNA strand are called the base triplet. The base triplets determine which amino acid will be placed into the protein as well as the sequence in which the amino acids will be joined.

Protein synthesis occurs in two stages

Stage 1: Transcription

Stage 2: Translation

Stage 1: Transcription

The first stage of protein synthesis, called transcription, occurs in the nucleus (see Figure 10 below).

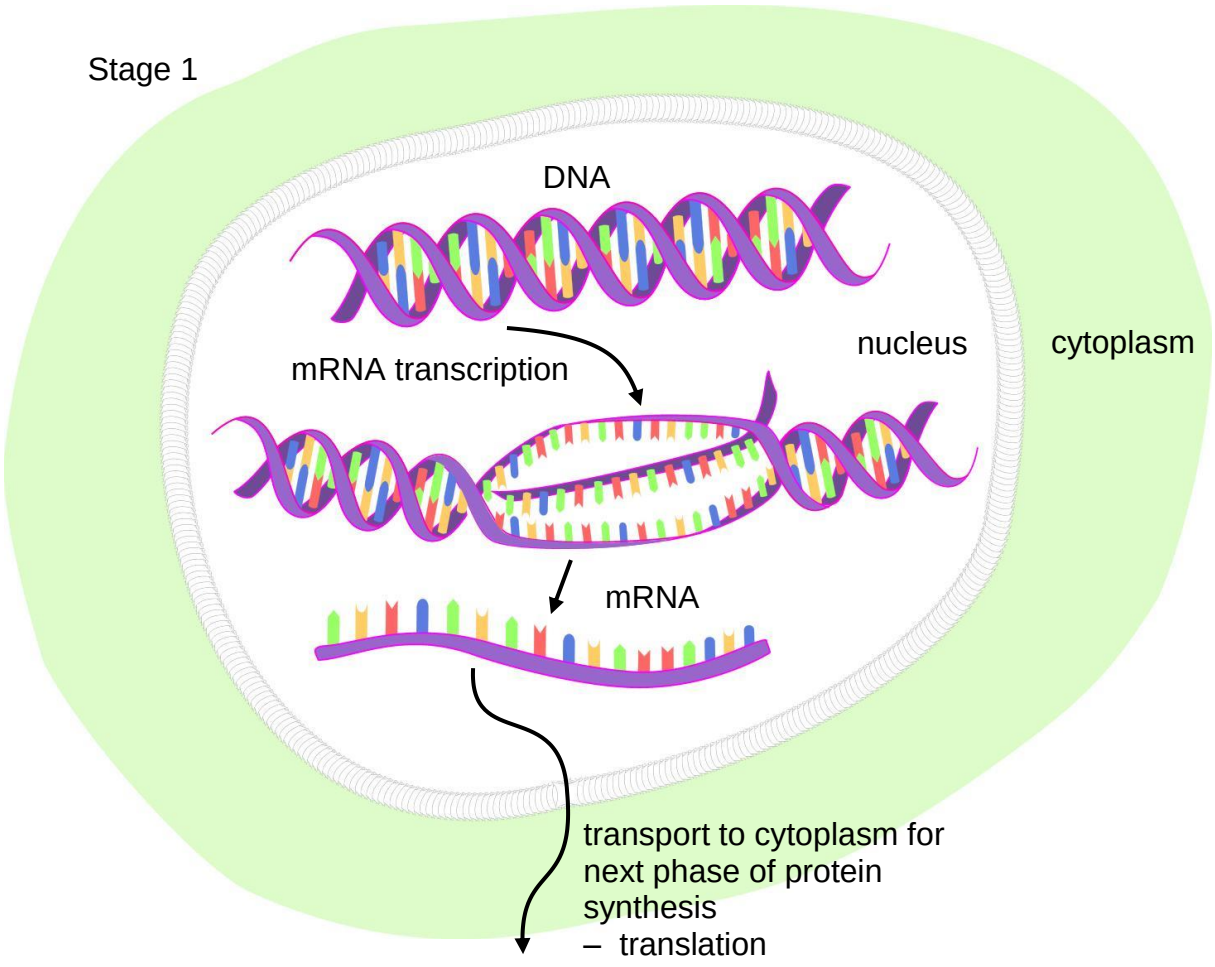


Figure 10: Transcription

1. A section of the DNA double helix unwinds. As a result,
    - the weak hydrogen bonds between the nitrogenous bases of DNA break
    - the DNA unzips (in this particular section of the DNA)
2. One strand acts as a template
3. This DNA template is used to form a complementary strand of messenger RNA (mRNA)
    - This is done using free RNA nucleotides in the nucleoplasm
    - The mRNA now contains the code for the protein which will be formed
    - Three adjacent nitrogenous bases on the mRNA are known as codons. These code for a particular amino acid.
4. mRNA moves out of the nucleus through a nuclear pore into the cytoplasm, where it attaches onto a ribosome

Stage 2: Translation

The second stage of protein synthesis, called translation (Figure 11) , occurs in the cytoplasm.

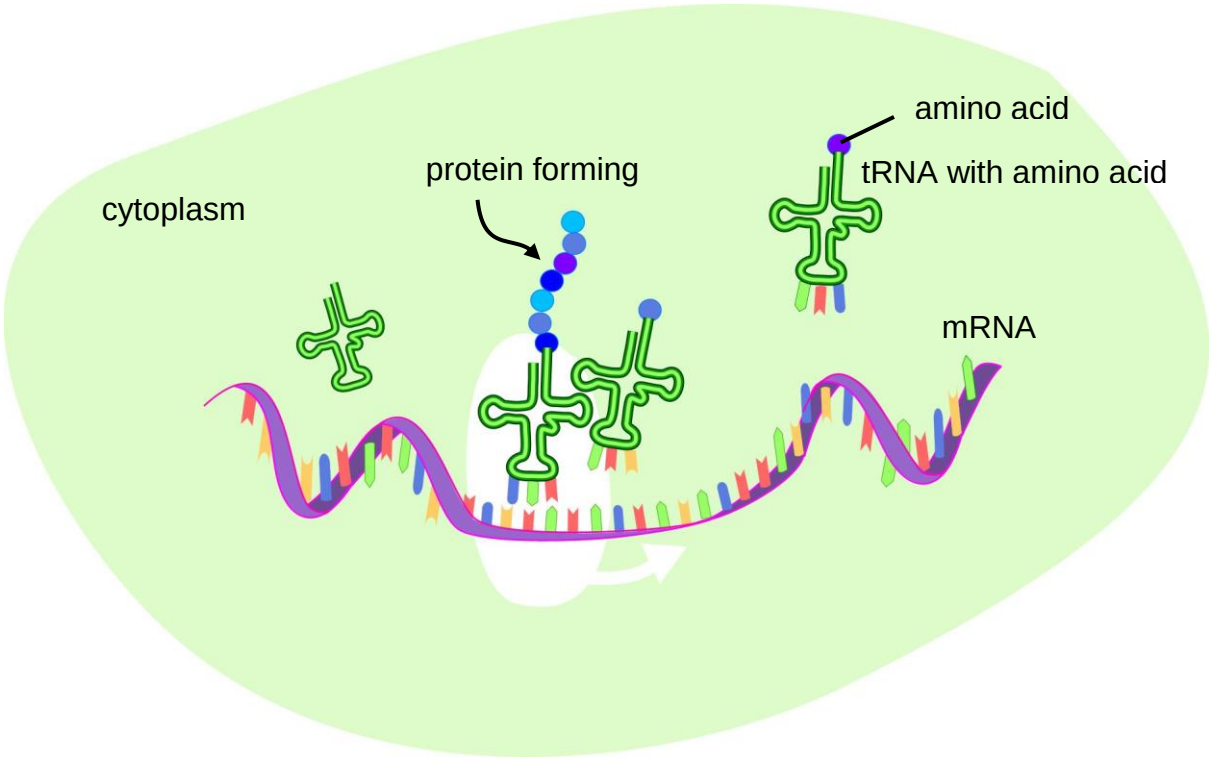


Figure 11: Translation

5. Transfer RNA (tRNA) in the cytoplasm has three adjacent nitrogenous bases known as the anti-codon
    - mRNA's codon will be complementary to a tRNA's anti-codon
    - Each tRNA will carry a specific amino acid
    - According to the codons on the mRNA, the tRNA will bring the required amino acid to the ribosome
6. The amino acids are linked by a peptide bond to form the required protein.

Figure 12 below shows the full process of protein synthesis

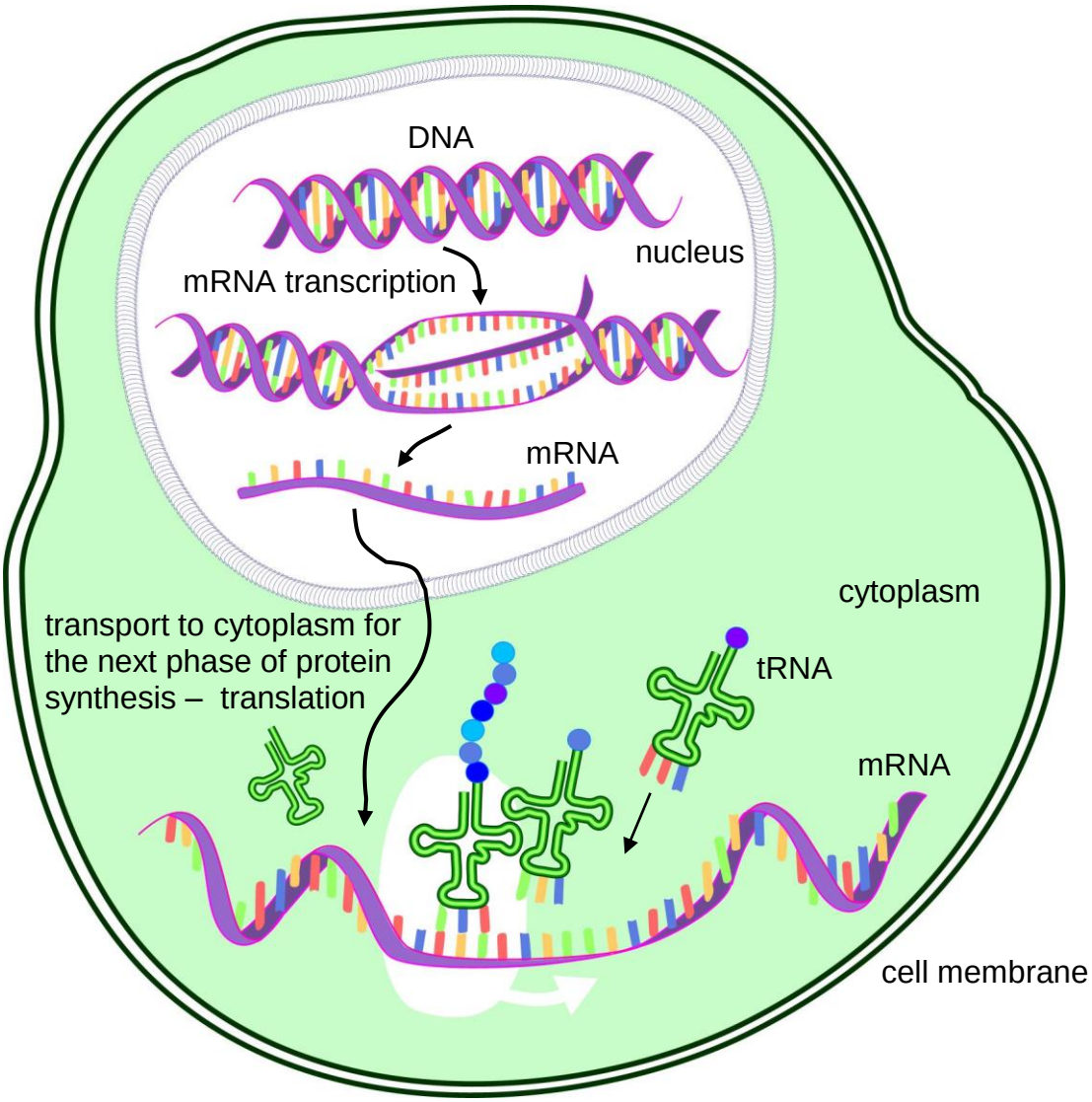


Figure 12: Protein synthesis

Note: it is important to know the difference between base triplets (DNA), codons (mRNA) and anti-codons (tRNA).

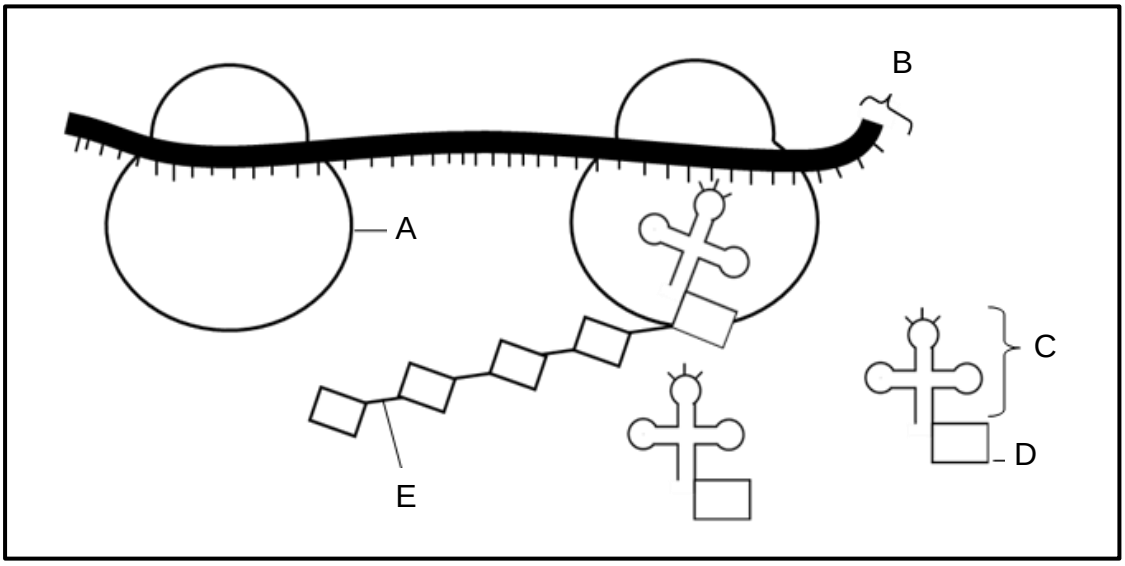
The effect of mutation on protein structure (DNA sequence)

- A mutation is a change in the nitrogenous base sequence of a DNA molecule (or a gene)
- since mRNA is copied from the DNA molecule during transcription.
- This will result in a change in the codons.
- As a result, different tRNA molecules carrying different amino acids will be required.
- The sequence of amino acids changes, resulting in the formation of a different protein.
- If the same amino acid is coded for, there will be no change in the protein structure.

Protein synthesis: https://www.youtube.com/watch?v=oefAI2x2CQM&t=43s

Activity 4: Protein synthesis

The diagram below represents a process that occurs during protein synthesis.



1. Identify the process above. (1)

2. Name …

   a) organelle A (1)

   b) molecule B (1)

   c) the bond at E (1)

3. Provide the letter and name of the molecule that …

   a) carries the amino acid (1)

   b) is the monomer of a protein (1)

4. Name and describe the process occurring in the nucleus which results in the formation of the mRNA molecule. (6)

(12)

Activity 5: Codons and amino acids

The sequence of amino acids in a protein molecule is coded for by DNA and RNA. The table below shows some mRNA codons and the corresponding amino acids.

mRNA codons	**amino acid**
AGC	serine
GAU	aspartate
CUA	leucine
UAU	tyrosine
UUC	phenylalanine
AGU	serine
GAC	aspartate
UUU	phenylalanine
CUC	leucine
GAG	glutamic acid

1. According to the table, how many codons code for phenylalanine? (1)

2. What is the anti-codon for glutamic acid? (1)

3. A section of mRNA has the following base sequence and is read from left to right:

   GAU CUC GAC AGC AUG ACC

   Give the …

   a) DNA base triplet for the last codon on this section of mRNA (1)

   b) 1st amino acid coded for by this section of mRNA (1)

(4)

DNA – The code of life: End of topic exercises

Section A

Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A- D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1.1 A molecule of RNA is copied from DNA by the process of

A transcription.
B mitosis.
C mutation.
D translation.

1.1.2 In a DNA molecule

A guanine pairs with adenine.
B adenine pairs with thymine.
C cytosine pairs with adenine.
D Guanine pairs with thymine.

1.1.3 A codon is a sequence of three nucleotides on a molecule of

A rRNA.
B mRNA.
C tRNA.
D DNA.

1.1.4 DNA was analysed and found to contain 14% T (thymine). What percentage of the molecule is cytosine?

A 14%
B 28%
C 36%
D 72%

1.1.5 A gene in a bacterium codes for a protein that has 120 amino acids. How many mRNA nucleotides code for this protein?

A 30
B 40
C 360
D 480 (5 × 2 = 10)

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

1.2.1 Proteins that form part of the chromosomes.

1.2.2 Which type of RNA travels from the nucleoplasm to the cytoplasm.

1.2.3 The nitrogenous base found in RNA but not in DNA.

1.2.4 A sugar that is a component of DNA.

1.2.5 A sudden change in the sequence / order of the nitrogenous bases of a nucleic acid.

1.2.6 The name of the bond that forms between amino acids in a protein molecule.

1.2.7 The type of nucleic acid that carries a specific amino acid.

1.2.8 A segment of DNA coding for a particular characteristic.

1.2.9 The bonds that form between nitrogenous bases in a DNA,

1.2.10 The organelle in the cytoplasm on which protein synthesis occurs.

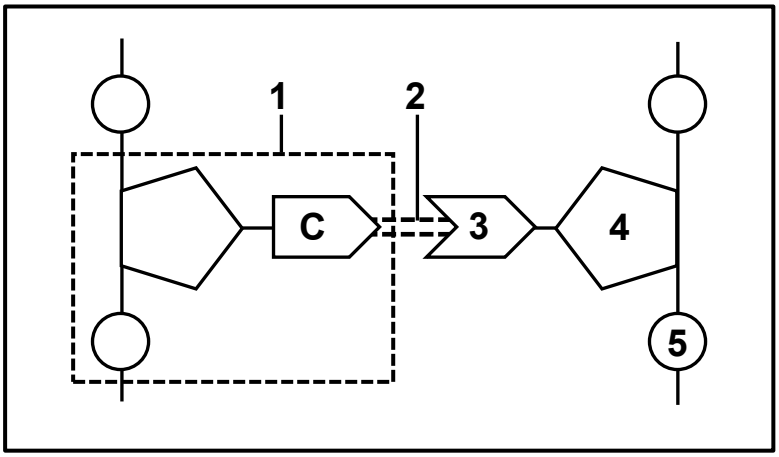
(10 x 1) = (10)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Contains ribose sugar	A: DNA B: RNA
1.3.2 Discovery of DNA	A: Mendel B: Darwin
1.3.3 Location of DNA.	A: nucleus B: mitochondria
1.3.4 The process where one DNA molecule produces two identical DNA molecules.	A: replication B: reproduction
1.3.5 Pairing of nitrogenous bases	A: DNA B: RNA

(5 x 2) = (10)

1.4 The diagram below represents a portion of a nucleic acid.



1.4.1 Name the nucleic acid. (1)

1.4.2 Name two places in animal cells where this nucleic acid may be found. (2)

1.4.3 Identify

a) portion **1** (1)

b) nitrogenous base **3** (1)

c) molecule **5** (1)

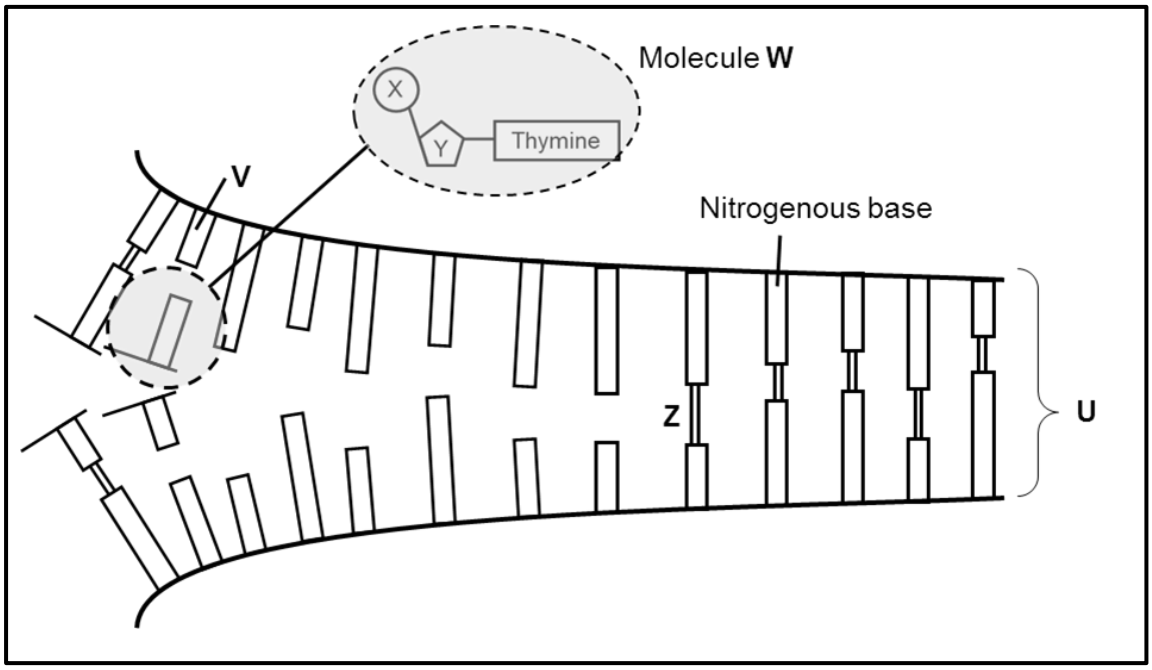
d) bond **2** (1)

1.4.4 What is the natural shape of this molecule? (2)

1.4.5 Name the process in which this molecules make a copy of itself? (1)

(10)

1.5 The diagram below represents DNA replication.



1.5.1 Identify the following:

a) molecules **W** and **U** (2)

b) parts of molecule **W** labelled **X** and **Y** (2)

c) bond **Z** (1)

d) nitrogenous base **V** (1)

1.5.2 Where in the cell does this process take place? (1)

1.5.3 Name the phase of the cell cycle where replication takes place. (1)

1.5.4 What is the purpose of DNA replication? (2)

(10)

Section A: [50]

Section B

Question 2

2.1 The following sequence represents a part of the nitrogenous base sequence on a DNA molecule.

TAC	TCT	CCA
Triplet 1	Triplet 2	Triplet 3

2.1.1. Write down the base sequence of the anticodon of triplet 1 shown above. (1)

2.1.2. The table below shows the amino acids that correspond with different mRNA codons.

mRNA codon	**Amino Acid**
AGA	arginine
AUG	methionine
GGU	glycine
AUC	isoleucine

a) Give the correct sequence of amino acids for DNA triplets 1 to 3. (2)

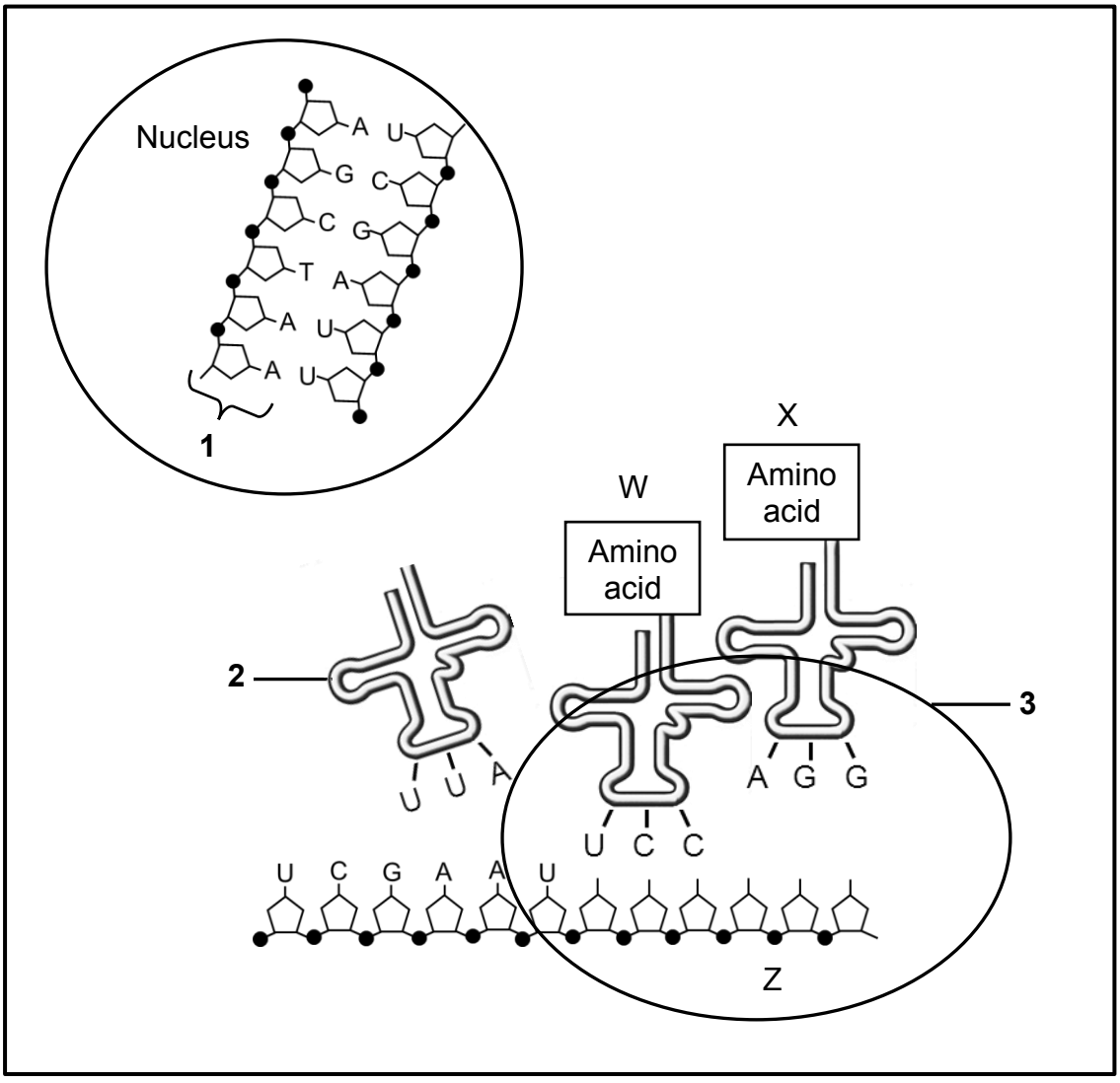
b) During DNA replication a mutation occurred on triplet 1 resulting in C being replaced by G. Describe how this mutation will affect the structure of the protein formed. (3)

2.1.3. Name and describe the process occurring in the nucleus which results in the formation of an mRNA molecule. (6)

2.1.4. Draw a RNA nucleotide with a complementary base to adenine. (2)

(14)

2.2 The diagrams below represent the process of protein synthesis. Study them and answer the questions that follow.



2.2.1 Identify the structures labelled **1,2** and **3**. (3)

2.2.2 Name and describe the stage of protein synthesis taking place at **Z** (5)

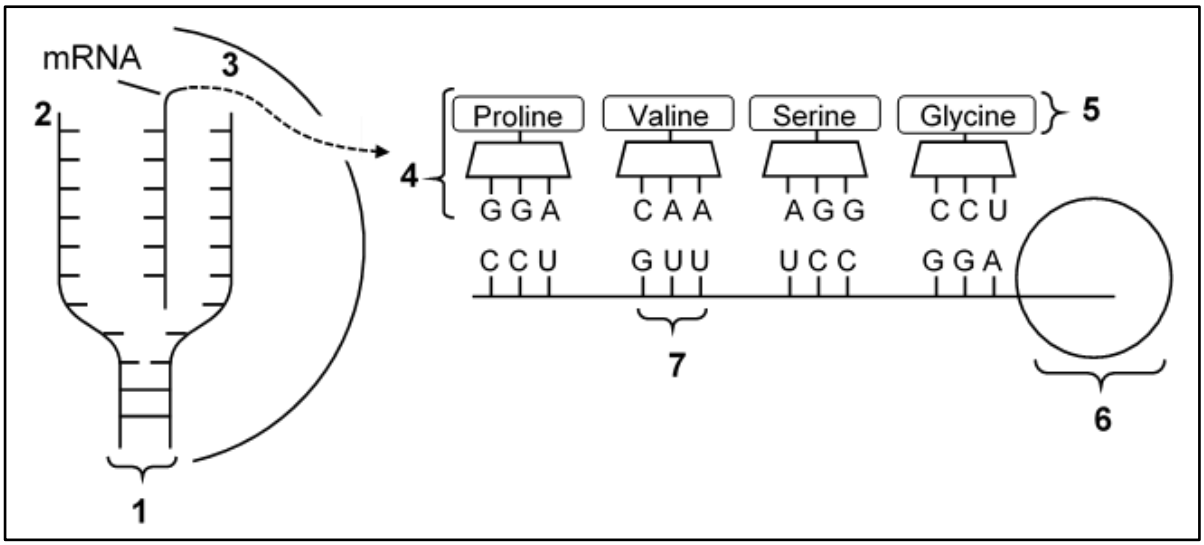
2.2.3 Using the table below, work out the names of the amino acids labelled **W** and **X**. (4)

Base Triplet on mRNA coding for the amino acid	Amino acid coded for
GAG	glutamate
CAG	histidine
AGG	arginine
CUG	leucine
UCC	proline
GUG	valine

(12)
[26]

Question 3

3.1 The diagram below represents two stages of protein synthesis.



3.1.1 Provide labels for:

a) molecule **1** (1)

b) organelle **6** (1)

3.1.2 Give only the number of the part which represents a:

a) DNA template strand (1)

b) monomer of proteins (1)

c) codon (1)

3.1.3 Describe *translation* as it occurs in organelle **6**. (4)

3.1.4 Provide the:

a) DNA sequence that codes for glycine (2)

b) codon for proline (2)

3.1.5 State two differences between a ***DNA*** nucleotide and an ***RNA*** nucleotide. (4)

(17)

3.2 The first 7 triplets of nitrogenous bases that form part of the gene coding for one chain of the haemoglobin protein that makes up red blood corpuscles in humans is shown below. Study the table and answer the questions that follow.

DNA Template	CAC	GTG	GAC	TGA	GGA	CTC	CTC
Base triplet number	1	2	3	4	5	6	7

3.2.1 How many of the following are coded for in the DNA template sequence above?

a) Nitrogenous bases (1)

b) Different types of tRNA molecules that are required to form the polypeptide from this piece of DNA. (1)

3.2.2 Write down the mRNA sequence for the triplets numbered **4** and **6** in the above table. (2)

3.2.3 Using the table below, determine the amino acid sequence coded for by triplet numbers **4** and **6.** (2)

Anticodons on tRNA coding for the amino acid	**Amino acid coded for**
CUC	glutamate
GUC	histidine
GGA	proline
GAC	leucine
UGA	threonine
CAC	valine

3.2.4. If the T in the 6th base triplet changed to A in the DNA template above, write down the new amino acid (using the table above) that this 6th triplet now codes for. (1)

(7)

[24]

Section B: [50]

Total Marks: [100]

2: Meiosis

CHAPTER 2: MEIOSIS

Introduction

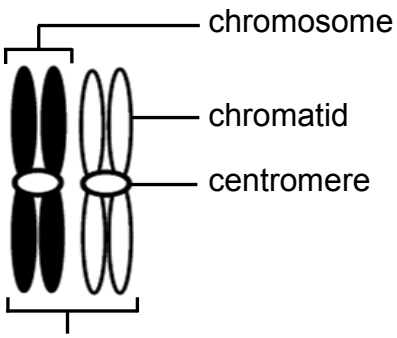
In Grade 10 you learnt that when a cell divides by **mitosis**, two exact copies of the mother cell are produced. Cells divide by mitosis for the purpose of growth and repair. Worn out or damaged cells are replaced by the mitotic division of somatic cells (body cells) and some organisms are able to reproduce asexually by mitosis.

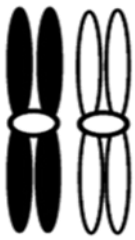
Meiosis is a special type of cell division that halves the number of chromosomes. Four genetically different haploid daughter cells are formed from one diploid cell.

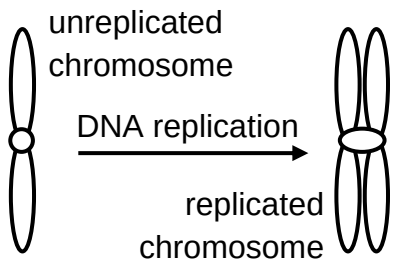
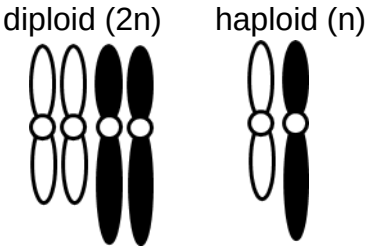
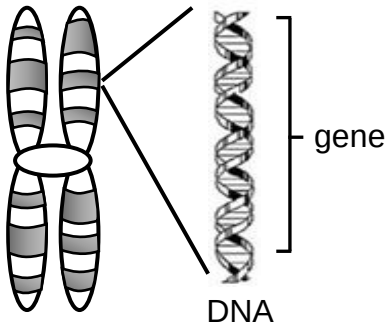
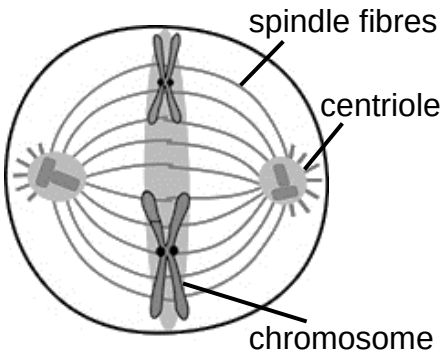
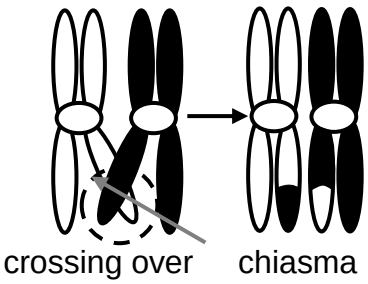
Meiosis is important because

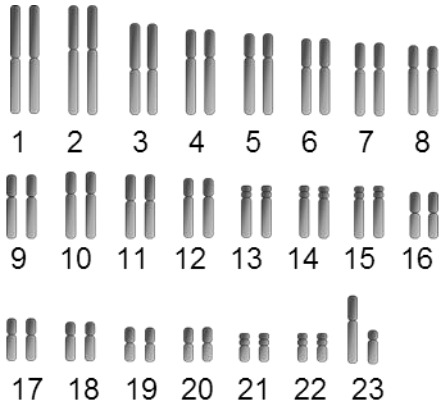
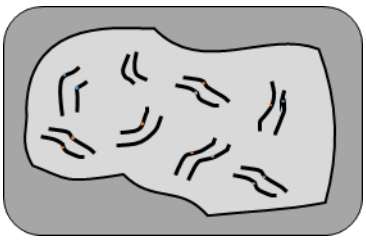
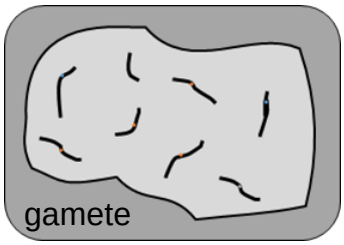
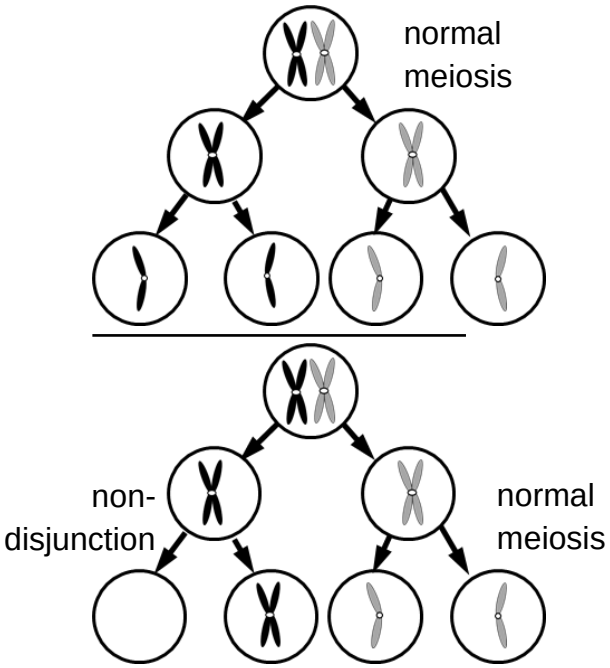
- haploid gametes are produced
- the doubling effect of fertilization on chromosome number of future generations is overcome
- genetic variation occurs

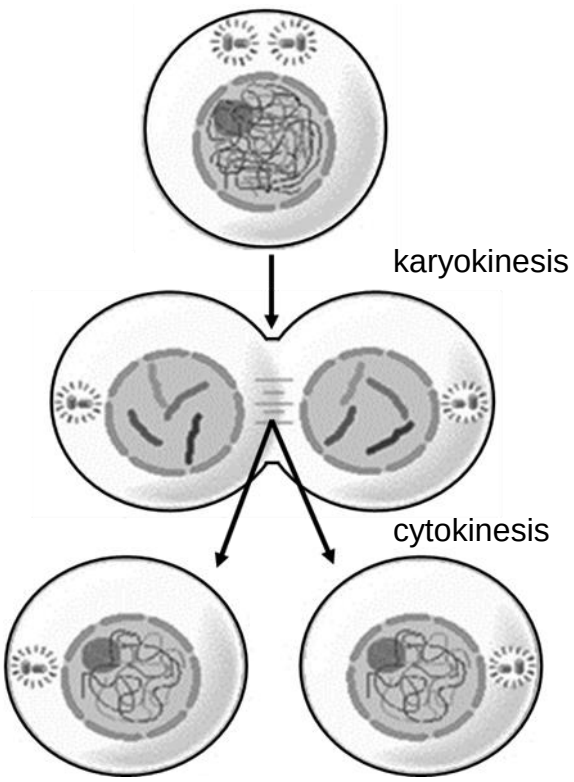
Key terminology

<table>
<tr><td>chromosome</td><td>a threadlike structure made up of DNA and protein found in the nucleus of most living cells, carrying genetic information in the form of genes</td><td rowspan="4"> 

homologous chromosomes – one from the mother and one from the father</td></tr>
<tr><td>chromatid</td><td>one of the two identical strands of a replicated chromosome</td></tr>
<tr><td>centromere</td><td>region where the two chromatids of a chromosome are held together</td></tr>
<tr><td>homologous chromosomes</td><td>a pair of chromosomes of the same shape, size and having similar genes for each characteristic occupying the same position</td></tr>
<tr><td>bivalent</td><td>a pair of homologous chromosomes which lie next to each other and are physically in contact with each other at a point where crossing over will occur</td><td>  </td></tr>
</table>

unreplicated chromosomes	an unreplicated "chromosome" has a single double-stranded DNA molecule	
replicated chromosomes	a replicated "chromosome" has two identical double-stranded DNA molecules	
interphase	the phase in the cell cycle when DNA replication occurs	
diploid (2n)	**two** complete set of chromosomes in a cell	
haploid (n)	**one** complete sets of chromosomes in a cell	
gene	a segment of DNA in a chromosome that contains the code for a particular characteristic	
centrosome	organelle (containing two centrioles) found only in animal cells	
centriole	structures formed when the centrosome divides into two; they move to opposite ends of the cell during cell division	
crossing over	Overlapping of homologous chromosomes resulting in the exchange of genetic material during Prophase I	
chiasma	point where two chromatids overlap during crossing over	

karyotype	a representation of the number, shape and arrangement of a full set of chromosomes in the nucleus of a somatic cell	
autosome	the first 22 pairs of chromosomes which control the appearance, structure and functioning of the body	
gonosomes (sex chromo-somes)	the pair of chromosomes (XX or XY) responsible for sex determination	
somatic cells (body cells)	Any cells in an organism excluding male and female gametes – they are diploid (have 2 sets of chromosomes) and are produced through mitosis	 somatic cell – chromosomes are in homologous pairs
sex cells (gametes)	specialized cells called gametes (sperm cell and egg cell). They have a haploid number of chromosomes and are produced through meiosis	 single unpaired chromosomes
non-disjunction	when homologous chromosome pairs fail to separate in meiosis	

karyokinesis	Karyo means “nucleus” and kinesis means “synthesis or division.” Karyokinesis is the process of division of the nucleus of a cell	
cytokinesis	Cyto means “cytoplasm,” and kinesis mean “synthesis or division.” Cytokinesis is the process of division during which the cytoplasm of a single cell divides into two daughter cells.	

Significance of DNA replication for meiosis

Each species of living organism has a characteristic number of chromosomes found floating in the nucleoplasm of the nucleus.

- When the cell is not dividing, the genetic material forms a tangled chromatin network.
- During interphase, DNA replication takes place.
- Single-stranded chromosomes become double-stranded.
- Each chromosome will now consist of two chromatids joined by a centromere.
- This ensures the sharing of the hereditary material by all the daughter cells that will be formed.

Meiosis – the process

Introduction

If meiosis does not occur, gametes will not be formed and sexual reproduction would not be able to take place.

- During meiosis haploid gametes are formed, these gametes have half the number of chromosomes.
- This is important so that the chromosome number is **not doubled** when fertilisation occurs. Instead, when two haploid gametes fuse, the **diploid** number is restored.
- Meiosis thus ensures that the same number of chromosomes within a species remains constant from generation to generation.

In animals, meiosis occurs in the sex organs (ovaries and testes) to produce gametes (gametogenesis).

In plants meiosis produces spores which are used for reproduction in mosses and ferns.

In flowering plants (angiosperms) meiosis takes place in the anther and in the ovule.

The process of meiosis

NOTE that a human cell has 46 chromosomes arranged in 23 pairs of homologous chromosomes. Explaining meiosis using a human cell is very complex. The same principle, however, applies to all somatic cells so for the sake of simplicity, meiosis will be explained using a cell with only 4 chromosomes.

In meiosis, the cell undergoes two divisions which are referred to as **Meiosis I** and **Meiosis II**.

- **Meiosis I** is a reduction division which reduces the diploid number of chromosomes to haploid.

First meiotic division

Although meiosis is a continuous process, the events are placed into phases for convenience.

Prophase I

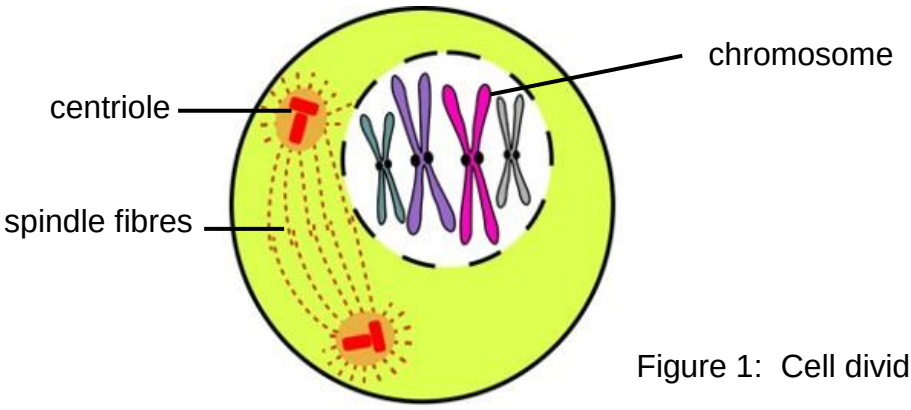


Figure 1: Cell dividing in Prophase I

- Nuclear membrane and nucleolus start to disappear.
- Centrosome splits and the two centrioles move apart forming spindle fibres.
- Chromatin network condenses into individual chromosomes and pairs of homologous chromosomes lie next to each other forming a bivalent.
- Inner chromatids from each homologous chromosomes overlap and touch each other at a point called the chiasma (plural: chiasmata) in a process called crossing over (see Figure 2)
- Chromatid segments break off and are exchanged, resulting in the exchange of genetic material.
- This process is called crossing over and it brings about variation.

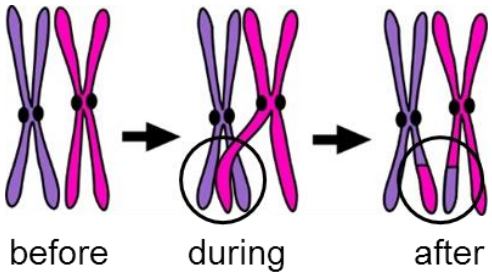


Figure 2: The process of crossing over

Metaphase I

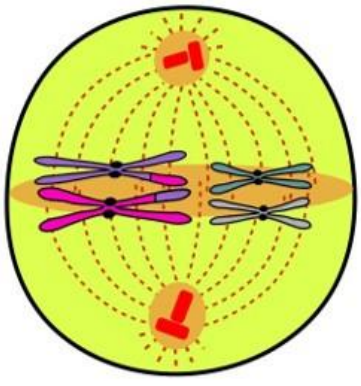


Figure 3: Cell undergoing Metaphase I

- Homologous chromosomes move to the middle of the cell (the equator). The two homologous chromosomes lie on opposite sides of the equator parallel to each other (Figure 3).
- Which chromosome lies on which side of the equator is totally up to chance. This is called **random arrangement** and brings about further variation.
- Each chromosome in the pair becomes attached to a spindle thread by the centromere.

Anaphase I

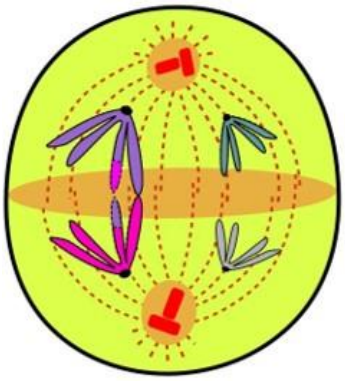


Figure 4: Cell undergoing Anaphase I

- One **whole chromosome** from each pair is pulled to opposite poles by contraction of the spindle fibres (see Figure 4).
- This separates the homologous chromosomes – one to each pole.

Telophase I

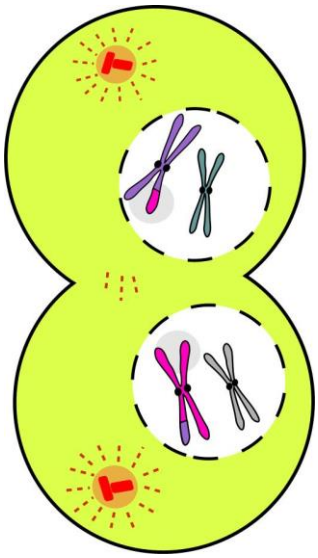


Figure 5: Cell undergoing Telophase I

- A new nuclear membrane forms around the group of chromosomes at each pole (Figure 5).
- Nucleolus returns.
- Cytokinesis (division of cytoplasm) splits the mother cell into two daughter cells.

Important: Each daughter cell now has **half** the number of chromosomes and each has a slightly different genetic make-up due to crossing over.

Second meiotic division

The second meiotic division takes place in **both** daughter cells formed during Meiosis I.

Prophase II

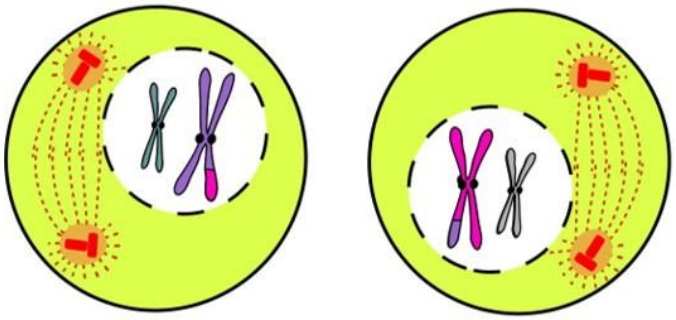


Figure 6: Cells undergoing Prophase II

- Nuclear membrane and nucleolus start to disappear.
- Centrosome splits into two centrioles and a spindle forms.
- Chromosomes are NOT in pairs (Figure 6).

Remember: Each chromosome is made of TWO chromatids.

Metaphase II

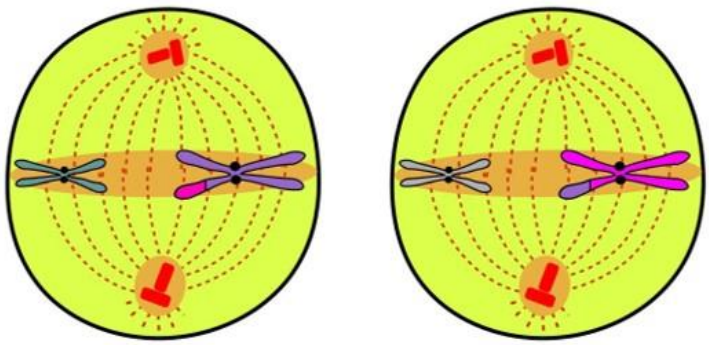


Figure 7: Cells undergoing Metaphase II

- Single chromosomes arrange themselves randomly along the equator with the centromere in line with the equatorial plane (Figure 7). Which chromatid faces which pole is totally up to chance.
- Each chromosome becomes attached to a spindle fibre.

Anaphase II

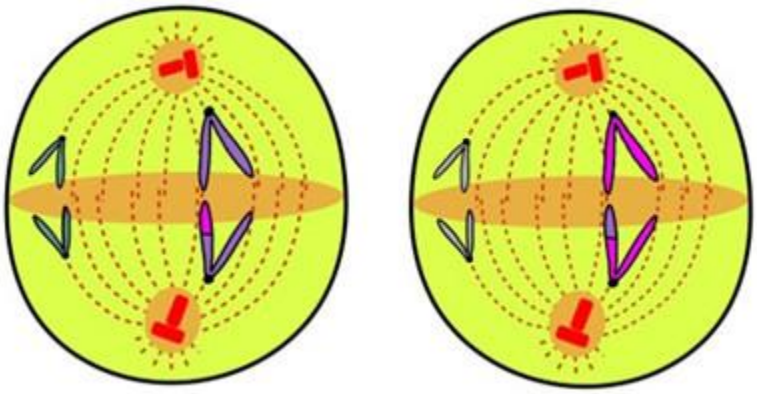


Figure 8: Cell undergoing Anaphase II

- The centromere splits and the two chromatids are pulled to opposite poles (Figure 8).

Telophase II

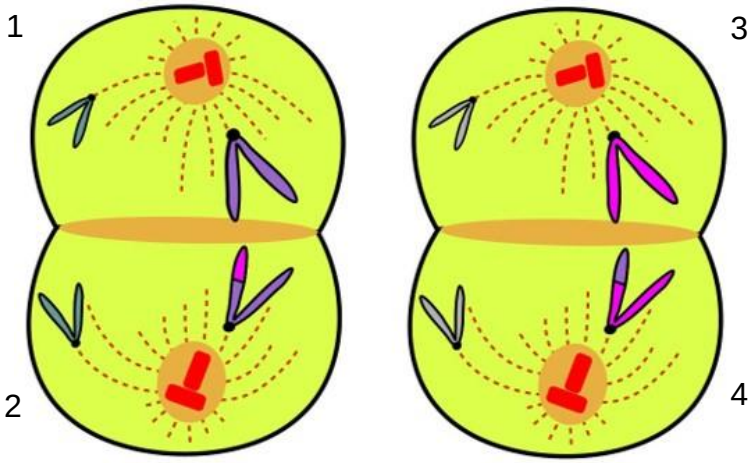


Figure 9: Cells at start of Telophase II

- A new nuclear membrane forms around the unreplicated chromosomes at each pole (Figure 9).
- Cytokinesis splits the cell into two new cells (Figure 10).

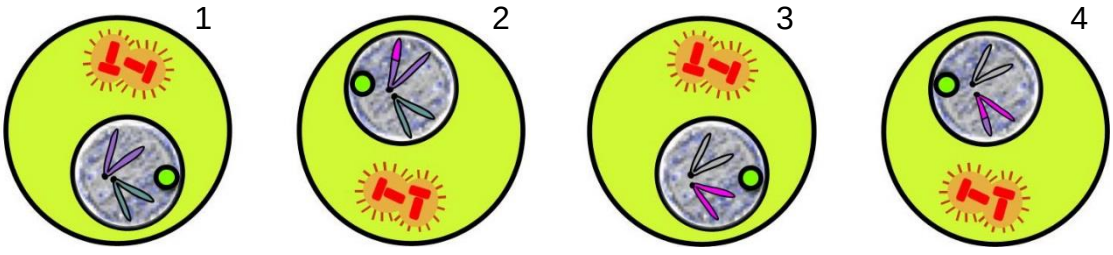


Figure 10: Daughter cells at the end of Telophase II

Important: As Meiosis II took place in TWO cells, there will now be FOUR daughter cells. These cells will be haploid and genetically different to each other.

The four stages of meiosis can be remembered in the following way - **PMAT**
Prophase – chromosome **PAIR up** (crossing over).
Metaphase – chromosomes move to **MIDDLE.**
Anaphase – chromosomes move **APART** to the poles.
Telophase – **TERMINAL** phase where daughter cells are formed.

Why is 'Crossing over' important?

- Crossing over brings about an exchange of genetic material during the process of gamete formation which results in the formation of new genetic combinations.
- This results in formation of gametes that will give rise to individuals that are **genetically different** from their parents and siblings.

Meiosis made SUPER EASY:
https://www.google.co.za/search?q=videos+on+meiosis&rlz=1C1AZAA_enZA747ZA747&oq=videos+on+meiosis&aqs=chrome..69i57j0l4.6731j0j8&sourceid=chrome&ie=UTF-8

Importance of meiosis

- Production of gametes (four daughter cells are formed).
- Halving of the chromosome number (diploid to haploid) so that the chromosome number remains constant from generation to generation within a species.
- Mechanism to introduce genetic variation through:
  - Crossing over during Prophase I.
  - The random arrangement of chromosomes at the equator during Metaphase I and II as can be seen in Figure 11 below.

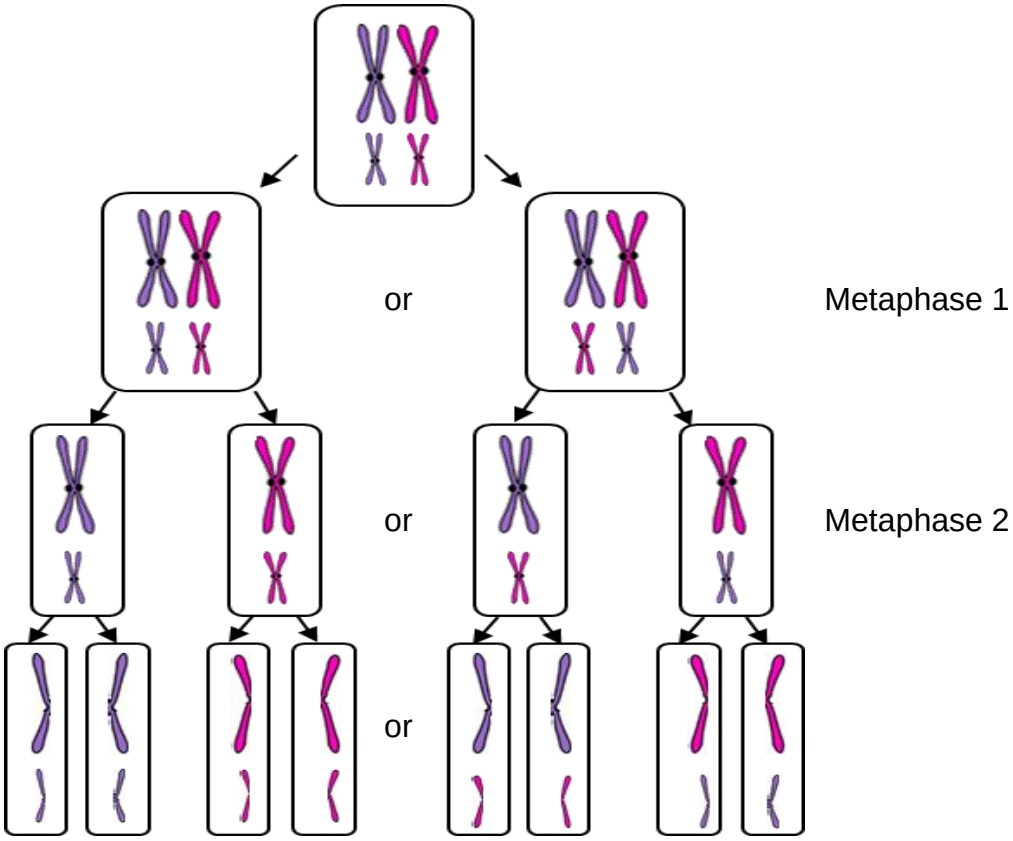


Figure 11: Random arrangement of chromosomes

Differences between meiosis I and meiosis II

Table 1: The differences between Meiosis I and Meiosis II

Meiosis I	Meiosis II
Chromosomes arrange at the equator of the cell in homologous pairs	Chromosomes line up at the equator of the cell individually
Whole chromosomes move to opposite poles of the cell	Chromatids move to opposite poles of the cell
Two cells are formed at the end of this division	Four cells are formed at the end of this division
The chromosome number is halved during meiosis I (diploid → haploid)	The chromosome number remains the same (haploid) during meiosis II
Crossing over takes place	Crossing over does not take place

Comparing mitosis and meiosis

Table 2: Showing the differences between mitosis and meiosis

Mitosis	Meiosis
Mitosis occurs in body cells	Meiosis occurs in sex organs
Both karyokinesis and cytokinesis occurs once	Both karyokinesis and cytokinesis occurs twice
Two daughter cells are formed	Four daughter cells are formed
Daughter cells are genetically identical to one another and to the parent cell	Daughter cells are genetically different from each other and from the parent cell
Chromosome number remains constant	Chromosome number is halved
Crossing over does not occur	Crossing over occurs

The differences between mitosis and meiosis as a rap song:
https://youtu.be/qH4WUUQ5pOI

- The only similarities are between mitosis (Prophase, Metaphase and Anaphase) and meiosis II (Prophase II, Metaphase II and Anaphase II).

The differences between mitosis and meiosis are illustrated in the following diagram.

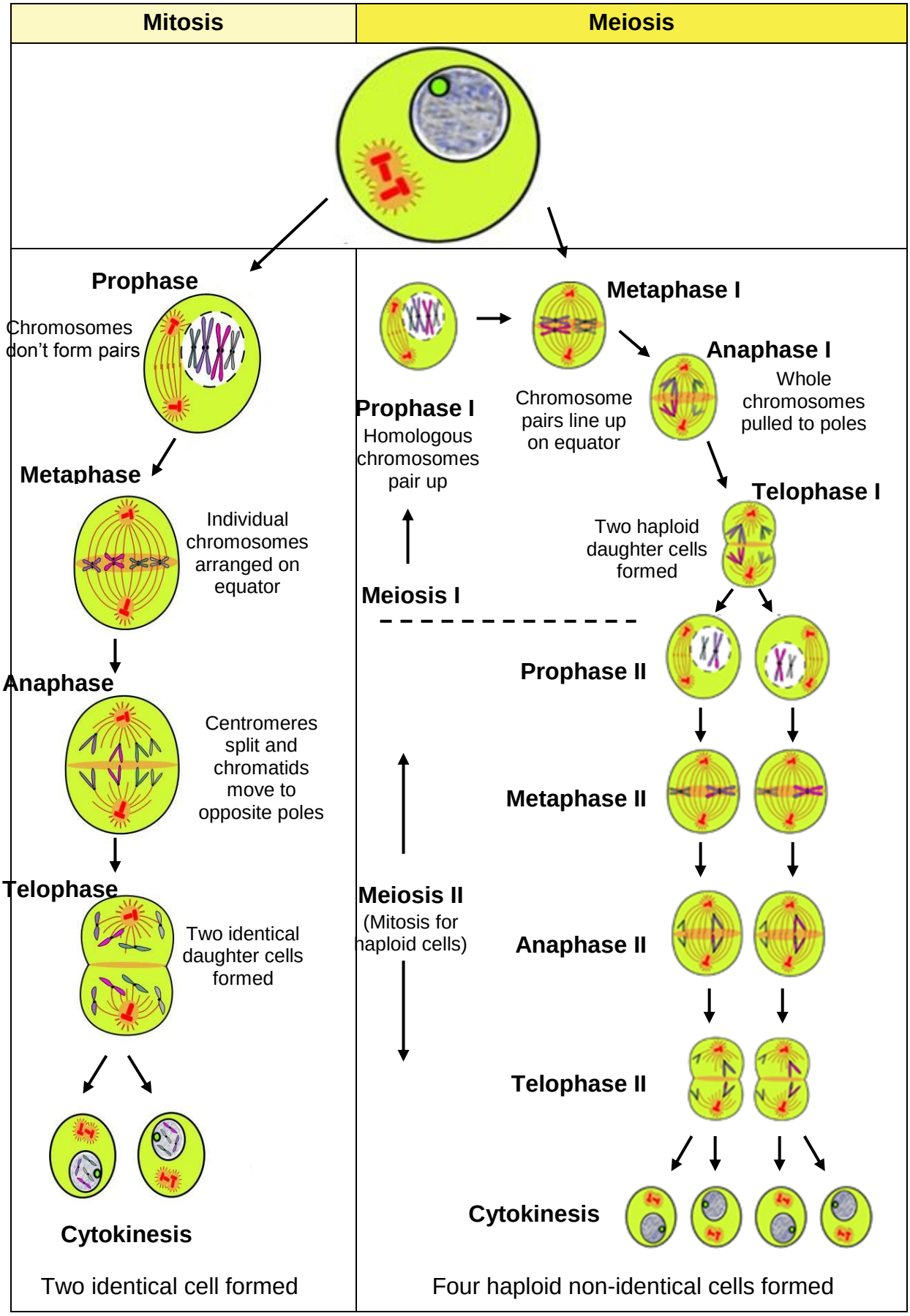


Figure 12: The difference between MITOSIS and MEIOSIS

Activity 1: Meiosis I and Meiosis II

1. Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A – D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1 Which one of the following correctly describes the daughter cells produced by meiosis?

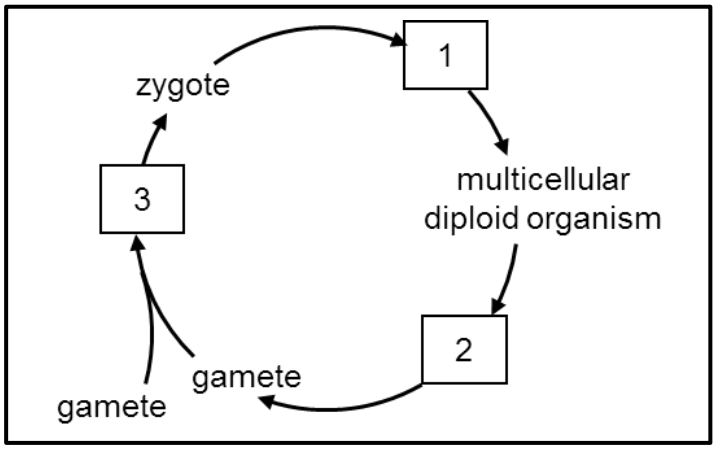
Cells produced by meiosis

	Chromosome number	Genetic composition
A	haploid	different
B	diploid	identical
C	diploid	different
D	haploid	identical

1.2 If there are 38 chromosomes in the body cell of a donkey. How many of these chromosomes are autosomes?

A 38 B 19 C 36 D 44

1.3 Use the sketch below to identify processes 1, 2 and 3.

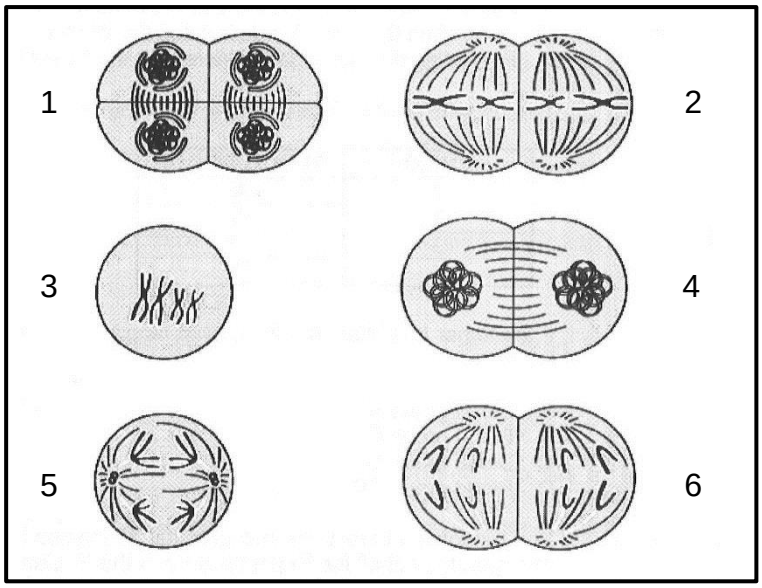


	1	2	3
A	meiosis	fertilisation	mitosis
B	fertilisation	mitosis	meiosis
C	mitosis	meiosis	fertilisation
D	fertilisation	meiosis	mitosis

1.4 Cytokinesis is a term that describes …

A nuclear division
B cytoplasmic division
C reduction of the chromosome number
D doubling the chromosome number

1.5 The diagrams below represent six different phases of meiosis taking place in a particular cell.



1.5.1 The diagrams below represent six different phases of meiosis taking place in a particular cell.

A 2 B 4 C 8 D 46

1.5.2 The correct sequence from the start of meiosis till the end is …

A 1, 2, 3, 4, 5, 6 B 6, 2, 5, 4, 1, 3

C 3, 5, 4, 2, 6, 1 D 3, 4, 5, 6, 1, 2

1.6 Interphase is the stage during which …

A nothing happens in the cell.

B a dividing cell forms a spindle.

C cytokinesis occurs.

D a cell grows and duplicates its DNA. (7 × 2) = (14)

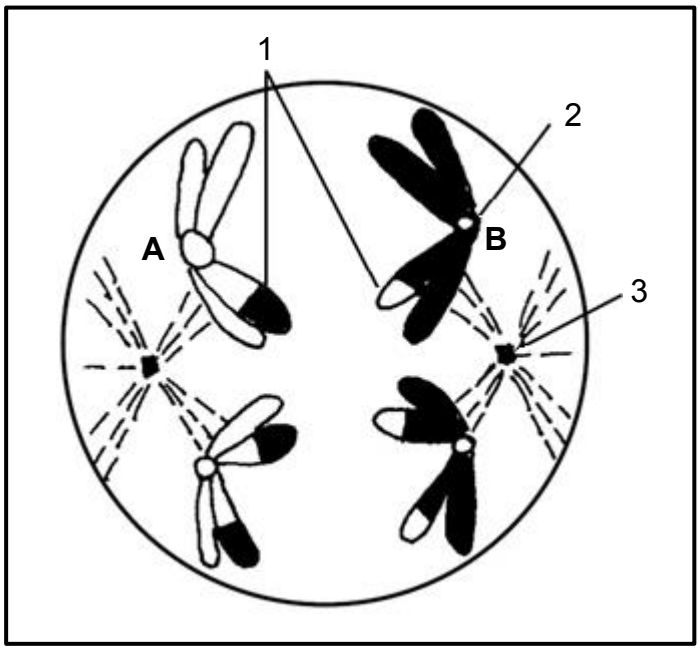
2. Each of the following questions consist of a statement in Column I and two items in Column II. Decide which item(s) relate(s) to the statement. Write **A only**, **B only**, **Both A and B** or **None** next to the question number.

	Column I	**Column II**
2.1	Chromosome number changes from diploid to haploid	A: Meiosis B: Mitosis
2.2	Takes place to form sex cells	A: Mitosis B: Meiosis
2.3	Replication of DNA takes place	A: before mitosis B: before meiosis

2.4	Crossing over takes place	A: Prophase in mitosis B: Prophase I in meiosis
2.5	Chromosomes are pulled to opposite poles	A: Anaphase in mitosis B: Anaphase I in meiosis
2.6	Results in genetic variation	A: crossing over B: random arrangement
2.7	Chromosomes lengthen to form a chromatin network	A: Metaphase B: Anaphase

(7 × 2) = (14)

3. Study the diagram below.



3.1 What type of cell division is occurring? (1)

3.2 What phase is depicted? (1)

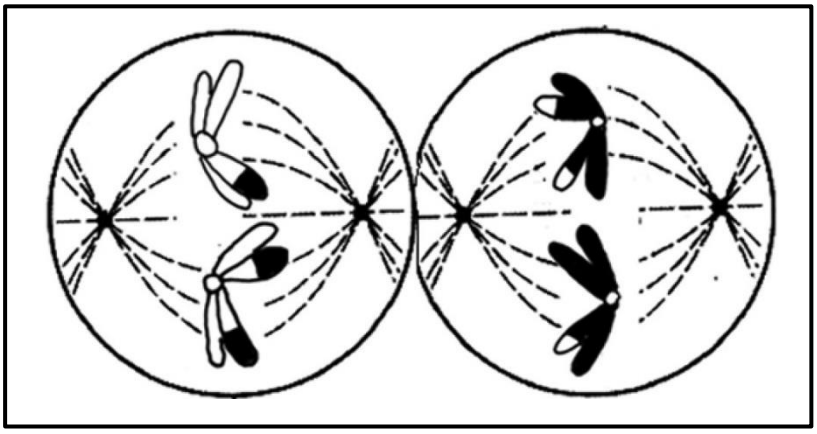
3.3 Provide labels for parts labelled 2 and 3. (2)

3.4 What process resulted in the exchange of segments labelled 1? (1)

3.5 Explain why the process mentioned in 3.4 is important. (1)

(6)

4. Refer to the diagram below which shows two cells dividing by meiosis.



4.1	Which phase of meiosis is depicted?	(1)
4.2	Give two visible reasons for your answer to 4.1.	(2)
4.3	Why do some of the chromatids have two different colours?	(1)
4.4	Do you think that these cells were taken from a human?	(1)
4.5	Give a reason for your answer to 4.4.	(1)
4.6	If these cells were taken from an angiosperm, name the two parts of the flower where this type of division would occur.	(2)
		(8)

5. Explain why meiosis is important for the survival of a human. (8)

(50)

Abnormal meiosis (chromosome mutation)

- Sometimes mistakes occur during the process of meiosis.
- This can happen in Anaphase I where there may be non-disjunction of homologous chromosomes into separate chromosomes (Figure 13).
- It can also happen in Anaphase II when there may be non-disjunction of chromosomes into single-stranded daughter chromosomes (chromatids).
- If there is non-disjunction of chromosome pair 21 in humans, it leads to the formation of an abnormal gamete with an extra copy of chromosome 21.
- If there is fusion between a normal gamete (with 23 chromosomes) and an abnormal gamete (with an extra copy of chromosome 21) it leads to Down Syndrome (47 chromosomes in the zygote).

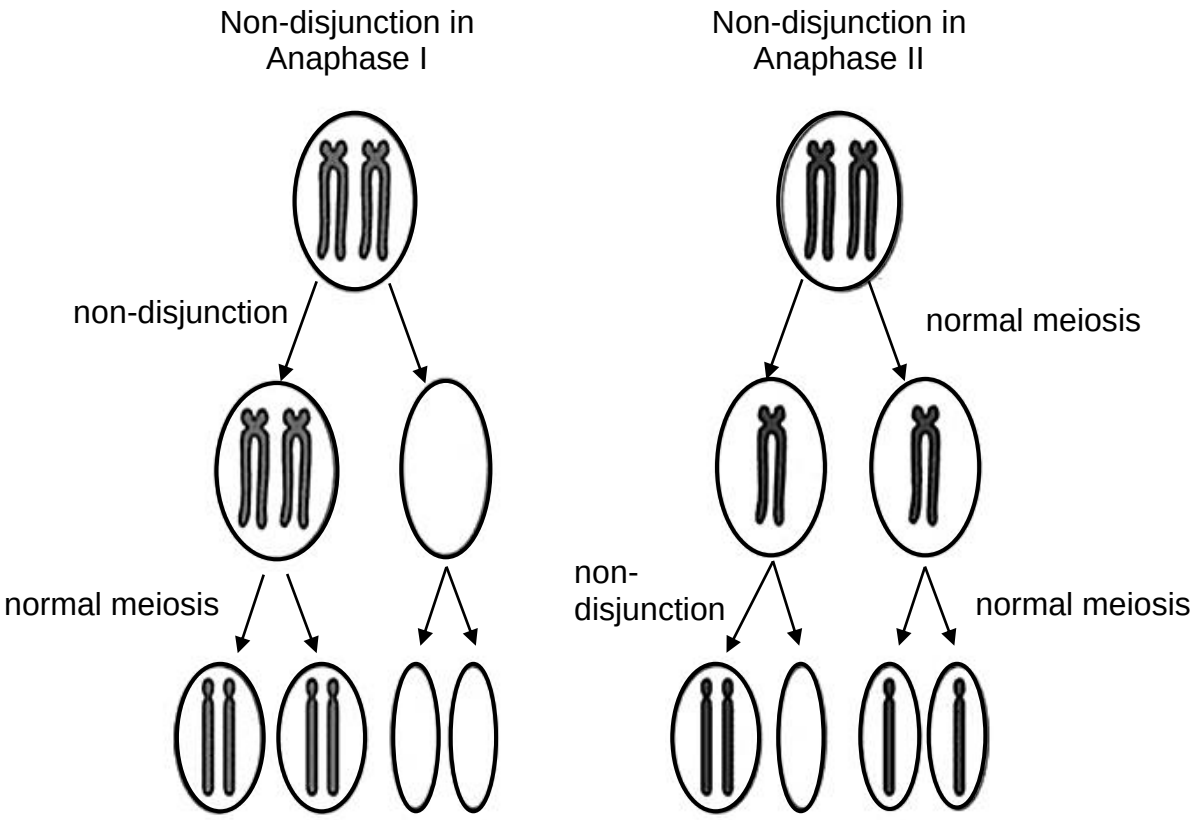


Figure 13: Non-disjunction of chromosomes resulting in Down Syndrome.
C represents a chromosome

ENRICHMENT

Figure 14: Boy with Down Syndrome

Down Syndrome is caused by the non-disjunction of chromosomes which results in the presence of an extra chromosome number 21 (referred to as trisomy).

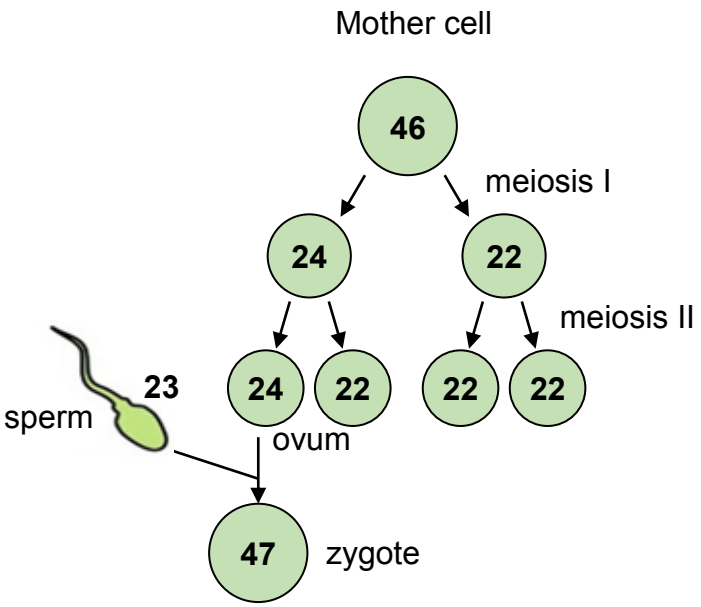


Figure 15: How a child with Down Syndrome is formed

This mutation leads to various malformations in the developing child, such as upwardly slanted eyes, small nose (with flat bridge) and mouth (Figure 14), various degrees of mental retardation, decreased muscle tone, hearing loss and heart defects.

The chance of non-disjunction occurring in sex cells increases with the age of a parent, especially the mother, and it is incurable. In the case of older parents, it is advisable to test the foetus while it is still in the uterus. An amniocentesis is the process by which amniotic fluid is removed, so that the karyotype of foetal cells in the amniotic fluid can be analysed. The parents can then decide whether or not to have the baby.

Meiosis: End of Topic Exercises

Section A

Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A – D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1.1 During which phase of meiosis do homologous chromosome pairs separate?

A Metaphase I
B Anaphase I
C Anaphase II
D Telophase II

1.1.2 Which of the following distinguishes Prophase I of meiosis from Prophase of mitosis?

A Homologous chromosomes pair up
B Spindle forms
C Nuclear membrane breaks down
D Chromosome becomes visible

1.1.3 Which one of the following events occurs during Metaphase I of meiosis?

A Homologous chromosomes arrange themselves at the equator.
B Centrioles move to the opposite poles.
C Chromosomes arrange themselves singly at the equator.
D The cytoplasm is split.

1.1.4 Which one of the following combinations results in genetic variation in organisms?

A Mitosis; sexual reproduction; mutations.
B Meiosis; asexual reproduction; mutations.
C Mitosis; meiosis; sexual reproduction.
D Meiosis; sexual reproduction; mutations.

1.1.5 In bees, females are diploid and males are haploid. Females and males produce haploid gametes. This means that

A females produce gametes by mitosis.
B males produce gametes by meiosis.
C males produce gametes by mitosis.
D Females have half the number of chromosomes that males have.

(5 × 2) = (10)

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

1.2.1 The division of the cytoplasm after a cell nucleus has divided.
1.2.2 The point of crossing over between two adjacent chromosomes.
1.2.3 The name of the process when homologous chromosome pairs fail to separate during meiosis.
1.2.4 Region where the two chromatids of a chromosome are held together.
1.2.5 Chromosome condition describing the presence of a single set of chromosomes in a cell.
1.2.6 The structure responsible for pulling chromosomes to the poles of an animal cell during cell division.
1.2.7 The DNA in a nucleus of a non-dividing cell.
1.2.8 The structure that is made up of two chromatids joined at the centromere
1.2.9 A phase in the cell cycle that occurs before cell division.
1.2.10 A source of genetic variation that arises during Metaphase I.

(10 × 1) = (10)

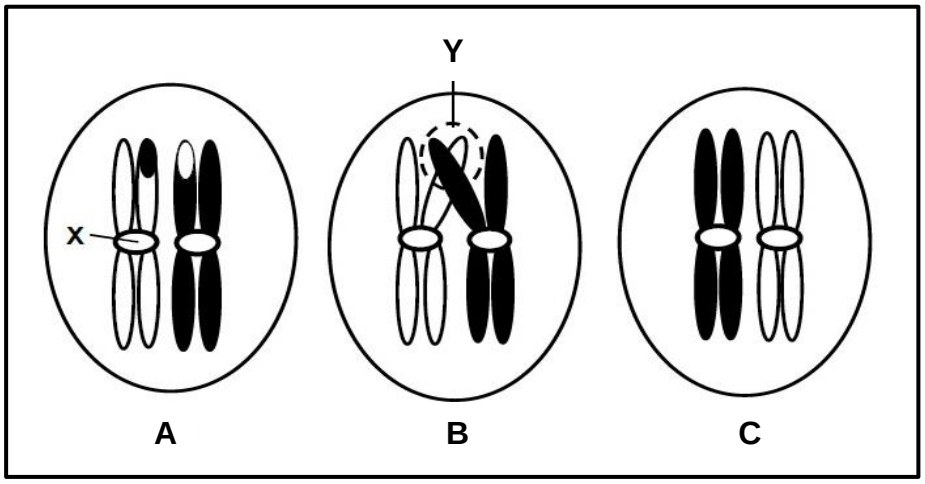
1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Chromosomes align at equator	A: Metaphase I B: Metaphase II
1.3.2 Occurs during Telophase of meiosis I	A: division of the cytoplasm B: centrioles move to the opposite poles
1.3.3 Phase during which chromatids are pulled to opposite poles	A: Anaphase I B: Anaphase II

1.3.4 Contributes to each gamete receiving DNA segments from each parent.	A: Prophase I B: Prophase II
1.3.5 The structure that moves chromosomes / chromatids to the poles during cell division.	A: centrosomes B: spindle fibres

(5 × 2) = 10

1.4 The diagrams below represent a chromosome pair in a female human cell. The cells (**A**, **B** and **C**) show different events in a phase of meiosis, which are not necessarily in the correct sequence.



1.4.1 How many pairs of chromosomes occur in a normal human cell? (1)

1.4.2 Give labels for:

a) region **X** (1)

b) area **Y** (1)

1.4.3 Name the organ in the human female where meiosis occurs. (1)

1.4.4 Name the

a) process occurring in diagram **B**. (1)

b) phase represented by the diagrams above. (1)

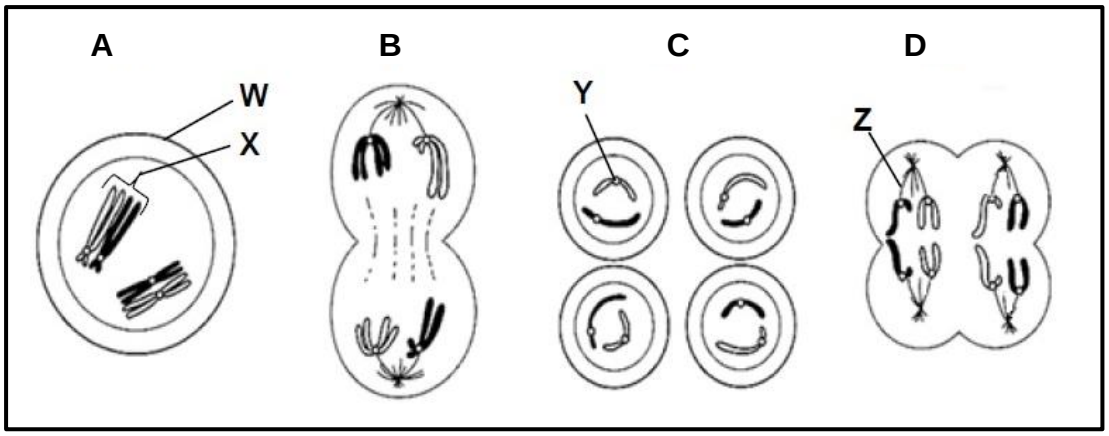
c) type of cell that would result from meiosis of this cell. (1)

1.4.5 Arrange letters **A**, **B** and **C** to show the correct sequence of the events. (1)

1.4.6 What is the biological importance of meiosis? (2)

(10)

1.5 The diagrams below show different phases in meiosis. Study the diagrams and answer the questions that follow.



1.5.1 Label structures **W** and **X**. (2)

1.5.2 How many chromosomes are present in each cell:

a) phase **A** (1)

b) phase **C** (1)

1.5.3 Give the letter of the diagram that represents Anaphase II. (1)

1.5.4 State the name and function of region **Y** and structure **Z**. (4)

1.5.5 Which phase precedes (occurs before) phase **A**? (1)

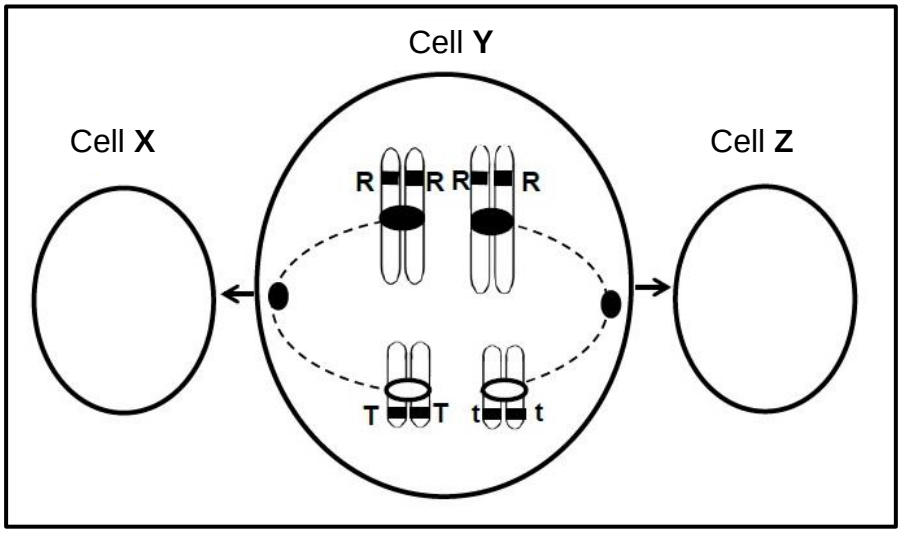
(10)

Section A: [50]

Section B

Question 2

2.1 The diagram below represents a phase in meiosis. Cell **Y** undergoes division to give rise to cells **X** and **Z**. Some alleles are indicated by letters.



2.1.1 Explain why cell **Y** does not belong to a human. (2)

2.1.2 How many chromosomes would be present in:

a) cell **X** at the end of Telophase **I**. (1)

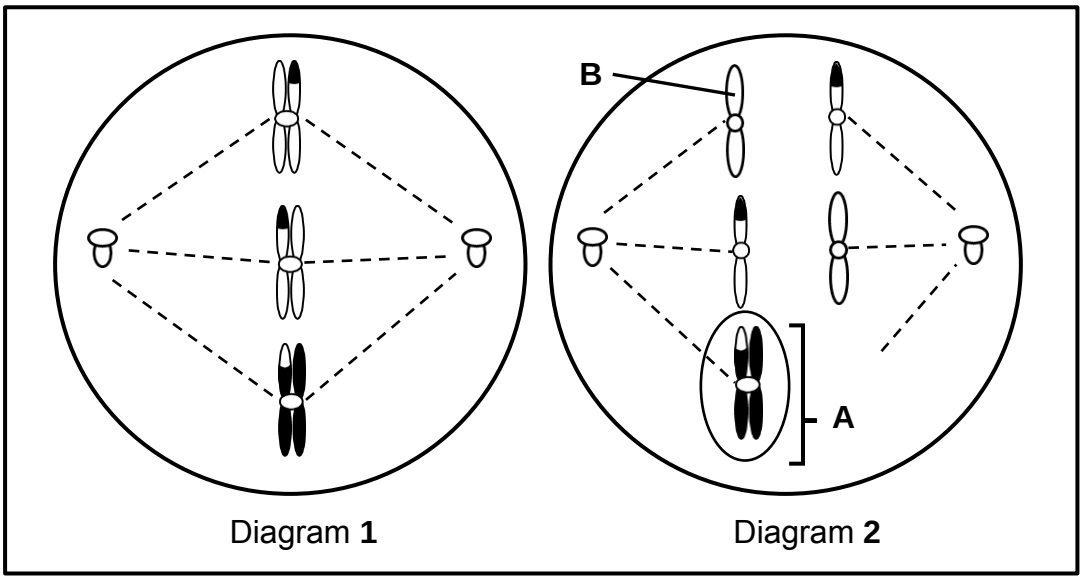
b) the daughter cells produced by cell **Z** after meiosis **II**. (1)

2.1.3 Draw a labelled diagram of a gamete that will result from cell **Y**. (5)

2.1.4 Describe the events of Anaphase II. (3)

(12)

2.2 Study the diagrams below representing two phases of meiosis and answer the questions that follow.



2.2.1 Identify the phase represented by:

a) Diagram **1** (1)

b) Diagram **2** (1)

2.2.2 Name the part labelled **B**. (1)

2.2.3 Describe what happens during the phase illustrated in Diagram **1**. (2)

2.2.4 In Diagram **2** the part circled, and labelled **A** is an abnormality during the process of meiosis.

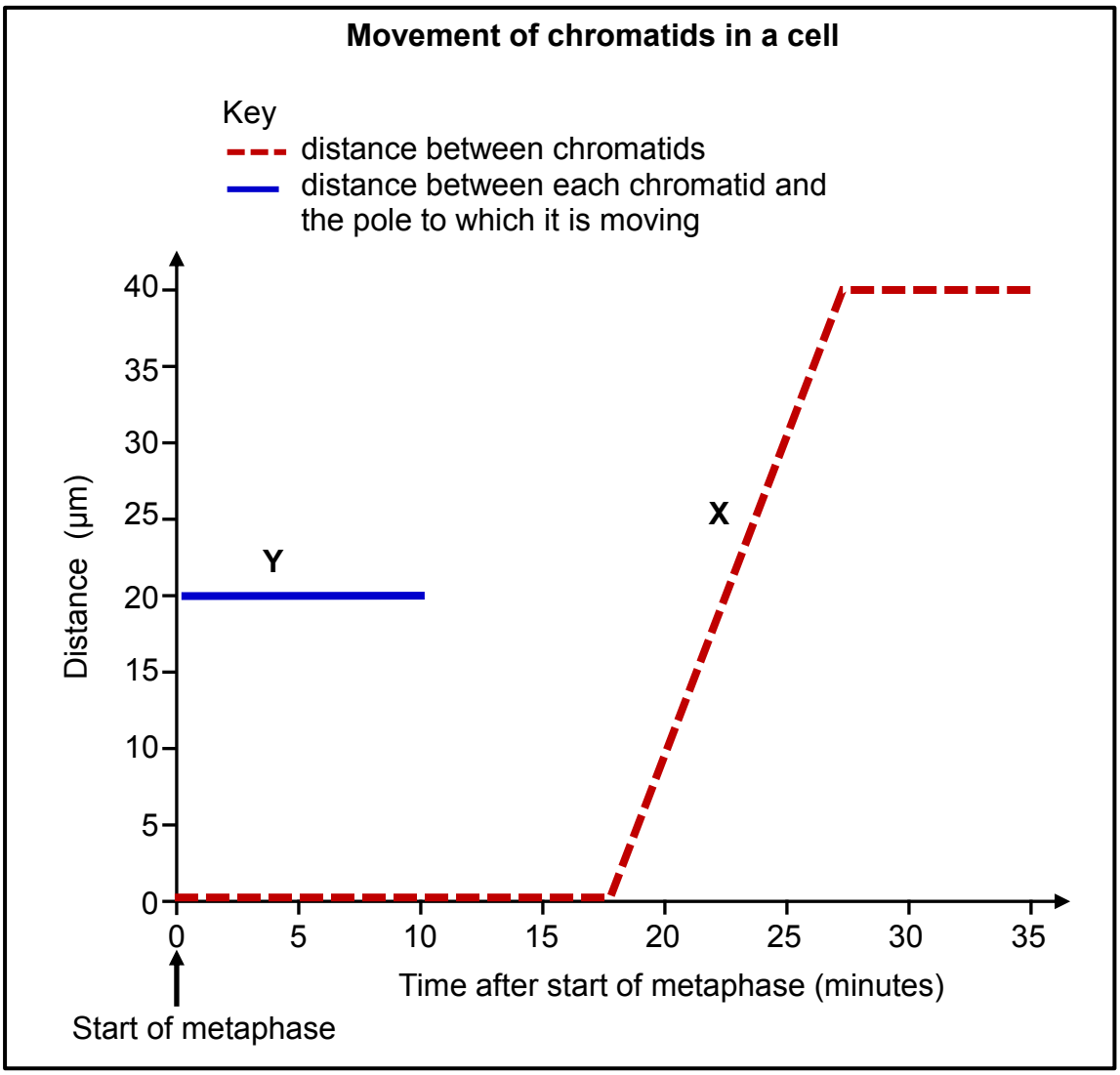
a) Name this abnormality. (1)

b) What genetic disorder would result in humans if this abnormality occurred in chromosome pair no. 21? (1)

c) Give one symptom of the genetic abnormality mentioned in question 2.2.4 (b). (1)

(8)

2.3 The graph shows information about the movement of chromatids in a cell that has just started Metaphase II.



2.3.1 Name one difference between Metaphase I and Metaphase II. (2)

2.3.2 What is the duration of Metaphase II in this cell? (1)

2.3.3 Use line X to calculate the duration of Anaphase II in this cell. (2)

(5)

[25]

QUESTION 3

3.1 Describe the behaviour of the chromosomes during the process of meiosis I by referring to the following phases:

3.1.1 Prophase I (6)

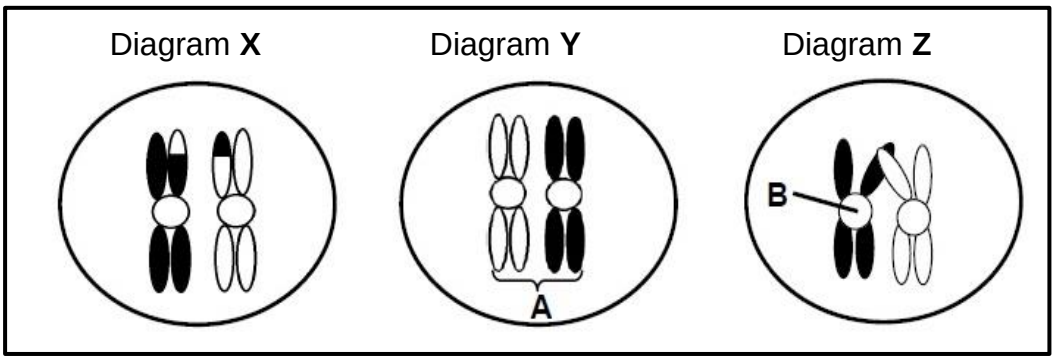
3.1.2 Metaphase I (3)

3.1.3 Anaphase I (2)

3.1.4 Telophase I (3)

(14)

3.2 The diagram below shows chromosome pair 21 in the nucleus of a cell of the ovary of a woman. The chromosomes are involved in a process that takes place in a phase of meiosis.

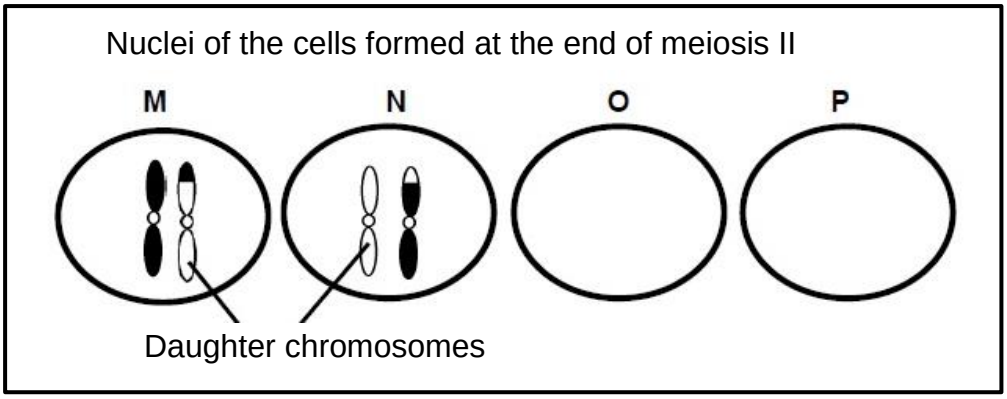


3.2.1 Give labels for **A** and **B**. (2)

3.2.2 Rearrange the letters **X**, **Y** and **Z** to show the correct sequence in which the events take place in this phase. (1)

3.2.3 Explain why chromosomes in Diagram X and Diagram Y are different in appearance. (3)

3.2.4 The diagram below shows the nuclei of the four cells that resulted from meiosis involving chromosomes in Diagram **X** above.



a) Explain why nuclei **O** and **P** do NOT have chromosomes. (2)

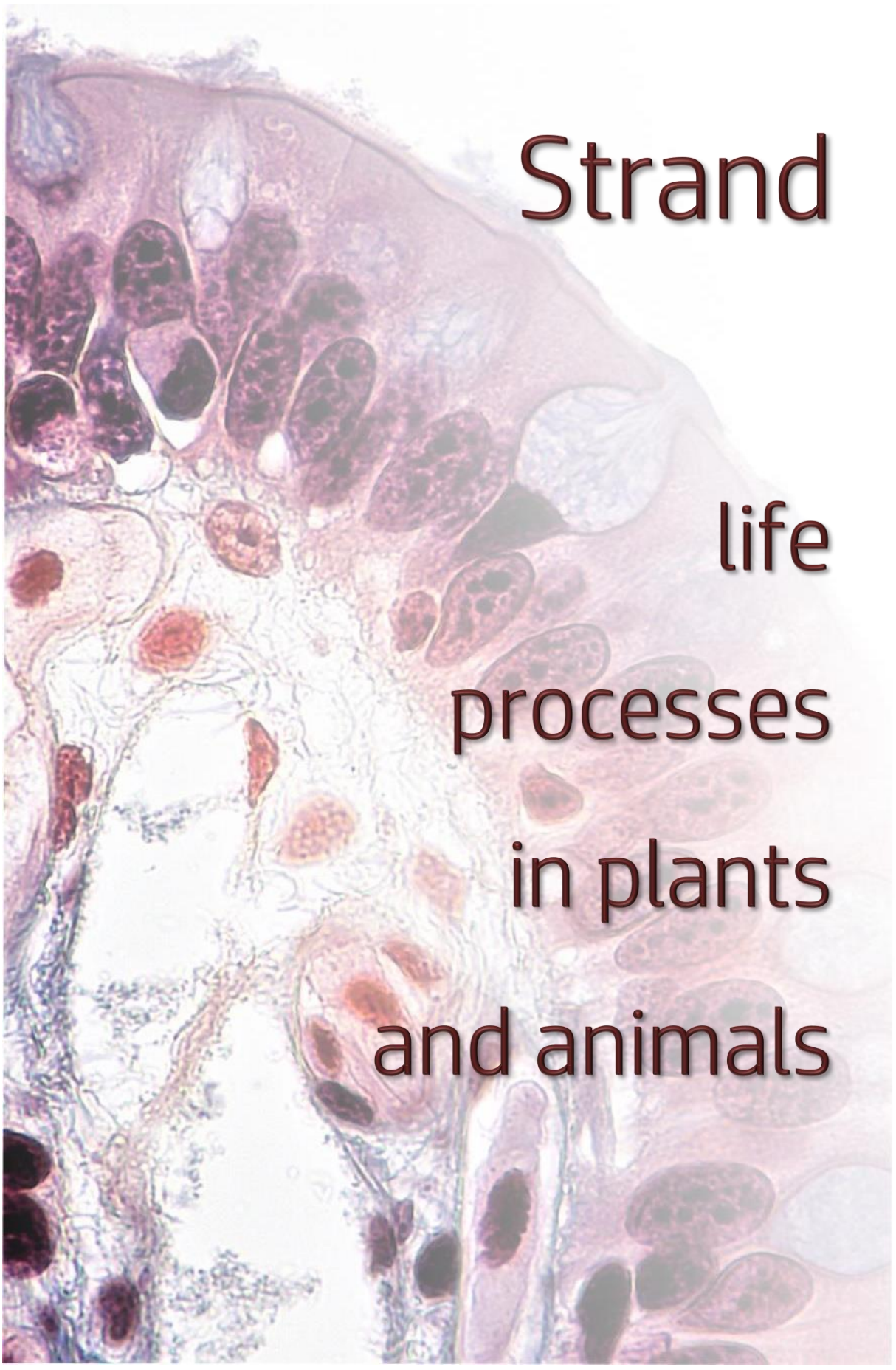
b) Name and explain the disorder that will result if Diagram **M** represents an egg cell that fuses with a normal sperm cell. (3)

(11)

[25]

Section B: [50]

Total Marks: [100]



Strand

life processes in plants and animals

3: Reproductive strategies in vertebrates

CHAPTER 3: REPRODUCTIVE STRATEGIES IN VERTEBRATES

Introduction

Reproduction ensures the continued existence of a species. Different species display different reproductive strategies to make sure that their offspring survive.

Reproductive strategies differ in:

- the number of eggs produced by the female
- the site of fertilisation, inside or outside the body of the female
- the place of development of the embryo and its nourishment
- how quickly the young can fend for themselves
- the type of parental care given to offspring.

Key terminology

reproductive strategy	structural, functional and behavioural adaptations that improve the chances of fertilisation and the survival of offspring
external fertilisation	fertilisation that takes place outside the female's body, usually in water
internal fertilisation	fertilisation that occurs inside the female's body where the male has deposited its sperm
ovipary	eggs are laid; the embryo develops outside the mother's body
ovovivipary	young develop from eggs fertilised internally and retained within the mother's body after fertilisation until they hatch
vivipary	the young develop inside the uterus of mother after eggs are fertilised internally; young are nourished through the placenta
amniotic egg	the embryo inside the egg is protected by a hard shell; the egg consists of many extra-embryonic membranes that serve different functions
extra-embryonic membranes	membranes that surround the developing embryo inside the amniotic egg or uterus.
amnion	produces amniotic fluid which cushions embryo and protects it from mechanical injury, temperature changes, dehydration
allantois	collects the embryo's nitrogenous waste and assists in the exchange of gases
chorion	allows for gaseous exchange in the amniotic egg and forms the placenta in mammals

yolk sac	contains the food reserves for the developing embryo
precocial development	when hatchlings are well developed as they hatch, able to move and feed themselves, with eyes open – limited parental care
altricial development	when hatchlings are underdeveloped as they hatch, unable to move or feed or fend for themselves – young require more parental care
parental care	includes the building of nests, protection, teaching of young and feeding – the care, or lack thereof, directly influences the survival of the young

External and internal fertilisation

- Fertilisation occurs when a sperm cell and egg cell fuse to form a zygote.
- Fertilisation can either occur outside or inside the female's body and varies in its water dependency.

External fertilisation

External fertilisation takes place outside the female's body. Water is required for fertilisation (Figure 1A and 1B).

Figure 1A: Salmon breeding (spawning) in a lake

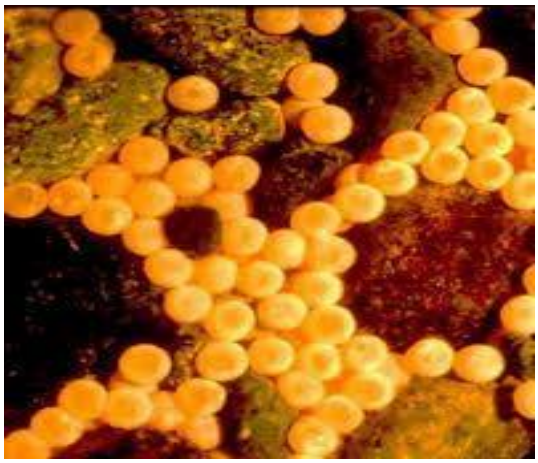


Figure 1B: Fertilised salmon eggs

Internal fertilisation

Internal fertilisation takes places inside the female's body. No water is required. See Figures 2 and 3.

Figure 2: Internal fertilisation in mammals via a penis

Figure 3: Internal fertilisation in birds

Comparison of external and internal fertilisation

Table 1 compares external with internal fertilisation.

Table 1: Comparison – external vs. internal fertilisation

External fertilisation	Internal fertilisation
• Requires water for fertilisation	• No water required for fertilisation
• Gametes (sperm and egg cells) are released into water	• Sperm cells are released into the female's body
• Many gametes released	• Fewer gametes released
• High mortality rates among young due to lack of protection. Eggs can easily desiccate or be predated on	• Lower mortality rates among young – protection provided by the mother's body or a hardened calcareous / leathery shell.
• e.g. fish and amphibia	• e.g. reptiles; birds and mammals

Ovipary, ovovivipary and vivipary

Ovipary, ovovivipary and vivipary are reproductive strategies that differ in respect to:

- where the zygote is formed
- where development occurs
- how the embryo receives its nourishment
- the type of egg or its presence or absence

Comparison of ovipary, ovovivipary and vivipary

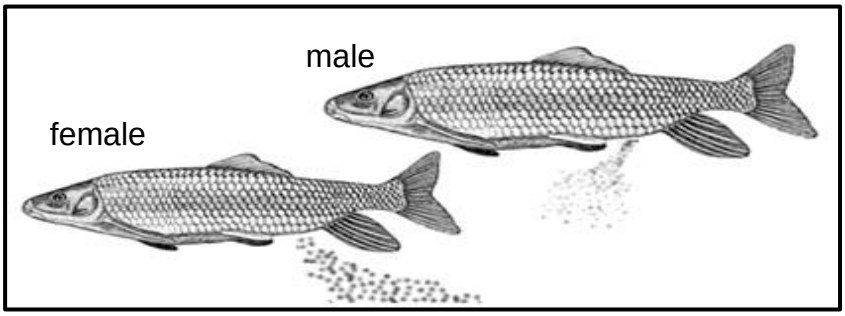
Table 2 compares the three reproductive strategies, namely, ovipary, ovovivipary and vivipary.

Table 2: Three reproductive strategies

	Ovipary	Ovovivipary	Vivipary
fertilisation	external or internal	internal	internal
development of embryo	external to the body of the female	inside the body of the female	inside the female's body
nutrition	Yolk is the only form of nutrition for the developing embryo and is usually present in small quantities	Yolk present in the egg. Young are independent of the mother's body	Young receive nutrition from the mother's body through the placenta
type of egg	jelly-like or calcareous	calcareous or leathery	None

Activity 1: Fertilisation

The diagram below shows a certain species of fish mating.



1. Identify the type of fertilisation displayed by the fish species. (1)
2. State two visible ways in which the chances of fertilisation in these fish are increased. (2)
3. Name the reproductive strategy used by these fish that involves the production of eggs. (1)
4. Give two reasons why there is no need for the eggs of these fish to be covered by a hard or leathery shell. (2)
5. Explain the challenge that external fertilisation poses and how organisms with external fertilisation overcome this challenge. (4)

(10)

The amniotic egg

The amniotic egg (Figure 4) is a major development in the evolution of animal life on land – from being water dependent for sexual reproduction, to being able to **reproduce without the availability of water**.

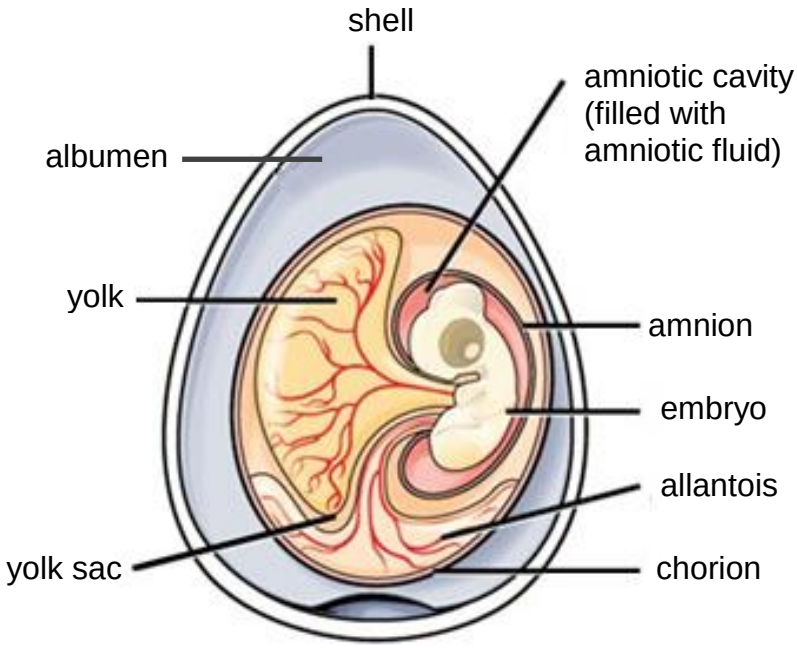


Figure 4: The amniotic egg

The amniotic egg consists of …

- The **developing embryo**
- Three extra embryonic membranes:
    - the **amnion** – produces amniotic fluid which cushions the embryo and protects it against mechanical injury, temperature changes and dehydration
    - the **allantois** – collects nitrogenous waste and assists in the exchange of gases
    - the **chorion** – allows for gaseous exchange in reptiles and birds, where a shell is present and in mammals, where no shell is present, it forms the placenta.

- The **yolk sac**

  The yolk sac contains the food reserves for the developing embryo. If yolk is present in smaller quantities, the young are hatched sooner, are under-developed and usually require more parental care. If yolk is present in larger quantities, the incubation period is longer, and the young are usually well developed when they hatch.

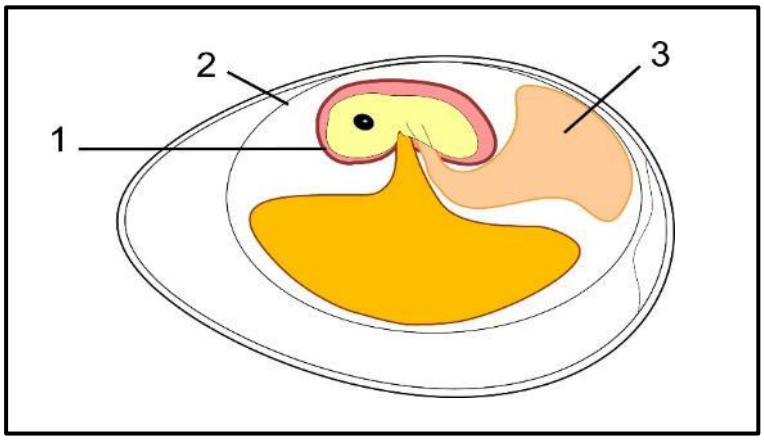
- A **hardened calcareous** or **leathery shell**

  The shell helps to protect the developing embryo from mechanical injury and prevent desiccation, while still allowing gases to move through.

The amniotic egg: https://youtu.be/Qq0kMEWzdHg

Activity 2: Amniotic egg

Study the diagram and answer the questions that follow.



1. Identify the membrane numbered 1 and 2. (2)
2. Describe any two functions of the fluid found in part 1. (2)
3. Identify the organ that will replace the function of membrane 3 in the adult organism. (1)
4. Explain why the allantois and yolk sac are non-functional in a human foetus. (2)
5. Briefly explain how the amniotic egg allowed life to evolve onto land. (5)

(12)

Precocial and altricial development

Precocial and altricial development are terms used to describe how well-developed offspring are at birth.

Major differences between precocial and altricial development

(see Figures 5, 6, 7 and 8)

Table 3: Comparing precocial and altricial development

	Precocial development	Altricial development
Development of the body	well developed	under developed
Eyes after birth	open	closed
Presence of fur / feathers	have fur / feathers	usually naked
Parental care required	low degree of parental care required	high degree of parental care required
Mobility	young can move soon after birth	young have limited ability to move freely
Yolk amount in egg	greater quantity	lower quantity

Figure 5: Ducklings with down feathers and open eyes

Figure 6: Salmon fry with fins and open eyes

Figure 7: Nesting birds – note the eyes are closed and their bodies naked

Figure 8: 'Pinkies' – rat (mammal) babies – note no fur and eyes are closed

Parental care

In higher-order animals, parental care is a **behaviour that increases the survival of the young**. As a reproductive strategy, those animals which invest more energy pre-natally (before birth) usually display very little parental care once young have been born. In animals where less energy is invested pre-natally, more post-natal parental care is offered.

Parental care can be seen in the following examples:

- Building of nests and incubation of eggs
- Guarding from predators
- Teaching offspring

Examples of parental care: https://youtu.be/7Ko07Md3XmU

Activity 3: Development and care

Study the diagrams below showing different forms of development

A

B

C

D

1. Write down the letters of the organisms which show
   a) altricial development (2)
   b) precocial development (2)
2. Ovoviviparous animals can display either precocial or altricial development. Explain how these development approaches differ in respect to
   a) the degree of parental care offered (4)
   b) how well young are developed at birth (2)
   c) the amount of yolk present in eggs (2)
3. Tabulate three differences between precocial and altricial development. (7)

(19)

4: Human reproduction

CHAPTER 4: HUMAN REPRODUCTION

Introduction

In this chapter we will be studying human reproduction. All organisms must reproduce to ensure the survival of the species. We will look at the structure of the male and female reproductive systems, puberty, how gametes are produced, and hormonal changes that occur in the menstrual cycle. We will also briefly study fertilisation and the development of the zygote, including implantation and gestation.

The understanding of this topic necessitates understanding the role of meiosis, mitosis and fertilisation in the human life cycle as illustrated in Figure 1 below.

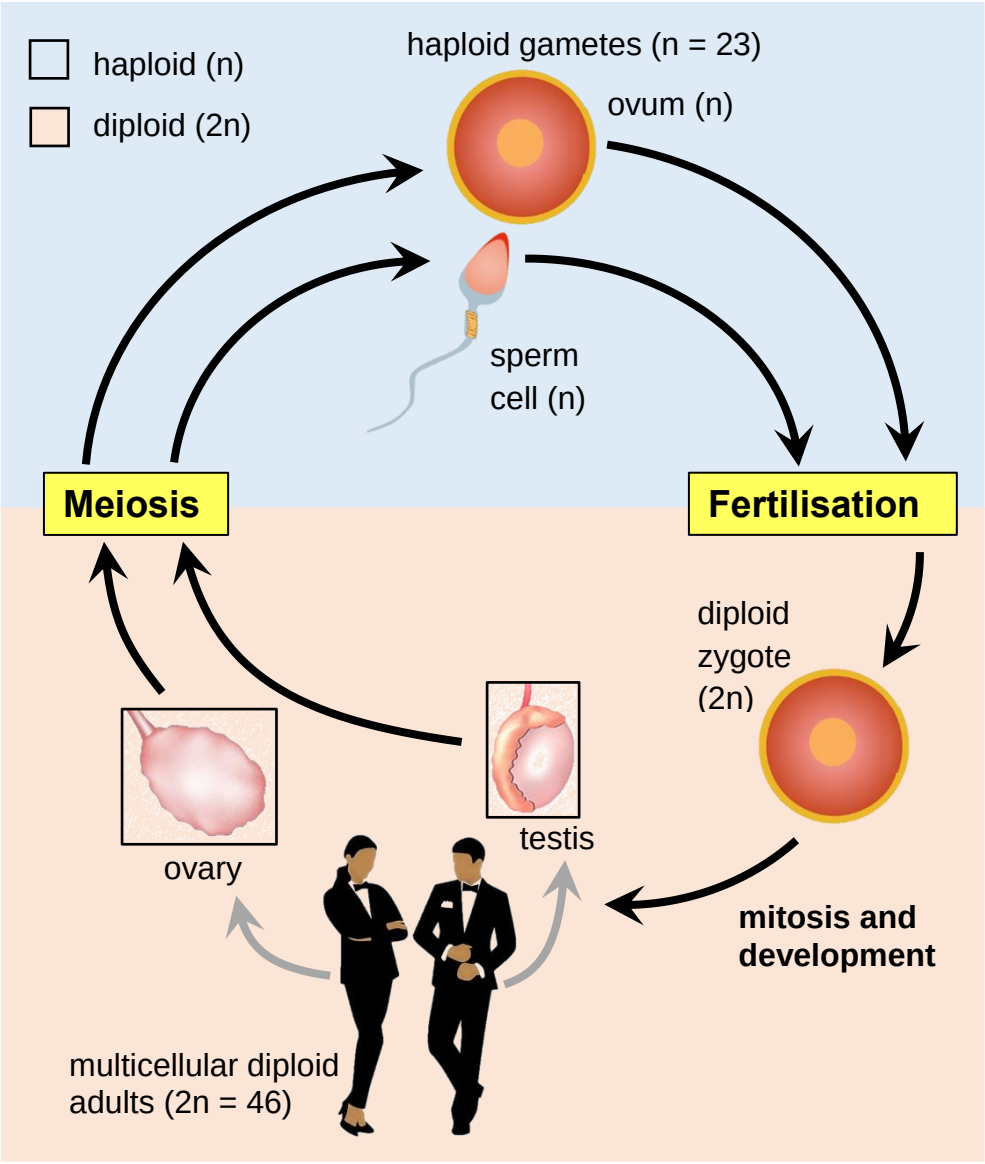


Figure 1: Human life cycle

All the body cells (somatic cells) of a human being are **diploid (2n)** i.e. have two sets of each chromosome. For humans to grow or to repair damaged tissues, the somatic cells divide by **mitosis.** The new cells produced by mitosis are identical to the original cells which divided.

Sexual reproduction requires two parents. Both the male and the female produce **gametes** (egg and sperm) by a reduction division referred to as **meiosis**. Meiosis ensures that the gametes are **haploid** i.e. they have only one set of chromosomes. When two gametes fuse (a sperm and an egg) as a result of **fertilization**, a diploid **zygote** is formed. The zygote then divides by mitosis to form a human.

Key terminology

gamete	an egg or sperm cell with half the number of chromosomes
gametogenesis	the process in which gametes are produced in the testes and ovaries through meiosis
oogenesis	the process that occurs when egg cells are made in the ovary through meiosis
spermatogenesis	the process that takes place when sperm cells are made in the testes through meiosis
germinal epithelium	cuboidal epithelium found on the surface of the testes and ovaries which gives rise to the cells which mature to form sperm cells and egg cells respectively

The male reproductive system

As shown in Figure 2 below, the male reproductive system consists of …

- the main male sex organ – a pair of testes in the scrotum
- various ducts and tubules – seminiferous tubules, epididymis, vas deferens and the urethra
- accessory glands – prostate gland, Cowper's gland and seminal vesicles
- the external genitalia – penis

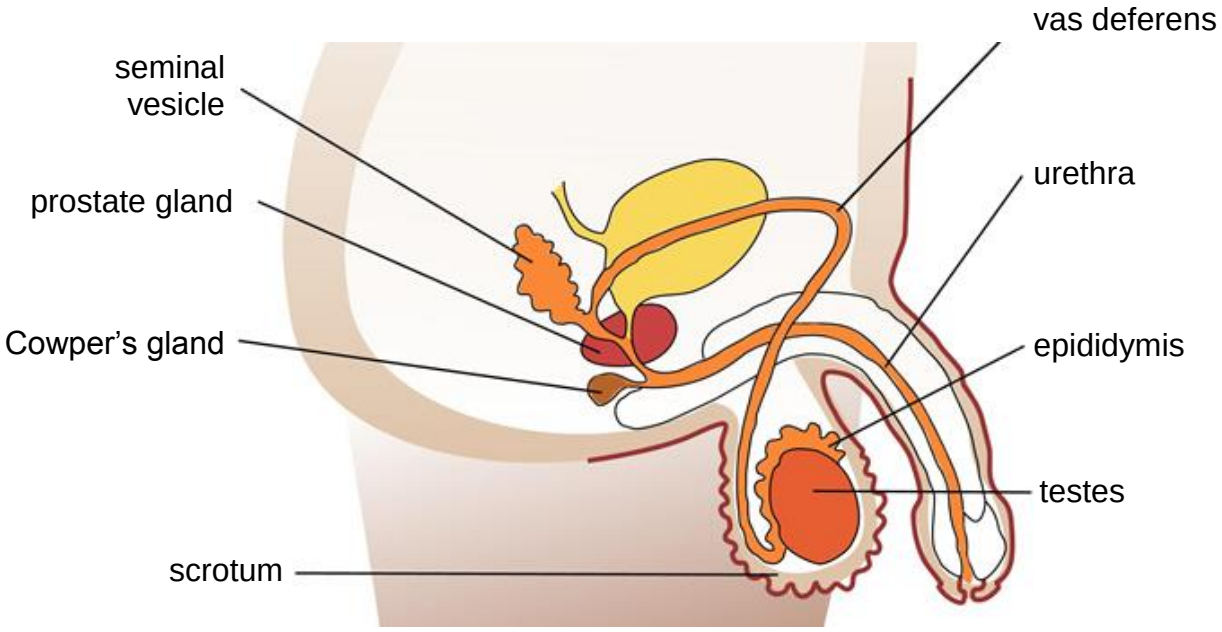


Figure 2: The male reproductive system

The functioning of each part of the reproductive system is explained in Table 1.

Table 1: Structure and function of the male reproductive system

Part	Structure	Function
testes	oval shaped glands, suspended in the scrotum	produce sperm cells and the hormone testosterone
scrotum	skin sac that holds the testes	protects the testes and holds the testes "outside" the body, at 2°C lower than body temp.
epididymis	coiled tubule on the outside of the testes but still in the scrotum	temporarily stores spermatids until they mature into sperm cells
vas deferens	muscular tube passing from the epididymis to the urethra	transports sperm from the epididymis to the urethra
urethra	tube which runs through the penis	transports urine and semen out of the body
prostate gland	gland found below the bladder, at the point where the urethra begins; the largest accessory gland	produces a nutrient-rich fluid that provides energy for the sperm cells
Cowper's glands	small pair of glands found below the prostate gland.	produces mucus that helps with the movement of sperm cells
seminal vesicles	medium sized pair of glands attached to the end of the vas deferens	produces alkaline fluid to neutralise vaginal acids which would kill sperm

The testes contain **seminiferous tubules** (see Figure 3).

- The tubules are lined by germinal epithelium cells which produce sperm cells.
- Some of the cells develop into **Sertoli cells** which provide nutrients for the spermatids to become mature sperm cells. The seminiferous tubules are surrounded by connective tissue that contain the **Cells of Leydig** which produce testosterone.

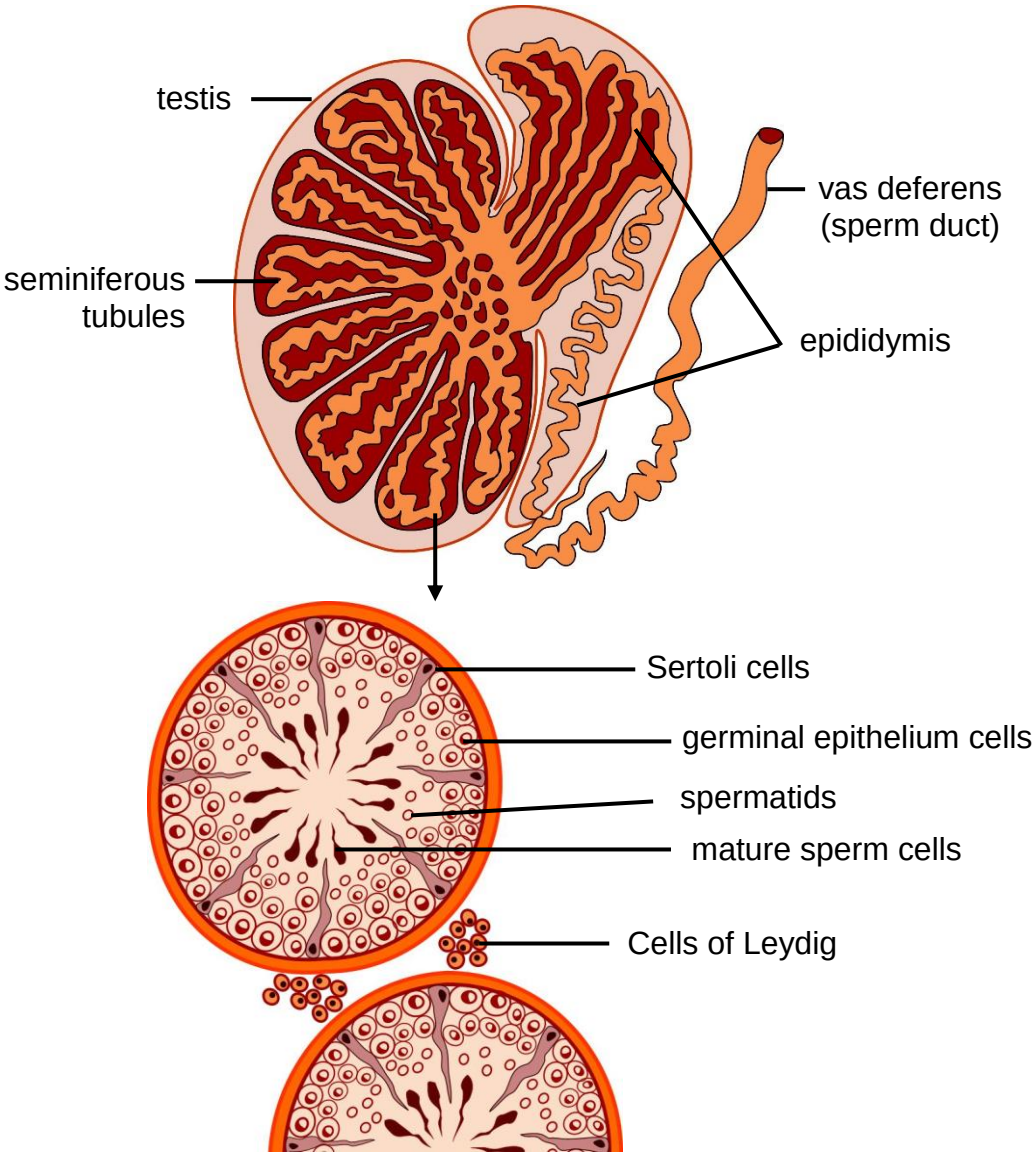


Figure 3: Cross-section through the seminiferous tubules of the testes

Testosterone has the following functions:

- development of the male secondary sexual characteristics
- stimulating the maturation of sperm cells

It is vitally important that the testes are suspended on the outside of the body, as this allows for temperature regulation to occur. The optimum temperature for sperm production is 2 to 3°C lower than normal body temperature.

If the temperature in the scrotum is high, it interferes with the quality of the sperm resulting in male infertility.

By having the testes suspended in the scrotum, the temperature of the testes can be adjusted by moving the testes closer to the body in cold conditions or further away from the body during warm conditions.

The male reproductive system: https://www.youtube.com/watch?v=k60M1h-DKVY

The female reproductive system

The female reproductive structure consists of:

- the main female sex organ – the ovaries
- the ducts – fallopian tubes
- the accessory organs – the uterus and the vagina
- the external genitalia – the vulva

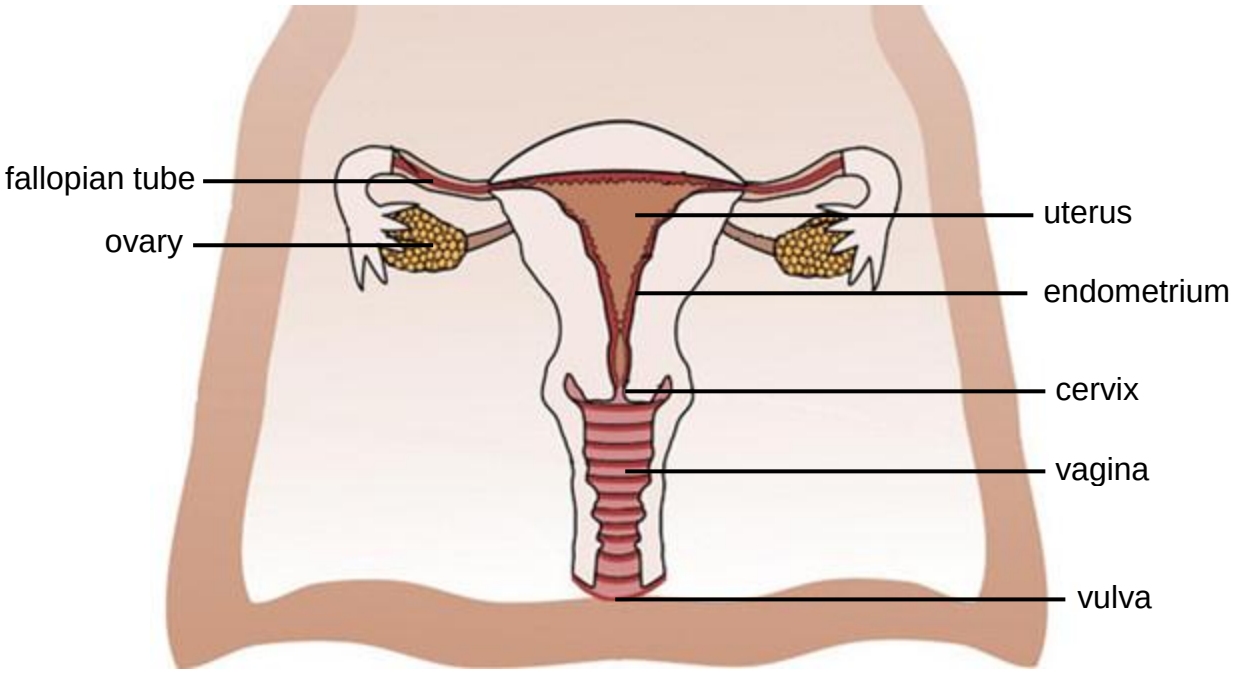


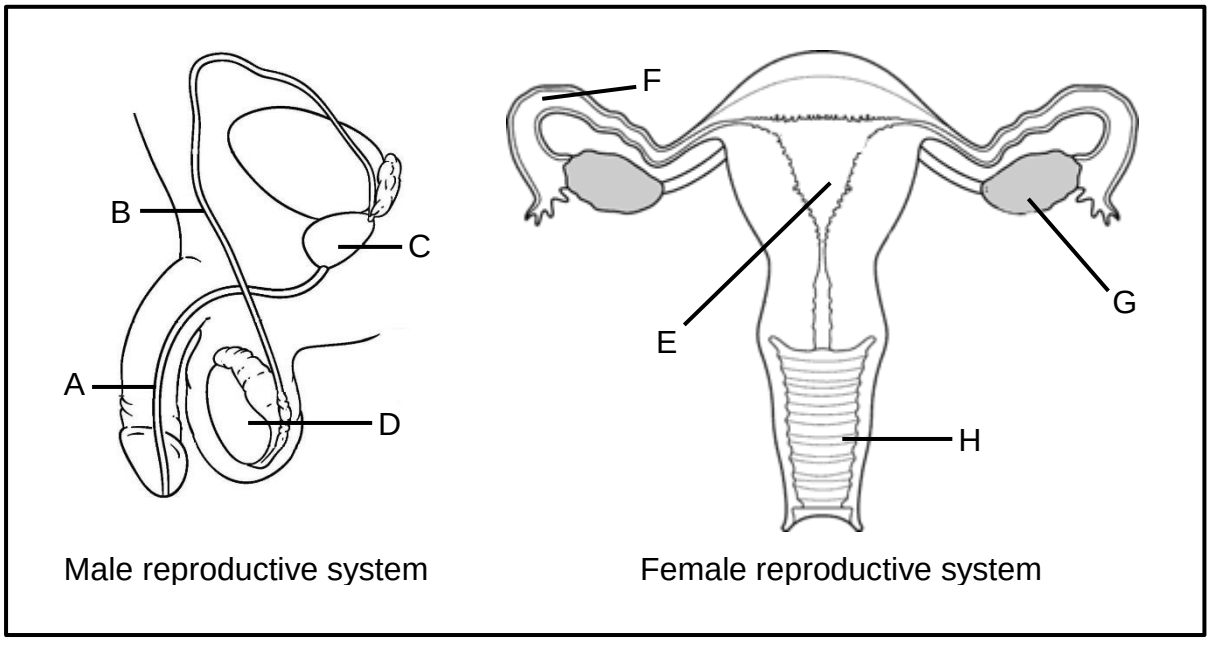
Figure 4: The female reproductive system

Table 2: Structure and function of the female reproductive system

Part	Structure	Function
ovaries	found as a pair, one on either side of the uterus, and surrounded by germinal epithelium	produce egg cells, secrete the hormones progesterone and oestrogen
fallopian tubes	connect the ovaries to the uterus – are lined with ciliated columnar epithelium which helps the movement of the egg cells	transports egg cells from the ovary to the uterus; the site of fertilisation
uterus	hollow, pear-shaped organ	houses and protects the embryo and foetus during pregnancy
endometrium	inner lining of the uterus	site of implantation and where the placenta forms
cervix	lower, narrow opening of the uterus	stretches and opens to allow the baby through during childbirth
vagina	muscular tube which runs from the cervix to the exterior	receives the penis and semen during sexual intercourse; the birth canal; passage for menstrual blood
vulva	opening to the vagina; covered by two vagina covers called the labia	protects the entrance to the vagina

Activity 1: Reproductive systems

Study the diagrams below showing the male and female reproductive systems.



Male reproductive system

Female reproductive system

1. Identify the parts labelled A – H. (8)
2. State one function of the each of the following:
   a) The fluid produced by C. (1)
   b) Part E (1)
3. Provide two functions of part H. (2)
4. Explain why it is necessary for part D to be 'outside' the human body in males. (2)

(14)

Puberty

Puberty is the period during which males and females reach sexual maturity. Puberty usually begins between the ages of 11 to 15, though it may occur much earlier or later depending on the individual. During puberty the sex hormones are produced which stimulate gametogenesis and sexual maturity. At the same time secondary sexual characteristics develop. Table 3 below lists the various changes in the development of males and females that take place during puberty.

Table 3: The development of males and females during puberty

Males	Females
male sex hormone testosterone is produced	female hormones oestrogen and progesterone are produced
growth of hair around the scrotum (pubic hair)	growth of hair around the vulva (pubic hair)
growth of hair in the armpits	growth of hair in the armpits
growth of hair on the face	
larynx enlarges / voice becomes deeper	
muscles enlarge and the shoulders become wider	the hips become wider and fat is deposited below the skin
penis and the testes enlarge	development of breasts

Gametogenesis

Gametogenesis is the term used to describe the process by which gametes are produced from the germinal epithelium in the sex organs.

It includes spermatogenesis and oogenesis.

Spermatogenesis

Spermatogenesis is the production of male gametes (sperm cells) in the testes of the male. It occurs in the germinal epithelium of the seminiferous tubules in the testes. This process happens under the influence of testosterone. During puberty the germinal epithelium contains a diploid number of chromosomes (46). These cells go through the process of meiosis forming haploid sperm cells with 23 chromosomes. The gametes may have (22 + X) or (22 + Y) chromosomes.

Spermatogenesis takes places as follows:

- Under the influence of testosterone, the diploid germinal epithelial cells (2n) lining the seminiferous tubules go through meiosis
- Each cell that goes through meiosis produces 4 haploid spermatids (n)
- Each spermatid matures to form a haploid sperm cell (see Figure 3 above)

Figure 5 below shows the structure of a human sperm cell. Each sperm cell is made up of a head, middle portion (neck) and a long tail.

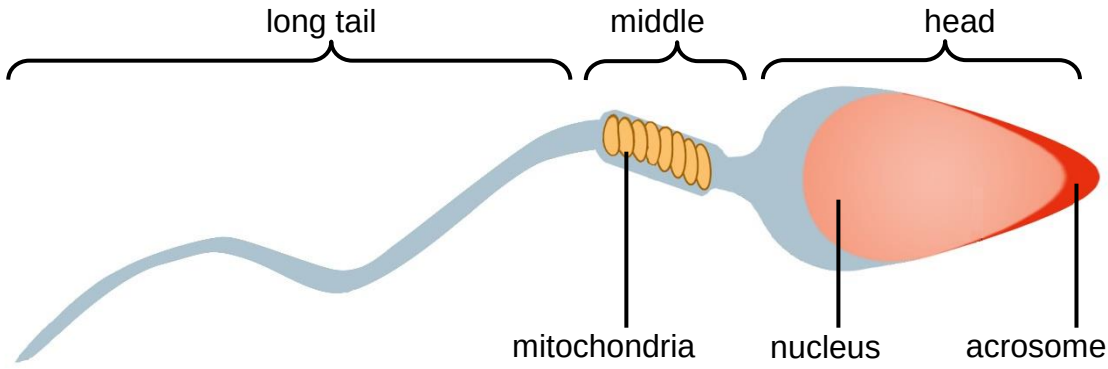


Figure 5: The structure of a sperm cell

- The head is mostly made up of the nucleus which contains 22 autosomes and one sex chromosome (X or Y).
- The acrosome (also in the head) contains enzymes that dissolve the outer layer of the egg allowing fertilisation to occur.
- The middle portion contains mitochondria which provide energy for the movement of the sperm cell.
- The long tail allows the sperm cell to propel itself forward (to swim) through fluid.

Oogenesis

Oogenesis is the production of female gametes (ova / egg cells) in the ovaries of a female. It occurs when the diploid germinal epithelium of the ovaries starts to produce follicles by mitosis.

Oogenesis takes place as follows:

- The diploid germinal epithelium cells (2n) of the ovaries go through the process of mitosis to form many follicles
- Every 28 days, the follicle stimulating hormone (FSH) stimulates one follicle. Only one cell inside of that follicle enlarges and goes through the process of meiosis
- Out of the 4 (four) haploid cells produced through meiosis, only one cell will survive to form a mature ovum
- The other three cells from meiosis will degenerate

Figure 6 shows the structure of a human egg (ovum). Each ovum is made up of follicle cells, a layer of jelly, cytoplasm and a haploid nucleus.

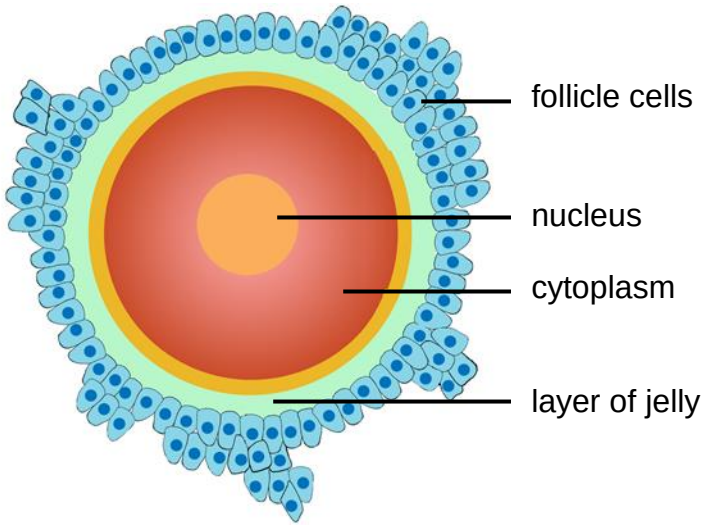


Figure 6: The structure of an ovum

- The nucleus contains 22 autosomes and one sex chromosome (X)
- The cytoplasm nourishes the egg
- The jelly layer provides protection for the early developmental stages of the fertilised egg

The structure of sperm and egg cells:
https://www.youtube.com/watch?v=CuxaXghfyeE&list=PLW0gavSzhMlQYSpKryVcEr3ERup5SxHl0&index=43

Activity 2: Gametogenesis

1. Name the organ where meiosis takes place in the male and female reproductive systems respectively. (2)
2. Define gametogenesis. (1)
3. Name the type of gametogenesis that takes place in the male and female reproductive systems respectively. (2)
4. Draw a fully labelled diagram of an ovum. (5)
5. Discuss the functions of the four main parts of a sperm cell. (8)

(18)

The menstrual cycle

Key terminology

Graafian follicle	mature follicle inside the ovary filled with fluid in which the ovum grows
ovulation	the release of an ovum from the Graafian follicle of the ovaries
endometrium	the inner lining of the uterus wall
menstruation	the monthly loss of blood and tissue as a result of changes that occur in the lining of the uterus
menopause	stage in the life of a woman when she stops ovulating and menstruating; usually occurs between the ages of 45 and 55
fertilisation	the fusion of the haploid sperm cell nucleus and the haploid egg cell nucleus to form a diploid nucleus of the zygote
implantation	the attachment of the embryo to the endometrium lining the uterus

The menstrual cycle refers to changes that occur in the ovaries and uterus of a female over a period of 28 days. This cycle begins at puberty and ends at menopause.

The menstrual cycle is made up of two separate cycles that happen at the same time:

1. Ovarian cycle
2. Uterine cycle

1. Ovarian cycle

The ovarian cycle refers to the development and release of an ovum (or egg cell). This takes place inside the ovary. The ovarian cycle begins when FSH (Follicle Stimulating Hormone) is secreted by the pituitary gland. FSH is transported to the ovary by the blood. The following diagram (Figure 7) illustrates the ovarian cycle.

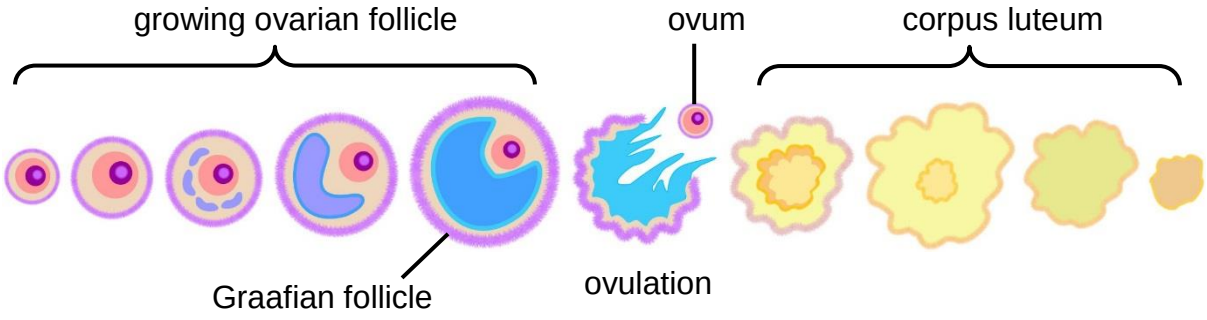


Figure 7: The ovarian cycle

1. FSH stimulates a primary follicle to become a **Graafian follicle** which contains a mature ovum (or egg cell).
2. As the Graafian follicle develops, it produces the hormone **oestrogen**, increasing the oestrogen levels in the blood.
3. Around Day 14, the Graafian follicle ruptures and releases an ovum in a process called **ovulation**. Ovulation is stimulated by the Luteinising Hormone (LH) which is released by the pituitary gland.
4. LH causes the ruptured Graafian follicle to change into a structure called the **corpus luteum**. The corpus luteum secretes the hormone **progesterone** increasing the levels of progesterone in the blood.

5. If fertilisation does not take place, the corpus luteum shrinks and stops producing progesterone. The ovum passes down the fallopian tube, enters the uterus and leaves the body through menstruation.

   NOTE:

   - If the ovum is fertilised, the corpus luteum remains active and continues secreting progesterone
   - Oestrogen and progesterone produced by the ovaries during the ovarian cycle influence the uterine cycle

2. Uterine cycle

The Uterine cycle shows the changes that occur in the uterus wall as it gradually thickens and becomes more vascular (richly supplied with blood vessels) over a period of 28 days.

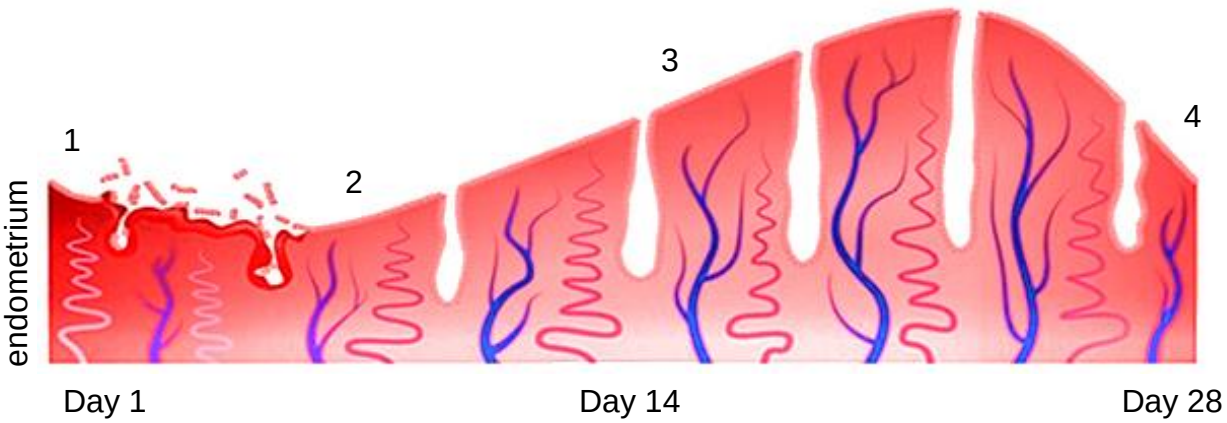


Figure 8: Illustrating the changes to the endometrium

1. The endometrium breaks down and is released (menstruation). This lasts for approximately 4 to 7 days.
2. The endometrium is stimulated by oestrogen to become thicker and develop more blood vessels and glands.
3. Progesterone stimulates the endometrium to become even thicker and develop more blood vessels and glands. This happens in preparation for possible implantation of the fertilised ovum.
4. If fertilisation does not take place, the endometrium tears away resulting in menstruation.

Figure 9 and Table 4 below summarise the changes that occur in the ovarian and uterine cycles over a period of 28 days (the menstrual cycle)

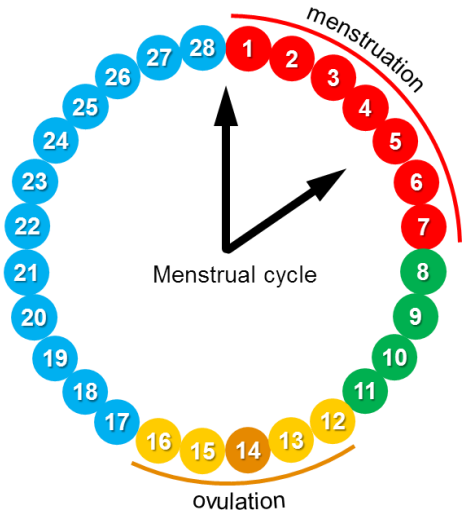


Figure 9: The menstrual cycle

Table 4: A summary of changes in the ovarian and uterine cycles

Days	Ovaries	Uterus
1 – 7	new follicles develop and secrete oestrogen	lining breaks down and is released (menstruation)
8 – 13	mature Graafian follicle develops and secretes oestrogen	oestrogen stimulates the endometrium to become thicker, more glandular and vascular
14	Graafian follicle bursts to release an ovum (ovulation)	
15 – 22	Graafian follicle becomes the corpus luteum which secretes progesterone	progesterone stimulates the endometrium to become even thicker, more glandular and more vascular to receive a fertilised ovum
23 – 28	no fertilisation: the corpus luteum shrinks and stops producing progesterone	
	with fertilisation: corpus luteum remains active and continues producing progesterone no more follicles develop no menstruation takes place	

The menstrual cycle:
https://www.youtube.com/watch?v=Vl2wRbO8LZU&list=PLW0gavSzhMlQYSpKryVcEr3ERup5SxHl0&index=11

Hormonal control of the menstrual cycle

The menstrual cycle is controlled by hormones. The ovarian cycle is influenced by follicle stimulating hormone and luteinizing hormone while the uterine cycle is influenced by oestrogen and progesterone. The levels of the hormones change during the different stages of the menstrual cycle and have an influence on each other.

The graph in Figure 10 below shows the changes in the levels of the individual hormones during the menstrual cycle.

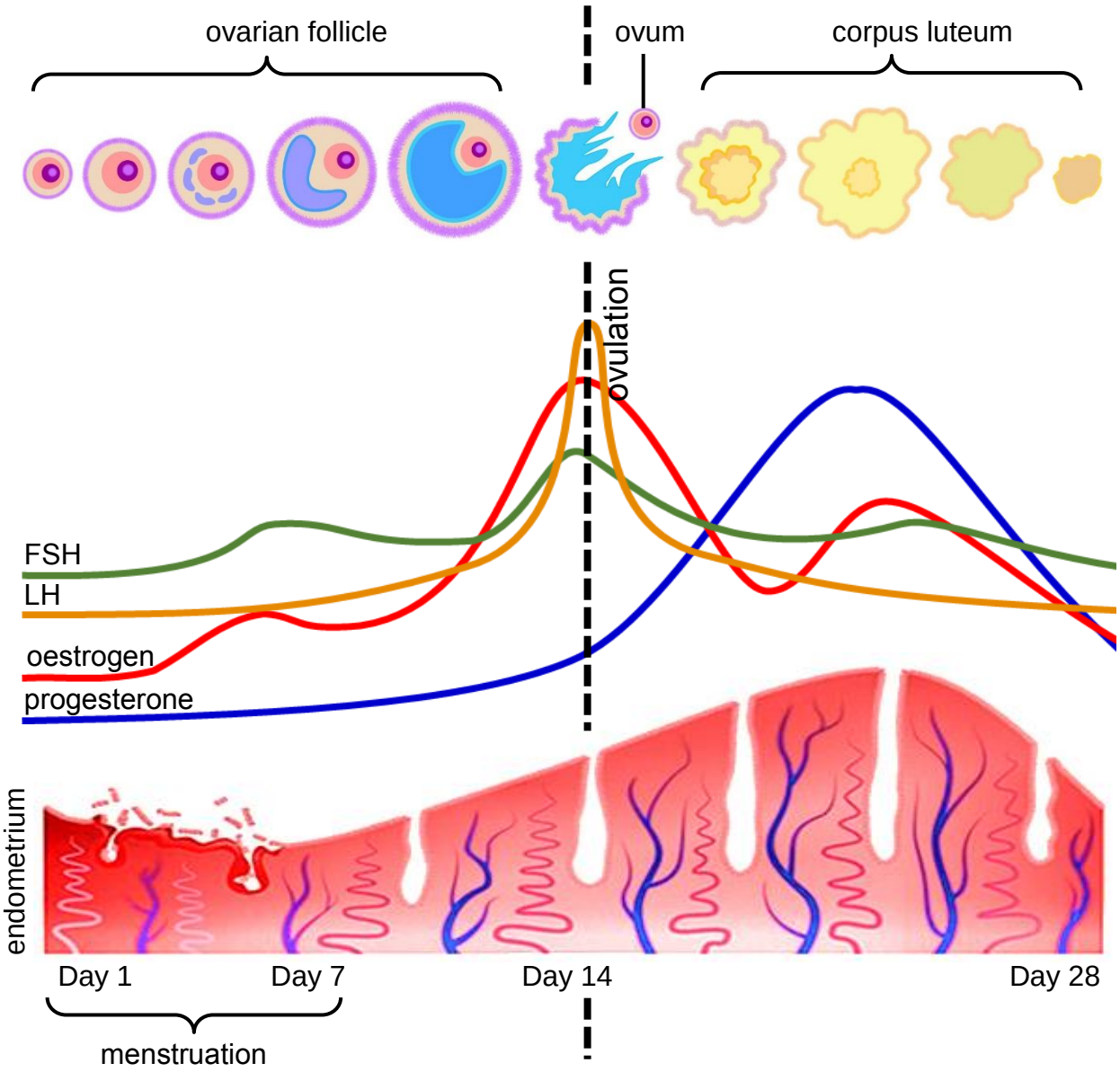


Figure 10: Hormonal control of the menstrual cycle

NOTE: This graph often appears in examinations. Make sure that you can interpret and understand what is happening to the levels of the different hormones and how they influence each other.

The hormonal control of the menstrual cycle takes place as follows:

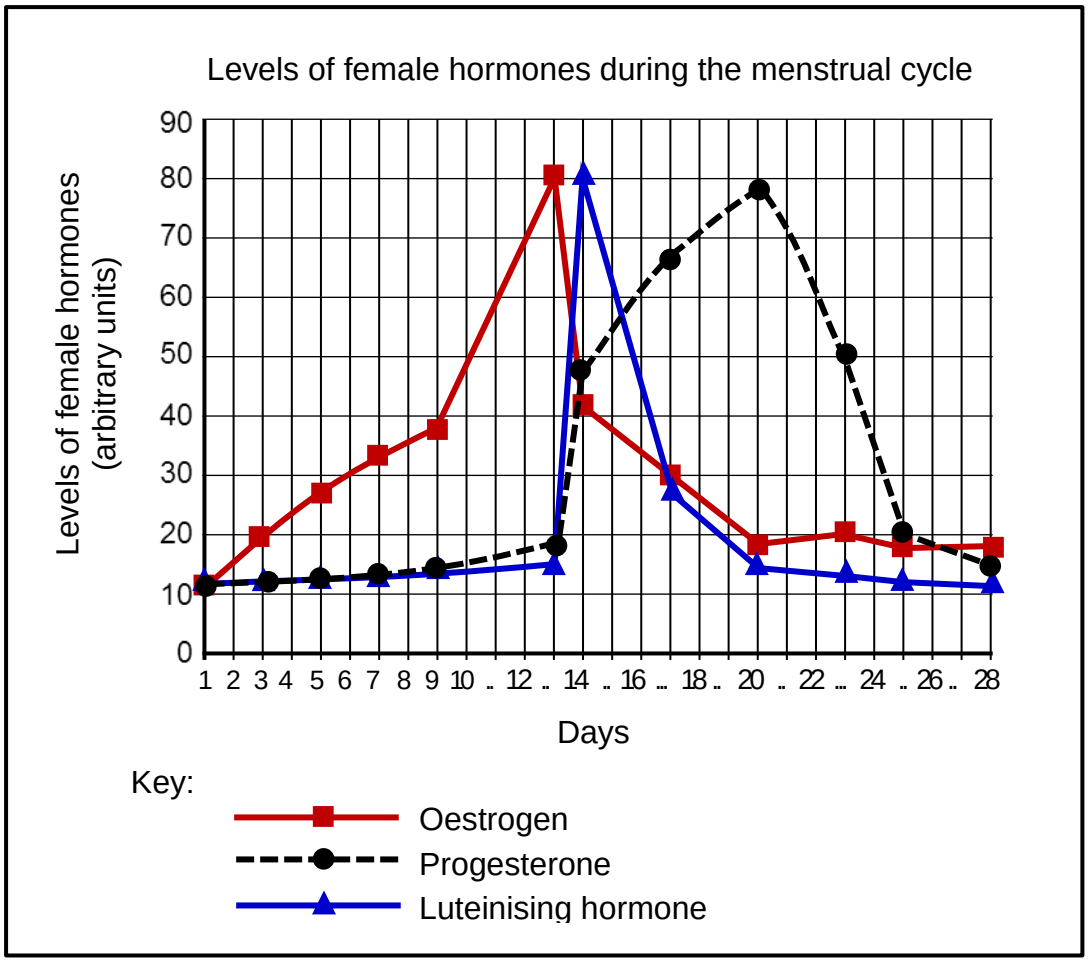
- Follicle stimulating hormone (FSH) released by the pituitary gland stimulates the development and maturation of a primary follicle in one of the ovaries
- As the follicle develops into a mature Graafian follicle it releases oestrogen
- The increasing oestrogen levels stimulate the pituitary gland to release luteinising hormone (LH)
- The increase in luteinising hormone (LH) causes ovulation to occur
- After ovulation occurs the Graafian follicle is changed into the corpus luteum which secretes progesterone
- The increased amount of progesterone prevents the release of follicle stimulating hormone and luteinising hormone (it inhibits them)
- As the corpus luteum breaks down the level of progesterone decreases, causing the endometrium to break down
- The endometrium and unfertilised ovum are released through the vagina as blood during menstruation
- Due to the decreased level of progesterone, the follicle stimulating hormone and the luteinising hormone are no longer inhibited. They are produced by the pituitary gland and the cycle begins again

Negative feedback mechanism between progesterone and FSH

A negative feedback system occurs in the menstrual cycle. A negative feedback mechanism is an interaction between two hormones, where an increase in one hormone stimulates an increase in the other hormone, which inhibits the first hormone, thus restoring balance. The negative feedback system can be seen in the hormonal control of the menstrual cycle where progesterone influences the secretion of follicle stimulating hormone. If the ovum is fertilised, the corpus luteum remains active and continues secreting progesterone. Increased levels of progesterone in the blood inhibit the secretion of the follicle stimulating hormone. As a result, no further development of the follicle occurs. Ovulation does not take place.

Activity 3: Hormones

Study the graphs below, then answer the questions that follow.

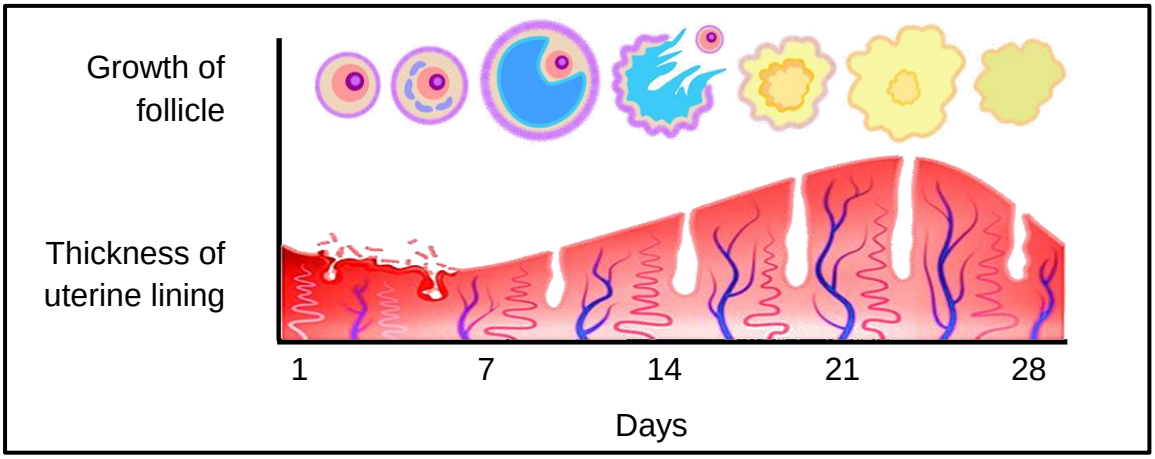


1. On which day did ovulation occur? (1)
2. Give one reason for your answer to question 1 that can be seen on the graph. (1)
3. Which structure in the ovary produces the following hormones?
   a) Oestrogen (1)
   b) Progesterone (1)
4. Explain why there is a sharp increase in the production of …
   a) oestrogen from day 9 to 13. (2)
   b) luteinising hormone from day 13 to 14. (2)
5. What conclusion can be drawn if the level of progesterone …
   a) Remains high from day 20 to 28? (1)
   b) Drops as shown in the graph above? (1)

(10)

Activity 4: Menstrual cycle

The diagram shows some of the changes that may take place during the menstrual cycle.



1. The menstrual cycle is controlled by hormones. Name one hormone that will increase in level between days 2 and 10. (1)

2. Give one observable reason for your answer to question 1. (2)

3. Explain what evidence there is in the diagram to indicate that no fertilisation took place? (3)

(6)

Fertilisation & development of zygote to blastocyst

During copulation (sexual intercourse) the penis is inserted into the vagina and sperm cells are released through ejaculation close to the cervix. The sperm cells swim through the cervix up into the uterus and through the fallopian tubes.

The haploid ovum released during ovulation enters the fallopian tubes. If an ovum (haploid) is present in the fallopian tubes, one sperm cell (haploid) may penetrate through the jelly layer and fertilise the ovum resulting in a diploid zygote. The nucleus of the ovum and the nucleus of the sperm cell fuse resulting in fertilisation.

The zygote divides by mitosis as it moves down the fallopian tube towards the uterus. Mitosis continues and a solid ball of cells known as the morula is formed. The morula develops into a hollow fluid-filled ball of cells called the blastocyst. Once the ovum is fertilised it takes approximately 5 days to form the blastocyst.

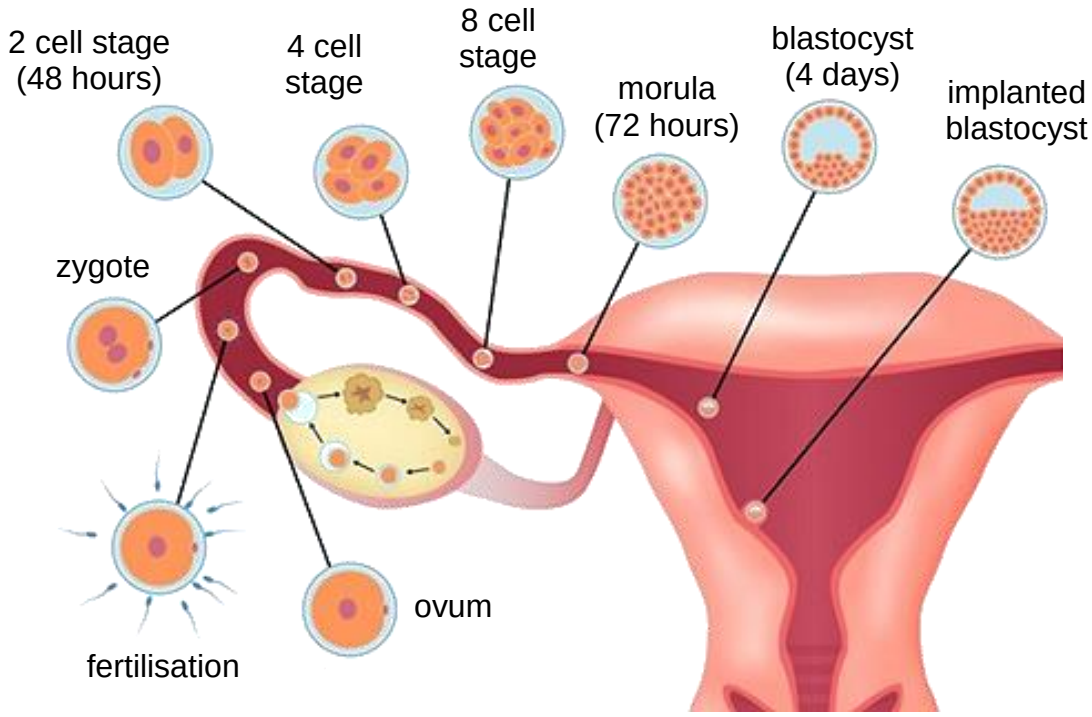


Figure 11: Fertilisation and development of the blastocyst

Development of the blastocyst to implantation:
https://www.youtube.com/watch?v=bHYAMjwgeV8

Implantation of the blastocyst and gestation

The blastocyst moves from the fallopian tube into the uterus where it embeds itself into the endometrium. This is known as implantation and takes place as follows:

- The outer cells of the blastocyst secrete enzymes which break down a small portion of the thickened uterine wall causing it to become softer
- The blastocyst sinks into this softer area and the outer layers develop into two extra-embryonic membranes called the **amnion** and the **chorion**
- The chorion extends finger-like outgrowths called the chorionic villi into the endometrium and form part of the placenta which secretes progesterone.
- The blastocyst is now called the embryo

The gestation period, also known as pregnancy, is the time in which the embryo develops inside the uterus. Gestation and the development of the embryo lasts for about 40 weeks or 280 days. After 12 weeks the embryo is known as a foetus.

The foetus contains extra-embryonic membranes and other structures which aid in the development of the embryo and these can be seen in Figure 11 below:

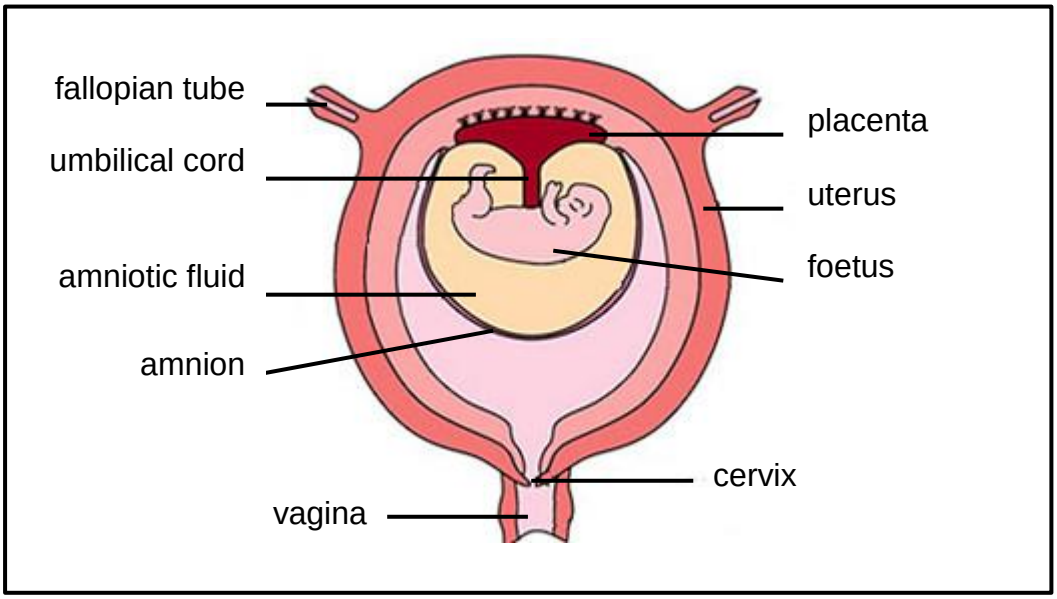


Figure 12: The foetus and its extra-embryonic membranes

The chorion, on the outside, forms the chorionic villi. The inner membrane, the amnion, becomes filled with amniotic fluid to form the amniotic sac. The amniotic fluid has the following functions:

- Protects the foetus against mechanical injury (shock-absorber)
- Prevents dehydration
- Maintains the temperature of the foetus
- Allows for free-movement of the foetus as it grows and develops

The umbilical cord attaches the foetus to the placenta and it contains umbilical blood vessels (see Figure 13 below):

- Two umbilical arteries which carry deoxygenated blood and waste products from the foetus to the placenta.
- One umbilical vein which carries oxygenated blood, nutrients, water and other substances from the placenta to the foetus.

The placenta is a temporary organ that forms in the area where the blastocyst implants. It allows for substances to be transferred by diffusion between the mother and foetus without any blood being in direct contact. This means that the mother and foetus' blood never actually mixes.

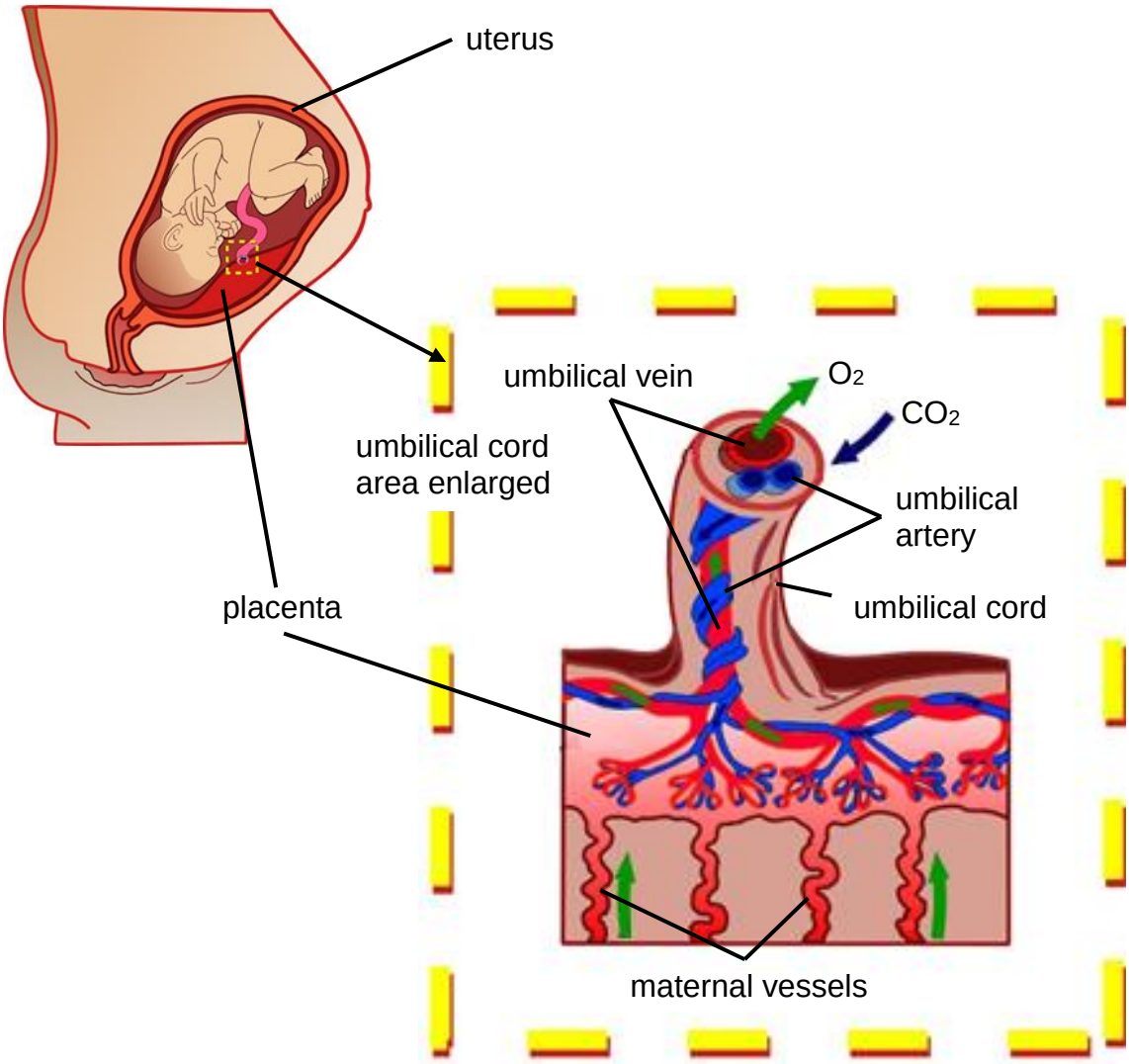


Figure 13: The umbilical cord

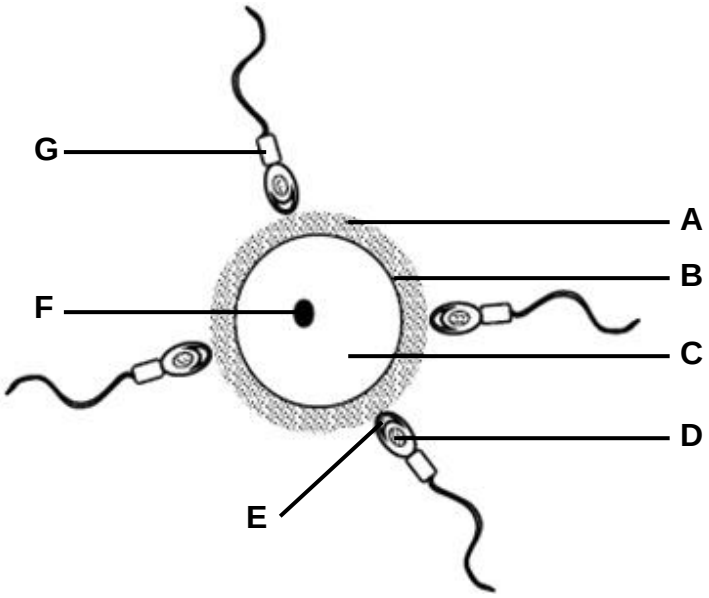
The placenta has the following functions:

- It is the point of attachment of the foetus to the mother
- It allows for diffusion of nutrients from the mother to the foetus
- It allows for the diffusion of oxygen from the mother to the foetus and for the diffusion of carbon dioxide from the foetus to the mother (gas exchange)
- It allows for the diffusion of waste products from the foetus to the mother
- After 12 weeks, the placenta secretes progesterone to maintain the pregnancy

The formation of a foetus: https://www.youtube.com/watch?v=-ekRRuSa_UQ&list=PLW0gavSzhMlQYSpKryVcEr3ERup5SxHl0&index=126

Activity 5: Fertilisation

The diagram below shows a human ovum about to be fertilised



1. Identify the parts labelled A – G. (7)
2. Give the letter of the part that …
   a) contains the mitochondria. (1)
   b) contains enzymes required to penetrate the ovum. (1)
   c) will enter the ovum during fertilization. (1)
3. Describe the developmental changes in the fertilised ovum until implantation occurs in the uterus. (5)
4. Define gestation. (1)

(16)

Reproduction in humans: End of topic exercises

Section A
Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A – D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D.

1.1.1 The following statements describe the functions of the placenta:

i. Serves as an attachment of the embryo to the mother
ii. Allows for the diffusion of dissolved nutrients from the mother to the foetus.
iii. Allows for diffusion of excretory wastes from the mother to the foetus
iv. Allows for diffusion of oxygen from the mother to the foetus.

Which one of the following combinations correctly describe the functions of the placenta?

A (i), (ii), and (iii)
B (ii) only
C (i), (ii) and (iv)
D (ii) and (iii)

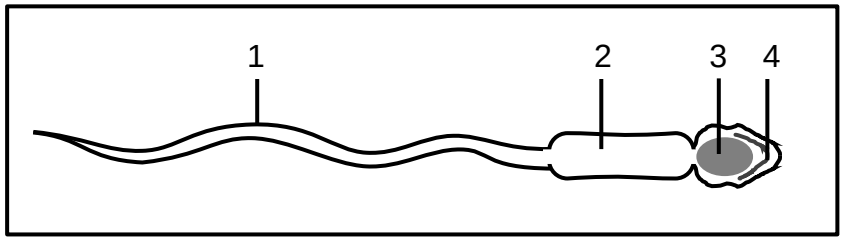
1.1.2 Contraceptive pills which prevent pregnancy are likely to contain…

A high levels of FSH and progesterone.
B high levels of LH and oestrogen.
C high levels of only FSH.
D high levels of only progesterone.

1.1.3 Before copulation the male sperm is stored temporarily in the…

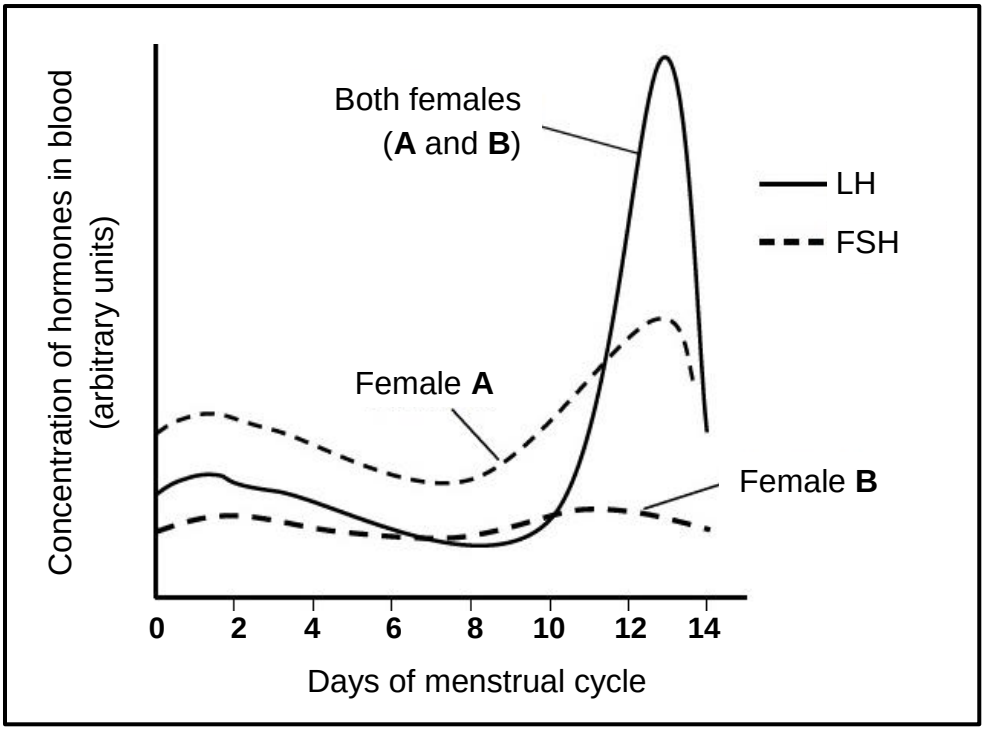
A seminal vesicles.
B scrotum.
C prostate gland.
D epididymis.

1.1.4 Which one of the following parts in the diagram of a sperm cell contains a haploid number of chromosomes?



A 1 B 2 C 3 D 4

1.1.5 The graph shows the changes in concentration of female hormones FSH and LH in two females during the first two weeks of the menstrual cycle.



Which one of the following statements is **correct** regarding female **A**?

A FSH increases on day 14 because the Graafian follicle is secreting progesterone.

B FSH increased after day 9 as the pituitary gland is secreting progesterone.

C FSH decreased after day 4 to ensure implantation occurs.

D FSH increases in the first two days to stimulate the development of the follicle.

(5 x 2) = (10)

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

1.2.1 The gland which produces a fluid to provide the sperm cells with energy.

1.2.2 The vesicle containing enzymes found in the head of a sperm cell.

1.2.3 The process which produces ova.

1.2.4 The type of fertilisation in which the nucleus of a sperm fuses with the nucleus of an ovum inside the body of the female.

1.2.5 A hormone that stimulates the development of the corpus luteum.

1.2.6 The fluid that protects the human embryo against injuries and large-scale temperature changes.

1.2.7 The blood vessel in the umbilical cord that transports nutrients to the foetus.

1.2.8 The inner lining of the uterus where implantation of the embryo occurs.

1.2.9 A type of reproduction in humans where the foetus develops inside the uterus.

1.2.10 The stage in humans were sexual maturity is reached.

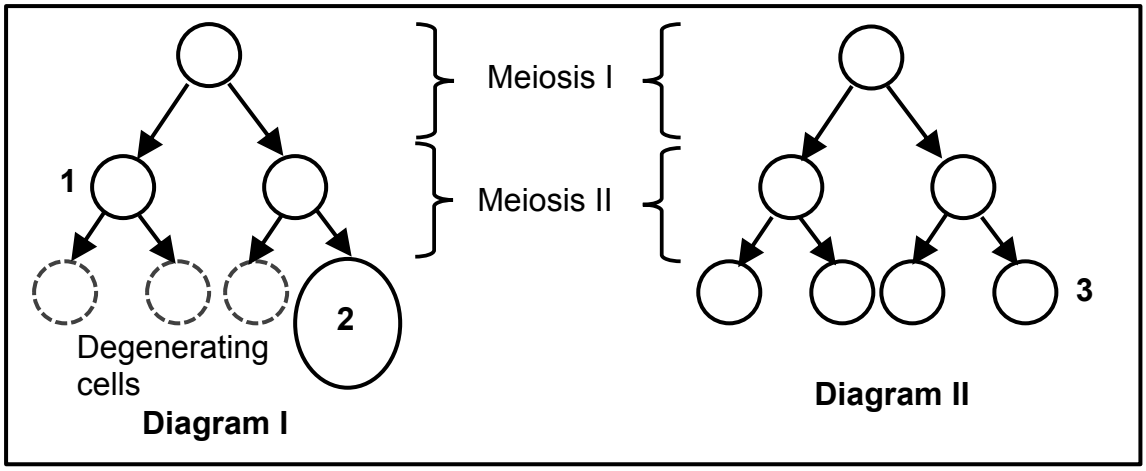
(10 x 1) = (10)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Forms the placenta	A: chorionic villi B: endometrium
1.3.2 The production of ova by meiosis	A: menopause B: ovulation
1.3.3 A hollow ball of cells into which fertilised ovum develops	A: amnion B: chorion
1.3.4 The reproductive structures where meiosis occurs.	A: testes B: ovaries
1.3.5 Place where fertilisation occurs in humans	A: cervix B: fallopian tube

(5 x 2) = (10)

1.4 Diagrams I and II below (not to scale) represent gametogenesis in human males and females (not in any particular sequence).



1.4.1. Identify the specific type of gametogenesis in Diagram I. (1)

1.4.2. Explain your answer to question 1.4.1 by referring to a visible difference between Diagram I and Diagram II. (2)

1.4.3. Where in the human body does the type of gametogenesis shown in Diagram II take place? (1)

1.4.4. Give the chromosome number of:

a) the cells at 1 (1)

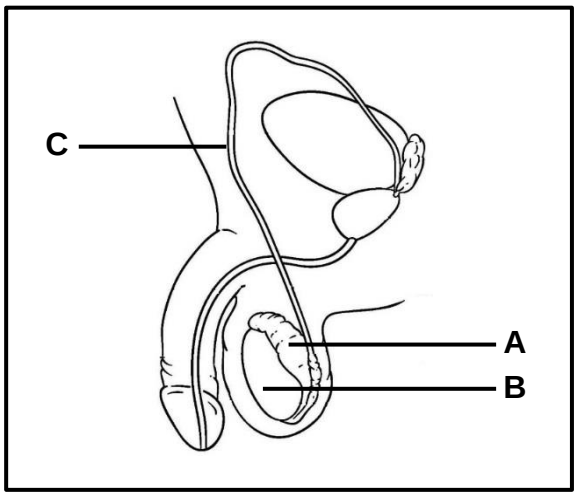
b) cell 2 (1)

1.4.5. Name two processes that take place during Meiosis I that lead to genetic variation in the four cells at 3 in Diagram II. (2)

1.4.6. Explain the implication for the human population size if the three cells referred to in Diagram I did not degenerate, but remained as gametes. (2)

(10)

1.5 Study the diagram below and answer the questions that follow.



1.5.1 Give labels for each of the following:

a) **A** (1)

b) **B** (1)

c) **C** (1)

1.5.2 State one function of part **A**. (1)

1.5.3 What is the name of the structure in which part **B** is enclosed? (1)

1.5.4 Explain the consequences for reproduction if part **C** is surgically cut. (3)

1.5.5 Explain why it would still be possible for an HIV-positive man to infect another person during sexual intercourse after part **C** is surgically cut. (2)

(10)

Section A: [50]

Section B

Question 2

2.1 An investigation was carried out to determine the effects of smoking during pregnancy on the baby's birth weight. Babies born weighing 2 499 g or less have a low birth weight.

The table below compares the percentage of babies with a low birth weight born to mothers who smoked with mothers who did not smoke in a certain city in 2009.

Birth weight (grams)	**Percentage of total births in 2009**	
	Mothers who smoked	**Non-smoking mothers**
< 1000	0,7	0,2
1000 – 1499	0,9	0,3
1500 – 1999	2,2	1,1
2000 – 2499	7,1	3,2

(adapted from www.ainw.gov.au)

2.1.1 Draw a histogram to represent the percentage of births in each weight group born to mothers who smoked. (6)

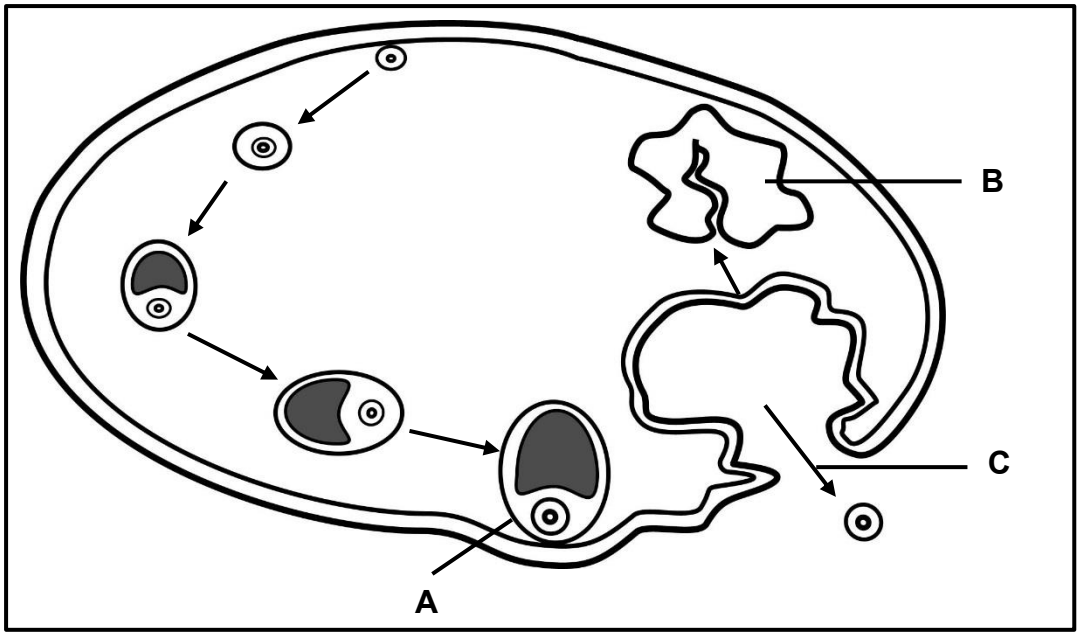
2.1.2 Why were babies that weighed more than 2 500 g at birth not included in the investigation? (1)

2.1.3 State a general conclusion for the investigation based on the data in the table. (2)

2.1.4 Describe how chemicals from cigarette smoke are able to reach the baby's blood from the mother's blood. (2)

(11)

2.2. The diagram below represents the sequence of events that takes place during the ovarian cycle of a female.



2.2.1 Give the name of the:

a) Hormone that controls the development of structure **A**. (1)

b) Process taking place at **C**. (1)

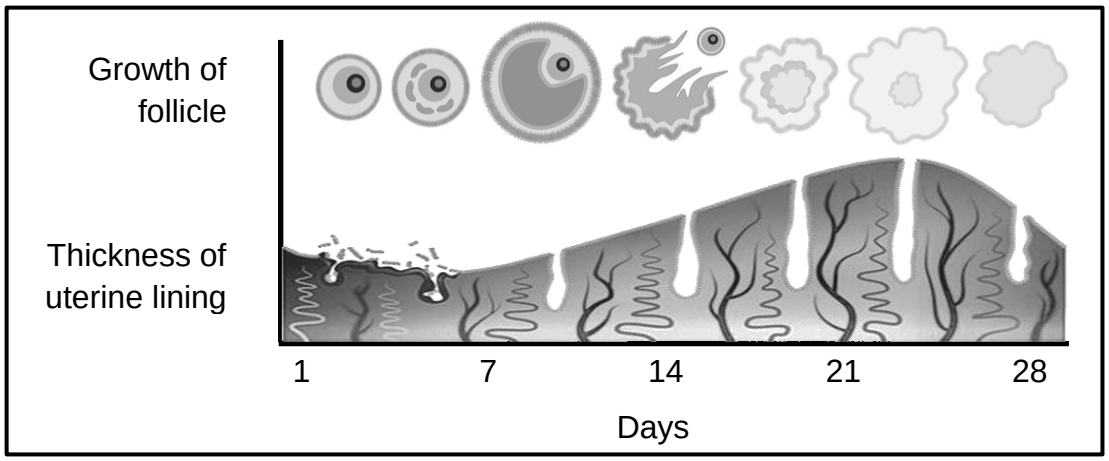
2.2.2 Structure B degenerates if fertilisation does not take place. Explain the implications of this for the …

a) ovarian cycle (2)

b) uterine cycle (2)

(6)

2.3. The diagram shows some changes during the menstrual cycle.



2.3.1 Describe the developmental changes in the fertilised ovum until implantation occurs in the uterus. (4)

2.3.2 Some females use an ovulation monitor so that they can be aware of the days when they are fertile. These monitors measure the level of hormones in the blood.

a) Why would females want to know when they are fertile? (1)

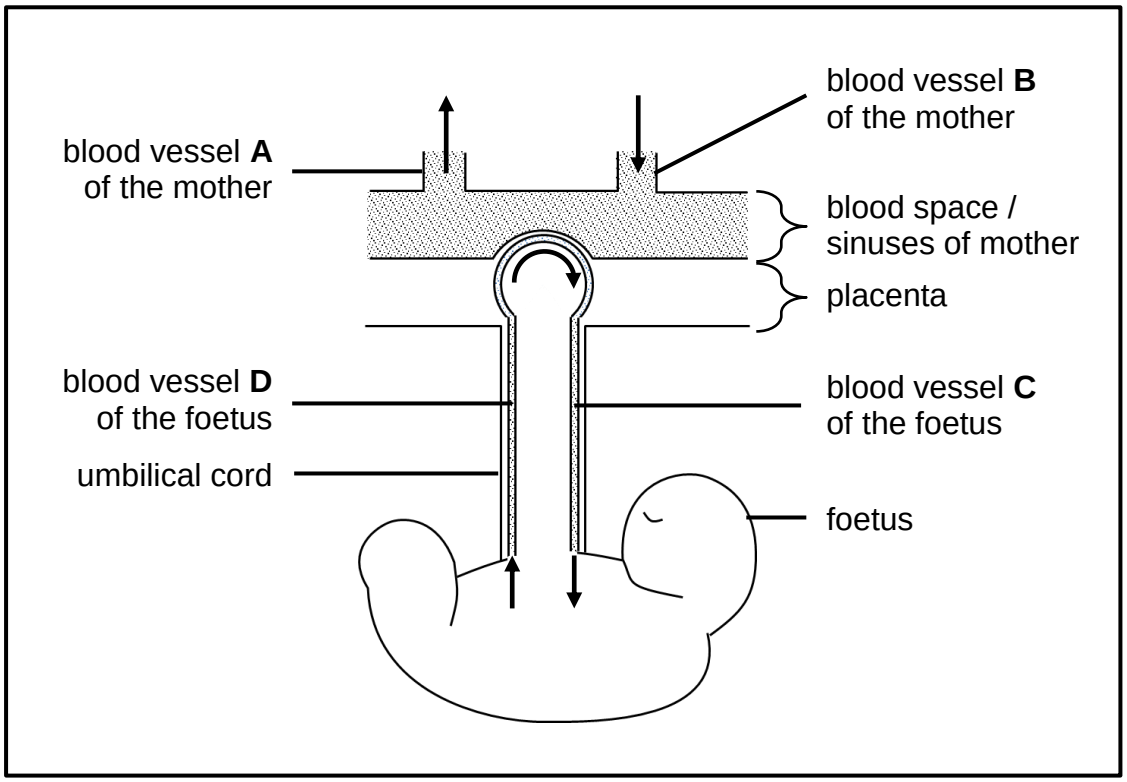
b) Explain which hormone is likely to be monitored by the ovulation monitor. (3)

(8)

[25]

Question 3

3.1 The diagram below represents the relationship between the blood system of the foetus and that of the mother. The arrows indicate the direction of blood flow in the blood vessels.



3.1.1 Apart from playing a role in the diffusion of substances from the mother's blood to the foetus' blood, and vice versa, state two other functions of the placenta. (2)

3.1.2 Blood vessel **D** is an artery. Tabulate two differences between the composition of the blood found in blood vessel **C** and blood found in blood vessel **D**. (5)

3.1.3 Explain one consequence for the foetus if blood vessel **D** becomes blocked preventing blood flow. (2)

3.1.4 If the blood of the mother and the blood of the foetus come into contact with each other, it could lead to the death of the foetus. Describe why this would occur. (2)

(11)

3.2 Read the following extract and answer the questions that follow.

> Several recent studies have suggested a gradual decline in sperm production in men. Endocrine disruptions as well as life style have been suggested as risk factors. One life style factor that may affect human fertility is driving a vehicle for a prolonged period. It is suggested that the driving position may increase the scrotal temperature.

3.2.1 State any one risk factor identified by the researchers. (1)

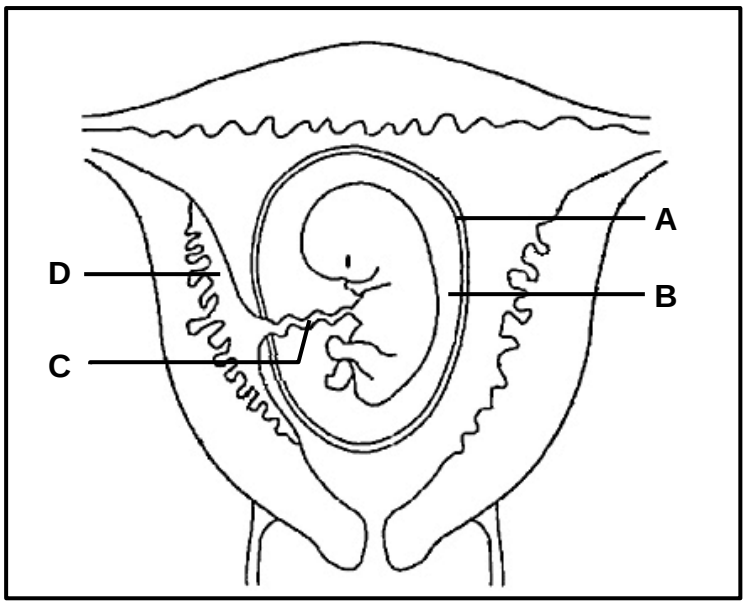
3.2.2 Explain why regular long-distance driving with no breaks could possibly lower the sperm count in healthy males. (3)

3.2.3 Suggest a consequence of lower sperm count in males. (2)

3.2.4 State any one daily life style trend or routine (other than the one mentioned in the extract) that should be avoided to maintain the optimum scrotal temperature. (1)

(7)

3.3 The diagram below represents a developing foetus in a human body.



3.3.1 Identify:

a) **A** (1)

b) **C** (1)

3.3.2 State two functions of the fluid **B**. (2)

3.3.3 Name one system in the baby's body that takes over the function of part **D** once the baby is born. (1)

3.3.4 Explain one negative impact on the foetal development if part **D** is reduced significantly. (2)

(7)

[25]

Section B: [50]

Total marks: [100]


Strand
diversity
change
and
continuity

5: Genetics and inheritance

CHAPTER 5: GENETICS AND INHERITANCE

Introduction

This section will build on what you have learnt about DNA, protein synthesis, meiosis and sexual reproduction and to help you understand how genetic characteristics e.g. physical structure, is passed down from generation to generation.

- Genetics is the study of heredity – how genetic characteristics are passed on from parents to child.
- Every individual inherits a set of genes found in chromosomes from a father and a mother which is unique to that individual but similar enough to identify the individual's species.

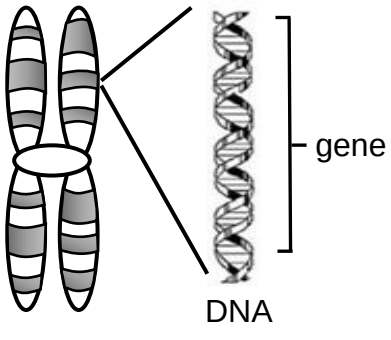
Key terminology

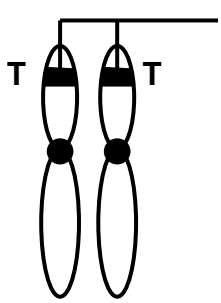
hereditary	passing of hereditary characteristics from parent to offspring
filial generation (F_1)	offspring of parent organisms
locus	the exact position (location) of a gene on a chromosome
genetic engineering	techniques used to change the genetic material of a cell or living organism – a form of biotechnology

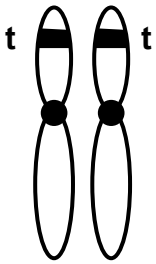
Concepts in inheritance

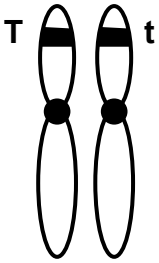
Table 1 below provides further definitions and explanations of key terms that you must know very well.

Table 1: Terms, their explanation and supporting diagrams and notes.

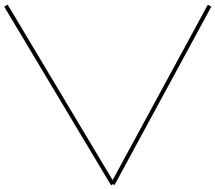
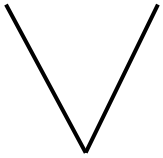
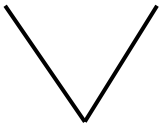
gene	a segment of DNA in a chromosome that contains the code for a particular characteristic	

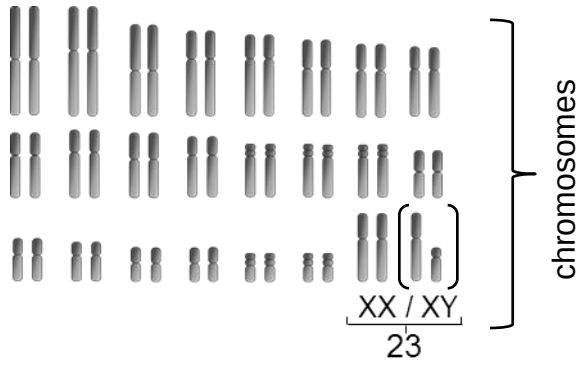
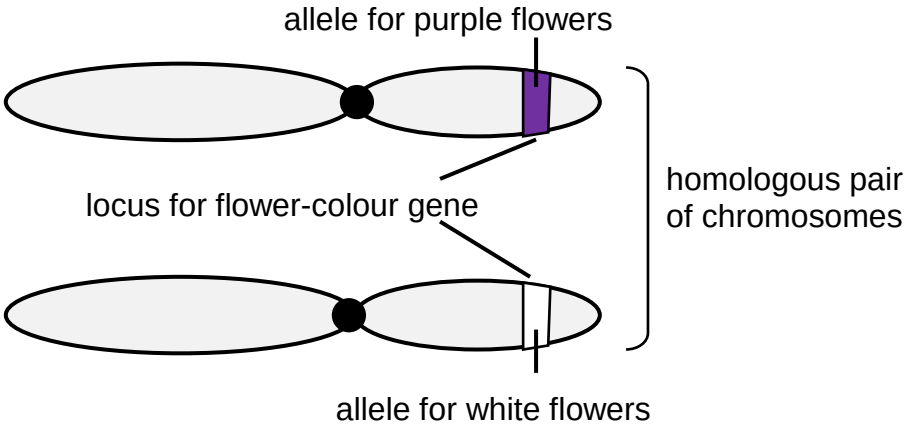
<table>
<tr><td>alleles</td><td>different forms of a gene which occur at the same locus on homologous chromosomes</td><td>dominant allele (T) – tall plant
recessive allele (t) – short plant</td></tr>
<tr><td>genotype</td><td>genetic composition of an organism</td><td rowspan="6"> 

homozygous dominant (both alleles are dominant)
genotype TT
phenotype – tall


homozygous recessive (both alleles are recessive)
genotype tt
phenotype – short


heterozygous (one dominant and one recessive allele)
genotype Tt
phenotype - tall</td></tr>
<tr><td>phenotype</td><td>the physical appearance of an organism based on the genotype, e.g. tall, short</td></tr>
<tr><td>dominant allele</td><td>an allele that is expressed (shown) in the phenotype when found in the heterozygous (Tt) and homozygous (TT) condition</td></tr>
<tr><td>recessive allele</td><td>an allele that is masked (not shown) in the phenotype when found in the heterozygous (Tt) condition; only expressed in the homozygous (tt) condition</td></tr>
<tr><td>heterozygous</td><td>two different alleles for a particular characteristic, e.g. Tt</td></tr>
<tr><td>homozygous</td><td>two identical alleles for a particular characteristic, e.g. TT or tt</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>monohybrid cross</td><td>only one characteristic or trait is shown in the genetic cross</td><td>Flower colour only, e.g. yellow or white flower – OR – shape of seeds only, e.g. round seeds or wrinkled seeds</td></tr>
<tr><td>dihybrid cross</td><td>two different characteristics shown in genetic cross</td><td>Example: flower colour, e.g. yellow or white flower – AND – shape of seeds, e.g. round seeds or wrinkled seeds</td></tr>
</table>

complete dominance	a genetic cross where the dominant allele masks the expression of a recessive allele in the heterozygous condition	- the allele for tall (T) is dominant over the allele for short (t) - offspring will be **tall** because the dominant allele (T) masks the expression of the recessive allele (t)	Tall (TT) x short (tt)  Tall (Tt)
incomplete dominance	cross between two phenotypically different parents produces offspring different from both parents but with an intermediate phenotype	a red-flowered plant is crossed with a white-flowered plant – with incomplete dominance, offspring will have **pink flowers - intermediate colour.**	red × white flower  pink flowers
co-dominance	cross in which both alleles are expressed equally in the phenotype.	red-flowered plant is crossed with a white-flowered plant – with co-dominance, the offspring has flowers with red and white patches	red × white flower  flowers with red and white patches
multiple alleles	more than two alternative forms of a gene at the same locus	blood groups are controlled by three alleles, namely I^A, I^B and i. all three alleles are present in a population, but an individual can only have two alleles	
sex-linked characteristics	traits that are carried in the sex chromosomes	Some examples: haemophilia and colour-blindness - alleles for haemophilia (or colour-blindness) are indicated as superscripts on the sex chromosomes, e.g. X^HX^H (normal female), X^HX^h (normal female), X^hX^h (female with haemophilia), X^HY (normal male), X^hY (male with haemophilia). Both haemophilia and colour blindness are caused by recessive alleles.	

karyotype	the number, shape and arrangement of the chromosomes in the nucleus of a somatic cell	
cloning	process by which genetically identical organisms are formed using biotechnology	Dolly the sheep was cloned using a diploid cell from one parent; therefore, it had the identical genetic material of that parent
genetic modification	manipulation of the genetic material of an organism to get desired changes	An example*:* insertion of the human insulin gene into the plasmid of bacteria so that the bacteria produce human insulin
human genome	mapping of the exact position of all the genes in all the chromosomes of a human	Example: haemophilia is the last gene on the X chromosome; gene number 3 on chromosome 4 is responsible for a particular characteristic
homologous pair of chromosomes	a set of one maternal and one paternal chromosome that pair up with each other inside a cell during meiosis – homologous chromosomes are the same size and shape, and carry the same or similar alleles	

Activity 1: Traits, genes and alleles

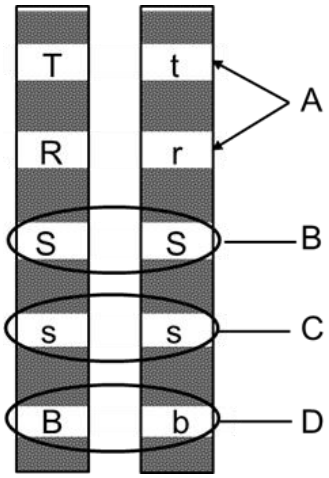
1. The paired letters in the diagram below represent alleles of a gene. A number of genes for different characteristics are shown. Write down the relevant letter (A – D) for:

   a) The homozygous dominant state

   b) Two alleles from different genes

   c) The homozygous recessive state

   d) The heterozygous state (4)



2. What is the relationship between a gene and a protein? (2)

3. What is an allele? (2)

4. What terms describe a pair of alleles that are:

   a) the same?

   b) different? (2)

5. Write a definition of homologous chromosomes using the terms “genes” and “alleles”. (3)

6. How are alleles represented? (1)

7. Fill in the table below with the missing genotype, phenotype (dominant or recessive), or alleles (TT, Tt, tt) (6)

Genotype	Phenotype	Alleles
homozygous dominant		
	short	t / t

8. Draw a pair of homologous chromosomes. Label the chromosomes with two sets of genes, one with homozygous dominant alleles, one with homozygous recessive alleles and one with heterozygous alleles. (5)

(25)

Mendel as father of genetics

Gregor Mendel, an Austrian monk (a type of priest), is regarded as the father of genetics for his work on garden pea plants that helped explain **how genes are passed from parents to offspring.**

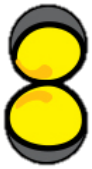
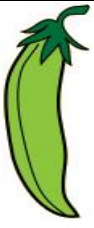
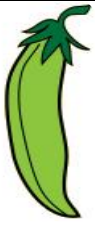
Figure 1: Gregor Mendel

Mendel's work on the genetics of peas began with the observation of peas to determine what traits were inherited. He noticed at least 7 traits that appeared to be inherited.

These traits were (see Table 2):

- seed shape
- seed colour
- pod shape (pod – the container holding a plant's seeds)
- pod colour
- flower colour
- flower position (whether axial – on the side, or terminal – on top)
- stem length

Table 2: Traits compared by Mendel

Seed		**Pod**		**Flower**		**Size**
shape	*colour*	*shape*	*colour*	*position*	*colour*	
 round	 yellow	 full	 green	 axial	 purple	 tall
 wrinkled	 green	 constricted	 yellow	 terminal	 white	short 

Mendel's Experiments

- Mendel noticed that garden peas occur in at least two heights – tall (T) and short (t)
- Since peas are self-pollinating, tall peas tend to produce tall peas, and short peas produce short peas.
- Mendel's first genetic cross involved tall peas cross-pollinated with short peas
- The result: in the first group of offspring (the **F_1** generation), the cross yielded only tall peas
- Mendel then took the F_1 peas and crossed them with themselves (interbreeding) to produce a second group of offspring (an **F_2** generation)
- The result: tall and short peas, in a ratio of 3:1 (3 tall: 1 short or dwarf)

This experiment of Mendel's may be illustrated in the diagram as in Figure 2 below.

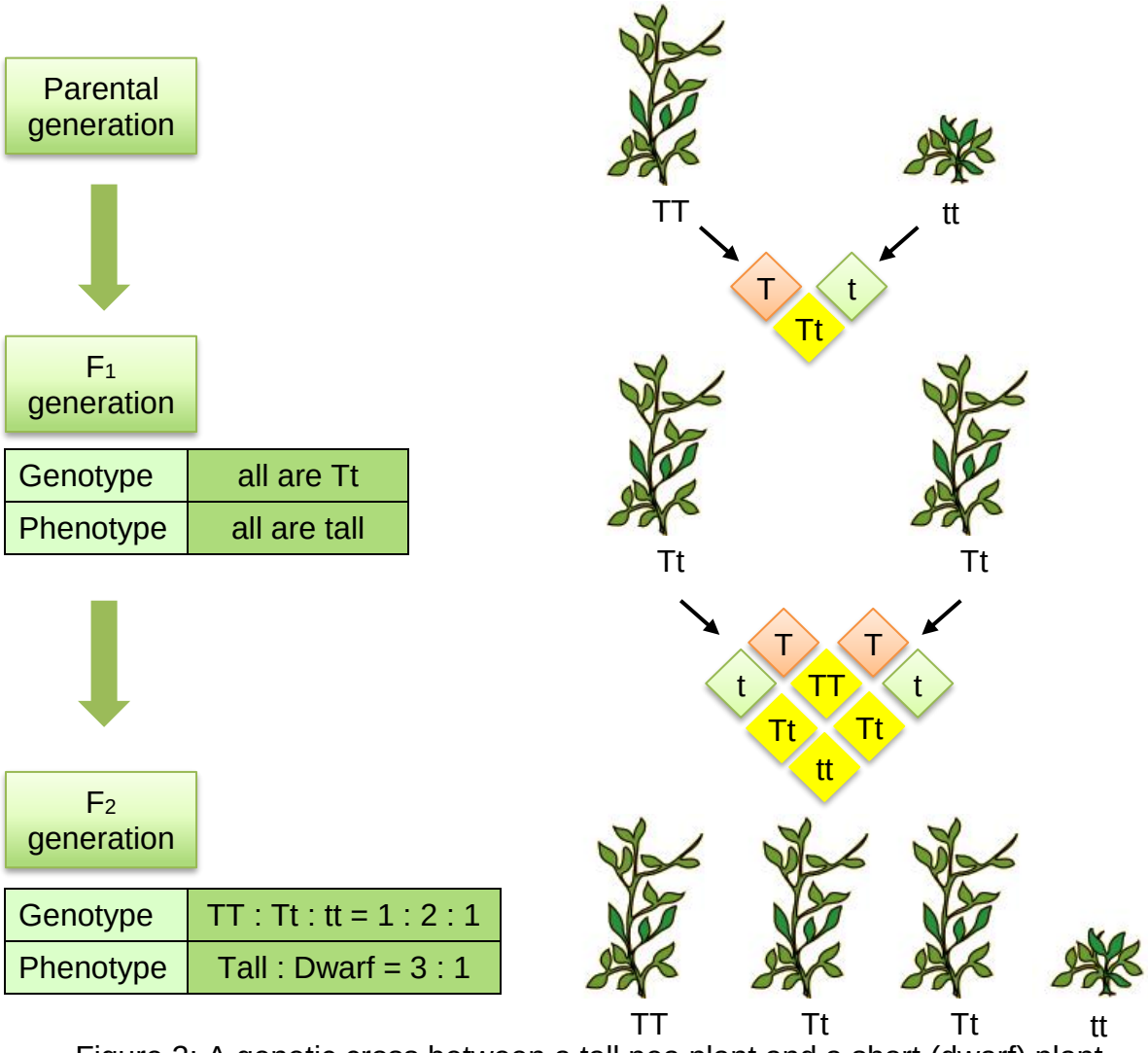


Figure 2: A genetic cross between a tall pea plant and a short (dwarf) plant

Mendel's Laws of Inheritance

Mendel formulated the following laws from his experiments.

Mendel's First Law of Inheritance: Law (principle) of Segregation

- Each trait is controlled by two factors (now known as alleles) situated on homologous chromosomes.
- When gametes form during meiosis, the two factors (alleles) are separated or segregated. A gamete contains one of the two factors (alleles) from each parent.

Mendel's Second Law of Inheritance: Law of Dominance

- Certain alleles of a gene exist in either a dominant or a recessive form.
- If the pair of alleles are different (one dominant, one recessive), the phenotype will only show the dominant trait.

Mendel's Third Law of Inheritance: Law (principle) of Independent Assortment

- Due to random arrangement of chromosomes at the equator during meiosis (gamete formation), any one of the two alleles of ONE characteristic can sort with any one of ANOTHER characteristic.
- The alleles of different genes move independently of each other into the gametes. They can therefore appear in the gametes in different combinations.

Genetic diagrams

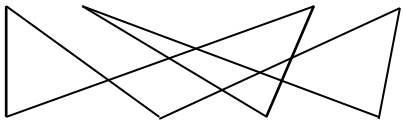
- It is important to start with a **PAIR** of alleles in the mother and another **PAIR** in the father because each individual inherits TWO alleles for a gene – one maternal and one paternal (the bivalent chromosomes).
- This **pair** may be identical (HOMOZYGOUS) or different (HETEROZYGOUS) alleles.
- Alleles are represented by **letters**: CAPITALS (for dominant alleles) or small letters (for recessive alleles).
- P stands for the **P**arent generation

- F stands for the offspring (**F**ilial generation) – remember **F** for Family.

  F_1 generation is the first filial generation, F_2 the second.

Genetic crosses

It is important to learn the **exact** layout because marks are allocated for the layout as well as the correct working out of the cross. Use the following genetic diagram or template to solve all genetic crosses.

<table>
<tr><th>Layout of a genetic diagram</th><th>Explanation</th></tr>
<tr><td>
P₁ Phenotype ……... x ……✓
Genotype …… x ……✓
Meiosis Gametes …… x ……..…….. ✓
Fertilisation 
F₁ Genotype ……..✓
Phenotype ……..✓
P_1 and F_1 ✓
Meiosis and fertilisation✓
</td><td rowspan="3">Visible trait is the phenotype e.g. tallness, shortness, etc.

The genetic make-up of the individual is its genotype e.g. TT or Tt or tt

The alleles segregate (or separate) during meiosis to form gametes. Each gamete has only one copy of each allele

During fertilisation the individual gets one allele of the gene form each parent

The matrix box used to determine the results of fertilisation is called a Punnet square</td></tr>
<tr><td>OR</td></tr>
<tr><td>
P₁ Phenotype ……... x ……✓
Genotype …… x ……✓
Meiosis Gametes …… x ……..…….. ✓
Fertilisation
<table>
<tr><td>Gametes</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>
F₁ Phenotype ……..✓
Genotype ……..✓
P_1 and F_1 ✓
Meiosis and fertilisation✓
</td></tr>
</table>

IMPORTANT: You may also be asked to work out the ratio or % chance of the various pheno-/genotypes occurring. So, if there are 4 possible geno- or phenotypes in total and only 1 having a particular phenotype, it will be a 1 in 4 ratio (25% chance)

You need to read genetics questions with great care to find the clues concerning:

- which characteristic (phenotype) is being examined, e.g.: shape of seeds
- which allele of the pair is dominant, e.g.: round
- whether the parents are homozygous or heterozygous for the characteristic: e.g.: both are heterozygous
- what letters are to be used (are they given OR must you choose letters), e.g.:

  R (dominant allele) and r (recessive allele)
- show how the alleles are separated during meiosis to form gametes
- show all the possible ways the sperm and egg can combine during fertilisation
- distinguish the phenotypes from the genotypes

Monohybrid crosses

Monohybrid crosses refer to genetic crosses that involve only a single characteristic or trait. ***Dihybrid*** crosses involve two characteristics or traits.

The following monohybrid crosses are dealt with:

- monohybrid crosses with complete dominance
- monohybrid crosses with incomplete dominance
- monohybrid crosses with co-dominance
- sex determination
- inheritance of sex-linked diseases
- multiple alleles e.g.: blood grouping

Monohybrid crosses with complete dominance

Mendel's work as discussed above shows monohybrid crosses with complete dominance. In complete dominance, the dominant allele masks or blocks the expression of the recessive allele in the heterozygous condition.

The following example represents a genetic cross which shows complete dominance.

Genetic problem 1

Seeds can be round or wrinkled. Use a genetic cross to show the genotype and the phenotype of the F_1 generation when two heterozygous plants with round seeds are crossed. The allele for round seeds is dominant over the allele for wrinkled seed. Use the letter **R** for round and **r** for wrinkled seeds.

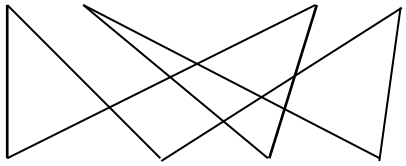
P_1 Phenotype **Round seeds** x **Round seeds**

Genotype **Rr** x **Rr**

Meiosis

Gametes **R** **r** x **R** **r**

Fertilisation



F_1 Genotype **RR** **Rr** **Rr** **rr**

Phenotype **round seeds** **round seeds** **round seeds** **wrinkled seeds**

OR

P_1 Phenotype **round seeds** x **round seeds**

Genotype **Rr** x **Rr**

Meiosis

Gametes **R** **r** x **R** **r**

Fertilisation

Gametes	**R**	**r**
R	**RR**	**Rr**
r	**Rr**	**rr**

F_1 Phenotype **round seeds** **round seeds** **round seeds** **wrinkled seeds**

Genotype **RR** **Rr** **Rr** **rr**

Genotypic Ratio : 1RR : 2Rr : 1rr (1:2:1)

Phenotypic Ratio: 3 Round seeds: 1 Wrinkled seed (3:1)

- A cross between two heterozygous (Rr) parents produces 25% homozygous dominant (RR), 50% heterozygous (Rr) and 25% homozygous recessive (rr) offspring. As such, the phenotypic ratio is 3 dominant : 1 recessive.

Activity 2: Monohybrid crosses with complete dominance

1. Mendel crossed homozygous plants with green seeds with homozygous plants which had yellow seeds and found that all the offspring were yellow (Figure 3). Construct a genetic diagram (using the above template) to show the **F_1** and **F_2** generations.

   Choose a letter for each allele. Note: use one letter: capitalised for the dominant allele and small (lower-case) for the recessive allele. (6 + 6)

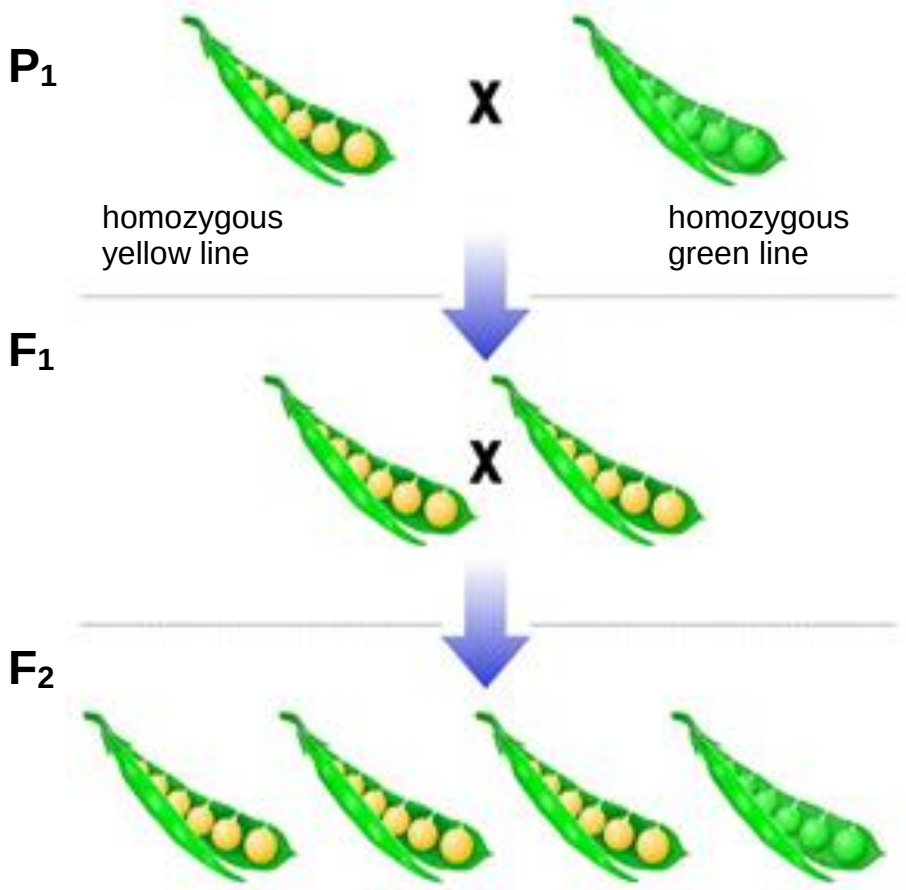


Figure 3: Monohybrid cross showing inheritance of seed colour

2. The ability to roll one's tongue (Figures 4 and 5) is a dominant characteristic. Explain (without a genetic diagram) why it is possible for a non-roller child to be born to parents who can both roll their tongues. Use the letters **R** and **r** in your answer. (3)

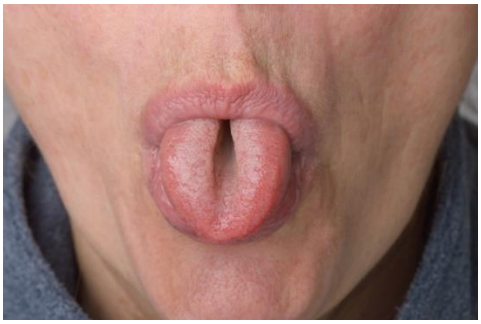


Figure 4: Tongue-roller

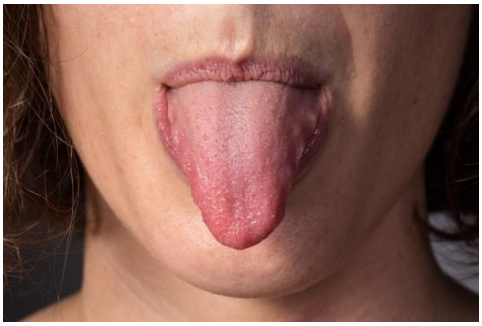


Figure 5: Non-roller

(15)

Monohybrid cross with incomplete dominance

Incomplete dominance is a cross between two phenotypically different parents where no allele of the gene is either dominant or recessive. The offspring is different to both parents and the alleles blend to form a **new phenotype**.

The following problem represents a genetic cross which shows incomplete dominance:

Genetic problem 2

A homozygous red-flowering plant crossed with a homozygous white- flowering plant will produce plants that have pink flowers (Figure 6).

Complete a genetic diagram to show how this is possible using the letter **R** for red and **W** for white.

P_1 Phenotype **Red** x **White**

Genotype **RR** x **WW**

Meiosis

Gametes **R R** x **W W**

Fertilisation

Gametes	R	R
W	RW	RW
W	RW	RW

F_1 Genotype **RW RW RW RW**

Phenotype **All Pink**

The characteristic being investigated is flower colour; the alleles are red (**R**) and white (**W**).

The genotype of the parents will be **RR** and **WW** as they are homozygous where both alleles for the gene are the same.

The fact that the offspring have a new phenotype **pink** which is formed from red and white, tells you that there is no dominant or recessive allele.

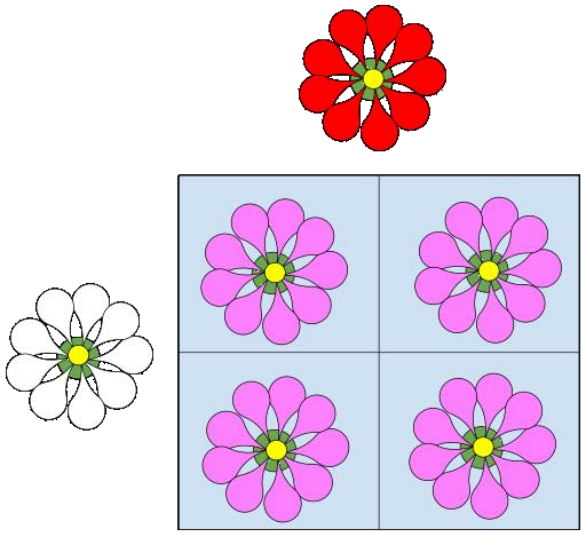


Figure 6: Monohybrid cross with incomplete dominance

Activity 3: Monohybrid cross with incomplete dominance

1. Two grey mice were mated. Some of the offspring were grey, others black and some white. How is this possible? Do a genetic cross to explain this result. (6)

2. Incomplete dominance is seen in the inheritance of hypercholesterolemia (high blood cholesterol levels). **H** represents the allele for very high levels and **L** for low levels.

   2.1 Sipho and Andiswa are both heterozygous for this characteristic and both have high cholesterol levels but not as high as their daughter Sihle who has levels that are six times above normal. She is homozygous for high cholesterol levels. Do a full genetic diagram to explain your answer. (7)

   2.2 What is the percentage chance that their next child will have …

   a) low cholesterol levels? (1)

   b) extremely high cholesterol levels like Sihle? (1)

(15)

Monohybrid crosses with co-dominance

In co-dominance **both** alleles of the gene are equally dominant so both will be expressed equally in the phenotype of the offspring.

The following problem represents a genetic cross which shows co-dominance:

Genetic problem 3

In cattle three colour variations are possible (Figure 7): red, white or red and white in patches. This comes about due to a red allele (**R**) and a white allele (**W**) for coat colour. Do a genetic cross between a red bull and a white female to show the possible offspring.

P_1 Phenotype **Red coat** x **White coat**

Genotype **RR** x **WW**

Meiosis

Gametes **R R** x **W W**

Fertilisation

Gametes	R	R
W	RW	RW
W	RW	RW

F_1 Genotype **RW RW RW RW**

Phenotype **All red with white patches**

Figure 7: Co-dominance in cattle showing 3 coat colours

The characteristic being investigated is coat colour which is controlled by two alleles R and W. The F_1 offspring show both phenotypes together so this is co-dominance.

The offspring will have a genotype of RW which is red and white patches.

Do this cross for yourself, and then cross two of the F_1 offspring to see what the possibilities would be in the F_2 generation.

Note: Inheritance of blood groups is also partly an example of co-dominance when the alleles I^A and I^B are involved. This will be dealt with later.

Sex determination

The following problem represents a genetic cross which shows inheritance of sex

Genetic problem 4:

A couple has three sons and the woman is pregnant again. Show by means of a genetic cross what the percentage chance is of the couple having a baby girl

P_1	Phenotype	**Male**	x	**Female**
	Genotype	**XY**	x	**XX**
Meiosis				
	Gametes	**X Y**	x	**X X**

Fertilisation

Gametes	**X**	**Y**
X	**XX**	**XY**
X	**XX**	**XY**

F_1	Genotype	**XX**	**XX**	**XY**	**XY**
		2 (XX)		**2(XY)**	
	Phenotype	**Female (50%)**		**Male (50%)**	
	Phenotypic ratio	**1:1**			

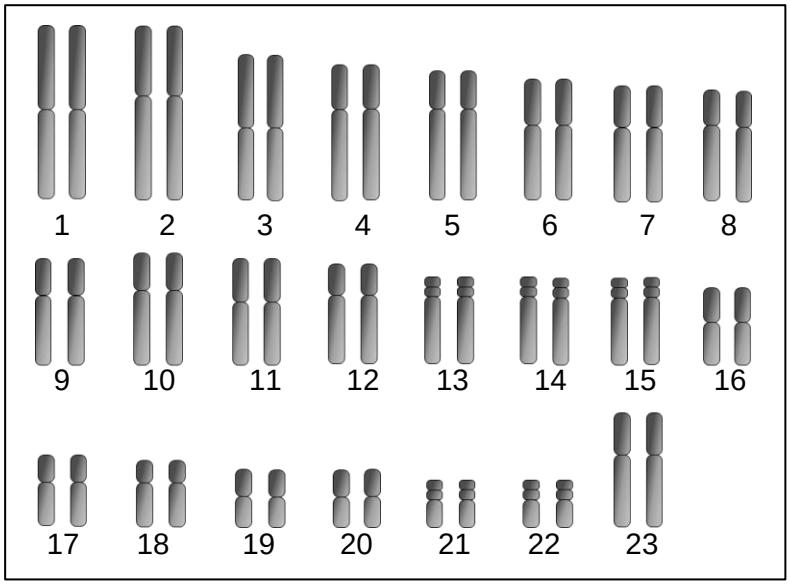
The genetic cross above shows that the percentage chance of having a boy or a girl is 50%.

In humans, there are 46 chromosomes (i.e. 23 from the mother and 23 from the father). Of these 46 chromosomes, 44 control the appearance, structure and functioning of the body. These are called **autosomes**. The remaining pair determines the sex of the individual and are called the **gonosomes**. In a female the gonosomes are two large X chromosomes and in the male there is one large X chromosome and a smaller Y chromosome.

Each species has its own unique number, shape and size of chromosomes – this is called the **karyotype**.

Examine the two karyotypes below to see if you can identify which comes from a female and which from a male.

Karyotype 1:



Karyotype 2:

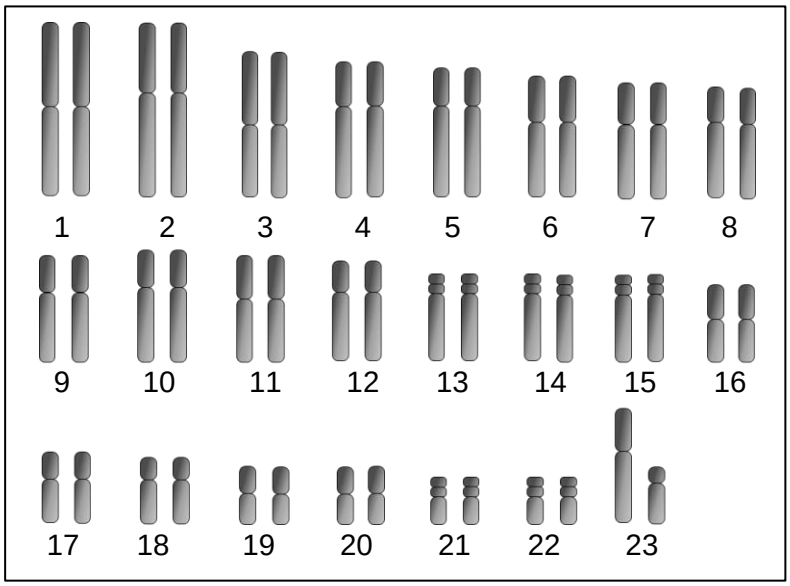


Figure 8: Female and male karyotypes

After meiosis, an egg cell will have 22 autosomes + an X gonosome. A female will have two large X gonosomes (as in karyotype 1 – see pair 23), while a male will have an X gonosome and a Y gonosome (as in karyotype 2 – see pair 23).

Males thus have two types of sperm: half will have 22 + X chromosomes, and the other half will have 22 + Y chromosomes. Depending on which sperm reaches the egg, there is a 50% chance of the zygote being male and a 50% chance of the zygote being female.

Sex-linked inheritance

Although most of the bodily characteristics are carried on the 22 pairs of autosomes, there are a few characteristics carried on the gonosomes only. Thus, for example, the gene for hair growing on the inside of the pinna (Figure 9) is carried on the Y chromosome, so only men will have this characteristic.

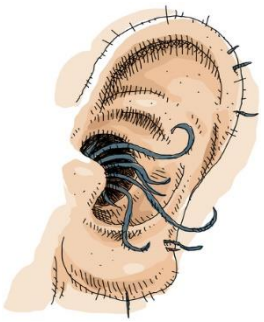


Figure 9: Hairy

Certain sex-linked genetic disorders are carried on the allele found on the X chromosome only. Two of these disorders are colour blindness and haemophilia.

- A person is **colour-blind** if unable to tell different colours apart. For example, red-green colour-blindness is caused by an absence of the proteins that make up the red or green cones (photoreceptors) in the retina of the eye resulting in the person not being able to tell the difference between red and green.
- **Haemophilia** is the inability of the blood to clot due to lack of a blood clotting factor. If the sufferer were to cut themselves, the wound would continue to bleed until a clotting factor is transfused in hospital.
- Colour-blindness and haemophilia is caused by the recessive allele on the X-chromosome normally shown as (X^b) for colour-blindness and (X^h) for haemophilia
- As a result, men who have only one X chromosome, have a greater risk of inheriting these disorders.
- Women, on the other hand, have a much lower chance of inheriting two X chromosomes which both carry the recessive allele for the disorder. If a woman inherits one X chromosome with the recessive allele for the disorder, she is called a **carrier** as she does not show signs of the disorder but can pass it on to her children.

Tables 3 and 4 below relate the inheritance of haemophilia and colour-blindness.

Table 3: Inheritance of haemophilia

Genotype	Phenotype
X^HX^H	Normal female
X^HX^h	Normal female (carrier)
X^hX^h	Haemophiliac female
X^HY	Normal male
X^hY	Haemophiliac male

Table 4: Inheritance of colour-blindness

Genotype	Phenotype
X^BX^B	Female with Normal vision
X^BX^b	Normal Female (carrier)
X^bX^b	Colour-blind female
X^BY	Normal male
X^bY	Colour-blind male

Do not add any letter to the Y chromosome since the Y chromosome does not have an allele to counteract the recessive allele for haemophilia and colour-blindness.

Activity 4: Sex-linked diseases

1. Haemophilia is a sex-linked disease caused by the presence of a recessive allele (**X^h**).
   A normal father and heterozygous mother have children. Construct a genetic cross to determine the possible genotype and phenotype of the children of the parents. (6)
2. Explain why the chances of men having a sex-linked disorder is much higher than it is for women. (4)

In an exam you may be asked to do other sex-linked disorders other than haemophilia and colour-blindness. Unless stated otherwise, follow the same format as in haemophilia and colour-blindness.

3. Read the following extract on cystic fibrosis and answer the questions that follow.

Cystic Fibrosis (CF)

CF is a progressive, genetic disorder caused by a recessive allele on chromosome number 7. One in twenty people of European descent carry the CF allele. One in 400 couples of European descent will be carriers of CF.

The disorder causes persistent lung infections and limits the ability to breathe over time. In people with cystic fibrosis, the defective gene causes a thick, build-up of mucus in the lungs and it clogs the airways and traps bacteria leading to infections and then eventually respiratory failure.

3.1 Explain why cystic fibrosis is not a sex-linked disease. (2)

3.2 Use a genetic cross to show what percentage of children will be affected if one of the parents is heterozygous and the other is homozygous normal. The recessive allele is represented as **b.** (6)

3.3 Maggie and William want to start a family, but Maggie's brother had cystic fibrosis. She doesn't want her own child to suffer as her brother did. Maggie and William decided to visit a genetic counsellor. Explain how this may help Maggie and William in their decision. (2)

(20)

Multiple alleles – blood type / group

The genetic crosses dealt with thus far involved two alleles of a gene, e.g.: T or t, R or W. Sometimes a characteristic is however controlled by more than two alleles. Blood type (or blood grouping) is an example of such a characteristic.

There are four blood types in humans: A, B, AB or O. These **phenotypes** are controlled by three alleles but <u>each person still inherits two alleles</u>. It is very important to know how to name (or write down) these three alleles as they are very specific to blood groups namely $\mathbf{I^A}$, $\mathbf{I^B}$ or **i**.

$\mathbf{I^A}$ is co-dominant to $\mathbf{I^B}$ whereas **i** is recessive to both. The genotypes for each blood group can then be specified as follows:

Genotype	Blood group
I^AI^A	A
I^Ai	A
I^BI^B	B
I^Bi	B
I^AI^B	AB
ii	O

Use of blood groups in paternity testing

The blood groups of the mother, possible father and child must be compared. If the blood groups of the adults do not correspond to or match the child's blood group then this man is not the father. If the blood groups of the adults correspond to or match the child's blood group, then there is a possibility that the man is the father and other tests need to be done as other men may have the same blood group.

Only DNA profiling can be conclusive as it looks at the similarities between the nucleotides in the DNA of the father and the child. Each DNA profile is unique to an

individual. 50 % of the DNA fragments / bands / bars are derived from the mother and 50 % from the father. If 50 % of the DNA fragments / bands / bars correspond with the father, then it can be claimed that he is the father of the child. DNA is viewed as more reliable evidence of paternity than the use of blood groups.

Example of a monohybrid cross using blood types:

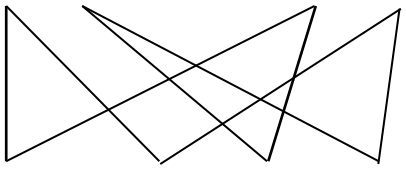
A man and a woman both have blood group **B**. Use a genetic cross to show how it is possible for them to have a child with blood group **O**.

P_1 Phenotype **Blood group B** x **Blood group B**

Genotype **I^Bi** x **I^Bi**

Meiosis Gametes **I^B i** x **I^B i**

Fertilisation



F_1 Genotype **I^BI^B I^Bi I^Bi ii**

Phenotype **3 Blood group B : 1 Blood group O**

OR

P_1 Phenotype **Blood group B** x **Blood group B**

Genotype **I^Bi** x **I^Bi**

Meiosis Gametes **I^B i** x **I^B i**

Fertilisation

Gametes	I^B	i
I^B	I^BI^B	I^Bi
i	I^Bi	ii

F_1 Phenotype **3 Blood group B : 1 Blood group O**

Genotype **I^BI^B I^Bi I^Bi ii**

Activity 5: Monohybrid crosses using blood types

1. If the child has blood group **O** and the mother blood group **A**, could the man with blood group **AB** be the father of that child? Use a genetic diagram to explain your answer. (6)
2. Human blood groups are controlled by multiple alleles.
   a) List all the alleles that control human blood groups. (3)
   b) How many of the alleles named in a) can any individual inherit? (1)

c) Give a reason for your answer to question b). (1)

d) Which 2 alleles are co-dominant in the inheritance of blood groups? (2)

e) A man has blood group **A** and his wife blood group **B**. Their first child has blood group **AB** and the second child blood group **O**. What can one conclude about the blood groups of their future children? (3)

(15)

Dihybrid crosses

Dihybrid crosses involve **two pairs** of alleles representing **two different** characteristics, e.g.: the height of a plant and the colour of its seeds.

According to the Law of Independent Assortment, alleles of different genes move (segregate) independently of each other into the gamete. They therefore appear on the gametes in different combinations.

Work through the following example of a dihybrid cross, and remember that the alleles for each characteristic could be either homozygous or heterozygous.

Example of a dihybrid cross

In pea plants, the allele for tallness (**T**) is dominant and the allele for shortness (**t**) is recessive. The allele for purple flowers is dominant (**P**) and the allele for white flowers is recessive (**p**). Two plants, heterozygous for both tallness and purple flowers were crossed.

- **Step 1**: Decide whether this concerns a monohybrid or a dihybrid cross.

  *Since two characteristics of each plant are mentioned (phenotypes: **height** of plant + **colour** of flower), it must be a dihybrid cross.*

- **Step 2:** Choose/ use letters to represent the alleles for the gene responsible for each characteristic.

  Let T = the allele for tall plants *Let t = the allele for short plants*

  Let P = the allele for purple flowers *Let p = the allele for white flowers*

- **Step 3**: Write down the phenotype of the two parents that would be producing gametes.

  tall purple X *tall purple* (as per question)

- **Step 4**: Write down the genotype of the parents.

  TtPp X TtPp

- **Step 5:** Show the gametes that each parent produces after meiosis. Each gamete must have two letters (dihybrid) – one from each characteristic.

  N.B. Remember Mendel's Law of Independent Assortment.

  (TP) (Tp) (tP) (tp) **X** (TP) (Tp) (tP) (tp)

- **Step 6:** Draw and complete a punnet square by writing in the combination of alleles in each block.

P_1	Phenotype	**Tall, purple**	x	**Tall, purple**
	Genotype	**TtPp**	x	**TtPp**
Meiosis				
	Gametes	(TP) (Tp) (tP) (tp)	x	(TP) (Tp) (tP) (tp)

Fertilisation

Gametes	**TP**	**Tp**	**tP**	**tp**
TP	TTPP	TTPp	TtPP	TtPp
Tp	TTPp	TTpp	TtPp	Ttpp
tP	TtPP	TtPp	ttPP	ttPp
tp	TtPp	Ttpp	ttPp	ttpp

F_1	Genotype	**9 different genotypes, as in the table above**
	Phenotype	**9 tall, purple flowered plants**
		3 short, purple flowered plants
		3 tall, white flowered plants
		1 short, white flowered plant

- **Step 7**: Determine the phenotypic ratios from the genotypes in the punnet square

Phenotypic ratio: 9:3:3:1

If there is one capital letter for the allele in the **F_1** generation, then that trait (characteristic) shows in the phenotype; if there are small letters then the recessive trait shows.

Activity 6: Dihybrid crosses

1. Two characteristics of an animal (length of the ears and shape of the lip) were studied. Each of these characteristics has two variations: Ears may be long or short, and the lip may be a wide or pointed.

   A male animal homozygous for wide lips (**LL**) and heterozygous for short ears (**Ee**) is crossed with a female animal that is heterozygous for wide lips (**Ll**) and homozygous for long ears (**ee**).

   1.1 What term describes a genetic cross involving two characteristics? (1)

   1.2 Give the

   a) dominant phenotype for the length of ears (1)

   b) recessive phenotype for the shape of the lip (1)

   c) possible genotype/s for an animal with short ears and a pointed lip (1)

   1.3 A male animal with genotype EELl is crossed with a female animal with genotype Eell. List all the possible gametes that could be produced by the male animal. (2)

   1.4 Explain how Mendel's Law of Independent Assortment applies to parents with LlEe genotypes during gamete formation. (4)

2. In humans the allele for short fingers (brachydactyly – a shortening of the fingers and toes), represented by **B**, is dominant over the allele for normal fingers (**b**). The allele for curly hair (**H**) is dominant over the allele for straight hair (**h**).

   Andrew, with genotype **Bbhh**, married Susan, with genotype **bbHh**.

   2.1 How do Andrew and Susan's phenotypes differ from each other? (2)

   2.2 List all possible genotypes of the gametes produced by Andrew. (2)

   (14)

Genetic lineage (Pedigree diagrams)

A pedigree diagram (also called a family tree) is used to study the inheritance of characteristics in a family over a number of generations.

The pedigree diagram in Figure 10 (see next page) shows inheritance of eye colour in humans over three generations of a family. Brown eye colour (**B**) is dominant over blue eye colour (**b**).

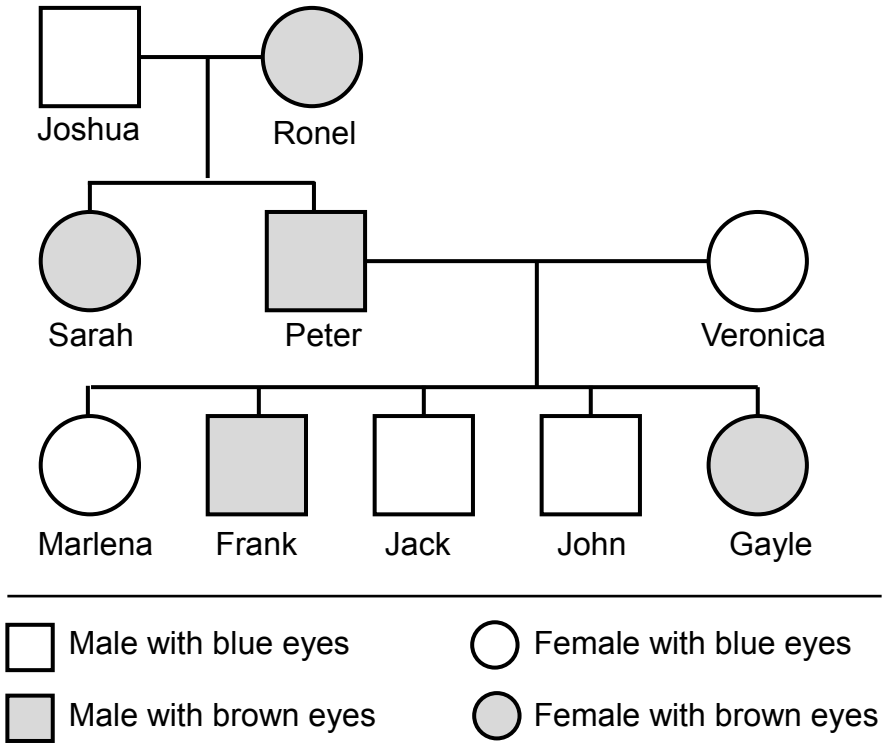


Figure 10: Pedigree diagram

- Squares represent males and circles represent females
- The horizontal line between a square (Joshua) and a circle (Ronel) shows that they have mated.
- The vertical line flowing from the horizontal line represents the offspring (Sarah and Peter) of the two parents (Joshua and Ronel).

Remember the following steps when interpreting pedigree diagrams:

- **Step 1:** Study any key and opening statement/s and look for dominant and recessive characteristics and phenotypes.

  Brown eye colour (B) is dominant over blue eye colour (b) – as stated in the problem

- **Step 2:** Write in the phenotypes of all the individuals as given in the problem.
  - *Joshua, Jack and John are males with blue eyes.*
  - *Veronica and Marlena are females with blue eyes.*
  - *Peter and Frank are males with brown eyes.*
  - *Ronel, Sarah and Gayle are females with brown eyes.*

- **Step 3:** Fill in the genotype of all the individuals with the recessive condition – it must have two recessive alleles (two lower case letters, e.g. **bb**).

Joshua, Veronica, Marlena, Jack and John will have the genotype 'bb'. The recessive characteristic only shows up in the homozygous condition

- **Step 4:** For every individual in the diagram that has the recessive condition, it means that each allele was obtained from each of the parents. Work backwards and fill in one recessive allele for each parent.

- **Step 5:** If the parents showed the dominant characteristic, fill in the second letter which represents the dominant allele (a capital letter, e.g. **B**).

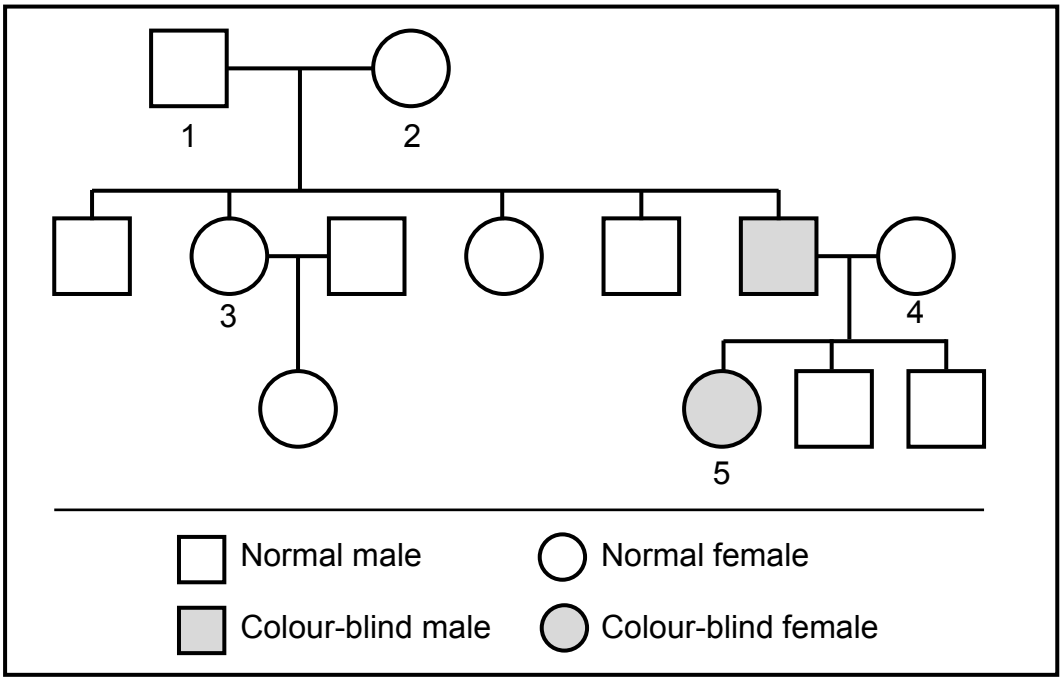
  The genotype of Peter is 'Bb' – working backwards from the offspring Marlena or Jack or John who are homozygous recessive. This means that one of the recessive alleles of Marlena, Jack and John, i.e. 'b', must have come from parent Peter and the other one from parent Veronica

- **Step 6:** Any other individual showing the dominant characteristic will most likely be homozygous dominant (**BB**) or heterozygous dominant (**Bb**).

  Ronel could be homozygous dominant (BB) or heterozygous dominant (Bb)

Activity 7: Pedigrees

1. The pedigree diagram below shows the inheritance of colour-blindness (also called Daltonism) in a family. Colour-blindness is sex-linked and is caused by a recessive allele (**d**). The ability to see colour normally is caused by a dominant allele (**D**).



Inheritance of colour-blindness

1.1 How many of the male offspring of parents 1 and 2 were normal? (1)

1.2 What percentage of males in this pedigree diagram are affected? Show your workings. (2)

1.3 State the genotype of

a) Individual 2 (1)

b) Individual 5 (1)

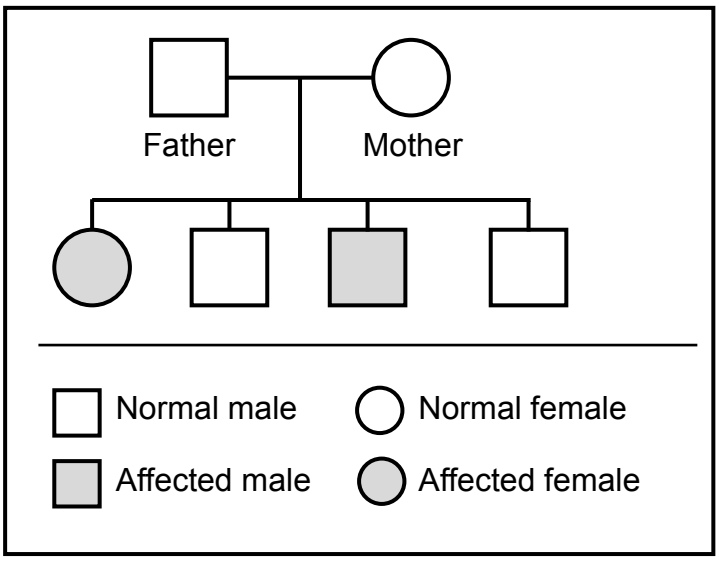
1.4 If individual 5 marries a normal male, what percentage of their daughters will have an allele for colour-blindness, but will not be colour-blind? (1)

2. The pedigree diagram below shows the pattern of inheritance of a certain genetic disorder controlled by a recessive allele. The dominant allele is represented by **N** and the recessive allele by **n**.

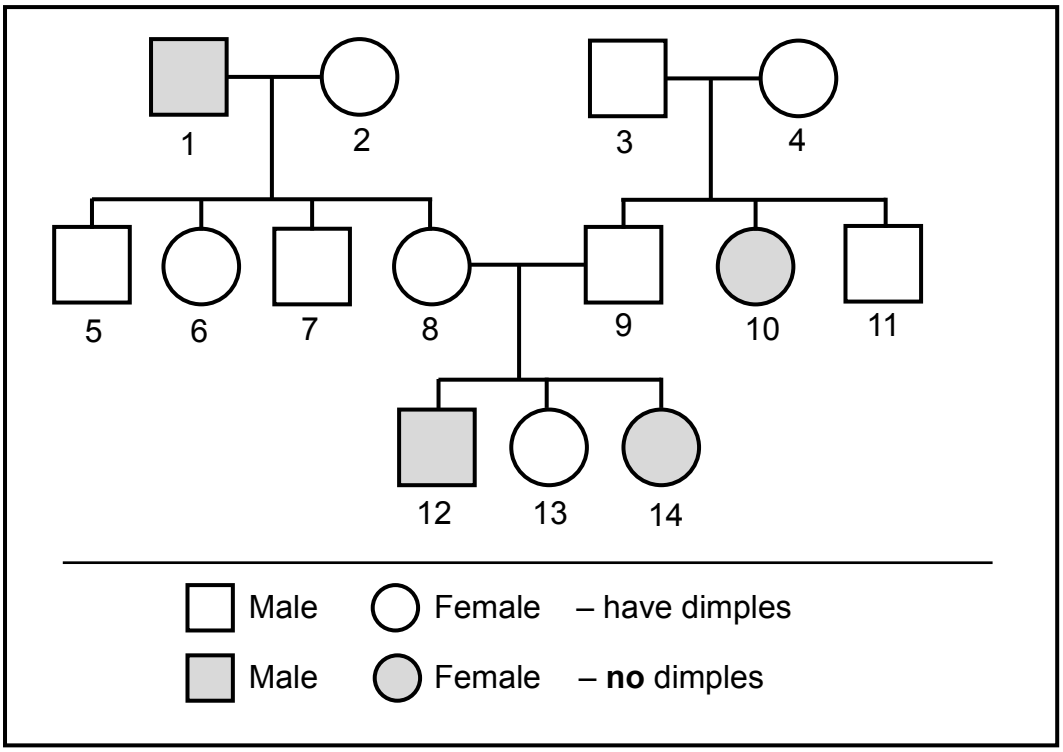
2.1 Explain why both parents must be heterozygous for this characteristic. (2)

2.2 Give the possible genotype(s) of the normal children. (2)

2.3 Provide evidence from the pedigree diagram to show that this characteristic is not sex-linked. (3)



3. Use the pedigree diagram below to answer the questions about dimples (small depressions on the cheeks when smiling). The dimple allele (**D**) controls whether a person has dimples or does not have dimples. The allele for having dimples is dominant to the allele for not having dimples (**d**).



3.1 How many family members have dimples? (1)

3.2 What is the genotype of the individuals?

a) **3** (1)

b) **4** (1)

3.3 State whether the following individuals are homozygous or heterozygous for having dimples:

a) **2** (1)

b) **9** (1)

3.4 State the family relationship between individual **12** and individual **2**. (1)

(19)

Mutations

A mutation is caused by a permanent change to the DNA of a cell. Mutations can be harmless, harmful or useful.

Harmless mutations mostly

- involve changes to the non-coding DNA (which makes up 98,5% of the DNA).
- This DNA is not involved in making proteins.

- It does not affect the structure or functioning of the cell/organism.
- Examples: freckles, blonde hair, baldness.

Harmful mutations

- change the DNA responsible for the production of a specific protein.
- This would cause changes to the organism's physical appearance or functioning due to an incorrect / defective protein being made.
- may cause a genetic disorder. Examples will be discussed below.

Useful mutations

- also change the DNA responsible for the production of a specific protein.
- If the protein made increases the organism's chance of survival, it would be seen as a useful mutation.
- If the gene is passed on, it will lead to genetic variation that is advantageous to the individual.
- Genetic variation is important to the processes of natural selection.
- In natural selection, organisms with traits that allow them to survive in the environment are more likely to pass on their genes.
- Natural selection (which will be discussed in chapter 9) is responsible for these mutations either being passed on to the future generations or not.

Mutations can occur in **genes** or **chromosomes**.

Gene mutations

Gene mutations occur during **replication** if a base pair is added, left out or doubled up. This changes the sequence of bases in DNA. Examples of gene mutations are haemophilia, colour-blindness, sickle cell anaemia, albinism.

- **Haemophilia** and **colour blindness** are sex-linked gene mutations on the **X**-chromosome.
- **Sickle cell anaemia** is an autosomal disease common in Central Africa, India and South America. It is caused by a gene mutation which results in a faulty haemoglobin molecule being formed. The red blood cells which are made have a half-moon shape (hence the term 'sickle'). Not only can these cells not carry enough oxygen (resulting in anaemia), but the shape means that the cells stick to each other blocking small capillaries. This causes damage in organs such as the brain and kidneys.

- **Albinism** is a rare group of genetic disorders which results in a lack of the pigment melanin. It is caused by a recessive gene mutation which prevents the normal development of colour in skin, hair or eyes.

  Unfortunately, there are many prejudices towards albinos. They are often portrayed as villains in movies, are regarded as bringing bad luck, and are at times murdered for their body parts.

  Albinos have weak eyes that are light sensitive and have a very light skin that is susceptible to skin cancer. They are perfectly normal in all other respects.

Chromosome aberrations

Chromosome aberrations occur during Anaphase I if the chromosomes of a bivalent do not separate. Both chromosomes go to the same pole, and thus the chromosome number of the gametes changes. An example of a chromosome aberration is Down syndrome.

Down Syndrome was discussed in Chapter 2 under abnormal meiosis. During Anaphase I / II, the non-disjunction of chromosome pair 21 will lead to the formation of a gamete with an extra (or one less) chromosome number 21. If this gamete fuses with a normal gamete, zygote with 3 (or only 1) chromosomes number 21 will form.

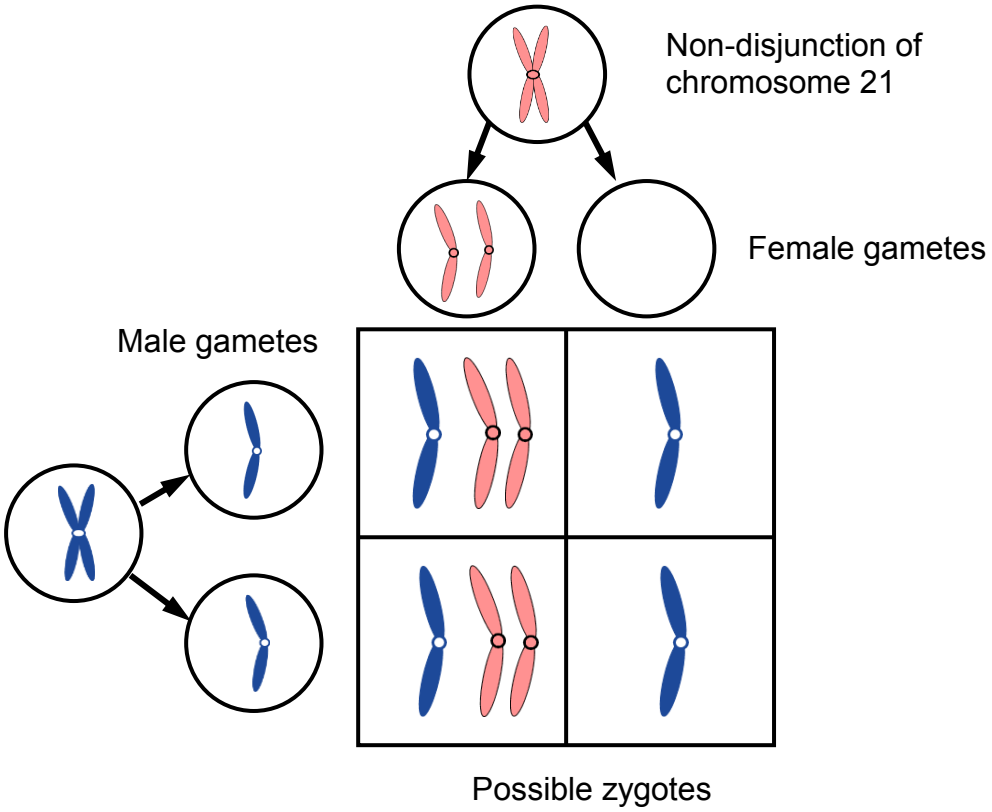


Figure 11: Punnet square showing chromosome aberrations

Biotechnology

For centuries, humans have used artificial selection to breed the best food crops, farm animals and pets (think of all the different varieties of dogs that exist today). With modern science, however, humans can manipulate the actual DNA of organisms.

Biotechnology is the use of organisms (e.g. bacteria) or biological processes to improve the quality of human life, as for example, in DNA profiling, genetic engineering, stem cell technology and cloning.

DNA profiling

DNA profiling was dealt with in Chapter 1. It is a form of biotechnology used for paternity testing, the identification of individuals, and for many other purposes.

Genetic engineering

Genetic engineering is used to alter the genome of a living cell for medical, industrial or agricultural purposes. This results in a **genetically modified organism** (GMO) or transgenic animal (animal with DNA from more than one species).

GMO's are used …

- to breed more productive crops or animals so that more food can be made
- to produce drugs or hormones (e.g. insulin) which have fewer side-effects and is cheaper
- to 'infect' cells to cure diseases (gene therapy) such as brain tumours and cystic fibrosis

One process used to produce a GMO is **recombinant DNA technology**. It can be used to manufacture human insulin using *E. coli* bacteria. The process can be summarised as follows:

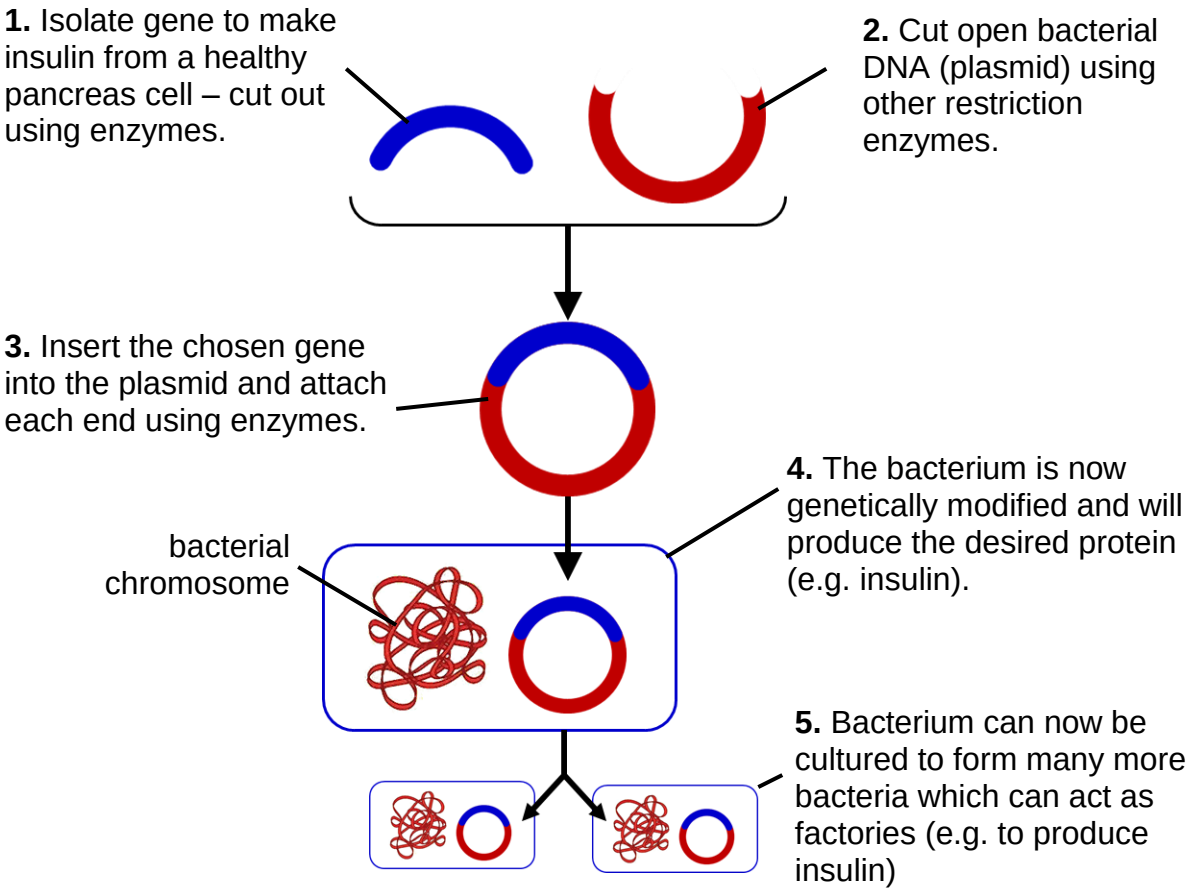


Figure 12: Recombinant DNA process

Advantages of genetically modified plants

- Pest resistance – the plants no longer taste good to insects.
- Herbicide tolerance – the crop plant is immune to poison, so large amounts can be used to kill the weeds.
- Disease resistance – these plants are hardy and do not get affected by diseases.
- Improved food quality – do not have damage due to pests or diseases so look good.
- Cold tolerance – rice and tobacco have been engineered to be unaffected by sudden drops in temperature.
- Drought or salinity tolerance – this helps plants grow in areas previously unsuitable for agriculture.
- Nutritionally enhanced – for example adding vitamin A to rice (a staple food in Asian countries) by introducing a gene from a daffodil.

- Incorporating vaccines into bananas/potatoes – this means that vaccines are made by the plant which can then be transported to countries easily without having to be refrigerated.

Disadvantages of GMO's

- GMO's contain glyphosate due to extensive spraying of herbicide.
- They are expensive so only 'rich' countries can benefit.
- The possibility of error is great as the process is complex.
- There has been no long-term safety testing as it is a relatively new technology.
- People may be allergic to the inserted gene e.g. brazil nut gene in soya beans.
- Widespread use of GMO crops may lead to a loss of biodiversity.
- New pathogens could be made for biological warfare.
- Ethically there is a fine line between what **can** be done and what **should** be done.

Only time will tell whether GMO's would solve the food security issues. Theoretically the potential benefits are huge, but there are significant risks. This also applies to the medical field and development of new drugs or ways to administer the drugs.

Stem cell technology

Stem cells are undifferentiated cells that have the ability to grow into any tissue in the body. They may be harvested from embryos left over after IVF treatment, from bone marrow and from blood in the umbilical cord. Skin and cartilage stem cells have also been used.

Notes about stem cells technology

- Embryonic stem cells are the most versatile as they have the ability to form any tissue. However, as the human embryos are killed, this is a controversial technology.
- Adult stem cells are much less controversial. Bone marrow has been used for a long time to treat cancers of the blood e.g. leukaemia, but other types of stem cell treatments are constantly being explored. Some of the procedures have involved:

- replacing dead cells in the heart after a heart attack
- growing skin tissue to treat burn victims
- growing nerve cells to treat spinal cord injuries and Parkinson's disease

However, a great deal more research is needed before these procedures are perfected. Parents who believe that there will be success in the future, are able to collect umbilical cord blood from their babies at birth. This blood can now be frozen and stored for future use. Although such facilities are available in South Africa, it is an expensive option.

Cloning

Cloning is the natural or artificial process of creating a genetically identical copy of an organism or biological material (e.g. tissue). The organism produced in this way is called a clone.

Cloning happens naturally when asexual reproduction takes place or a plant is self-pollinated or when identical twins are formed from a single zygote. These processes all give rise to individuals with DNA identical to that of the parent.

Biotechnology has enabled cloning to produce a new individual that is an exact copy of the organism from which the body cell was taken.

- In July 1996, Dolly the sheep, was the first cloned mammal using an adult cell, in this case a mammary gland cell.
- In April 2003, Futhi the cow, was the first cloned animal in South Africa and in this case a cell from the ear of a prize-winning dairy cow was used.

Figure 13: Dolly

Figure 14: Futhi

Note: IVF (invitro fertilisation) is not cloning as a sperm and an egg are used to form an embryo. The embryo is genetically different to either of the parents.

Advantages of cloning

- Therapeutic cloning can replace damaged tissue e.g. skin, heart cells and bone marrow, so helping to save human lives.
- Genetic diseases could be prevented.
- Superior animals may be bred to improve food supply and quality.
- Research in any form improves skills and could open other avenues due to spin-off technologies which could help mankind in the future.

The process of cloning

The description of the cloning process that follows is related to Figure 15 below.

- Sheep A is the superior animal to be cloned. Sheep B is inferior, but hardy, so it can survive the harvesting of eggs.
- An egg cell from sheep B is taken and the nucleus is removed.
- A body (somatic) cell from the genetically superior sheep (sheep A) is collected.
- The nucleus with DNA from cell A is removed and placed into the "empty" egg cell B.
- The egg cell is stimulated with a shock so that it starts dividing by mitosis.
- The egg cell now has DNA from the superior sheep A and will grow into an embryo.

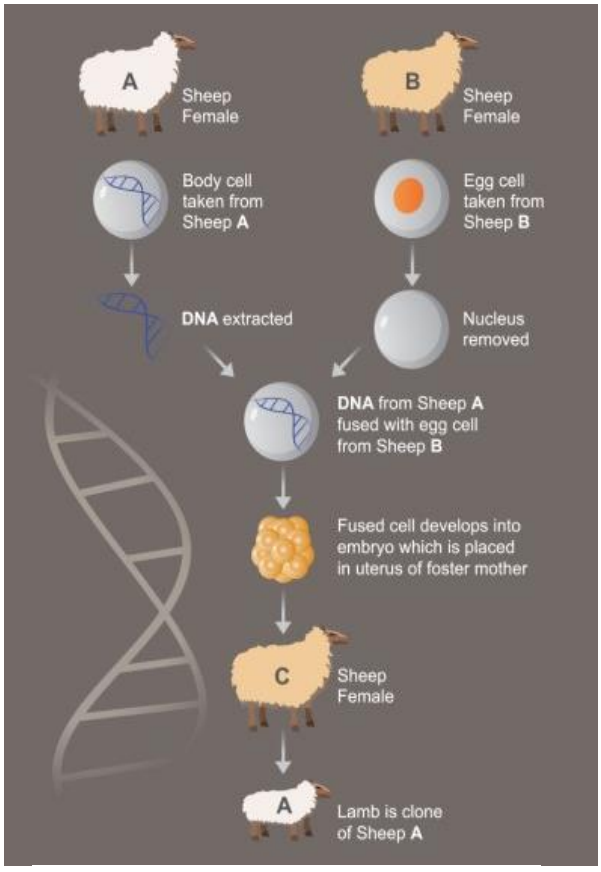


Figure 15: Cloning a sheep

- The embryo is then placed into the uterus of a surrogate or foster mother (sheep C) and should develop to full term.
- The baby (lamb) is clone of sheep A meaning it will be an exact copy of sheep A.

Activity 8: Biotechnology

1. Read the section of an article below taken from www.greens.org.

> In the 1950's, the media were full of information about the great new scientific miracle that was going to kill all harmful insects in the world, wipe out insect-borne diseases and feed the world's starving masses. That was DDT.
>
> There are claims that genetic engineering will feed the starving and help eliminate disease. The question is the price tag. As has been with most technologies, such as DDT and nuclear energy, the promise of benefit in the short-term is overwhelmed by long-term disasters.
>
> As more human genes are being inserted into non-human organisms to create new forms of life that are genetically partly human, new ethical questions arise.
>
> What percent of human genes does an organism have to contain before it is considered human?
>
> The Chinese are now putting human genes into tomatoes and peppers to make them grow faster. You can now be a vegetarian and a cannibal at the same time!
>
> What about the mice that have been genetically engineered to produce human sperm? How would you feel if your father was a genetically engineered mouse?
>
> *http://www.greens.org/s-r/20/20-01.html*

1. What do present day scientists possibly learn from using DDT in the 1950s? (2)
2. Explain what is meant by "the question is the price tag". (2)
3. Explain two short term benefits and one long term disaster of GMO food. (6)
4. What is meant by "you can now be a vegetarian and a cannibal"? (2)
5. What method could be used to insert human genes into mice? (1)
6. How would YOU feel if you father was a genetically engineered mouse? (2)

(15)

Mitochondrial DNA and tracing genetic links

Mitochondrial DNA (mtDNA) is important for an understanding of evolution.

- Mitochondrial DNA (mtDNA) is found in mitochondria and contains 37 genes which are needed to make the proteins involved in cellular respiration.
- As there is no crossing over involving mtDNA, the only changes that occur are due to mutations.
- mtDNA mutates at a regular rate so scientists are able to analyse these mutations to work out a timeline of genetic ancestry.
- Only the mother's mtDNA is passed on to her offspring (male and female). This is because the father's mtDNA is found in the cytoplasm of the sperm cell which is discarded, together with the tail, at the time of fertilisation.
- So, by analysing the mtDNA, the scientists can compare the mutations of different people to see how closely related they are.

Furthermore, the more mutations that are found, the older that race is believed to be. This research has found that our common female ancestor most likely lived about 150 000 years ago in East Africa. She has been named "Mitochondrial Eve". The map (Figure 16) shows early human migrations. This evidence supports the theory that the human race evolved in Africa and then migrated to other parts of the world where they evolved into the various races. This will be covered in the chapter on Human Evolution.

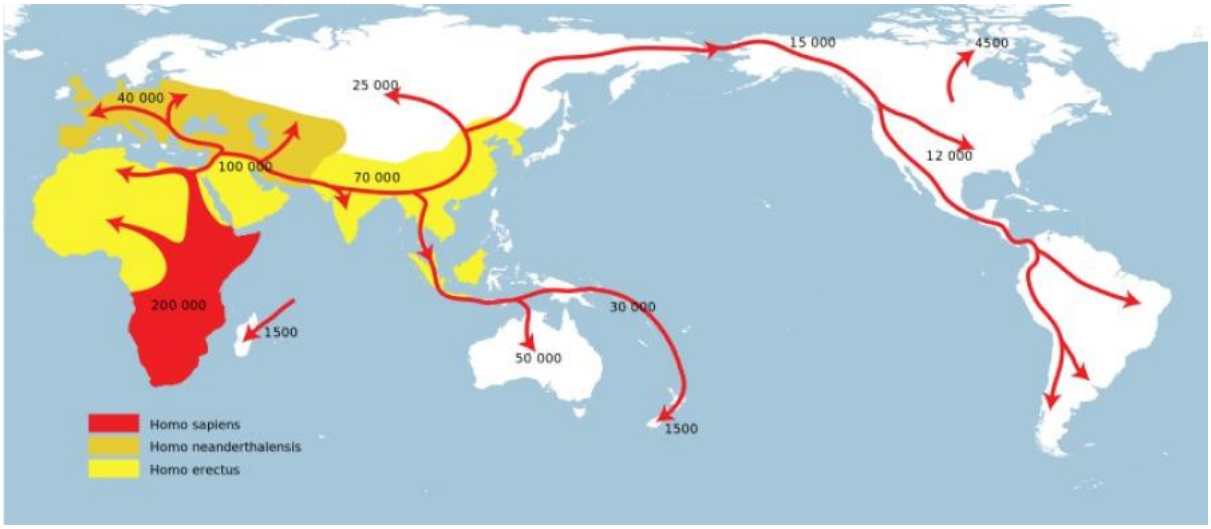


Figure 16: Movement of early Hominins (Out of Africa Hypothesis)

Note: Studies into the DNA on the Y chromosome have traced the most likely common male ancestor ("Nuclear Adam") to a male who lived approximately 60 000 years ago.

Enrichment

Crossing over: https://www.youtube.com/watch?v=pdJUvagZjYA

Independent Assortment: https://www.youtube.com/watch?v=-Zzp3mLIycM

Gametes (fertilisation): https://www.youtube.com/watch?v=QyY8yb9S--s

Mendel's work (terminology): https://www.youtube.com/watch?v=Lsj-Ij53CkA

Monohybrid crosses using a Punnett square: https://www.youtube.com/watch?v=9AiE9ADkhNM

Genetics and inheritance: End of topic exercises

Section A

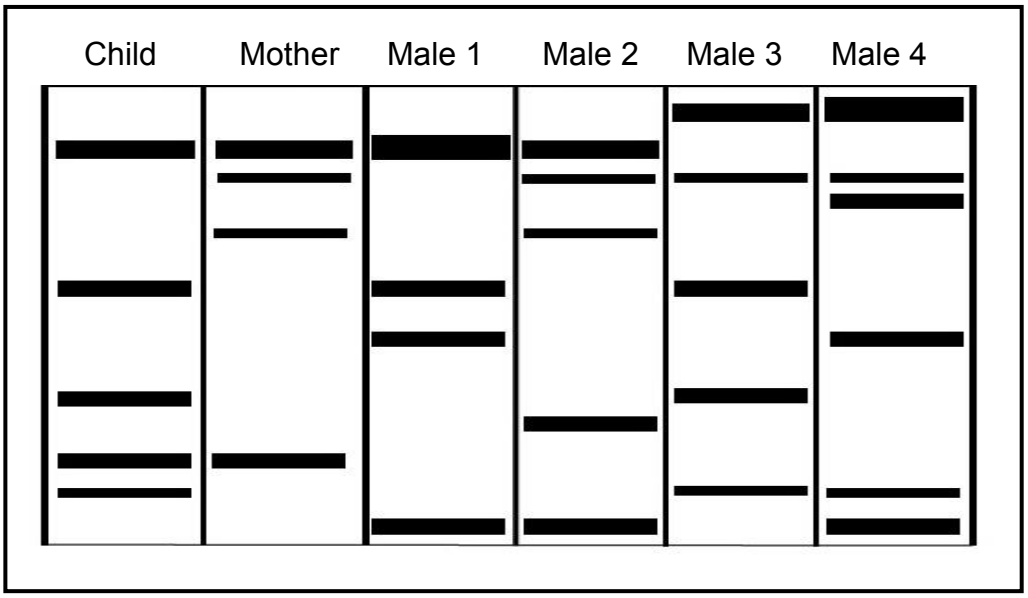
Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A – D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1.1 If a recessive allele on the X-chromosome is passed on to the offspring it is an example of…

A sex-linked inheritance
B incomplete dominance
C multiple alleles
D co-dominance

1.1.2 The diagram below shows the DNA profiles of a child, her mother and four males. There is uncertainty about who the biological father is. To establish paternity, DNA profiling was conducted.



Which male is the biological father of this child?

A Male 1
B Male 2
C Male 3
D Male 4

1.1.3 The advantage of cloning is that it…

A will reduce the variation within a population.
B produces genetically identical individuals with desirable characteristics.
C will enable offspring to survive under any unfavourable conditions.
D Is the only scientific technique that is accepted by all religious denominations and faiths.

1.1.4 In humans, brown eye colour is dominant over blue eye colour. A mother with blue eyes has two children; a boy with brown eyes and a girl with blue eyes. The eye colour of the father is…

A brown, because the allele for brown eye colour is sex-linked.
B brown, because at least one of the parents must have brown eyes.
C blue, because at least two other members of the family have blue eyes.
D blue, because at least one of the parents must be heterozygous for eye colour.

1.1.5 An extra finger in humans is rare, but is due to a dominant gene. When one parent is normal and the other parent has an extra finger and is homozygous for the trait, what is the chances that their children will be normal?

A 0%
B 25%
C 50%
D 75%

(5 x 2) = (10)

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

1.2.1 Undifferentiated animal cells that can form any type of tissue.

1.2.2 Type of inheritance where none of the two alleles is dominant over the other and an intermediate phenotype is produced.

1.2.3 The breeding of organisms by humans to achieve a desirable phenotype.

1.2.4 The physical appearance of an organism.

1.2.5 A genetic disorder characterised by the absence of blood clotting factor.

1.2.6 Organisms that have different alleles at a given locus.

1.2.7 A human disorder caused by the non-disjunction of chromosome pair 21.

1.2.8 The type of variation in a population with no intermediate phenotypes.

1.2.9 A genetic cross involving two characteristics.

(9 x 1) = (9)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 A specific pattern of bands representing a unique sequence of nucleotides that resemble bar codes	A: DNA profiling B: DNA replication
1.3.2 The number, shape and arrangement of all the chromosomes in the nucleus of a somatic cell	A: Karyotype B: Genome
1.3.3 Identical alleles for a trait	A: Heterozygous B: Homozygous
1.3.4 An allele that is not shown / expressed in the phenotype when found in the hetero-zygous genotype	A: Dominant B: Recessive
1.3.5 An example of biotechnology	A: Cloning B: Genetic modification

(5 x 2) = 10

1.4 Read the extract on the next page and answer the questions that follow.

Genetic engineering involves a process whereby a gene is isolated from one organism and transferred into another organism. This gene can become part of the new host's genome. Usually the gene transfer takes place between organisms from different kingdoms.

For example, a gene from a certain bacterium codes for an enzyme that deactivated a herbicide (a weedkiller). This gene is isolated from the bacterium and inserted into the chromosome of a crop plant. The resulting plant will now be herbicide-resistant.

Before the products of genetic engineering can be sold, many tests must be done.

Some seed companies have exclusive rights to sell the seeds that they have genetically engineered. Farmers cannot used seeds harvested from the crops that they have grown. Farmers must buy seeds from the seed companies every time they want to plant the crop.

Adapted from *Microbiology and Biotechnology*, 1994

1.4.1 What is meant by the term *genome* referred to in the extract. (1)

1.4.2 State one way in which genetic engineering described in the extract differs from selective breeding. (2)

1.4.3 Give one reason why the products of genetic engineering must undergo many tests before they can be sold. (1)

1.4.4 Explain the value of growing herbicide-resistant crops. (3)

1.4.5 State three advantages of genetic engineering in crop production other than those mentioned in the extract above. (3)

1.4.6 Give a reason why seed companies insist that they must have the exclusive rights to the selling of seeds. (2)

(12)

1.5 Gregor Mendel conducted breeding experiments with pea plants to study the inheritance patterns of four different traits (plant height, seed shape, seed colour and seed coat colour).

For each trait, for example plant height, he crossed homozygous tall plants with homozygous dwarf plants. The offspring in the F_1 – generation were then interbred to form the F_2 – generation. He did the same for each of the other traits.

The results obtained for the F_2 – generation are shown in the table below.

Trait	Results of F_2-crossing		Ratio
Plant height (Tall or dwarf)	Tall:	787	2,84 : 1
	Dwarf:	277	
Seed shape (Round or wrinkled)	Round:	5 474	**X**
	Wrinkled:	1 850	
Seed colour (Yellow or green)	Yellow:	6 022	**Y**
	Green:	2 001	
Seed coat colour (Grey or white)	Grey:	705	3,15 : 1
	White:	224	

[Adapted from Basic Concepts in Biology, 3rd edition.,C.Starr, 1997]

1.5.1 What is the expected phenotypic ratio for the trait involving two heterozygous parents? (1)

1.5.2 From the results, calculate X and Y. Also state which trait provided a ratio closest to the expected phenotypic ratio mentioned in question 1.5.1. Show all working. (3)

1.5.3 Give a possible reason why the ratio selected in question 1.5.2 was closest to the theoretical ratio. (2)

1.5.4 Using the results, state whether the allele for round seeds or for wrinkled seeds is dominant. (1)

1.5.5 State one factor that Mendel controlled during these breeding experiments. (1)

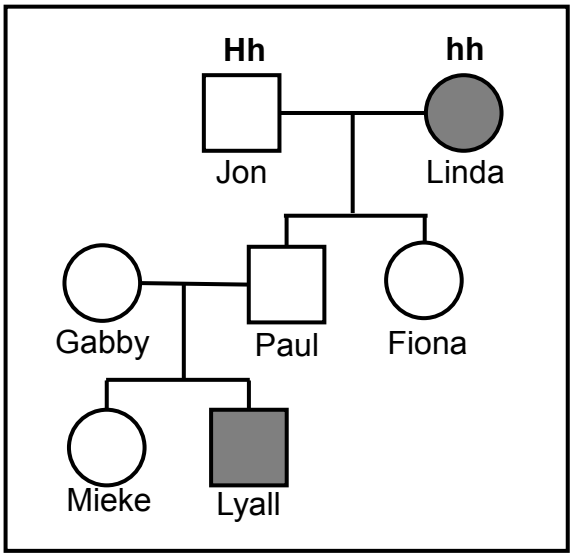
(8)

Section A: [49]

Section B

Question 2

2.1 The diagram shows the pattern of inheritance of deafness in a family. The letter **H** represents the allele for hearing and **h** represents the allele for deafness.



2.1.1 How many of each of the following are represented in the diagram?

a) Males (1)

b) Generations (1)

2.1.2 Give the

a) phenotype of Jon (1)

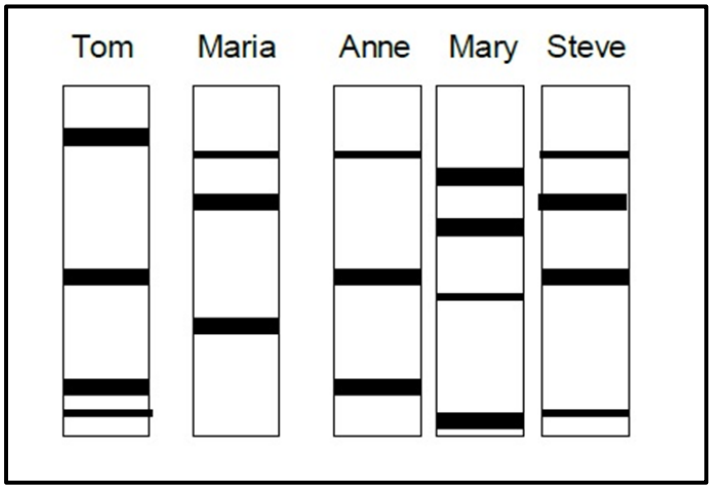
b) genotype of Paul (1)

2.1.3 Both Lyall's parents can hear, yet he is deaf. Explain how deafness is inherited. (2)

2.1.4 Lyall marries a woman is homozygous dominant for hearing. Use a genetic cross to show the percentage chance of them having a deaf child. (7)

(13)

2.2 Tom and Maria have three children. One of the three children was adopted. A DNA profile for each member of the family was prepared to determine if Tom is the father of all three children (Anne, Mary and Steve). The DNA profiles are given below.



2.2.1 Which one of the children was adopted? (2)

2.2.2 Explain your answer to question 2.2.1. (2)

(4)

2.3 Humans have different blood groups which are coded for by a number of alleles. Mary has genotype I^Ai and her son Joseph has blood type AB.

2.3.1 How many alleles code for blood groups? (1)

2.3.2 Give all the possible genotypes for Joseph's father. (3)

(4)

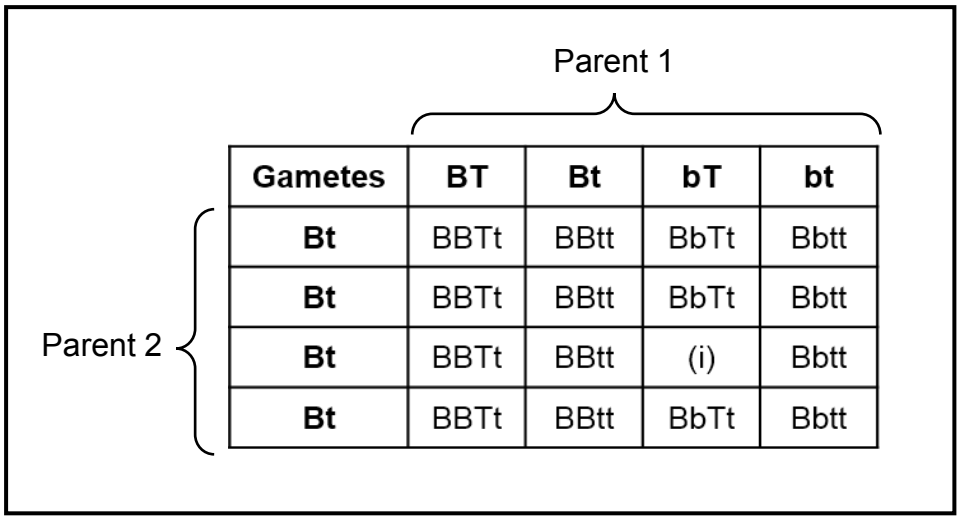
2.4 Haemophilia is a genetic disorder caused by a recessive allele on the X-chromosome. A haemophiliac female marries a normal male. Explain why all their sons will be haemophiliacs. (4)

[25]

Question 3

3.1 Coat colour in mice is controlled by two alleles, black (**B**) and grey (**b**). Tail length is controlled by two alleles, long (**T**) and short (**t**).

The Punnett square below shows a part of the cross between two mice. Genotype **(i)** has been left out.



Gametes	BT	Bt	bT	bt
Bt	BBTt	BBtt	BbTt	Bbtt
Bt	BBTt	BBtt	BbTt	Bbtt
Bt	BBTt	BBtt	(i)	Bbtt
Bt	BBTt	BBtt	BbTt	Bbtt

3.1.1 Give the

a) genotype of parent 1 (2)

b) phenotype of parent 2 (2)

c) genotype of offspring (i) (1)

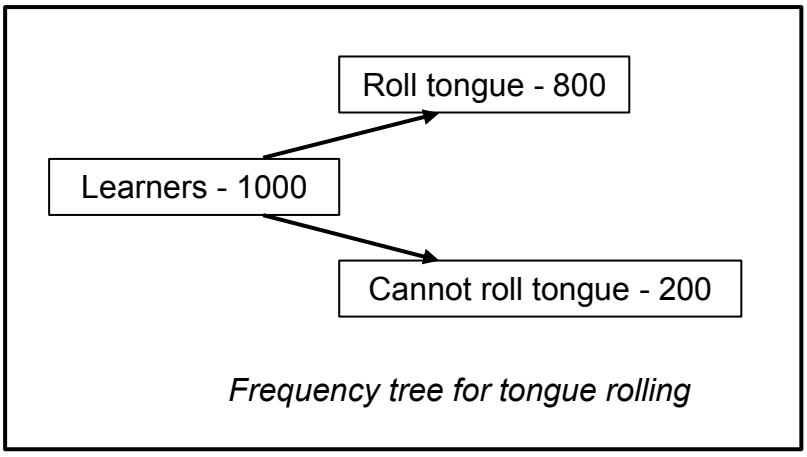
3.1.2 What percentage of the offspring above is grey with short tails? (1)

3.1.3 State the genotypes of two gametes from the table above that will result in offspring that are heterozygous for both colour and length of tails if fertilisation occurs. (2)

(8)

3.2 A class of Grade 11 learners conducted an investigation to determine the frequency of dominant and recessive characteristics in their school. The characteristic investigated was the ability to roll one's tongue.

The results obtained were recorded in the frequency tree as shown below.



Frequency tree for tongue rolling

3.2.1 List three steps that the learners need to follow while planning this investigation. (3)

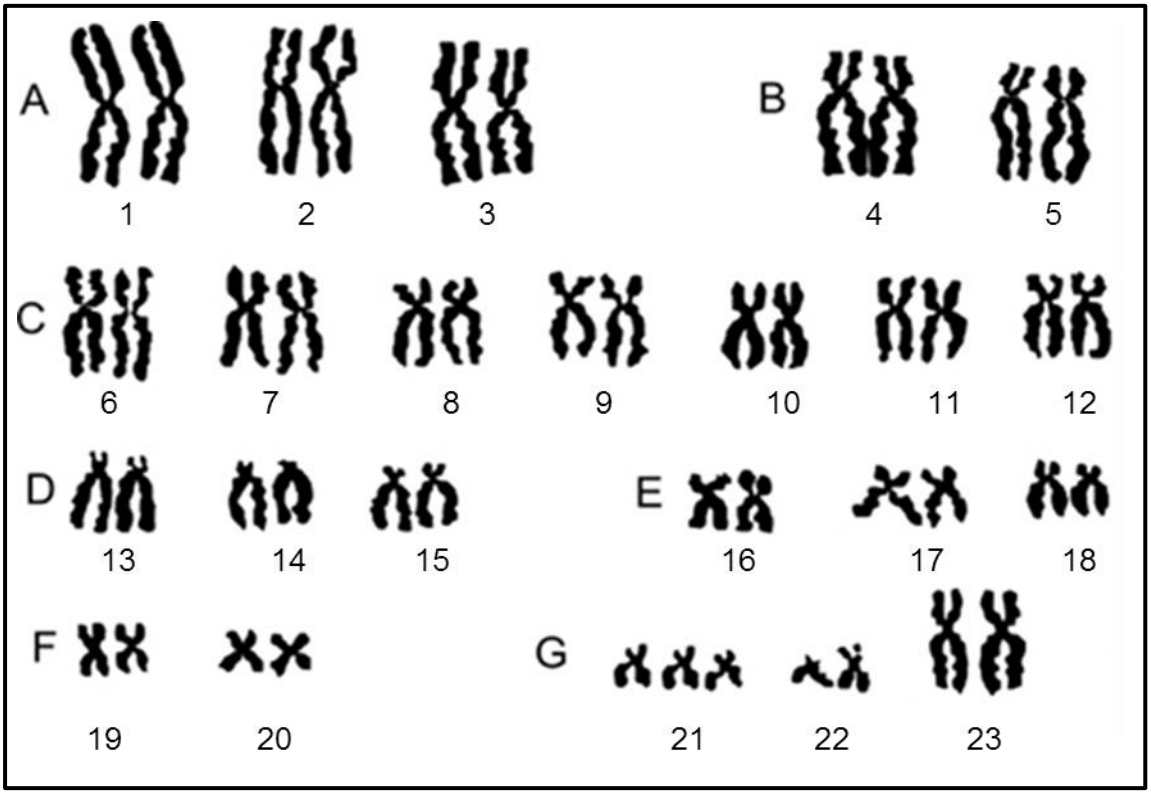
3.2.2 Use the data given in the frequency tree to plot a bar graph. (5)

3.2.3 Would you classify the ability to roll one's tongue as a continuous or discontinuous variation? (1)

3.2.4 Explain your answer to question 3.2.4 (2)

(11)

3.3 The diagram below is a representation of the chromosomes in a human cell.



3.3.1 How many autosomes are in this cell? (1)

3.3.2 This individual is a female. Explain why this conclusion is made. (1)

3.3.3 What evidence is there to show that this individual has a genetic disorder? (1)

3.3.4 Identify the genetic order mentioned in question 3.3.3. (1)

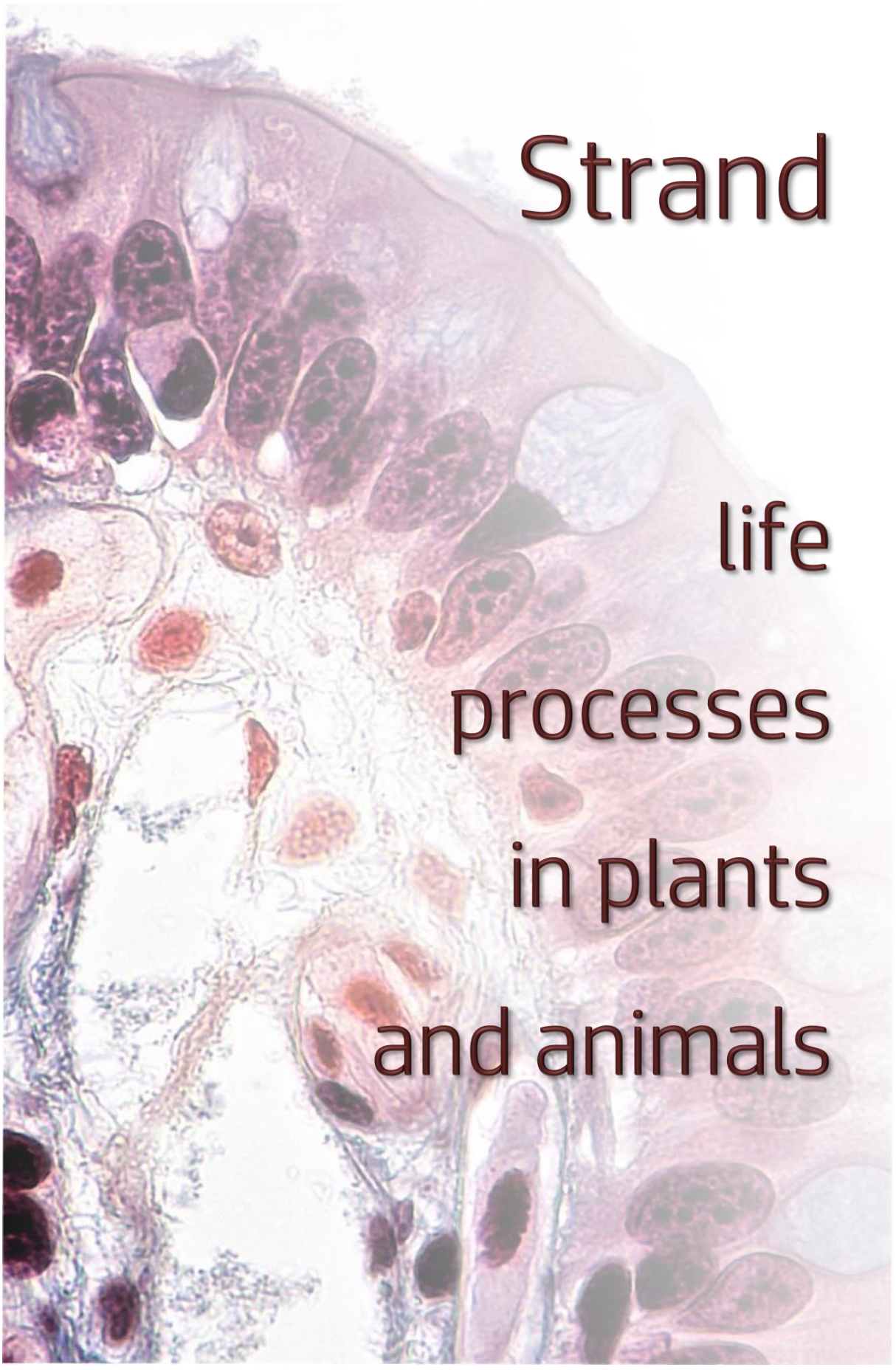
3.3.5 Name the process that resulted in this genetic disorder. (1)

(5)

[24]

Section B: [49]

Total Marks: [98]



Strand

life processes in plants and animals

6: Human responses to the environment

CHAPTER 6: HUMAN RESPONSES TO THE ENVIRONMENT

Introduction

Humans respond to the environment in various ways to maintain homeostasis, function efficiently and protect themselves from danger. The human nervous system with its receptor organs allows the body to respond.

Key terminology

receptor	structure that receives a stimulus and converts it into an impulse
effector	gland or organ that brings about a response to stimuli received by the body
stimulus	detectable change in the internal or external environment
impulse	electrical signal created by receptor organs in response to stimuli
transmit	to send something from one place to another
autonomic nervous system	controls our involuntary bodily functions; it is divided into the parasympathetic and sympathetic nervous system
peripheral nervous system	consists of nerves that extend outside the central nervous system (brain and spinal cord)

Human responses to the environment

In order to survive all organisms must be able to respond to the environment. To achieve this, humans have two co-ordinating systems which allow them to adapt to changes within the environment and maintain their internal conditions. A co-ordinating system consists of receptors and effectors which respond to stimuli and allow for changes to take place. These two systems are the nervous system and the endocrine system. The nervous system is made up of nerves and is a fast responding system. The endocrine system involves hormones which are released into the blood and is a much slower responding system.

The human nervous system

Key terminology

cranium	part of the skull that contains and protects the brain
meninges	protective membranes surrounding the brain & spinal cord
cerebrospinal fluid	fluid around the brain and spinal cord to aid in protection
grey matter	part of the brain and spinal cord consisting of cell bodies and dendrites
white matter	part of the brain and spinal cord consisting of myelinated axons
neuron	specialised nerve cells which transmits nerve impulses
dendrites	fibres that transmit impulses to a cell body in a neuron
nerve	bundle of neurons
synapse	the gap between the axon of one neuron and the dendrite of another
neurotransmitter	chemicals which carry impulses across the synapse
homeostasis	the tendency of living organisms to maintain their internal environment constant within narrow limits irrespective of changes in the external environments
Alzheimer's disease	disease caused by nerve defects usually in older people and characterised by memory loss and confusion
multiple sclerosis	disease cause by damage to the myelin sheath of neurons and characterised by physical and mental disabilities

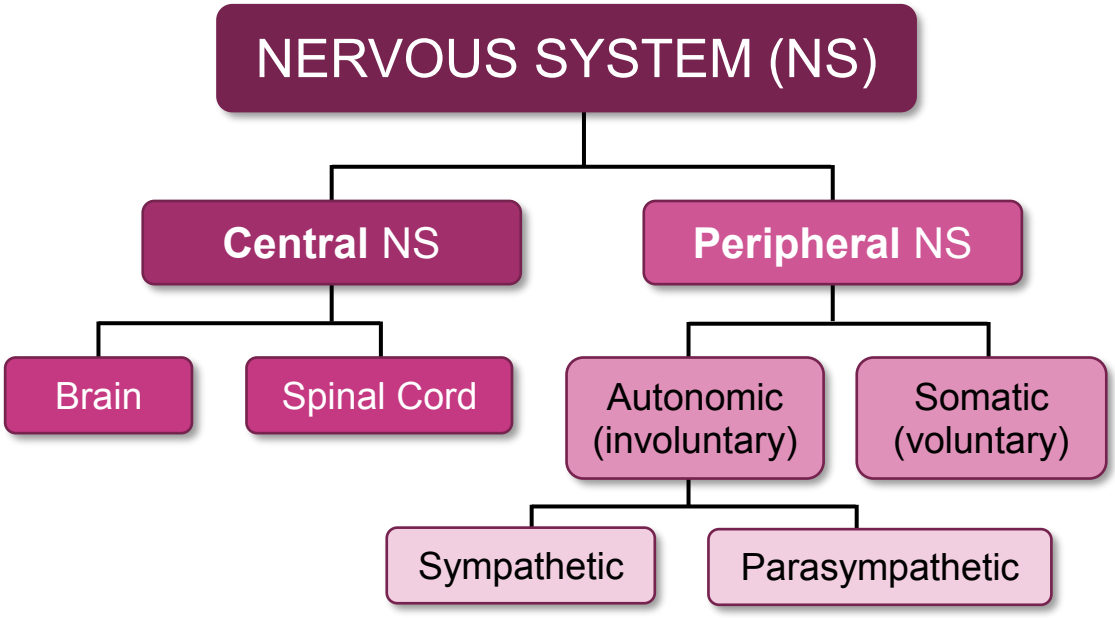


Figure 1: The human nervous system

Central nervous system & peripheral nervous system

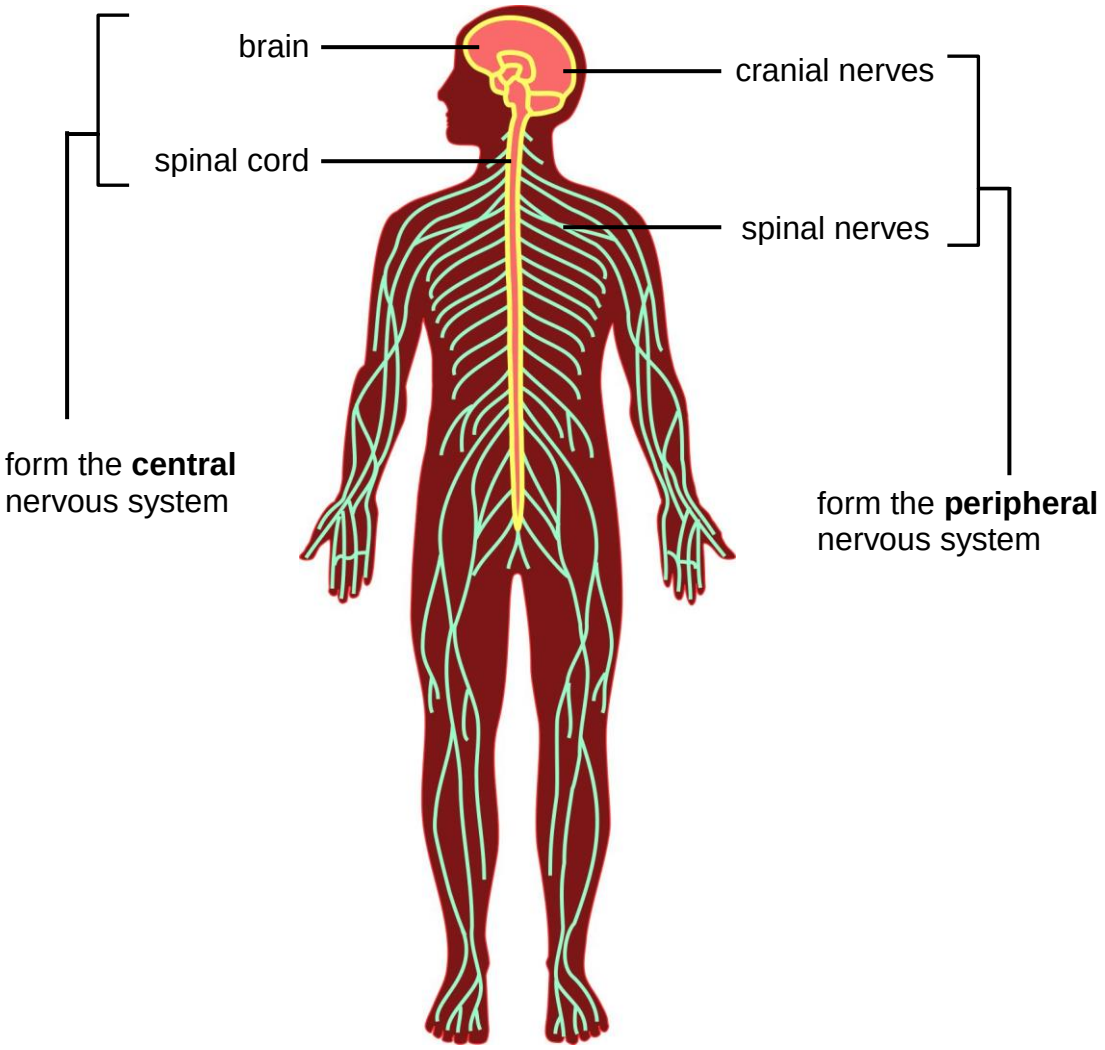


Figure 2: The central nervous system and peripheral nervous system

As illustrated in Figures 1 and 2 above, the human nervous system may be divided into two parts.

- The central nervous system which consists of the brain and spinal cord.
- The peripheral nervous system which consists of an autonomic part which is involuntary (one that can't be controlled) and a somatic part which is voluntary (under conscious control).

  Examples of a voluntary action would be running, jumping, eating or walking. Involuntary actions, or reflex actions, include breathing and sneezing.

  - The autonomic part may be further divided into the sympathetic and the parasympathetic systems, which work antagonistically (in an opposing manner).

Humans experience many changes throughout the day to which they must respond. These changes are known as stimuli. A stimulus may be internal (e.g. body temperature, water, sugar levels, carbon dioxide and oxygen concentrations) or it may be external (e.g. pain, environmental temperature, danger). Regardless of whether a stimulus is internal or external, we must be able to respond.

The central nervous system

The central nervous system is made up of the brain and spinal cord.

The brain

The brain is made up of delicate nervous tissue which cannot repair itself. The brain is of vital importance because it controls all functioning of the human body. For this reason, it is well protected in three ways:

- It is inside a bony **cranium**
- It is surrounded by three membranes called the **meninges**
- It is cushioned by a fluid called **cerebrospinal fluid**

Figure 3 shows various important structures of the brain, and their location relative to each other.

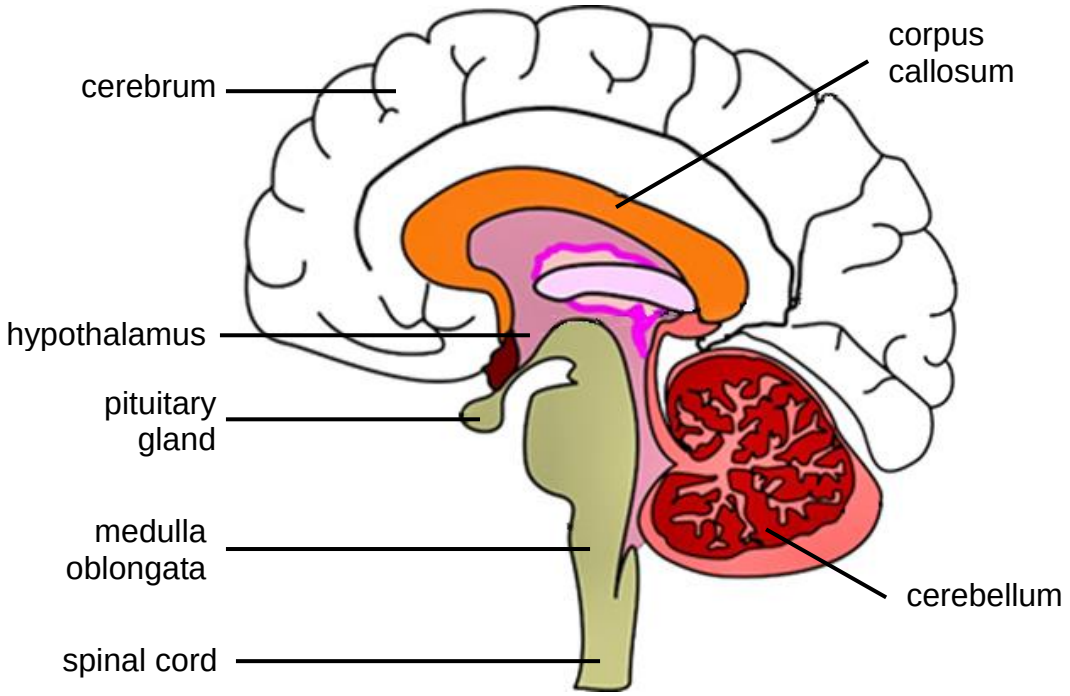


Figure 3: The structure of the brain

Table 1 below shows the location and function of various parts of the brain.

Table 1: The structure and function of various parts of the brain

Structural adaptation	Function
cerebrum	
• the largest part of the brain • divided into two hemispheres (left and right) which are connected by the **corpus callosum**	• controls voluntary functions (walking, speaking, writing) • receives and interprets sensations from sense organs (hearing, sight, feeling, taste, smell) • higher thought processes (memory, intelligence, reasoning) • to allow communication between the two halves of the brain
cerebellum	
• second largest part of the brain • located behind and below the cerebrum	• co-ordinates skeletal muscles to bring about balance while moving, as in walking or running • maintains balance and posture • maintains muscle tone
medulla oblongata	
• lower part of the brain • continues down into the body as the spinal cord	• controls breathing, peristalsis, heartbeat, swallowing • transmits impulses from the spinal cord to the brain • controls less important reflexes: blinking, coughing, sneezing, vasodilation, vasoconstriction and salivating
hypothalamus	
• a small section of the brain just above the pituitary gland	• a control centre for things such as hunger, thirst, sleep, body temperature, emotions

Parts of the brain: https://www.youtube.com/watch?v=-nH4MRvO-10&t=86s

The spinal cord

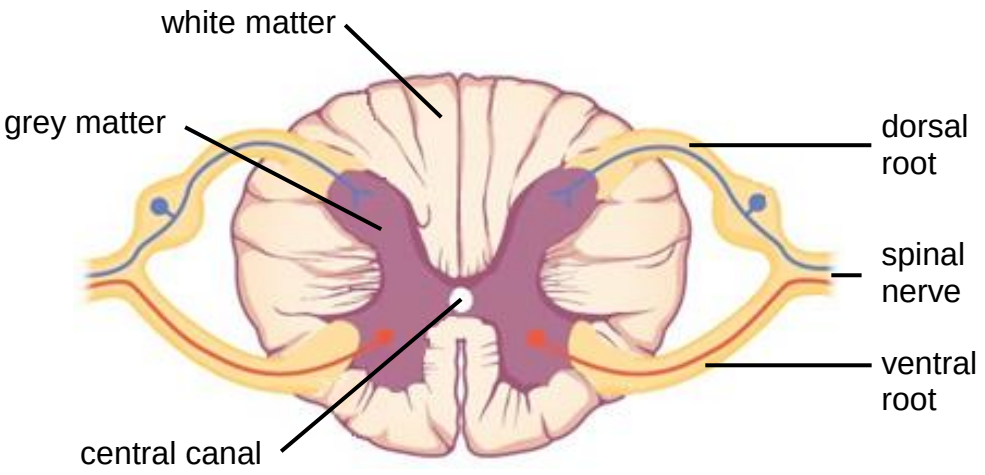


Figure 4: Internal structure of the spinal cord.

The spinal cord is made up of delicate nervous tissue which cannot repair itself. It is therefore protected by:

- 33 vertebrae (bone) with discs of cartilage between them to act as shock absorbers
- three membranes called the meninges
- cerebrospinal fluid

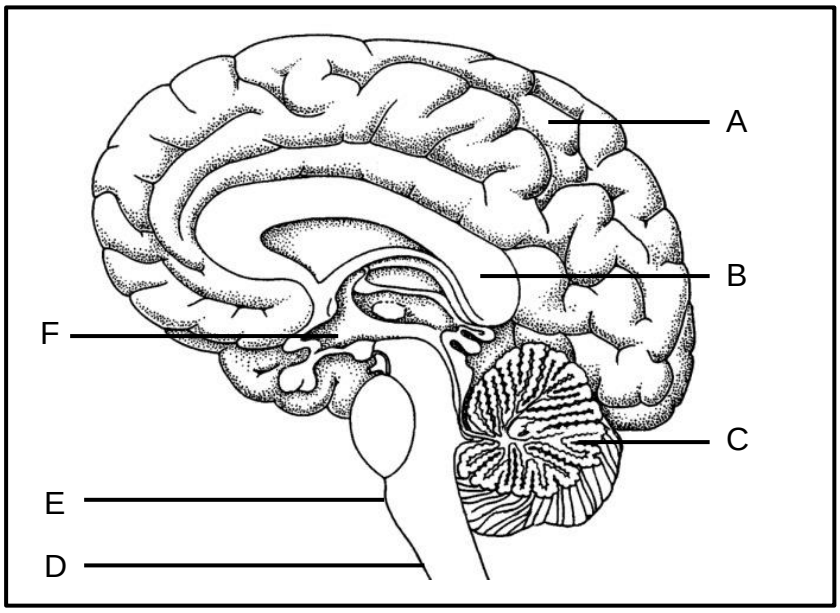
The spinal cord passes from the medulla oblongata to the lumbar region in the lower back. Thirty-one pairs of spinal nerves are attached to the spinal cord through the openings between the vertebrae. Each spinal nerve has a dorsal root which enters and a ventral root which leaves the spinal cord.

The spinal cord has the following functions:

- transmits impulses from receptors to the brain and from the brain to the effectors
- contains reflex centres that function automatically to protect the body

Activity 1: The central nervous system

Study the diagram below representing the human brain.



1. Give the names of the parts labelled A to C. (3)
2. Give the letter and the name of the part responsible for:
   a) co-ordinating all voluntary movements (2)
   b) memorising a cell phone number (2)
3. Explain two functions of parts:
   a) E (2)
   b) F (2)
4. Provide two ways in which part D is protected. (2)
5. Which functions of the body might be affected if the lower back part of the head receives a significant impact in a car accident? (2)

(15)

Neurons

Neurons are the structural units of the nervous system. Neurons are specialised cells which connect the brain and spinal cord to all other parts of the body.

As illustrated in Figure 5 below, neurons have the following structures:

- dendrites – transmitting impulses towards the cell body
- a cell body (with nucleus) – controlling the metabolism of the cell
- an axon – transmitting impulses away from the cell body

- a myelin sheath – insulating the axon and speeding up transmission of impulses; the myelin sheath is enclosed by a membrane called the neurilemma which helps to repair damaged neurons

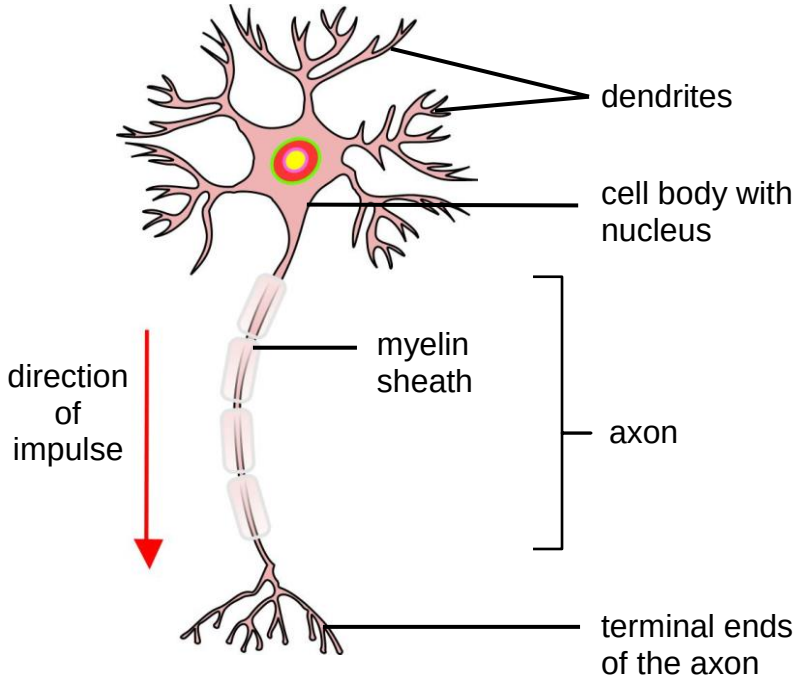
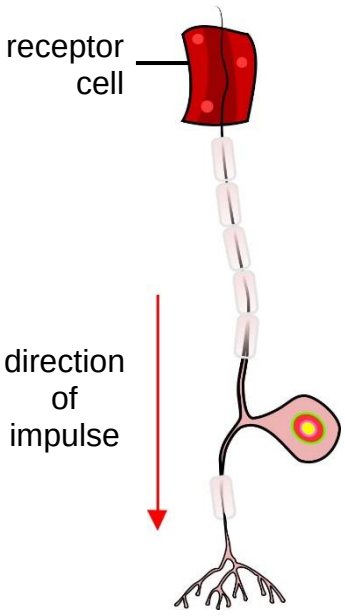


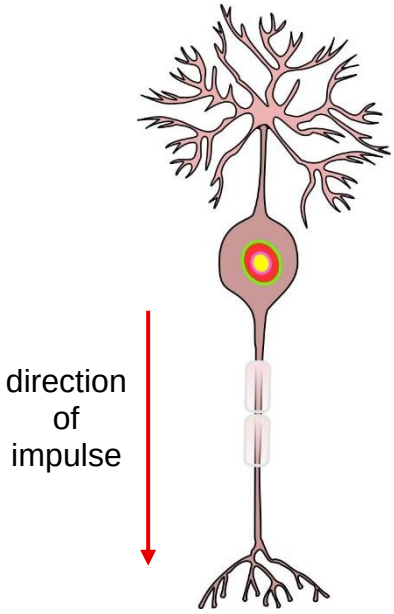
Figure 5: Structure of a motor neuron

There are three types of neurons: sensory neurons, interneurons and motor neurons. These are illustrated in Figures 6A to 6C.



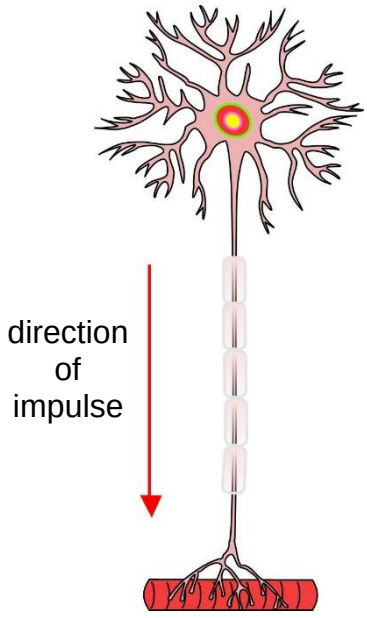
Sensory neurons transmit impulses from receptors to the central nervous system.

Figure 6A: Sensory neuron



An interneuron connects a sensory neuron to a motor neuron in the central nervous system.

Figure 6B: Interneuron



Motor neurons transmit impulses from the central nervous system to the effectors (muscles and glands) in the body.

Figure 6C: Motor neuron

Synapse

A synapse (see Figure 7 below) is a functional connection between the axon of one neuron and the dendrites of another neuron. The connection is established by neurotransmitters, chemicals that move across the gap between axon and dendrite to transmit the impulse.

Significance of a synapse

- It ensures that the impulse moves in one direction only
- It prevents continuous stimulation of the neurons

- It ensures that the impulse is transmitted from the sensory neuron to the motor neuron

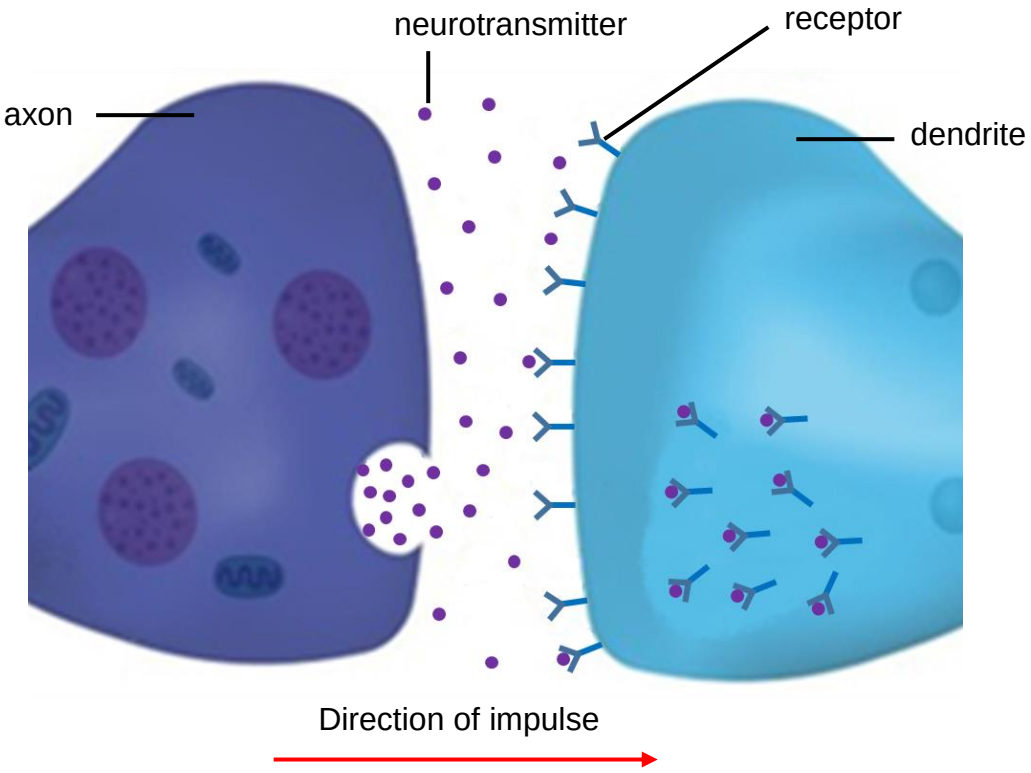
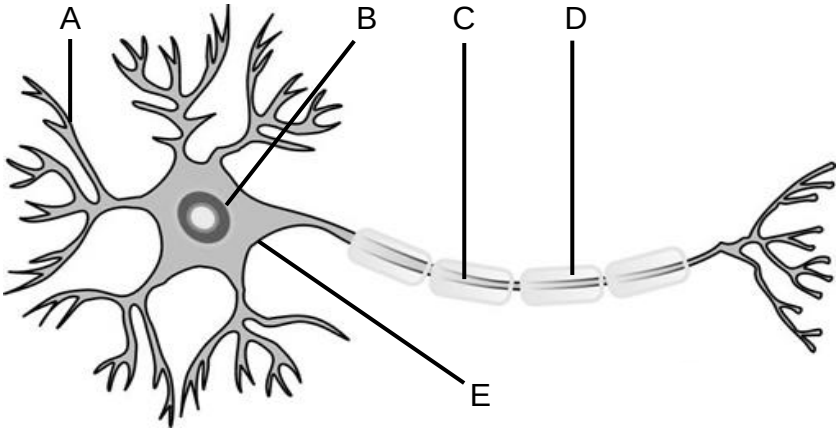


Figure 7: A synapse

Types of neurons:
https://www.youtube.com/watch?v=n0Zc01e1Frw&list=PLW0gavSzhMlQYSpKryVcEr3ERup5SxHl0&index=48

Activity 2: Neuron structure

The diagram below represents the structure of a neuron.



1. Name the type of neuron shown in the diagram above. (1)
2. Identify the parts A to E. (5)
3. Provide the functions of the following parts:
   a) C (1)
   b) D (1)
4. Describe the pathway of an impulse through the neuron shown above. (1)
5. Draw a fully labelled diagram to show the structure of a neuron which receives impulses and transmits them to the central nervous system. (4)

(13)

Reflex action and reflex arc

- A **reflex action** is a quick, automatic response to a stimulus. Examples: knee-jerk, sneezing and quickly removing a body part away from danger to respond to pain.
- A **reflex arc** is the pathway along which an impulse is transmitted to bring about a response to a stimulus during a reflex action.

Significance of Reflex action

- The reflex action allows for a quick response, without thinking about it, to prevent damage to the body.

The diagram below (Figure 8) can be used to explain how a reflex action takes place. The arrows in the diagram show the reflex arc.

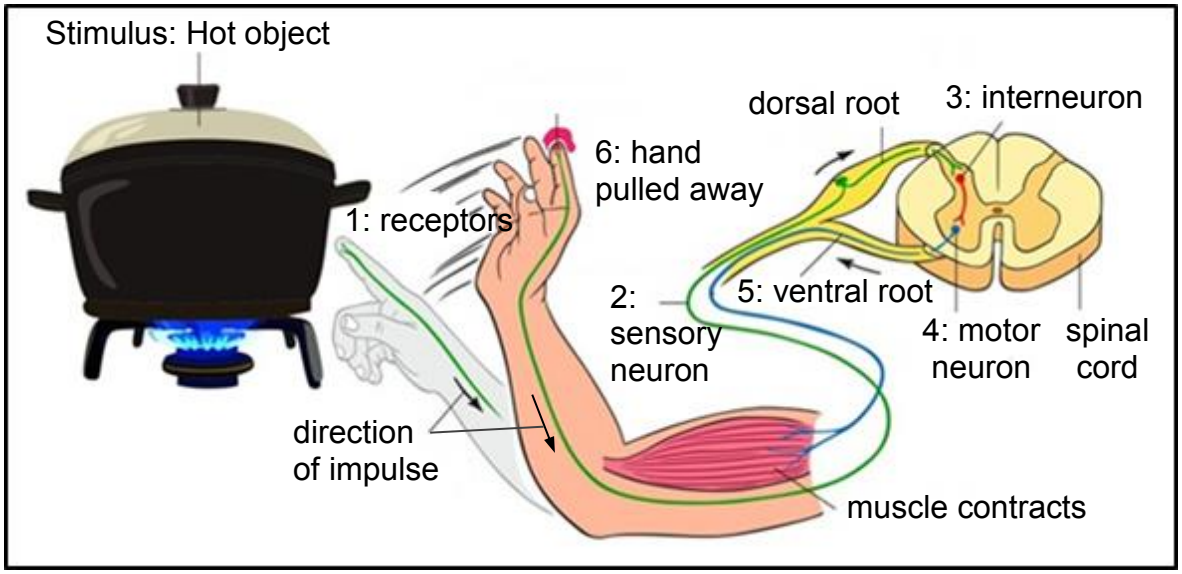


Figure 8: A reflex action

The reflex action of a person touching a hot pot:

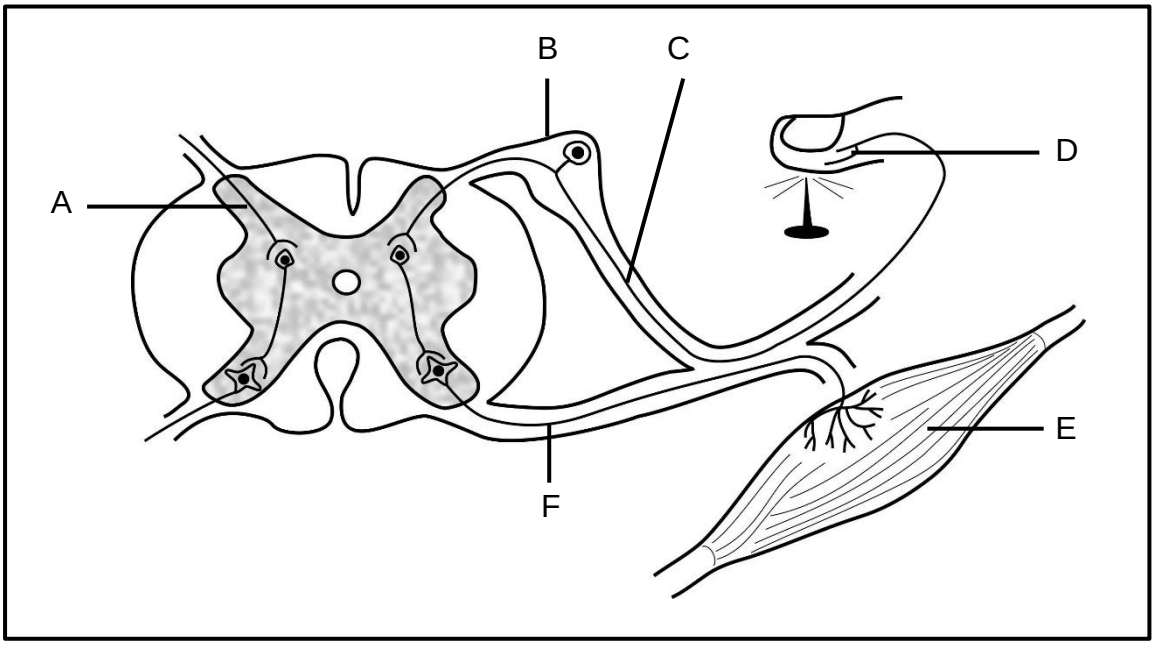
1. The stimulus is detected by receptors and converted into a nerve impulse.
2. The nerve impulse is transmitted along the sensory neuron through the dorsal root to the spinal cord.
3. The impulse is transmitted from the sensory neuron to an interneuron in the spinal cord.
4. The impulse is transmitted from the interneuron to a motor neuron in the spinal cord.
5. The impulse exits the spinal cord through the ventral root and is transmitted along the axon of the motor neuron to the effector organs (muscle; this causes the muscles in the arm to contract).
6. The hand pulls away from the stimulus quickly.

This reflex action does not include the brain. Impulses will reach the brain after the reflex arc is complete and pain will be felt.

How a reflex arc functions: https://www.youtube.com/watch?v=Nn2RHLWST-k

Activity 3: Reflex arc

The diagram below shows the reflex arc. Study the diagram, then answer the questions below.



1. Give only the letter of the part that represents the:
   a) effector (1)
   b) interneuron (1)
   c) sensory neuron (1)
2. State one function of each of the following parts:
   a) D (1)
   b) F (1)
3. Explain why the brain is not initially involved in the reflex action. (3)
4. Explain the effect on the body if the following parts were cut:
   a) C (4)
   b) F (4)

(16)

Activity 4: Practical investigation on reaction times

Thando conducted an experiment to determine which gender has the faster reaction time amongst his classmates. Out of 15 learners in his class he randomly selected a sample of 5 girls and 5 boys. The following steps were followed for each member of the sample during the experiment:

- Thando held a meter ruler between his thumb and index finger just above the 100 cm mark.
- The pupil placed the thumb and index finger on either side of the meter ruler at the 0 cm mark, with only the thumb touching it.
- As Thando dropped the meter ruler the pupil caught it by closing the thumb and forefinger.
- During each trial Thando recorded the distance at which the meter ruler was caught.
- The procedure was repeated five times for each pupil.

The table below shows the average distance at which the meter ruler was caught by 5 boys and 5 girls over five trials.

Average distance at which the meter ruler was caught over 5 trials (cm)

Boys	**average distance (cm)**	**Girls**	**average distance (cm)**
Boy 1	5,8	Girl 1	4,8
Boy 2	5,0	Girl 2	4,7
Boy 3	4,9	Girl 3	4,2
Boy 4	4,8	Girl 4	4,0
Boy 5	4,6	Girl 5	3,9
overall average	5,02	**overall average**	4,32

1. Identify the:
    a) independent variable of the experiment, and (1)
    b) dependent variable of the experiment. (1)
2. Give two reasons why the results of this experiment may be regarded as reliable. (2)
3. Mention two factors which should be kept constant during the experiment. (2)
4. Thando's initial hypothesis was rejected on the basis of the results obtained. Suggest what Thando's initial hypothesis could have been. (2)

(8)

The peripheral nervous system

The peripheral nervous system consists of all the nerves found outside of the central nervous system. The peripheral nervous system consists of 12 pairs of cranial nerves which are connected to the brain and 31 pairs of spinal nerves which are connected to the spinal cord.

The peripheral nervous system can be divided into two parts:

- the somatic nervous system which controls voluntary muscles
- the autonomic nervous system which controls involuntary muscles

The peripheral nervous system has the following functions:

- transmits impulses from the receptors to the central nervous system via the sensory neurons
- transmits impulses from the central nervous system to the effectors via the motor neurons

Somatic Nervous System

The somatic nervous system controls voluntary (skeletal) muscles. The nerves in this system allow the body to react to changes in the external environment.

Autonomic Nervous System

The autonomic nervous system controls involuntary actions. The nerves in this system allow the body to react to changes in the internal environment so that homeostasis can be maintained.

The autonomic nervous system can be subdivided into the sympathetic nervous system and the parasympathetic nervous system. Each organ in the human body is supplied by two both types of nerves: sympathetic nerves and parasympathetic nerves.

The sympathetic nervous system is responsible for the fight or flight function in emergency situations while the parasympathetic system restores the body to a normal state after an emergency situation. The two systems thus work antagonistically to each other.

Table 2 below shows how these systems work in opposition to bring about homeostasis.

Table 2: Effects of the sympathetic and parasympathetic nervous systems

Sympathetic system	Parasympathetic system
increases heart rate	decreases heart rate
constricts blood vessels in the skin (vasoconstriction)	dilates blood vessels in skin (vasodilation)
increases blood pressure	decreases blood pressure
widens bronchioles	narrows bronchioles
decreases peristalsis	increases peristalsis
causes relaxation of the bladder wall	causes contraction of the bladder wall
stimulates sweat secretion	no effect
dilates pupils	constricts pupils
stimulates secretion of adrenalin	no effect

Note: Adrenalin is a very important hormone that will be discussed in a later chapter. It works with the sympathetic nervous system to prepare the body for dangerous or stressful situations.

Disorders, injuries and Effects of Drugs on the Nervous system

There are many disorders and injuries which can affect the nervous system. The use of drugs can temporarily or permanently affect the functioning of the nervous system. How much the nervous system will be effected depends on many things.

Alzheimer’s disease

Alzheimer’s disease is a neurodegenerative disease which means there is progressive brain cell death that occurs over time. The disease is irreversible.

It is not yet known what causes the disease. In most cases, the first symptoms appear after the age of 60 but it has been seen in people as young as 40.

There is no known cure but the symptoms can be managed.

Symptoms:

- memory loss
- confusion

Multiple sclerosis

Multiple sclerosis is a disease that affects young adults between the ages of 20 and 40. The body’s immune system attacks the myelin sheath covering neurons which prevents them from functioning properly. The reason why this happens is unknown. There is no known cure for this disease. The symptoms can be managed with medication.

Symptoms:

- loss of speech and vision
- difficulty walking
- pain
- fatigue
- memory loss

Injuries

There are many causes of brain and spinal cord injuries, but the most common cause is motor vehicle accidents.

Brain injuries can affect movement, memory and speech but this depends on the part of the brain that is injured. In severe cases, they may lead to long-term mental health issues.

A damaged spinal cord could result in paralysis and the inability to move or feel anything below the point of injury.

There is no way of regenerating damaged nerve tissue, however regular occupational and physical therapy may allow patients to regain some feeling and function.

Medical researchers claim that stem cell therapy may in future be used to repair spinal cord injuries, degenerative diseases such as multiple sclerosis and Parkinson's disease.

Effects of drugs (Not examinable)

Drugs change the way in which impulses are transmitted in the central nervous system, mainly by affecting how quickly or slowly the neurotransmitters can pass across the gap in the synapse. Depending on the type of drug used (e.g.: marijuana, ecstasy, heroine, tik) either the sympathetic or the parasympathetic nervous system will become more stimulated. This can lead to side-effects such as:

- reduced co-ordination
- increased heart rate
- increased blood pressure
- decreased appetite
- hallucinations and paranoia

Sense Organs

Sense organs contain a high concentration of receptor cells which are able to detect stimuli to bring about a response. We will study the eye and the ear.

The human eye

Key terminology

rods	receptor cells found in the retina of the eye which are sensitive to dim light and help to distinguish between black and white
cones	receptor cells found in the retina of the eye which are sensitive to bright light and help to distinguish between different colours
pupil	central opening within the iris which allows light to enter

pupillary mechanism	regulation of the pupil size to control the amount of light entering the eye
accommodation	the ability of the lens of the eye to alter its shape for clear vision when viewing both near and distant objects
field of vision	the area that one eye can see
convex	a shape which curves outwards, thicker in the middle than the edges
concave	a shape which curves inwards, thinner in the middle than the edges

The receptors that detect light are called rods and cones. These are situated in the retina at the back of the human eye. The eyes are found as a pair positioned at the front of the skull. The field of vision from each eye overlaps which allows a slightly different image of the same object from each eye. Two types of imaging occur as a result:

- **Binocular vision:** vision using two eyes with overlapping fields of view so that the separate images are combined and interpreted as one image by the brain.
- **Stereoscopic vision:** the ability to form three dimensional images which provides the ability to judge distance, depth and the size of an object.

Structure of the eye

Figure 9 below gives a view of an eye from the front.

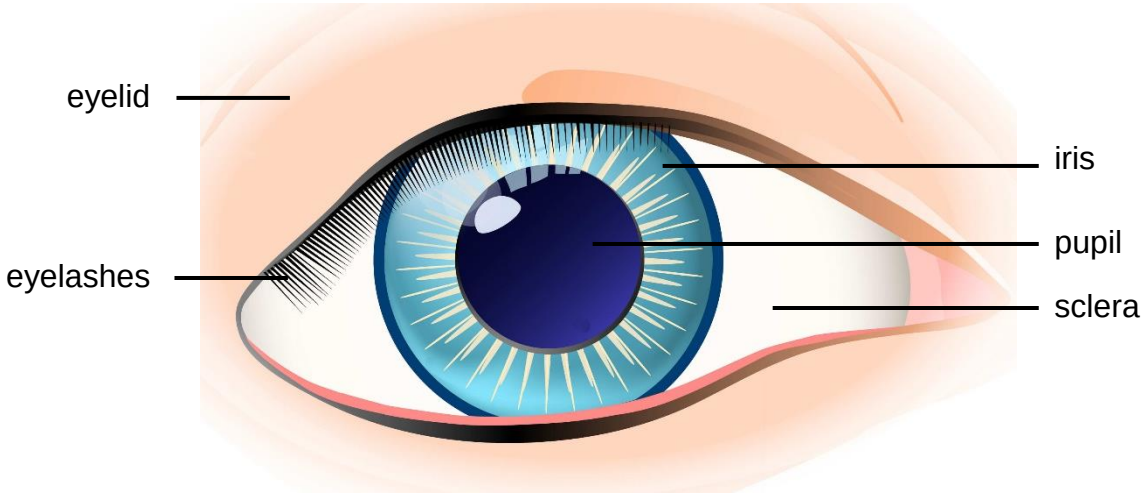


Figure 9: Front view of human eye

The eyeballs lie inside a bony cavity. Connective tissue and fat surround the eyeball to protect it from mechanical injury. The front of the eye is protected by eyelids, which have eyelashes to stop foreign particles from entering the eye. The coloured part of the eye is the known as the iris. The opening in the centre of the iris is the pupil. The sclera is a white outer covering layer.

The internal eye can be divided into three layers: the sclera, choroid and the retina. These layers, and other parts of the internal eye are shown in Figure 10 below.

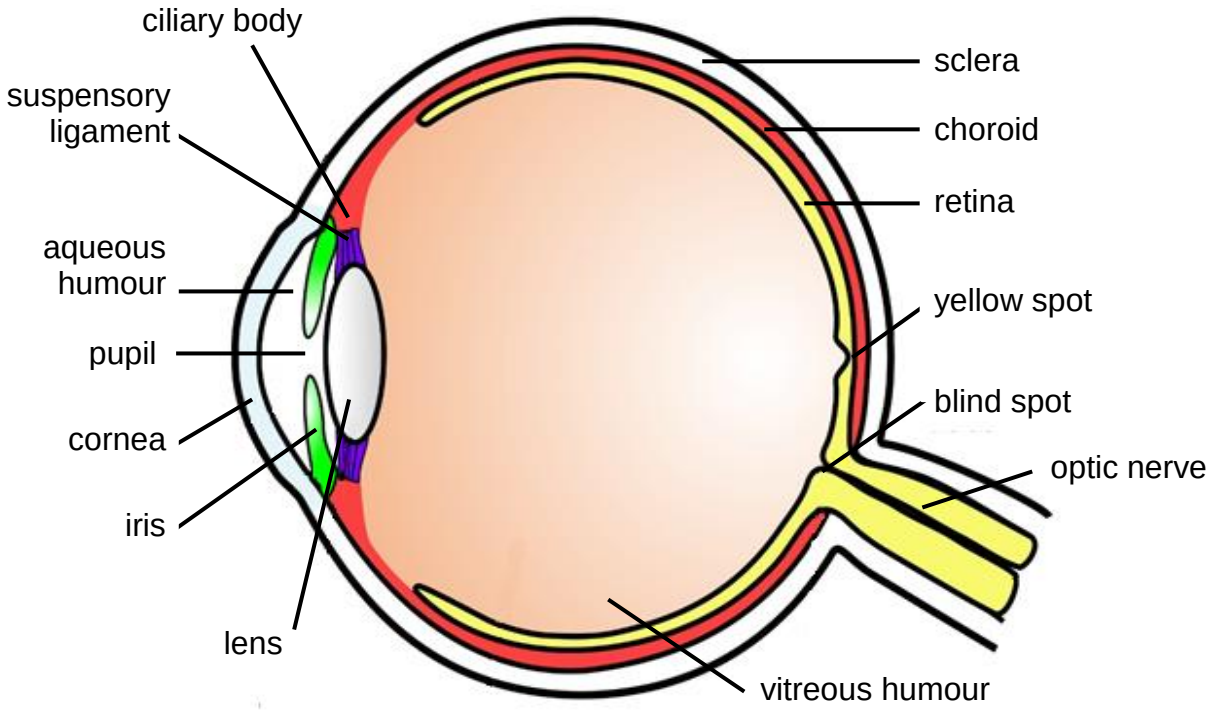


Figure 10: A longitudinal section of the eye

The structural adaptation and function of the parts of the eye shown above are laid out in Table 3 below.

Table 3: Structural adaptations and functions of various parts of the eye

Structural adaptations	Functions
sclera	
• tough, white inelastic layer that covers eye towards the posterior • adaptation: protection of the eye because it is inelastic	• protects the inner structures of the eye • maintains the shape of the eye

cornea	
• transparent continuation of the sclera in the front of the eye which is convex (bulgy) • adaptation: transparency allows light to pass through; the convex shape causes refraction (bending) of the incoming light	• allows light to pass through • causes refraction (bending) of the incoming light to create an image on the retina
choroid	
• a dark coloured layer which contains blood vessels and pigments	• pigments absorb light to prevent the reflection of light • blood vessels supply nutrients and oxygen to the cells of the retina
ciliary body	
• contains ciliary muscles and it is the thickened part at the anterior of the choroid	• ciliary muscles contract or relax to alter the tension on the suspensory ligaments
suspensory ligaments	
• ligaments attached to the ciliary body	• suspensory ligaments hold the lens in position during accommodation • tension on the suspensory ligaments changes to alter the shape of the lens
iris	
• the coloured portion of the eye, with an opening at its centre, called the pupil; the iris contains two types of muscles to control the size of the pupil	• controls the amount of light entering the eye through the pupillary mechanism
retina	
• inner layer of the eye which contains the rods and cones that are sensitive to light	• rods respond to low intensity light, provide night vision as well as peripheral vision • cones respond to bright light and provide sharp, clear colour vision • neurons carry impulses from the rods and cones through the optic nerve to the cerebrum
yellow spot	
• small indentation at the back of the eyeball containing the most cones	• area of clearest vision
blind spot	

• small area on the retina, below the yellow spot; contains no rods or cones, and hence no vision • area where the blood vessels enter the eye • area where the optic nerve leaves the eye	• area of no vision • inner parts of the eye are supplied with oxygen and nutrients • impulses are transmitted to the cerebrum for interpretation
lens	
• elastic and biconvex structure behind the pupil of the iris; held in place by suspensory ligaments • transparent	• changes shape to allow the eye to focus on near and distant objects • allows light to pass through
aqueous humour	
• watery fluid found in the space between the cornea and the lens	• maintains the shape of the cornea • plays a small role in the refraction of the incoming light
vitreous humour	
• jelly-like substance found behind the lens	• maintains the shape of the eyeball • plays a small role in the refraction of the incoming light

Structures of the human eye: https://www.youtube.com/watch?v=syaQgmxb5i0

Accommodation

Accommodation is the ability of the eye to alter the shape of the lens to ensure that a clear image always falls on the retina whether the object is near or distant. The process is explained in Table 4 below, and illustrated in Figures 11A for near vision and 11B for distant vision.

Table 4: Accommodation of the human eye

Near vision (***less*** than 6 m from the object)	**Distant vision** (***more*** than 6 m from the object)
• ciliary muscles contract • suspensory ligaments slacken (loosen) • tension on the lens decreases • lens becomes more convex (bulgy) • this causes light rays to bend more • a clear image is focused on the retina	• ciliary muscles relax • suspensory ligaments tighten (become taut) • tension on the lens increases • lens becomes less convex (flatter) • this causes light rays to bend less • a clear image is focused on the retina

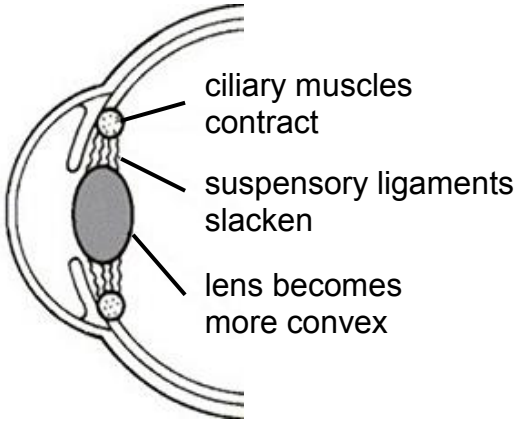


Figure 11A: Near vision

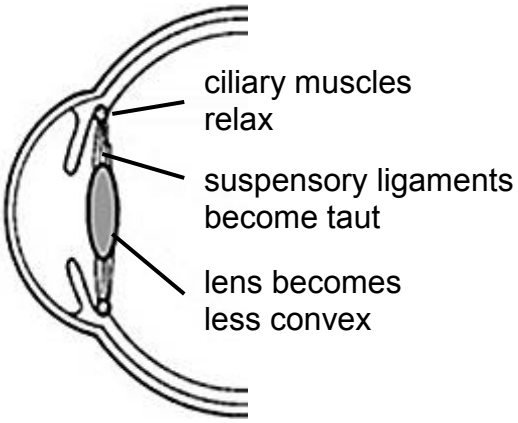


Figure 11B: Distant vision

Pupillary mechanism

Pupillary mechanism refers to the process by which the diameter of the pupil is altered to control the amount of light entering the eye. The intensity of the light is the stimulus that changes the size of the pupil. The iris controls the amount of light entering the pupil. It has circular and radial muscles which act antagonistically to change the size of the pupil.

Table 5 and Figures 12A and 12B below show the pupillary mechanism as it occurs in bright light and in dim light conditions.

Table 5: Pupillary mechanism

Bright light conditions	Dim light conditions
• radial muscles cause iris to relax • circular muscles of the iris contract • the pupil constricts (gets smaller) • the amount of light entering the eye is reduced	• radial muscles cause iris to contract • circular muscles of the iris relax • the pupil widens (gets bigger) • the amount of light entering the eye is increased

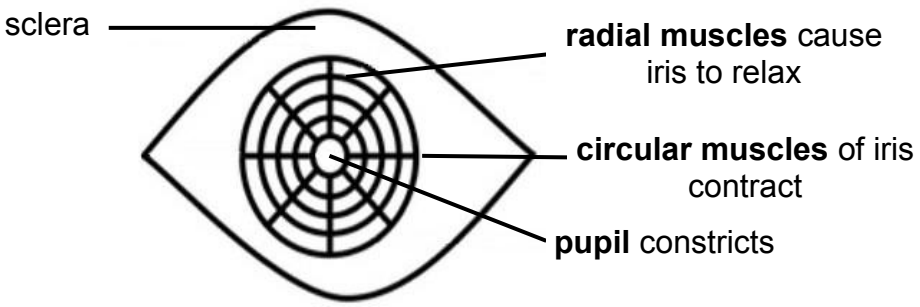


Figure 12A: Bright light conditions

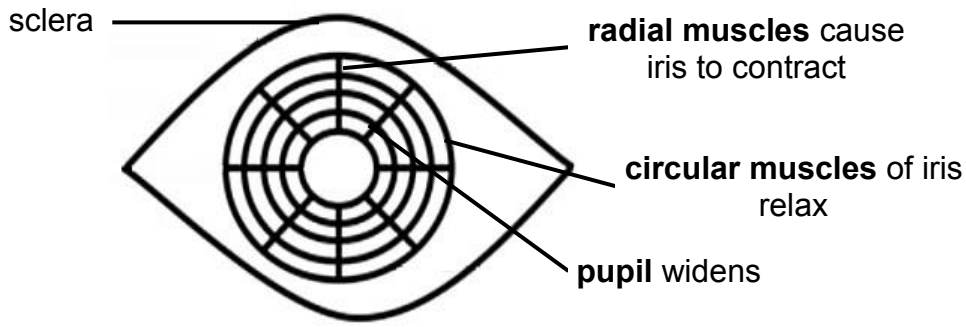


Figure 12B: Dim light conditions

Note: The radial and circular muscles of the iris work antagonistically. This means when one is contracted, the other is relaxed.

Visual defects

1. **Short-sightedness** occurs when a person has the ability to see nearby objects but cannot see distant objects clearly.

   Nature of the defect: when looking at distant objects, the light rays focus in front of the retina, causing blurred vision. The defects may be caused by:

   - an eyeball that is too long
   - the cornea being too curved for the length of the eyeball
   - the inability of the lens to become less convex

   Treatment: wear glasses with concave lenses

Figures 13A and 13B below show short-sightedness and its treatment.

Defect

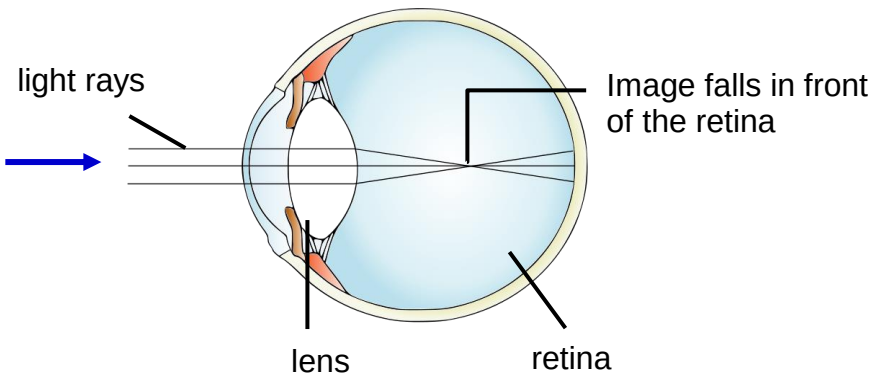


Figure 13A

Treatment

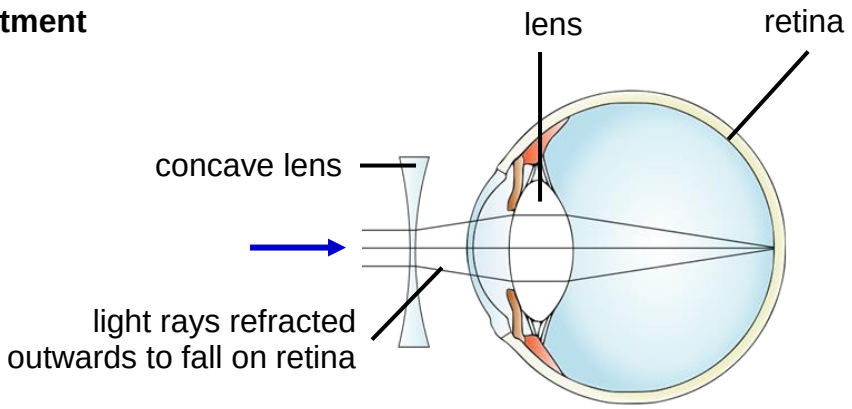


Figure 13B

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2. **Long-sightedness** occurs when a person has the ability to see distant objects but is unable to see nearby objects clearly.

   Nature of the defect: when looking at nearby objects, the light rays focus behind the retina, causing blurred vision. The defects may be caused by:

   - an eyeball that is too short (rounded)
   - the cornea not being curved enough for the length of the eyeball
   - the inability of the lens to become more convex

   Treatment: wear glasses with convex lenses

Defect

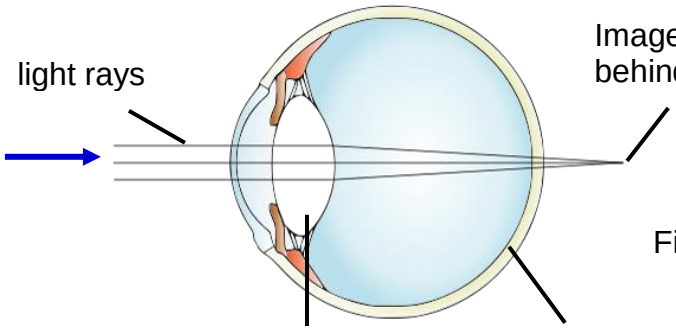


Figure 14A

Treatment

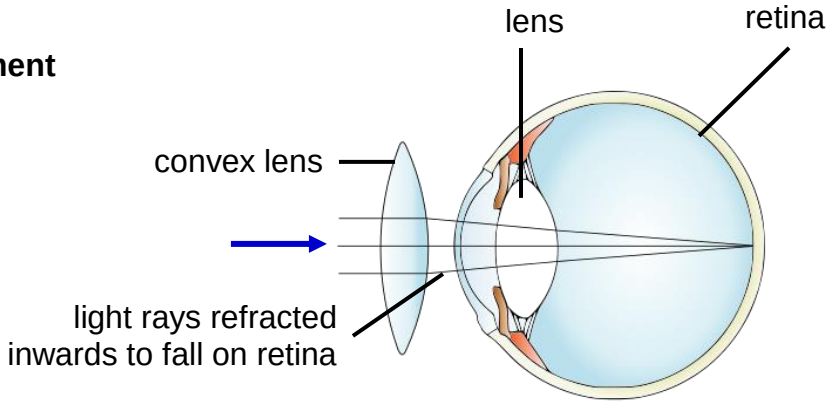


Figure 14B

Figures 14A and 14B: Long-sightedness and its treatment

3. **Astigmatism** occurs when the cornea or lens is not equally rounded in all directions as it normally would be (see Figure 15A and 15B).

Normal

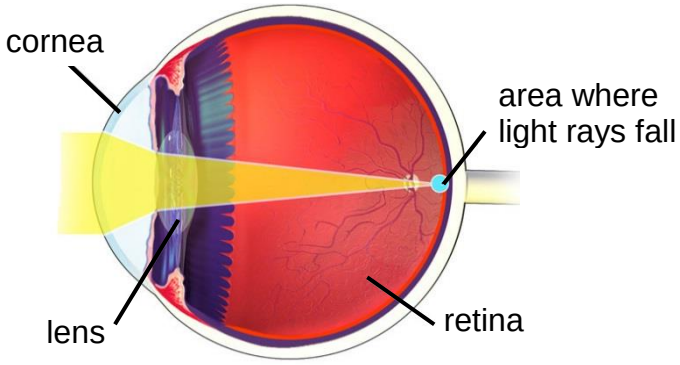


Figure 15A

Astigmatism

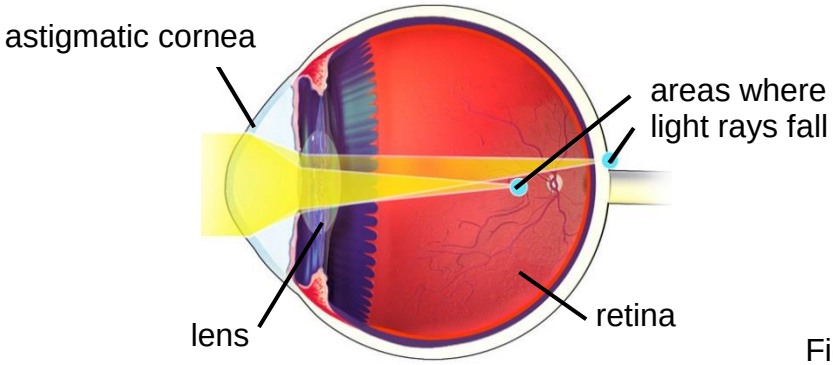


Figure 15B

Figures 15A and 15B: Human eye with normal and astigmatic cornea

With an astigmatic cornea, light entering the eye is not focussed evenly on the retina. This leads to:

- blurred vision
- headaches
- squinting of the eyes

Treatment of astigmatism may include:

- glasses with prescription lenses
- contact lenses
- laser therapy

4. **Cataracts** occur when the clear transparent lens becomes **cloudy**. This prevents light from entering the eye and results in blurred vision. The cataract develops slowly and increases in size over time (see Figures 16A and 16B).

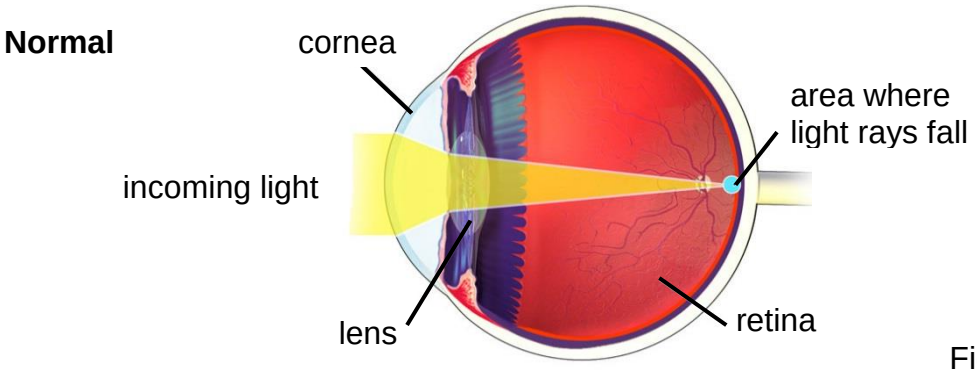


Figure 16A

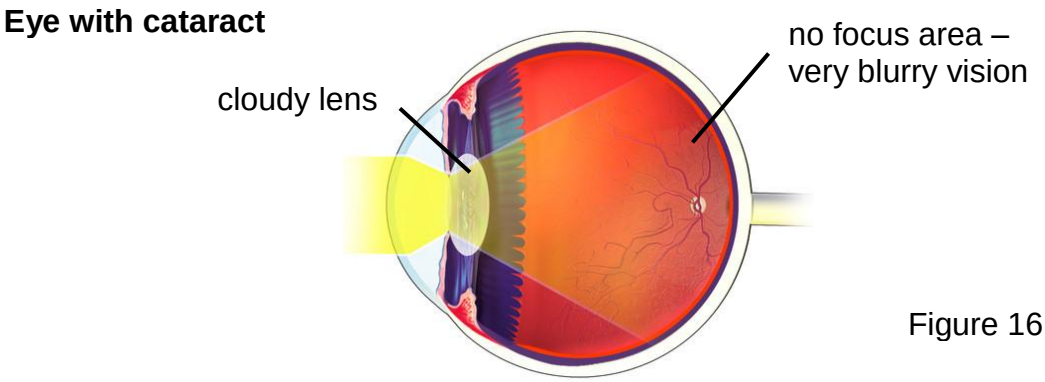


Figure 16B

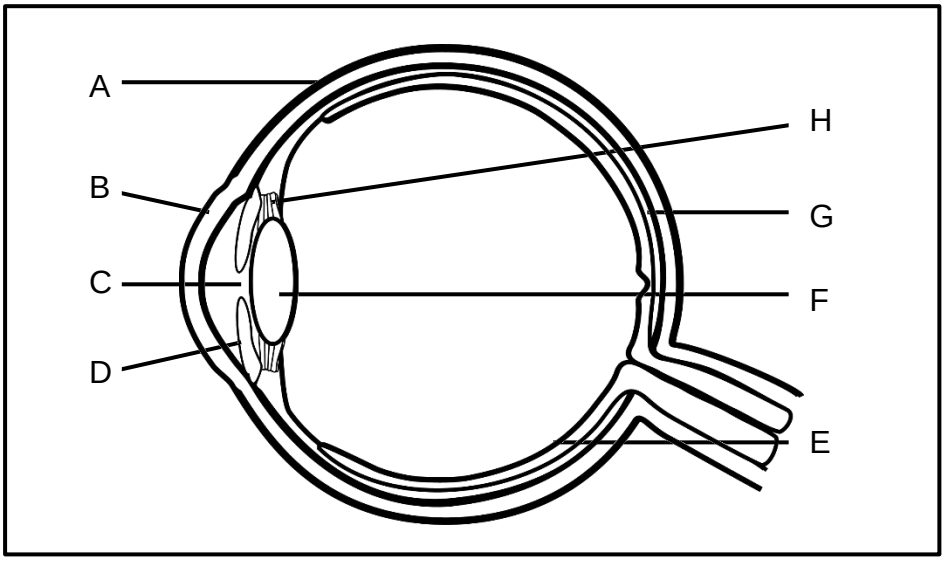
Figures 16A and 16B: Human eye with clear lens and with cataracts

Treatment:

- In the beginning, spectacles may be used.
- As the cataract develops, surgery may be required. During surgery, the lens is removed, and a synthetic lens is inserted.

Activity 5: The human eye

The diagram below represents a section through a human eye.

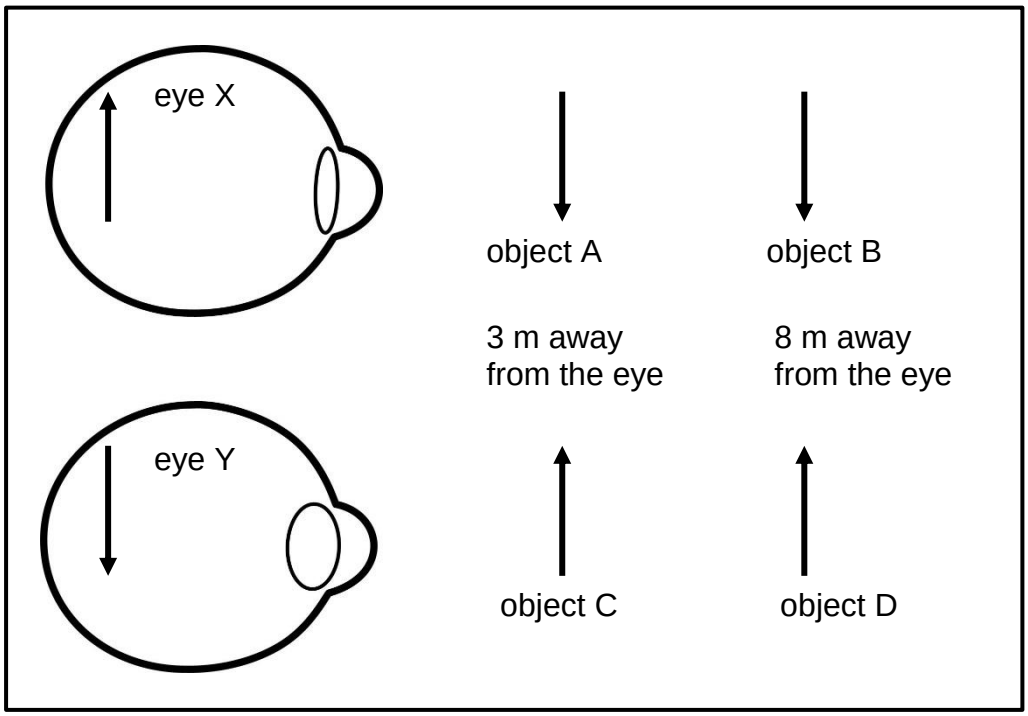


1. Identify parts C, D and H. (3)
2. Explain how part B is adapted to perform its function. (2)
3. Provide the functions of E and G respectively. (2)
4. Write down the letter only for the part that
   a) is able to change shape to refract light (1)
   b) provides structural support to the eyeball (1)
5. Name and describe the process which involves the iris controlling the amount of light entering the eye when a person is exposed to bright light. (5)

(14)

Activity 6: Accommodation

The diagram shows two eyes (X and Y) focused on objects (represented by arrows) at different distances from the eye. Objects A and C were 3 metres away from the eye. Objects B and D were 8 metres away from the eye. The diagrams below are not drawn to scale.



1. Write down the letter of the object that:
   a) eye Y is focussed on (1)
   b) eye X is focussed on (1)
2. a) Name the eye defect which results in the inability of the eye Y to focus on the object D. (1)
   b) Name the type of lens used to rectify the defect in 2(a) above. (1)

3. Identify and describe the process that allows eye Y to form a clear image on the retina. (5)

(9)

Activity 7: Case study on visual defects

Read the extract below and answer the questions that follow.

Kayise, age 60, had failed her vision test for her driver's license. All her life she had suffered from extreme near-sightedness. In fact, without her glasses she was legally blind. When she was denied her license renewal, Kayise came to Dr Nobadula for help. During an examination, it became clear that Kayise had cataracts in both eyes. A cataract is a clouding of the lens in the eye, which reduces vision. The lens is inside the eye and focuses light onto the retina at the back of the eye, where an image is recorded. The lens also adjusts the eye's focus. The lens is made of mainly water and protein. The latter is arranged so the lens stays clear, allowing light to pass through it. Yet, with age, the protein may form clumps that cloud the lens. This is a cataract. The best solution to Kayise's situation was surgery that removed the cataracts and implanted tiny artificial lenses within the eye. Dr Nobadula conducted this procedure. Today, for the first time in her life, Kayise enjoys 20/20 vision without glasses.

1. Describe what is meant by near-sightedness. (2)
2. Which type of lens can be used to correct this defect? (1)
3. What causes the clouding to form in the lens? (1)
4. In your opinion, what would happen to Kayise if she did not have surgery? (1)
5. Explain the cause of Kayise's near-sightedness and why she did not need glasses after surgery. (4)
6. Describe what happens to light rays in the eye of a person with cataracts. (3)
7. Name one other visual defect not mentioned in the extract above. (1)

(13)

The human ear

Key terminology

organ of Corti	receptor for hearing
crista (plural: cristae)	receptor which detects changes in speed and direction of the head
maculae	receptor which detects changes in the position of the head
semicircular canals	canals which are fluid filled and contain receptors

ampulla (plural: ampullae)	swelling at the base of the semicircular canals which contains the crista
vestibule	structure made up by the sacculus and utriculus, these contain the maculae
grommet	small structure inserted into the tympanic membrane; has a hole through the middle to allow air flow

Figure 17 below shows the structure of the ear.

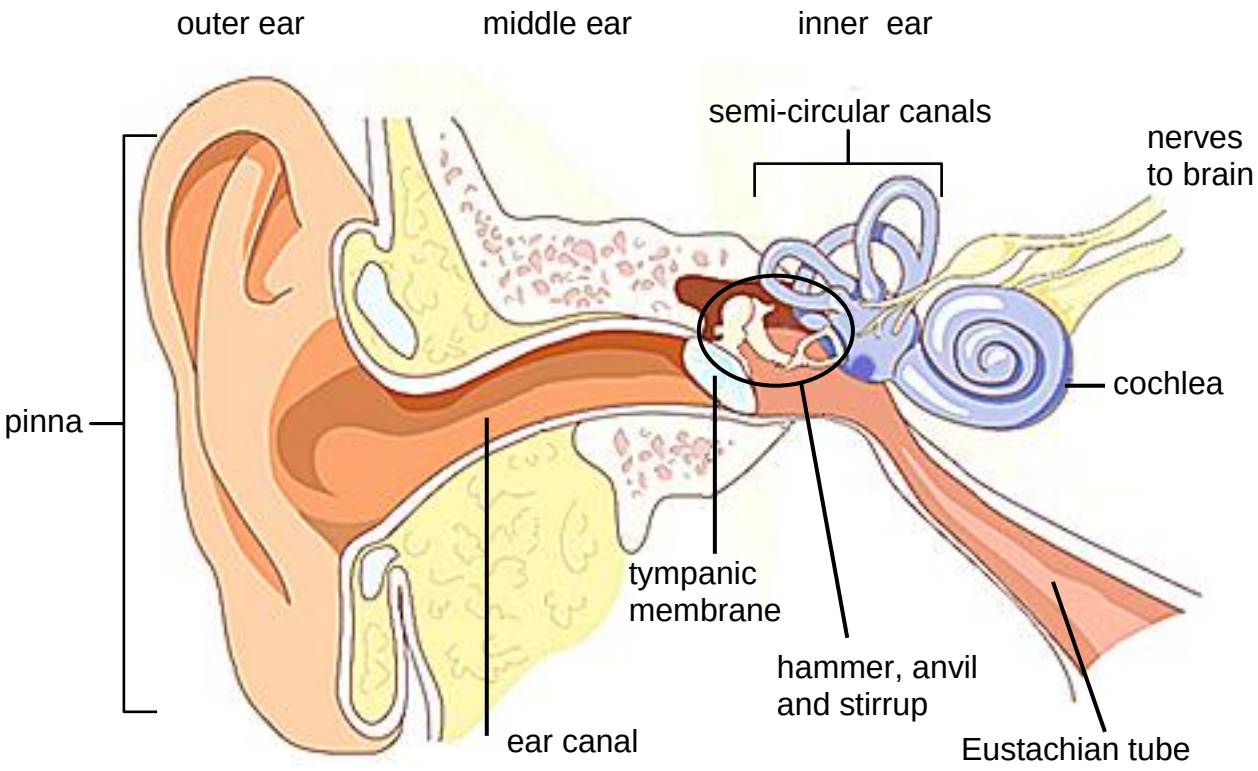


Figure 17: Structure of the human ear

As shown above, the ear may be divided into three sections: the outer ear (Figure 18), the middle ear (Figure 19) and the inner ear (Figure 20).

The outer ear

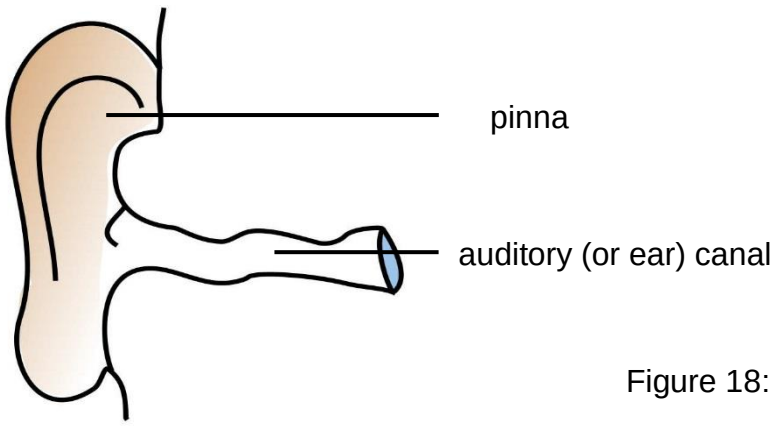


Figure 18: The inner ear

Table 6 below lists the structural adaptations and functions of the various parts of the outer ear.

Table 6: Structural adaptions and function of the outer ear

pinna	
• cartilage flaps situated on the out-side of the ear	• direct sound waves into the auditory canal
auditory canal	
• tube which passes from the pinna to the tympanic membrane	• transmits sound waves to the tympanic membrane • has little hairs which prevent foreign bodies from entering the ear • has wax which prevents the tympanic membrane from drying out

The middle ear

The middle ear (Figure 19) is an air-filled cavity within the skull. It is separated from the outer ear by the tympanic membrane and is separated from the inner ear by the round window and the oval window. Table 7 list its structural adaptations and functions.

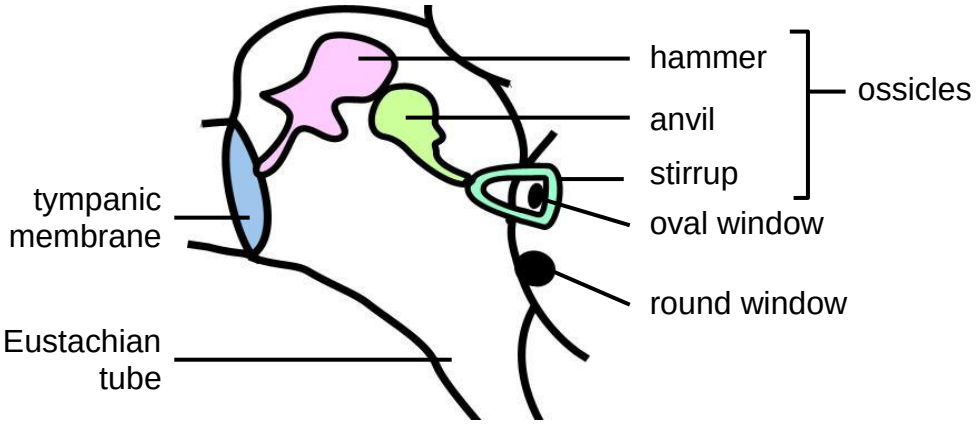


Figure 19: The middle ear

Table 7: Structural adaptations and functions in the middle ear

tympanic membrane	
• thin membrane separating the inner ear from the middle ear	• sound waves moving in auditory canal cause it to vibrate • transmits sound waves to the middle ear

ossicles	

• three irregularly shaped bones:
  ○ hammer (malleus) – largest, connected to tympanic membrane
  ○ anvil (incus) – middle bone, joining the malleus to the stapes
  ○ stirrup (stapes) – smallest, connected to the round window
	• vibrations from the tympanic membrane are transmitted through the ossicles to the inner ear
	• serve to amplify the vibrations (make them larger)

oval window	
• membrane separating the middle ear from the inner ear	• transmits vibrations from the middle ear to the inner ear
round window	
• membrane situated below the oval window	• absorbs excess pressure waves from the inner ear – stop vibrations being echoed
Eustachian tube	
• thin tube connecting the middle ear to the back of the throat	• equalising pressure on both sides of the tympanic membrane

The inner ear

The inner ear lies within the bones of the skull and is made up of the semi-circular canals, vestibule (sacculus and utriculus) and the cochlear which are continuous with each other (Figure 20). The structural adaptations and functions of the various parts are listed in Table 8.

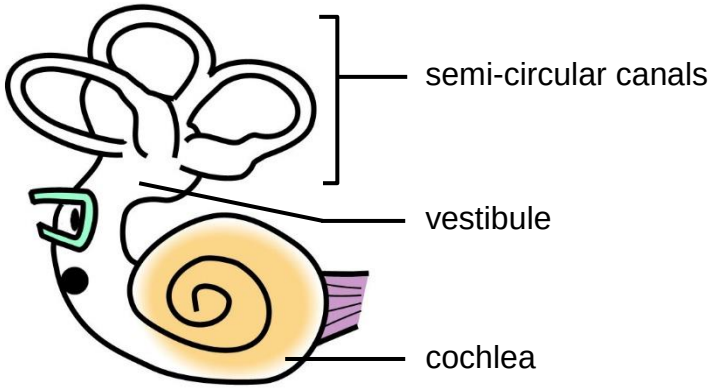


Figure 20: Inner ear

These structures are made up of bony cavities and are called the bony labyrinth. This labyrinth is filled with a fluid called perilymph. Suspended in the perilymph is a

system of membranes called the membranous labyrinth. This labyrinth contains a fluid called endolymph.

Table 8: Structural adaptation and functions of parts of the inner ear

Structural adaptations	Functions
semi-circular canals	
• three semi-circular canals are arranged at right angles to each other • they are located above the vestibule • each canal has an enlarged area, called the ampulla, at one end • inside the ampulla are receptors (cristae)	• cristae detect changes in speed and direction and generate impulses sent to the cerebellum

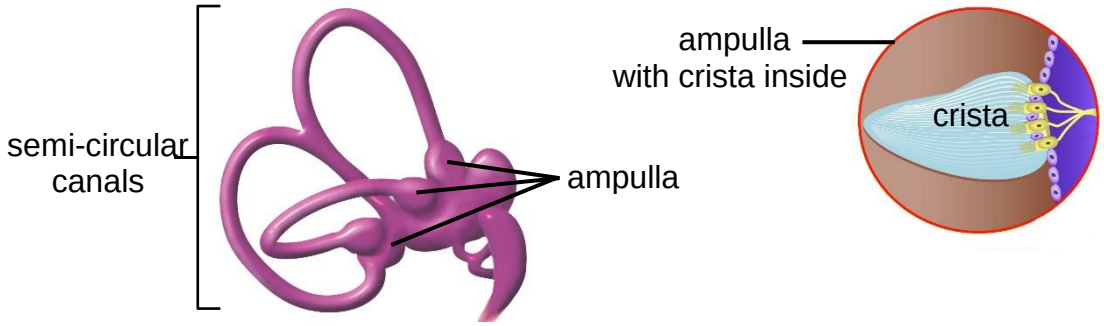



Figure 21: Semi-circular canals with crista in ampulla	
vestibule	
• made up of two membranous sacs called the sacculus and utriculus (both filled with endolymph); inside each are receptors called maculae • maculae have tiny hair cells covered with a jelly-like substance and tiny calcium carbonate stones.	• receptors (maculae) detect changes in the position of the head with respect to gravity

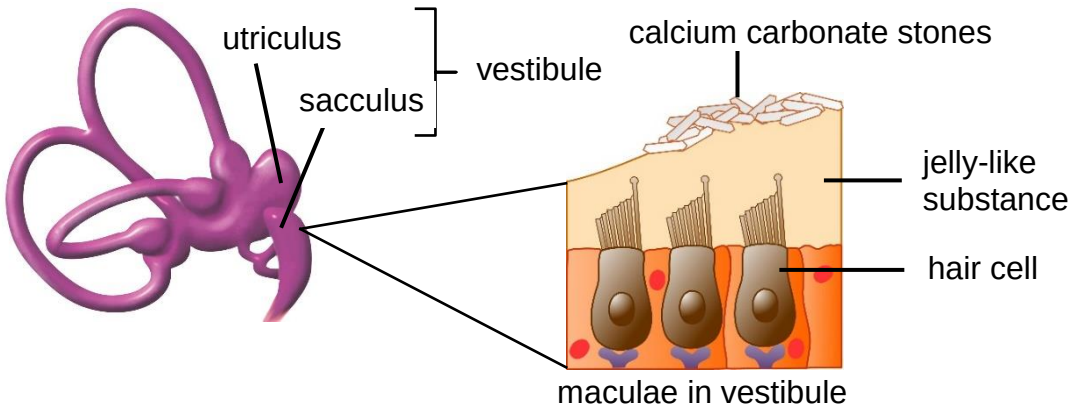



Figure 22: Vestibule with detail of maculae	

cochlea	
• divided into three chambers • the upper and lower chambers are filled with perilymph • middle chamber is filled with endolymph, and contains the organ of Corti • organ of Corti contains tiny hairs embedded into a membrane	• organ of Corti is receptor responsible for interpreting sound • it converts the stimulus of sound into an impulse

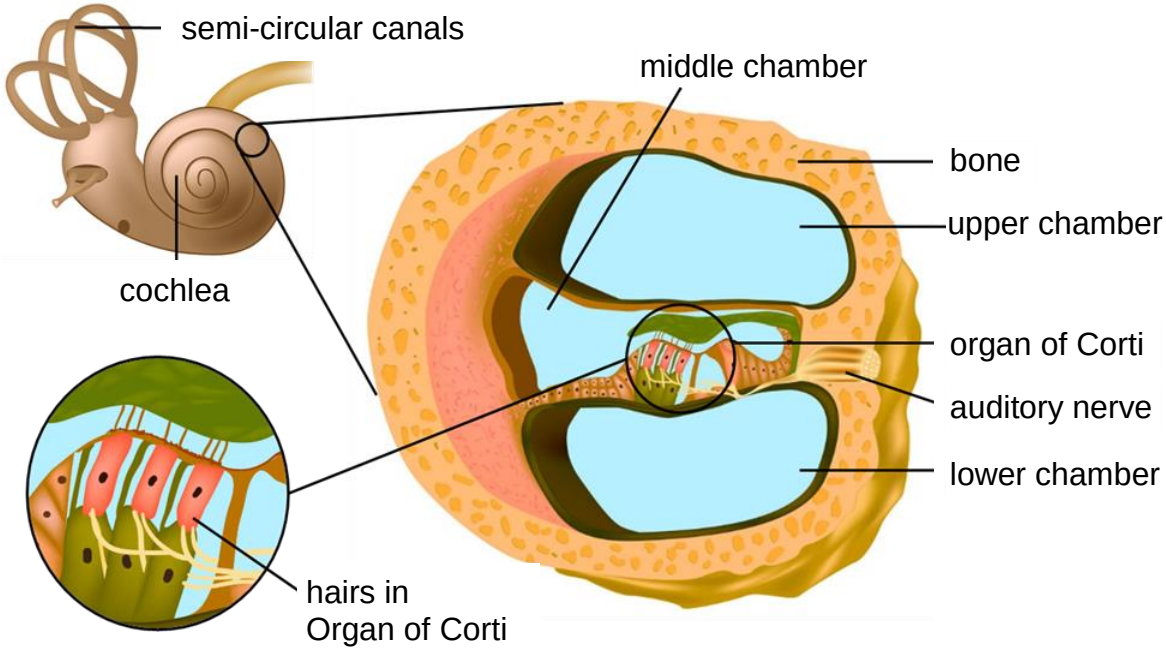
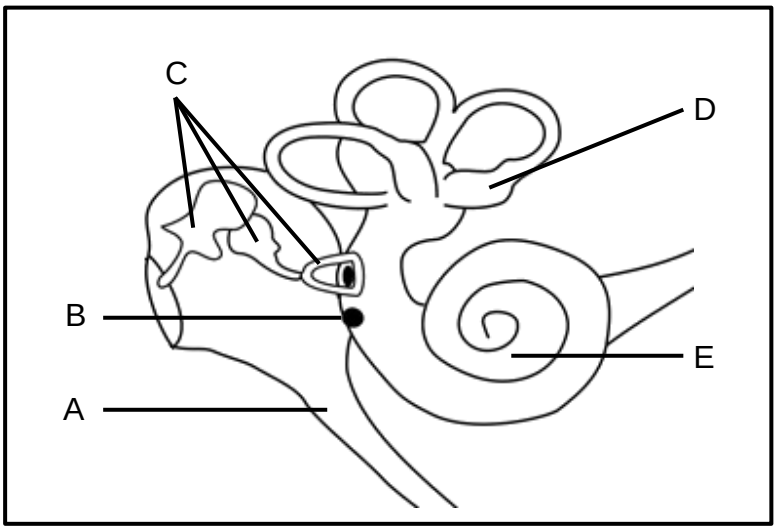


Figure 23: Cochlea, in cross-section, and detail of hairs in the organ of Corti

Structures of the ear: https://www.youtube.com/watch?v=HMXoHKwWmU8

Activity 8: The human ear

The diagram below represents a part of the human ear.



1. Identify:
   a) part A (1)
   b) part B (1)
   c) part E (1)
2. Provide the collective name for the bones found at C. State two functions of these bones. (3)
3. The structure labelled D contains receptors.
   a) Name the receptors found in this structure. (1)
   b) Give the stimulus to which these receptors respond. (2)

(9)

Functioning of the human ear

The human ear has two functions:

- hearing
- maintaining balance

Hearing

Hearing (illustrated in Figure 24 below) is the process in which sound waves are transmitted through the ear and impulses are generated which are sent to the cerebrum for interpretation. This process occurs as follows:

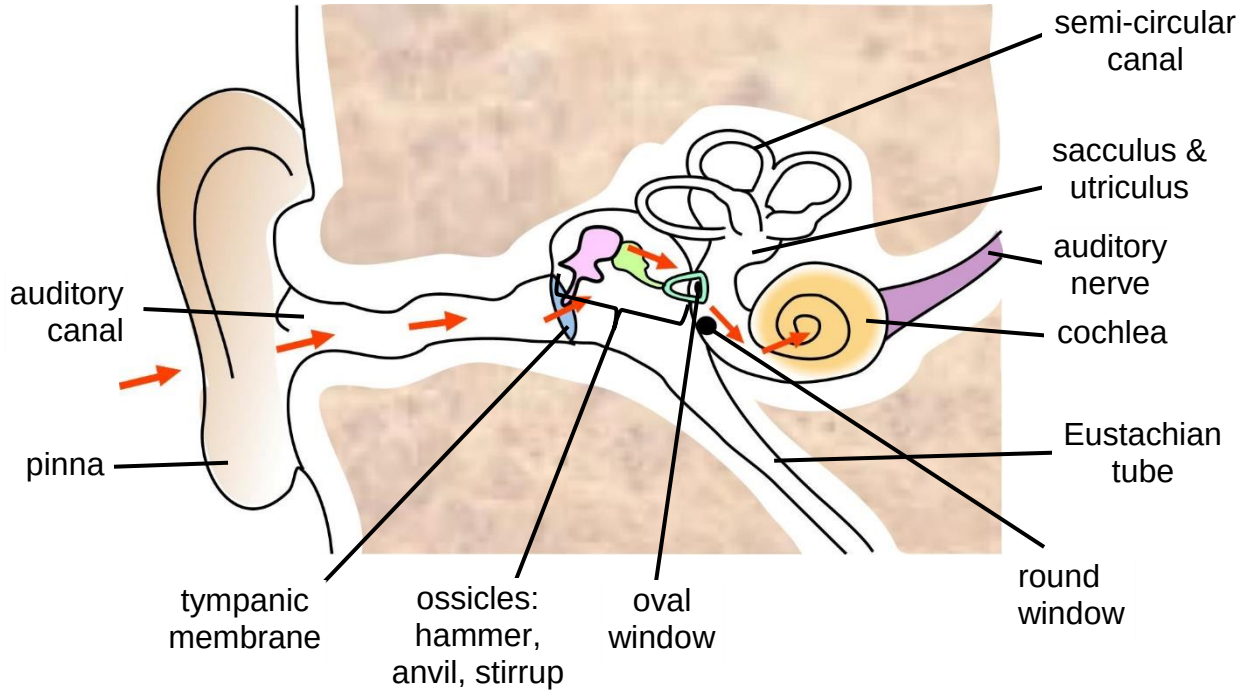


Figure 24: The process of hearing

- The pinna traps and directs sound waves into the auditory canal towards the tympanic membrane.
- The tympanic membrane vibrates as the sound waves strike against it.
- The vibrating tympanic membrane causes the ossicles to vibrate.
- The hammer, anvil and stirrup amplify and transmit the vibrations to the oval window.
- The oval window is smaller than the tympanic membrane. As a result, the pressure increases, causing the sound to be amplified.
- The vibrating oval window causes pressure waves to travel through the endolymph in the cochlea.
- The organ of Corti in the middle chamber of the cochlea is stimulated.
- The stimulus is converted into a nerve impulse which is transmitted to the auditory nerve.
- The auditory nerve transmits the impulse to the cerebrum for interpretation.
- The pressure waves in the cochlea are absorbed into the middle ear through the round window and exit the body via the Eustachian tube.

Maintaining balance

Balance is the process in which receptors in the inner ear detect changes in the position of the head and respond to gravity as well as changes in speed and

direction of the body. Balance is brought about by the cristae ampullae of the semi-circular canals and the maculae in the sacculus and utriculus. This process occurs as follows:

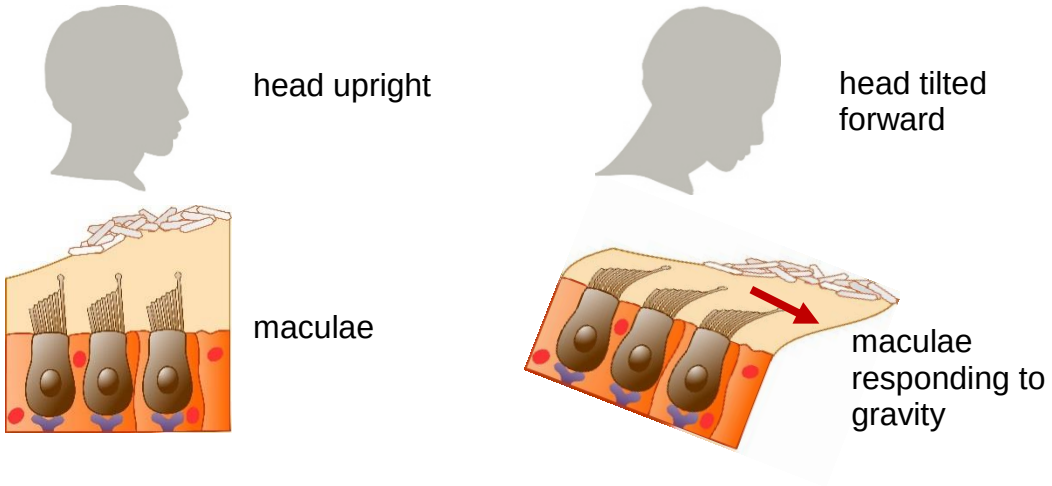


Figure 25A: Position of the macula
with head upright (left) and tilted forward (right)

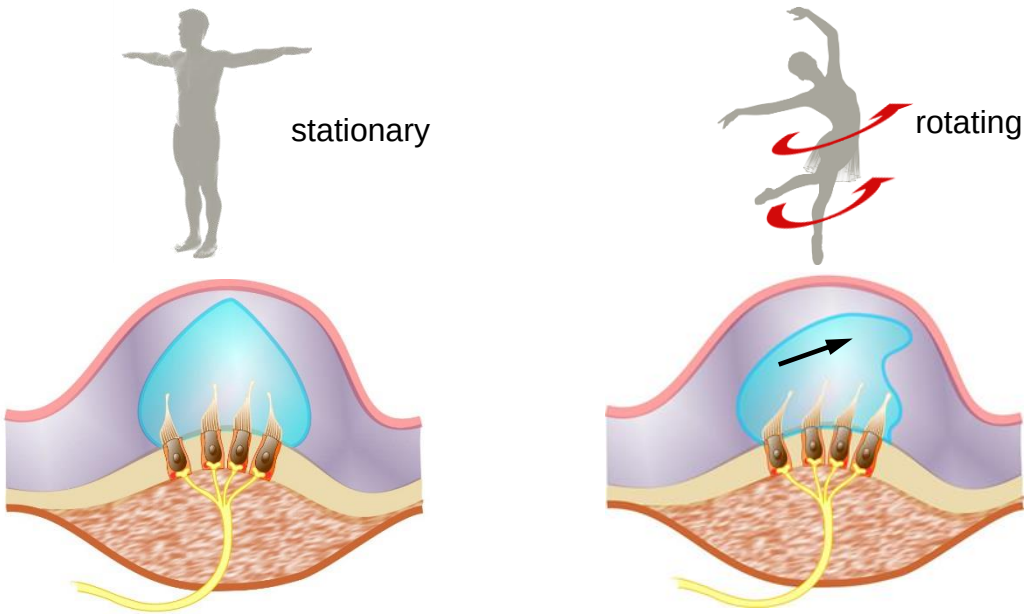


Figure 25B: Position of the macula when stationary (left)
and when rotating (right).

- The sacculae and utriculae
    - contain special receptors called maculae that are stimulated.
    - When the position of the head changes,
    - the pull of gravity stimulates

- sensory hair cells in the maculae to generate impulses.
- The impulses generated from the maculae are sent to the cerebellum.
- The cerebellum sends impulses to the skeletal muscles to restore the balance.

- The ampullae
  - are situated at the end of semi-circular canals contain cristae.
  - The three semi-circular canals are positioned in three different planes
  - and therefore, any sudden changes in the speed and direction of body movement,
  - cause the endolymph to move in at least one of the semi-circular canals.
  - The movement of endolymph stimulates
  - the cristae to generate impulses which are sent to the cerebellum.
  - The cerebellum sends impulses to the skeletal muscles to restore the balance.

Hearing defects

Middle ear infection occurs when excess fluid builds up in the middle ear. It is caused by pathogens entering through the Eustachian tube. The fluid cannot drain through the Eustachian tube due to the infection from the pathogen which causes it to become inflamed.

Treatment:

- medication
- **grommets** are used for young children. A grommet is a draining tube which is put into the tympanic membrane through surgery which allows moisture from behind the tympanic membrane to drain out.

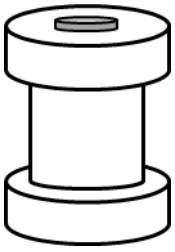


Figure 26: A grommet

Deafness refers to a total or partial hearing loss. It may be caused by:

- injury to parts of the ear, nerves or parts of the brain responsible for hearing
- hardening of ear tissues such as the ossicles

Treatment:

- hearing aids
- cochlear implants

Figure 27: Hearing aid

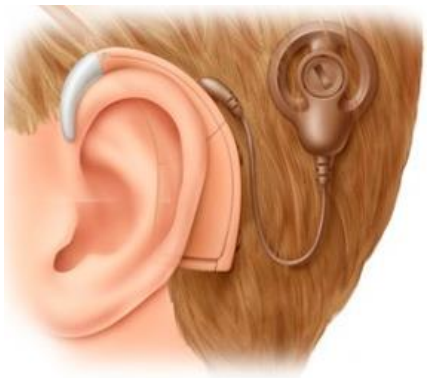
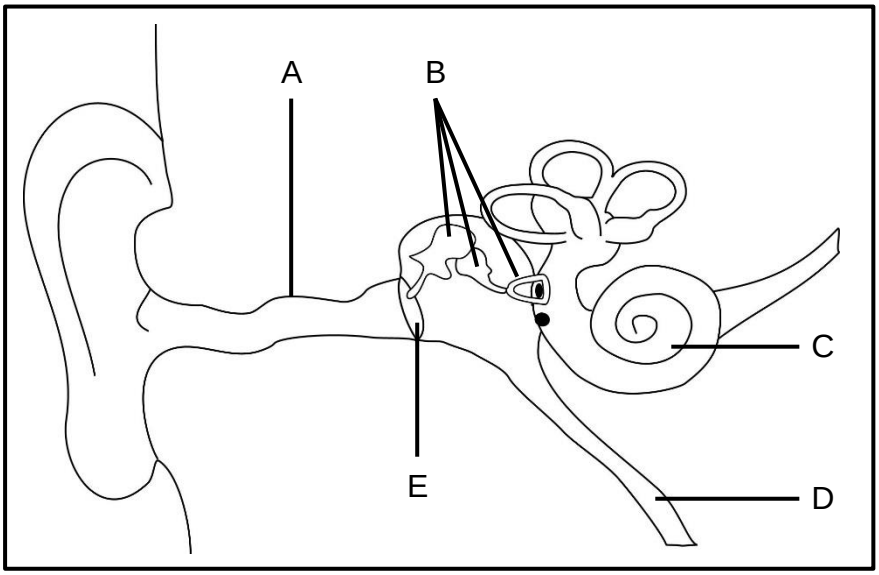


Figure 28: Cochlear implant

Activity 9: Balance, hearing and defects

Study the diagram below, then answer the questions that follow.



1. Write down the letter only of the part which:
   a) amplifies the vibrations from the tympanic membrane (1)
   b) contains the receptors for hearing (1)

2. Otosclerosis is a genetic form of hearing loss caused by the stirrup becoming immovable. Explain how this conditions may cause hearing loss. (3)

3. Two devices used to treat deafness are hearing aids and cochlear implants. The way in which they function is given in the table below:

Device	Method of functioning
hearing aid	receives, transmits and amplifies sound vibrations
cochlear implant	receives sound vibrations and converts them into an electrical impulse which is transmitted directly to the auditory nerve

By referring to the diagram above, give the letters of the parts where the defect may occur:

a) when a hearing aid is used (2)

b) when a cochlear implant is used (1)

4. The vestibular branch of the auditory nerve transmits impulses from the semi-circular canals to the cerebellum. Explain the consequence if this nerve is infected by a virus. (2)

(10)

Human responses to the environment: End of topic exercises

Section A

Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A- D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1.1 Which one of the following pathways represents a reflex arc?

A Muscle → spinal cord → brain
B Effectors → spinal cord → receptor
C Receptor → spinal cord → brain
D Receptor → spinal cord → muscle

1.1.2 The process in the eye which allows a person to adapt to see at different distances:

A Pupillary mechanism
B Astigmatism
C Accommodation
D Cataracts

1.1.3 Which one of the following is a function of the medulla oblongata?

A Controls voluntary muscular activities.
B Processing all sensory information.
C Balance and co-ordination.
D Controls heartbeat and breathing.

1.1.4 A patient experiences slight visual and speech disturbance after a serious head injury. Which section of the brain has possibly been damaged?

A Cerebrum
B Cerebellum
C Hypothalamus
D Medulla oblongata

1.1.5 A person can feel pain in his legs but cannot move his legs. This is as a result of damage to the…

A sensory neuron.
B sensory and motor neuron.
C motor neuron.
D sensory and interneuron. (5 × 2) = (10)

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

1.2.1 The part of the neuron that conducts impulses away from the cell body.
1.2.2 The part of the autonomic nervous system that tends to slow down organ activity.
1.2.3 A disorder of the nervous system that is characterised by the breakdown of the myelin sheath of neurons.
1.2.4 A group of nerve cell bodies of neurons that form a swelling outside the spinal cord.
1.2.5 The part of the nervous system that is made up of cranial and spinal nerves.
1.2.6 A collective name for the membranes that protect the brain.
1.2.7 The part of the brain that maintains muscle tone, balance and equilibrium.
1.2.8 The division of the nervous system that controls involuntary actions and has a homeostatic function.
1.2.9 The structure that connects the left and right hemispheres of the brain, allowing communication between them.
1.2.10 A disorder of the central nervous system that leads to memory loss in humans. (10 x 1) = (10)

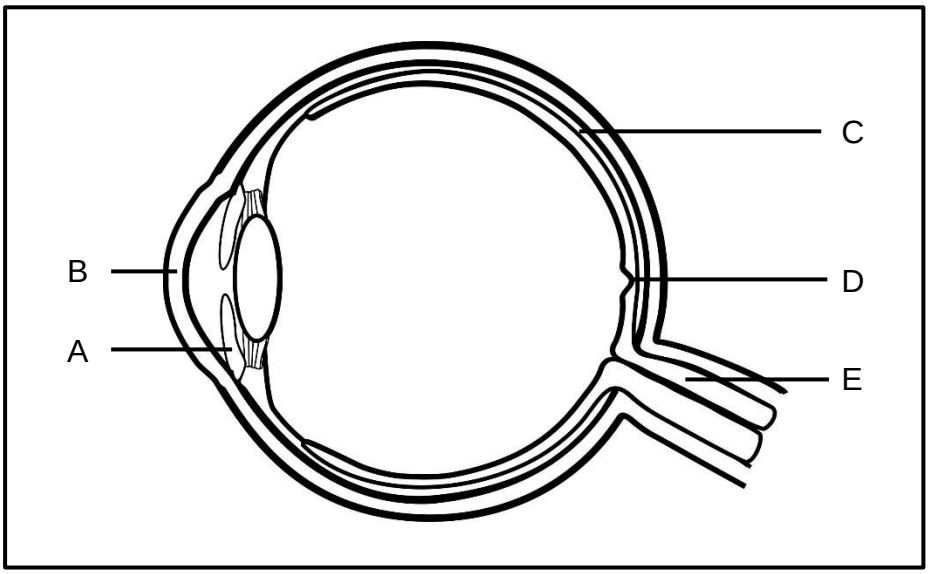
1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 The part of the brain that connects the two hemispheres	A: corpus callosum B: cerebellum

1.3.2 A brain disorder that results in memory loss	A: Alzheimer's disease B: Multiple sclerosis
1.3.3 A structure in the nervous system that detects a stimulus.	A: effector B: receptor
1.3.4 The part of the autonomic nervous system that controls involuntary actions.	A: sympathetic B: parasympathetic
1.3.5 The central nervous system is made up of the…	A: cranial and spinal nerves B: brain and spinal chord

(5 x 2) = (10)

1.4 The diagram below represents the structure of the human eye



Give the letter and name of the part which:

1.4.1 Regulates the amount of light entering the eye (2)

1.4.2 Supplies food and oxygen to the eye (2)

1.4.3 Transmits impulses to the brain (2)

1.4.4 Contains cones and is the area of clearest vision (2)

1.4.5 Assists in the refraction of light rays (2)

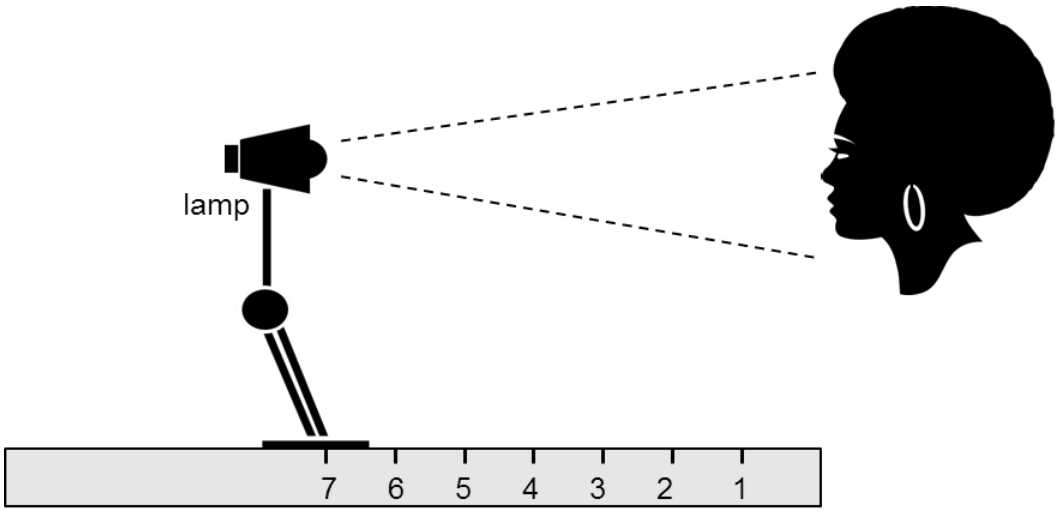
(10)

Section A: [40]

Section B

Question 2

2.1 An experiment was conducted to investigate the diameter of the pupil to change in light intensity. A lamp was placed at various distances from the face of a person as shown. Study the diagram and the table of data below to answer the questions.



2.1.1 Suggest a possible hypothesis at the start of the investigation. (2)

2.1.2 Which two factors should be kept constant during the investigation? (2)

2.1.3 Identify the:

a) Independent variable (1)

b) Dependent variable (1)

The table below shows the diameter of the pupil when the light was placed at various distances from the person's face.

Position of lamp	Diameter of the pupil (mm)
1	1,2
2	1,8
3	2,4
4	3,0
5	3,6
6	4,2
7	4,8

2.1.4 Based on the available data would you accept, or reject the initial hypothesis? (1)

2.1.5 What conclusion can be deduced from the available data? (2)

2.1.6 Suppose the lamp was moved from position 7 to position 2. Describe the mechanism that caused the change in the diameter of the pupil. (4)

2.1.7 Name the process mentioned in question 2.1.6. (1)

2.1.8 Plot a bar graph to represent the data gathered during this investigation. (7)

(21)

2.2 Read the extract below and answer the questions that follow.

A LINK BETWEEN CONCUSSION AND BRAIN DAMAGE

In 2002 a former American football player was found dead in his truck. The doctor who handled the autopsy discovered that the football player had severe brain damage and that his death was caused by repeated blows to the head or repeated concussions. He called this disorder chronic traumatic encephalopathy (CTE).

A more recent study was conducted that involved the brains of 165 people who played football at high school, college or professional level. The study found evidence of CTE in 131 of the brains.

(adapted from www.wikipedia.org and www.theatlantic.com)

2.2.1 The part of the brain affected by CTE is the cerebrum. State two possible symptoms of this disorder. (2)

2.2.2 State one way in which the brain is protected. (1)

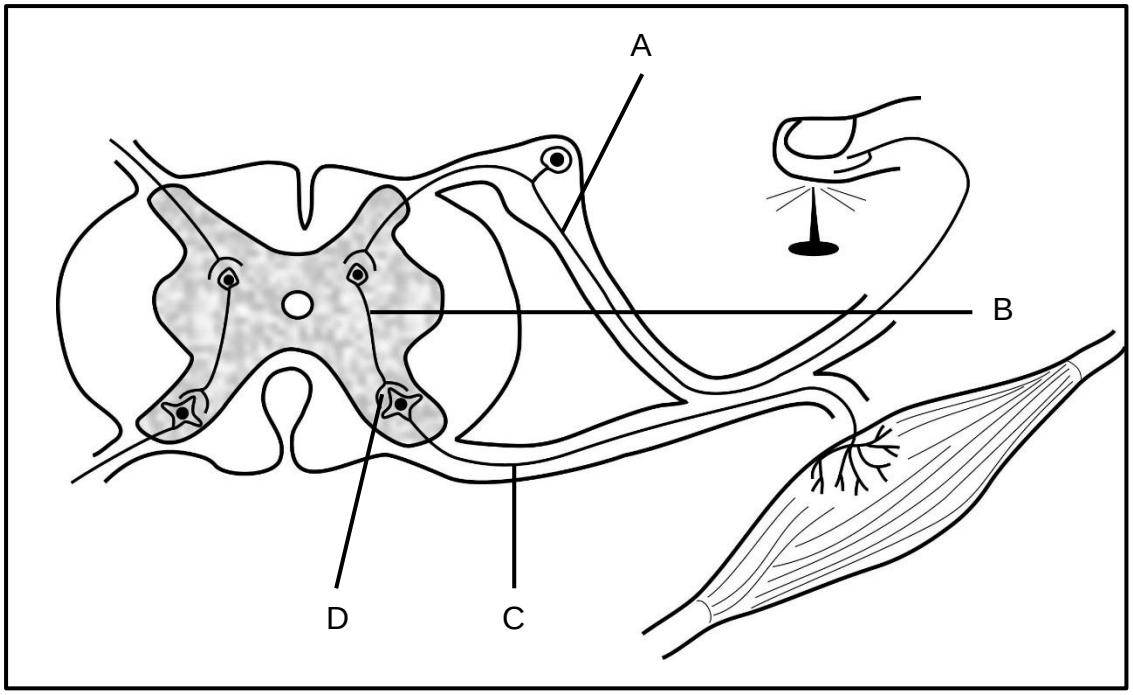
2.2.3 Explain why CTE does not usually affect essential life processes such as breathing or heart rate. (2)

(5)

[26]

Question 3

3.1 Study the diagram of a reflex arc below.



3.1.1 What is a reflex action? (1)

3.1.2 Label the following:

a) The functional connection at **D**. (1)

b) Neuron **B** (1)

3.1.3 State the significance of the microscopic gap indicated by **D** (1)

3.1.4 Write down in the correct order, the letters only of the neurons involved from the time a stimulus is received until a response takes place. (2)

3.1.5 Explain the consequences for a reflex action if neuron **C** is damaged. (2)

3.1.6 Draw a labelled diagram to represent the structure of neuron **A**. (5)

(13)

3.2 Read the article below and answer the questions that follow.

The discovery of Alzheimer's Disease (AD)

Alzheimer's disease (AD) is an irreversible brain disease that slowly destroys brain cells, causing loss in memory and thinking skills serious enough to interfere with daily life. The symptoms first appear after the age of 60, making it the most common cause of dementia among older people. (continued on next page ..)

Continued: It is a neurological brain disorder named after a German physician, Alois Alzheimer, who first described it in 1906. He noticed changes in the brain of a woman who had died after an unusual mental illness. Her symptoms included memory loss, language problems and strange behaviour. After she died he inspected her brain and found many clumps and tangled bundles of nerve fibres.

Abnormal clumps, tangled-bundles of nerve fibres and the loss of connections between brain cells are all symptoms of the disease. AD gets worse over time, with death due to organ failure usually occurring two to eight years after the start. At present there is no cure.

adapted from: www.ALZinfo.org. Fischer Centre for Alzheimer's Research Foundation.

The table below presented by the World Health Organisation shows the percentage of people in the general western population affected by AD in different age groups.

Age groups (years)	Percentage patients with AD (%)
65-69	1,4
70-74	2,8
75-79	6,6
80-84	11,1
85+	23,6

3.2.1 What was the percentage increase of patients with AD, between the oldest two age groups? (1)

3.2.2 What seems to be the earliest symptoms of Alzheimer's disease? (1)

3.2.3 Describe what the person's brain looked like when it was dissected. (2)

3.2.4 What is the main cause of death in a person with AD? (1)

3.2.5 Use the table to plot a histogram to show the occurrence of AD. (6)

(11)

[24]

Section B: [50]

Total marks: [90]

7: The human endocrine system and homeostasis

CHAPTER 7: THE HUMAN ENDOCRINE SYSTEM AND HOMEOSTASIS

Introduction

Various human mechanisms enable us to respond and react to the outside environment so as to maintain a constant internal environment. Our responses are controlled by the **nervous** and **endocrine** systems and to an extent, the **immune** system. The working together of these systems helps to maintain stability within the organism and so protects us.

The human nervous system responds via:

- a rapid response to stimuli
- the use of electrical impulses and neurotransmitters

The endocrine response is controlled by the endocrine glands situated throughout the body. This response is:

- a slower response that has a long-lived effect
- as the endocrine glands produce and release specific hormones into the bloodstream.
- An effector organ is targeted, and
- a response is initiated.
- When endocrine organs are either over- or under stimulated, endocrine disorders are observed.

Key terminology

endocrine system	a system responsible for chemical co-ordination and regulation of various activities in the body
homeostasis	a process of maintaining a constant internal environment (blood and tissue fluid) within the body.
hormones	chemical messengers in the body. they travel in the bloodstream and cause an effect elsewhere in the body
negative feedback	operate in the human body to detect changes or imbalances in the internal environment and to restore balance

osmoregulation	regulation of the water balance in the internal environment
osmotic pressure	a measure of the concentration of solutes (e.g. salt, glucose) present in a solution; this may determine whether a cell loses or gains water
antagonistically	to work in opposite ways; if one hormone causes an increase of a substance, the other hormone will cause a decrease of that substance, e.g. insulin and glucagon
thermoregulation	the control of the body temperature to keep it as close to 37°C as possible
endothermic	relates to an organism that generates heat internally through a metabolic process to maintain a constant body temperature
vasoconstriction	narrowing of blood vessels
vasodilation	widening of blood vessels
evaporation	heat loss when sweat changes into water vapour on the surface of the skin
conduction	transfer of heat between objects which are in contact
convection	as warm air rises it is replaced by cooler air
radiation	heat transfer between two objects which are not in contact

Homeostasis is the tendency of an organism or cell to regulate its internal conditions, usually by a system of feedback controls, so as to stabilize health and functioning, regardless of the outside changing conditions.

The difference between the important secretory glands

Mammals produce secretions from exocrine and endocrine glands. The main differences between the two are listed in Table 1 below. Examples of each are given together with their secretions.

Table 1: Exocrine and endocrine glands – the main differences

Exocrine glands	Endocrine glands
• have ducts • secretions released into a cavity or on a surface • *Examples*: salivary glands (saliva), sweat glands(sweat)	• ductless • hormones released into the bloodstream • *Examples*: pituitary (ADH), thyroid (TSH), pancreas (insulin)

Note: The pancreas is both an endocrine and an exocrine gland. As an exocrine

gland it secretes digestive enzymes into the small intestine. As an endocrine gland it secretes insulin and glucagon into the bloodstream.

Figures 1 and 2 give examples of exocrine and endocrine glands with their secretions.

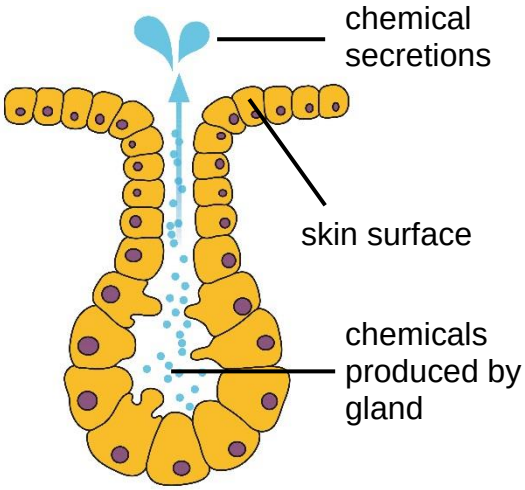


Figure 1: Exocrine gland

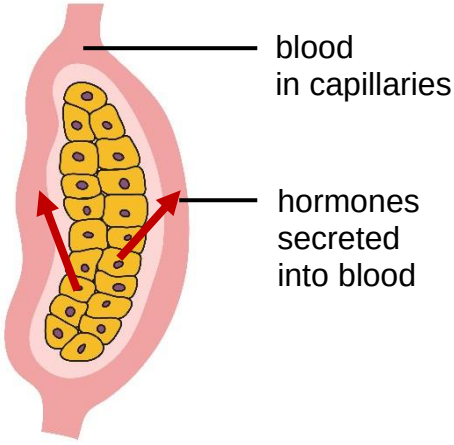


Figure 2: Endocrine gland

Endocrine glands

The endocrine system has many important endocrine glands that secrete hormones into the bloodstream where they are transported to their target site (such as an organ). These hormones do not work in isolation and often interact with other hormones in a sequence of events. They can work to produce a common effect, or they can work antagonistically.

Hormones: Hormones are organic compounds that act as messengers in the body. Most hormones are proteins with some being steroids (lipids). They are only needed in small amounts and they give a more lasting response than a nerve response. Hormones may be over-secreted or under secreted resulting in certain disorders.

The basic functions of hormones are:

- reproduction, growth and development
- maintenance of the internal environment (by **stimulating** or **inhibiting** the functioning of cells / organ)
- regulation of metabolism by controlling production, usage and storage of energy

Figure 3 shows the location of the human endocrine glands and the hormones produced there. The function of the hormones is discussed later.

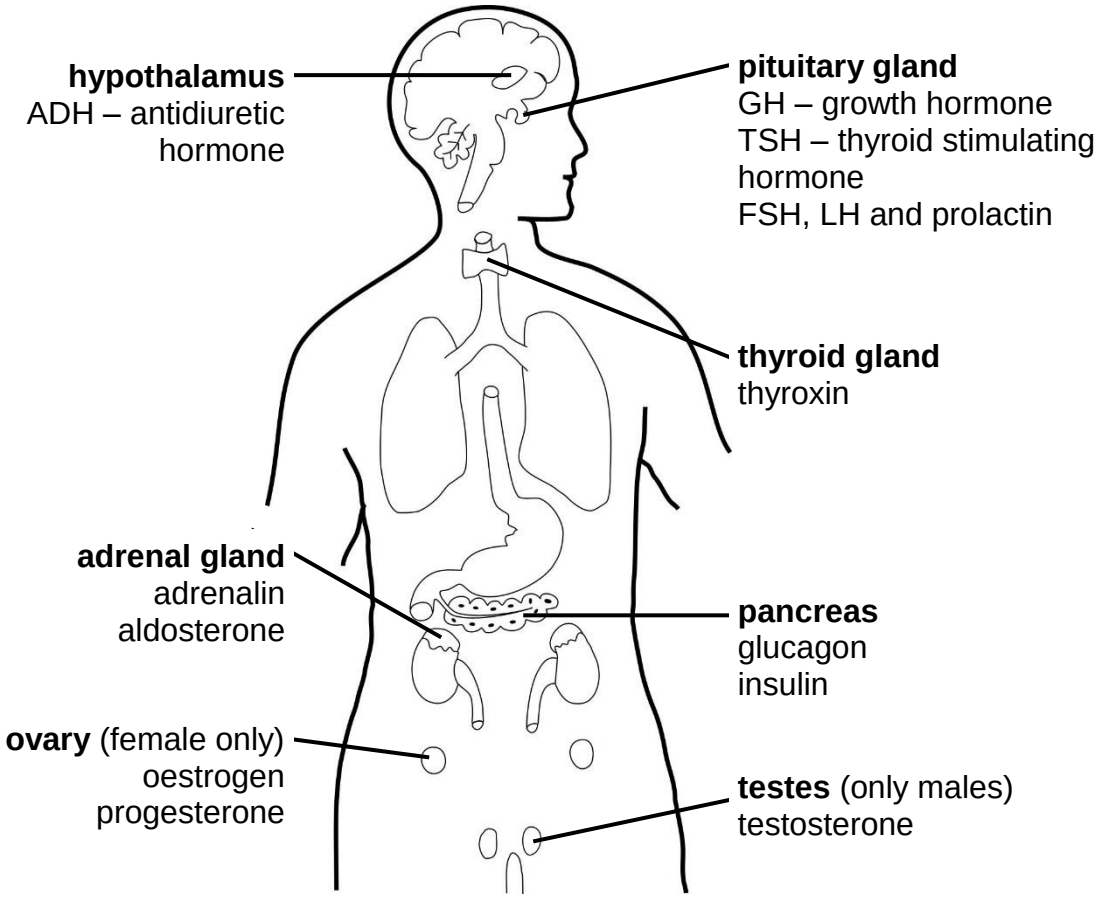


Figure 3: Endocrine glands and the hormones they secrete

Introduction to the endocrine system:
https://www.youtube.com/watch?v=SHgNaomqlRA

The hypothalamus and pituitary gland

The hypothalamus is a small area of the human brain, located above and connected to the pituitary gland (see Figure 4). It produces and secretes important hormones and is a link between the nervous and the endocrine systems.

The hypothalamus plays an important role in controlling vital functions in the human body. In this text the focus is on the anti-diuretic hormone (ADH), produced by the hypothalamus.

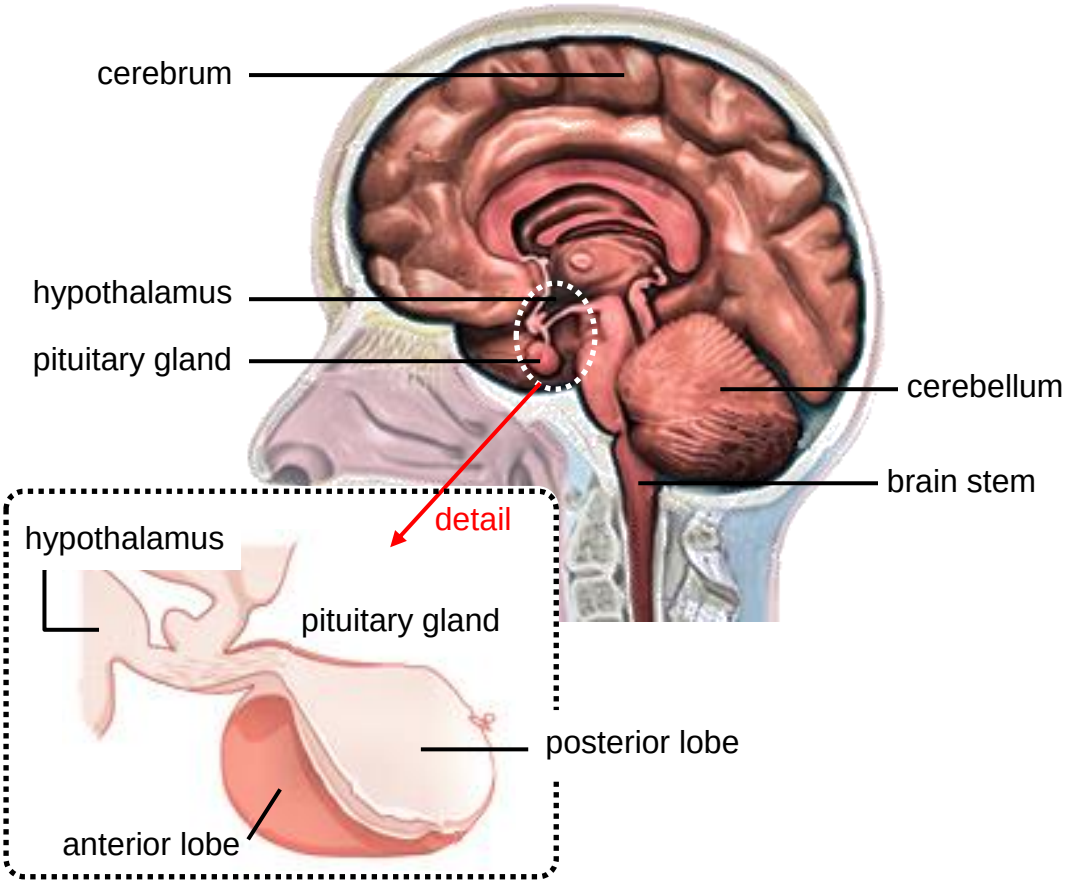
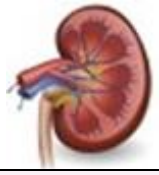
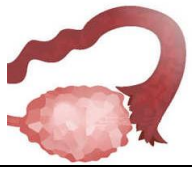
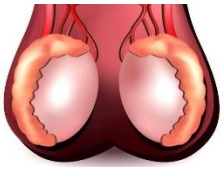
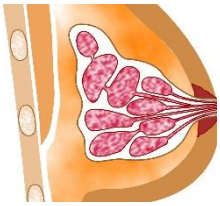
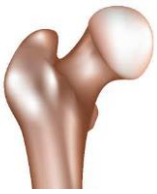


Figure 4: Location of hypothalamus and pituitary gland in the human brain, with detail of link between the two glands.

Table 2 below lists the hormones released by the hypothalamus and the pituitary gland. The function and target organ/s or gland/s are also given.

Table 2: Endocrine glands, the hormones secreted and their function and target

Hormones secreted	Target organ / gland	Functions of hormone
hypothalamus		
• ADH (antidiuretic hormone), also called vasopressin	• kidneys 	• stimulates the re-absorption of H_2O into the tubules • protects the body against dehydration
pituitary gland (anterior lobe)		
• TSH (thyroid stimulating hormone)	• thyroid gland 	• stimulates growth of thyroid gland • stimulates thyroid gland to secrete the hormone thyroxin

• FSH (follicle stimulating hormone)	• ovaries 	• stimulates development of follicles • stimulates the ovaries to produce the hormone oestrogen • stimulates the development of ova (eggs) in the female
	• testes 	• stimulates the testes to produce spermatozoa
• LH (luteinising hormone)	• ovaries	• stimulates ova maturation • stimulates ovulation (release of the ovum)
	• testes	• stimulates the production of the male hormone testosterone
• prolactin	• mammary glands 	• stimulates milk production and secretion
• GH (growth hormone)	• Bone and muscle cells 	• Stimulates the growth of long bones and skeletal muscles

Other important endocrine glands that make up the endocrine system are:

- the adrenal glands,
- the ovary in females and the testes in males,
- the pancreas, and
- the thyroid gland.

All the endocrine glands are essential for ensuring healthy metabolism.

Adrenal glands

These two triangular shaped glands are situated on top of each of the kidneys (see Figure 5). The adrenal glands have a central medulla region and an outer cortex. The two hormones produced and secreted from the adrenals, that we will discuss, are **adrenalin** and **aldosterone** (see Table 3).

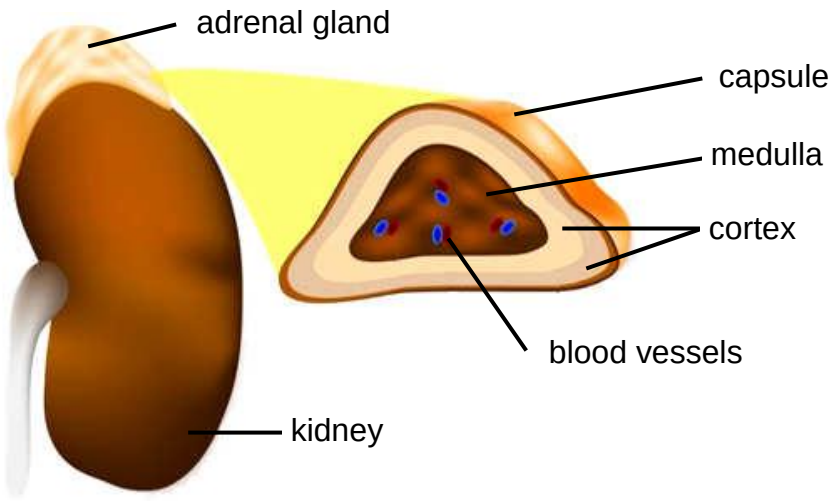


Figure 5: Location and structure of one of the adrenal glands

Table 3: Adrenal hormones, target organs / areas and their functions

Target areas / organs	Functions
adrenalin (the 'fight or flight' hormone)	
• heart • liver • skeletal muscles • eye muscles • skin • lungs • body cells	• increased heart rate and blood supply to cardiac muscles • stimulates the liver to increase conversion of glycogen into glucose • increased blood supply to skeletal muscle • stimulates pupil dilation • decreased blood supply to 'less vital' organs (digestive system and the skin) • increased breathing rate • increased metabolic rate
aldosterone	
• kidneys	• regulates the salt (sodium / Na^+ and potassium / K^+) concentration in the blood; works together with ADH to achieve this

The reproductive glands

The hormones released by the human reproductive glands (see Figures 6A & 6B) are important in reproduction and for stimulating the secondary characteristics at onset of puberty.

In females the ovaries are stimulated by FSH from the pituitary gland. The ovaries themselves release oestrogen and progesterone which play different roles in the menstrual cycle. In males the cells of Leydig in the testes secrete the male hormone testosterone which stimulates sperm production and maturation.

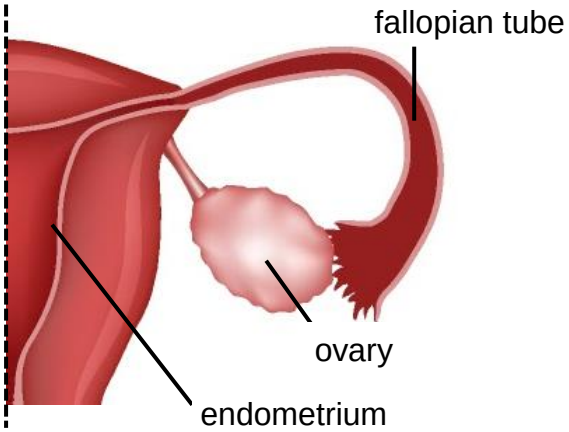


Figure 6A: Ovary

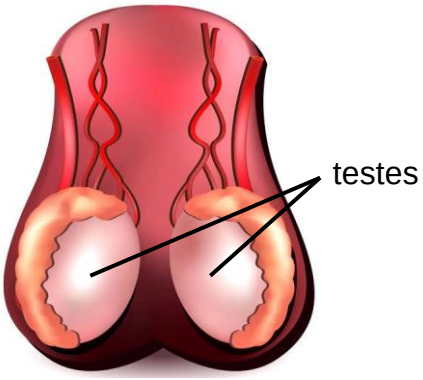


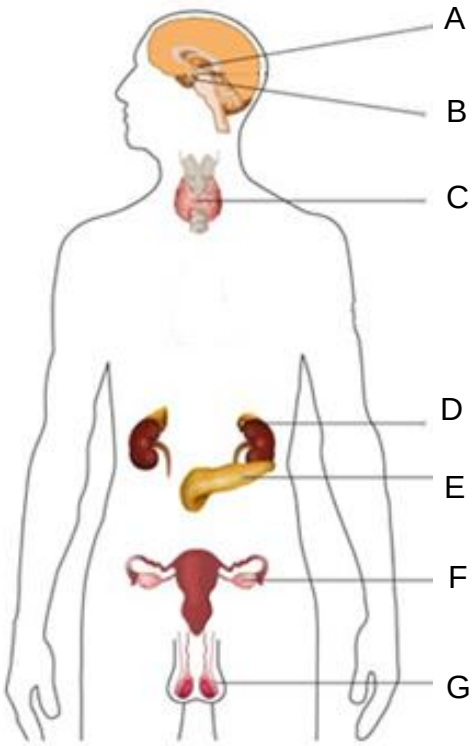
Figure 6B: Testes

Table 4: Hormones released by the human reproductive glands and their functions

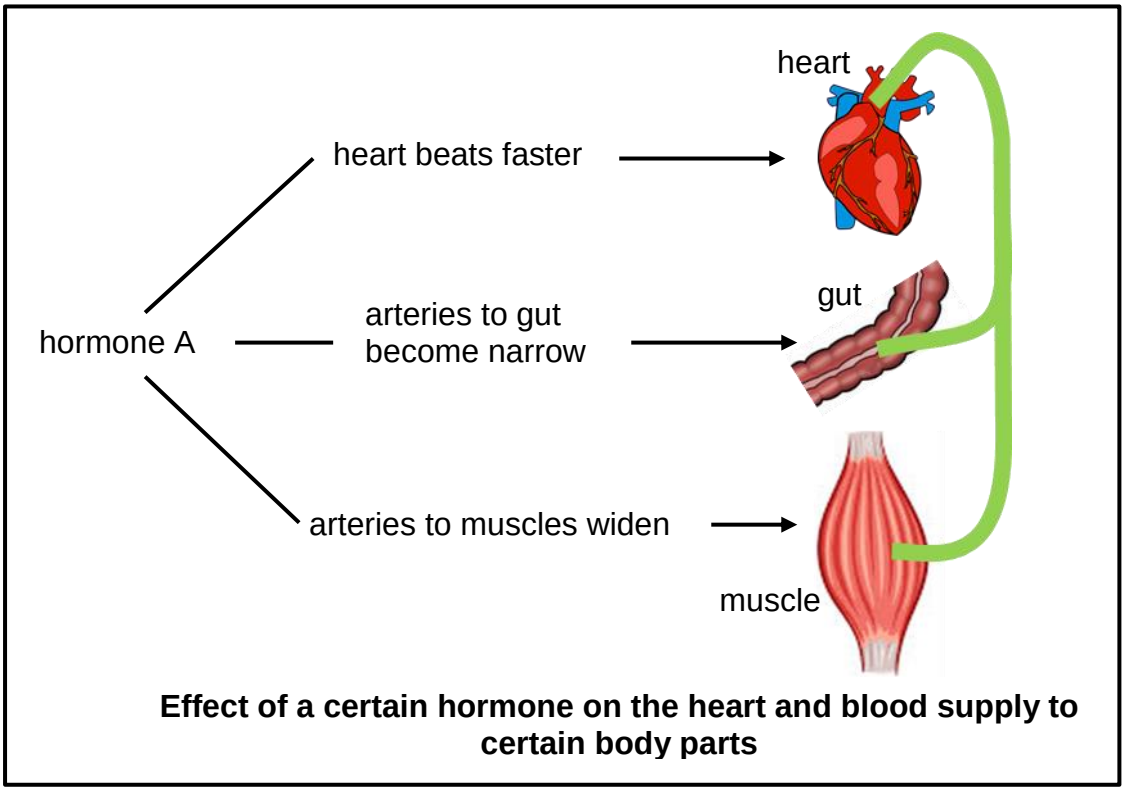
Ovaries	Testes
Oestrogen • promotes the thickening of the endometrial wall • promotes the development of the female secondary sexual characteristics at puberty • promotes fertility **Progesterone** • promotes further thickening and vascularisation of the endometrial wall • maintains implantation of embryo during pregnancy	**Testosterone** • stimulates the development of the male sex organs and the secondary characteristics during puberty • promotes the maturation of the sperm

Activity 1: Endocrine glands and their hormones

The diagram shows some of the human endocrine glands. Name the glands labelled A to G, and list the hormone/s produced by each gland. (20)



Activity 2: Effects of a hormone



Effect of a certain hormone on the heart and blood supply to certain body parts

1. Give the name of hormone A. (1)
2. State the position of the gland that secretes hormone A in the human body. (1)
3. Explain the importance of the narrowing of the arteries to the gut under emergency conditions. (4)
4. Name the part of the human eye that is also affected by hormone A. (1)
5. Explain the influence of hormone A on the part named in question 4. (3)

(10)

Negative Feedback

A negative feedback mechanism is an interaction between two hormones in which one hormone stimulates an increase in another hormone which then inhibits the first hormone, thus restoring balance.

The following is the general sequence of events in a negative feedback mechanism:

- an imbalance is detected by the receptor
- a control centre is **stimulated**
- the control centre **responds**
- a **message** sent to target organ/s which are the effectors
- the effector **responds**
- it **opposes (reverses)** the imbalance
- **balance** is restored

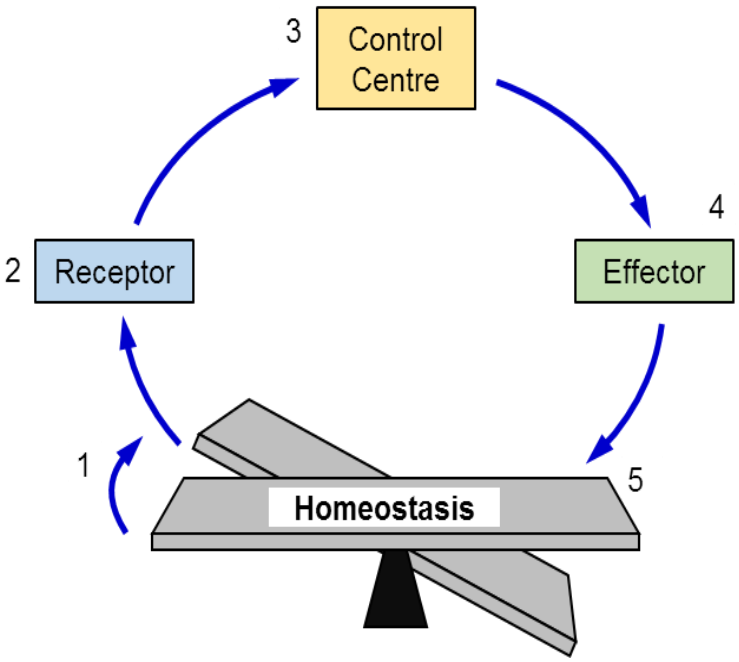


Figure 7: Homeostasis mechanism

As illustrated in Figure 7, an imbalance triggers a stimulus to the receptors at 2. When stimulated, the receptors generate an impulse that is transmitted to the control centre at 3. The control centre responds by sending an impulse to the effector which is the target organ at 4. The target organ then reverses the imbalance and balance is restored at 5.

Homeostatic control of the internal environment

The tissue fluid which surrounds our cells constitute the internal environment. The conditions within cells depend on the conditions within the internal environment. When faced with changes from either the external or internal environment the human body controls this effect and **homeostasis** is achieved.

Without homeostasis, organs, systems and ultimately, the whole organism, may be negatively affected. The important variables and homeostatic mechanisms that will be discussed are the:

- maintenance of water levels
- maintenance of salt levels
- regulation of thyroxin levels
- maintenance of glucose levels
- regulation of the CO_2 concentrations
- regulation of body temperature

It is important to understand the reasons why certain factors must be controlled and how this is carried out.

The main mechanisms for maintaining homeostasis

Table 5 below is a summary of six important homeostatic controls humans possess to ensure stability within their internal environment.

Table 5: Homeostatic control of internal environment

Stimulus	Reason for importance of regulation	Effector/s
Water	All metabolic reactions require a balance of water and salt concentrations in the blood and surrounding tissue fluid.	Kidneys and the skin
Salts	The presence of dissolved salts in the blood and tissue fluid determines the osmotic pressure which may contribute to the cell losing or gaining water by osmosis affecting the balance of these fluids	Kidneys

CO_2	The presence of CO_2 produced during cellular respiration affects the pH of the blood and tissue fluid. Enzymes are extremely sensitive to pH variations.	Lungs
Glucose	The concentration of glucose in the body needs to be controlled to ensure that energy levels can be maintained, and metabolic functioning can continue.	Liver and pancreas
Thyroxin (T4)	Cellular metabolism is regulated by the hormone thyroxin. Slight variations in the amount of thyroxin can have a severe effect on the metabolic rate of an individual.	Thyroid gland
Temperature	An increase or decrease from normal body temperature can affect metabolism due to the effect on enzyme activity. High temperatures denature enzymes whereas low temperatures slow down enzyme activity.	Skin

Negative feedback in the control of water balance – OSMOREGULATION

The maintenance of the water balance is very important to ensure that body metabolism continues. The homeostatic control of water and salt levels in blood and tissue fluid is carried out in a negative feedback system known as **osmoregulation**.

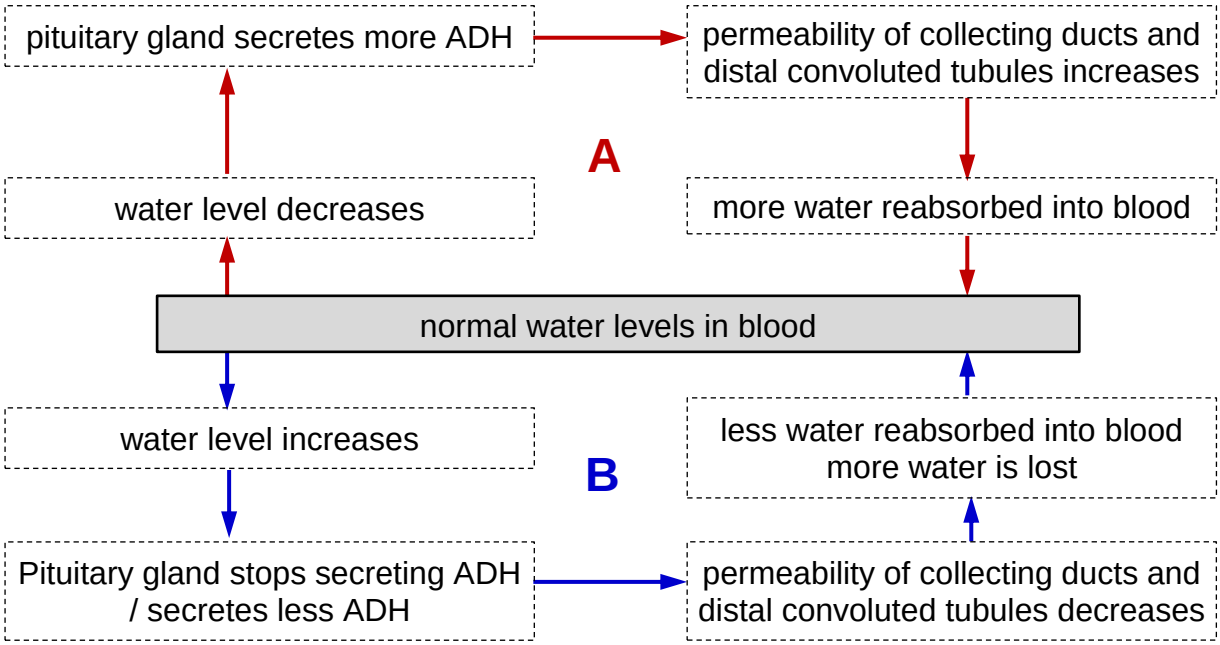


Figure 8: Negative feedback control of water levels in blood and tissue fluid

Figure 8 above and Table 6 below show how the body regulates:

A Levels of water when there is a drop **below normal** (dehydration), and

B Levels of water when there is an increase **above normal** (overhydration)

Table 6: Osmoregulation

A – decreased water level	B – increased water level
Dehydration - when the water levels in the blood and tissue fluids are low	**Overhydration** is when water levels in the blood and tissue fluids are high.
May be due to **excessive exercise**, **hot temperatures**, **increased sweating** or **decreased water intake**.	May be due to **cooler temperatures**, **little exercise** with **no sweating** and an **excessive intake of water.**
Low levels of water in the blood and tissue fluid is detected by receptor cells (**osmoreceptors**), in the **hypo-thalamus** of the brain.	Water levels in the blood and tissue fluid are high, and this is detected by the **osmoreceptors** in the **hypo-thalamus**.
Impulses are sent to the **pituitary gland** and **antidiuretic hormone (ADH)** is released.	**Impulses** are sent to the **pituitary gland** and **less anti-diuretic hormone (ADH)** is released.
The hormone is transported in the blood to the **effector organ**, the **kidney**. The **permeability** of the **collecting duct** and the **distal convoluted tubule** is **increased**.	**Collecting ducts** and **distal convoluted tubules** in the **kidney** become **less permeable**.
More water is **reabsorbed** and passed into the **blood**.	**Less water** is **reabsorbed** into the blood.
The **blood** becomes more **dilute** and **concentrated urine** is **excreted**.	More water is lost, **more dilute urine** is **excreted**.

Water levels in the blood and tissue fluid return to normal and **homeostasis** is achieved.

Negative feedback in the regulation of salt concentration

The osmotic pressure in the blood and tissue fluids is affected by the presence of solutes. Glucose and salts make up the solutes. **Sodium ions (Na^+) and potassium ions (K^+)** are salts that are regulated in a negative feedback system.

Figure 9 and Table 7 show how the body regulates the:

A levels of salt concentration in the blood when they drop below normal, and

B levels of salt concentration in the blood when they rise above normal.

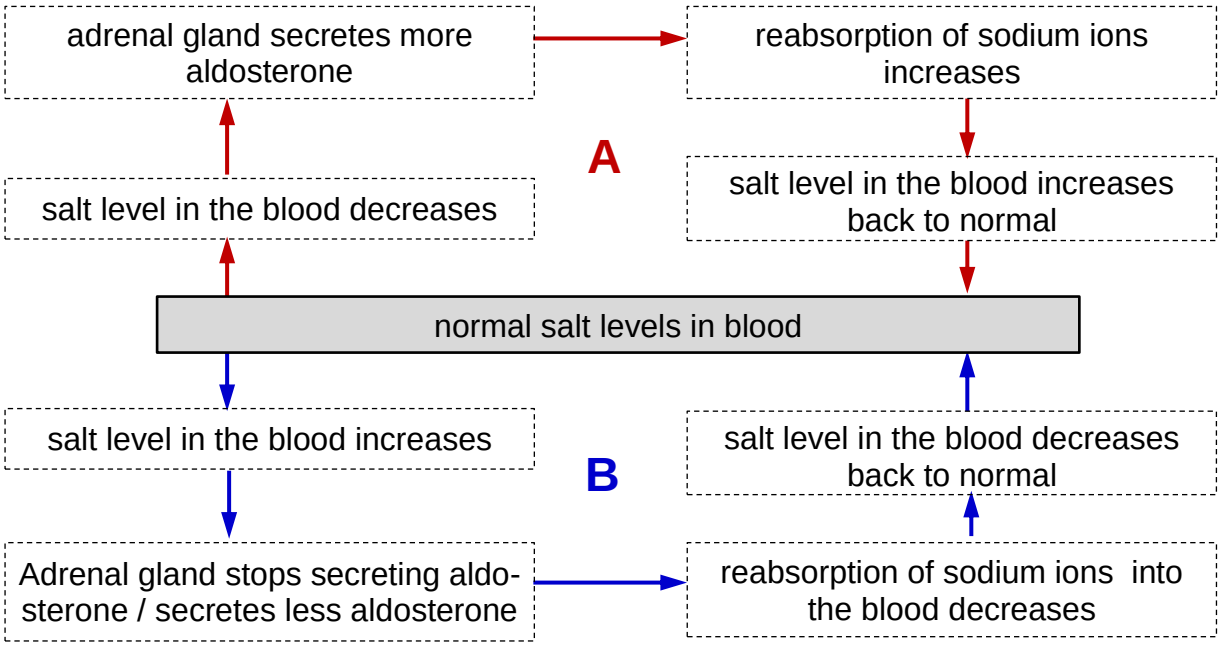


Figure 9: Negative feedback control of salt concentration in the blood

Table 7: Homeostatic control of salt concentrations

A – low salt level	B – high salt level
Low salt levels in blood and tissue fluids.	When the **salt levels** in the blood and tissue fluids are increased.
Receptor cells in the **kidney** detect decreased sodium ion levels.	**Receptor cells** in the **kidney** will detect an increased presence of sodium ions.
The **adrenal gland** in the kidney secretes the hormone **aldosterone.**	The **adrenal gland** stops releasing **aldosterone**.
Aldosterone stimulates the **reabsorption** of **sodium ions** from the filtrate and back into the blood.	**Sodium ions** will **no**t be **reabsorbed.**
Less sodium is excreted in the **urine**.	**More sodium** is excreted in the **urine**.

The salt concentration of the blood and tissue fluid returns to normal and **homeostasis** is maintained.

The regulation of water and salt levels in humans:
https://www.youtube.com/watch?v=BugGCBAk_Os

Negative feedback regulating of carbon dioxide concentrations

Carbon dioxide levels in the blood affect the pH of the blood and this can have an effect on metabolic processes. CO_2 is one of the end products of cellular respiration. CO_2 dissolves in water forming carbonic acid. The more carbon dioxide there is in the blood, the more acidic the blood becomes. Changes in pH influence enzyme activity. Figure 10 and Table 8 show the bodies response to an increase in CO_2 levels in the blood.

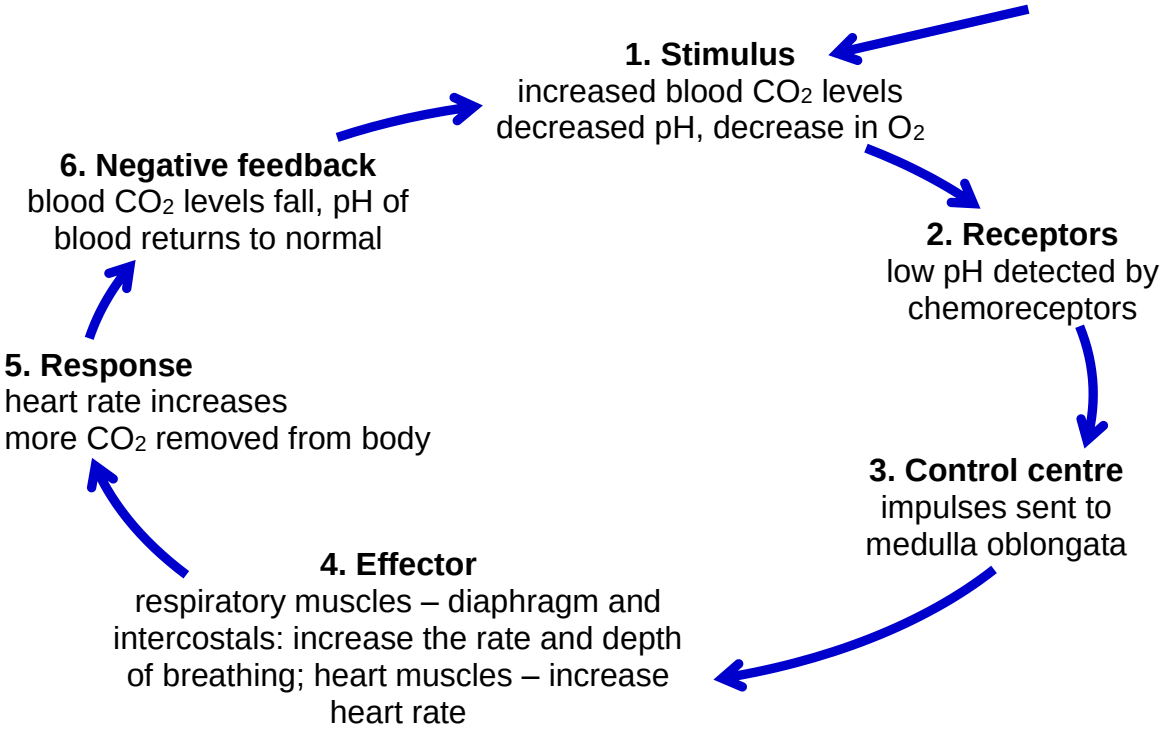


Figure 10: Negative feedback regulation of carbon dioxide levels in the blood

Table 8: Homeostatic control of blood CO_2 levels

1	High concentrations of CO_2 lead to the formation of carbonic acid. As a result, the pH of the blood will drop (the blood becomes more acidic).
2	Chemoreceptors in the carotid artery are stimulated by the drop in pH.
3	Impulses are sent to the medulla oblongata.
4	Breathing and heart muscles are targeted. Diaphragm and intercostal muscles contract increasing the rate and depth of breathing.
5	Heart rate increases.
6	More CO_2 moves to the lungs to be exhaled therefore blood CO_2 levels return to normal. **Homeostasis** is maintained.

Negative feedback mechanism regulating blood glucose levels

Carbohydrates are very important short-term energy storage molecules in all living organisms. In cellular respiration glucose is broken down to release energy which is stored in ATP.

The endocrine gland that secretes hormones that regulate the blood glucose levels is the pancreas. Pancreatic hormones, insulin and glucagon, work antagonistically (in opposite ways) to maintain blood glucose levels.

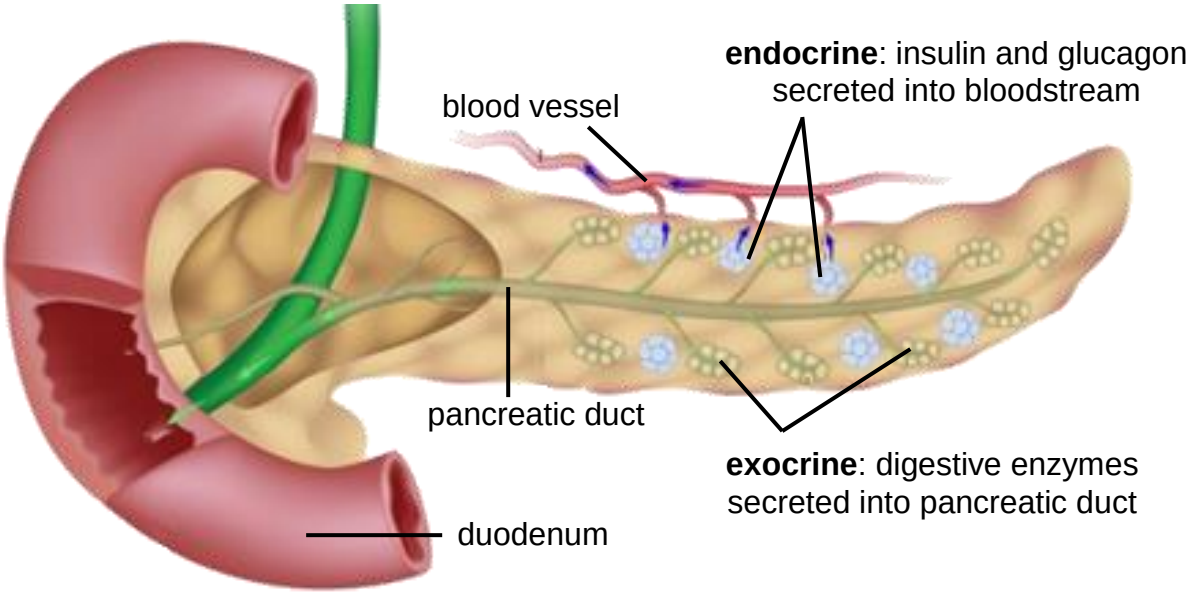


Figure 11: The pancreas showing its function as both an endocrine and exocrine gland

Blood glucose levels need to be maintained. Table 9 and Figure 12 show how:

- **A** **high** blood glucose levels are regulated, and
- **B** **low** blood glucose levels are regulated by the liver and pancreas.

Table 9: Regulation of blood glucose levels

A – high blood glucose	B – low blood glucose
Increased blood glucose levels are detected by the Islets of Langerhans in the pancreas.	**Decreased blood glucose** levels are detected by the Islets of Langerhans in the pancreas.
The Islets of Langerhans respond by secreting **insulin i**nto the bloodstream.	**Glucagon** is secreted by the Islets of Langerhans into the blood-stream.

Insulin is transported to the **liver** which is the **effector** organ.	Glucagon is transported to the **effector** organ, the **liver.**
Enzymes in the liver catalyse the conversion of excess **glucose into glycogen.** Glycogen is a **storage** carbohydrate.	Glycogen is **broken down** into **free glucose.** Glucose is released into the bloodstream.
Glucose **levels** in the blood return to **normal.**	**Glucose levels** are **increased** to **normal** levels.

In people with normal pancreatic functioning glucose levels are maintained and **homeostasis** is achieved.

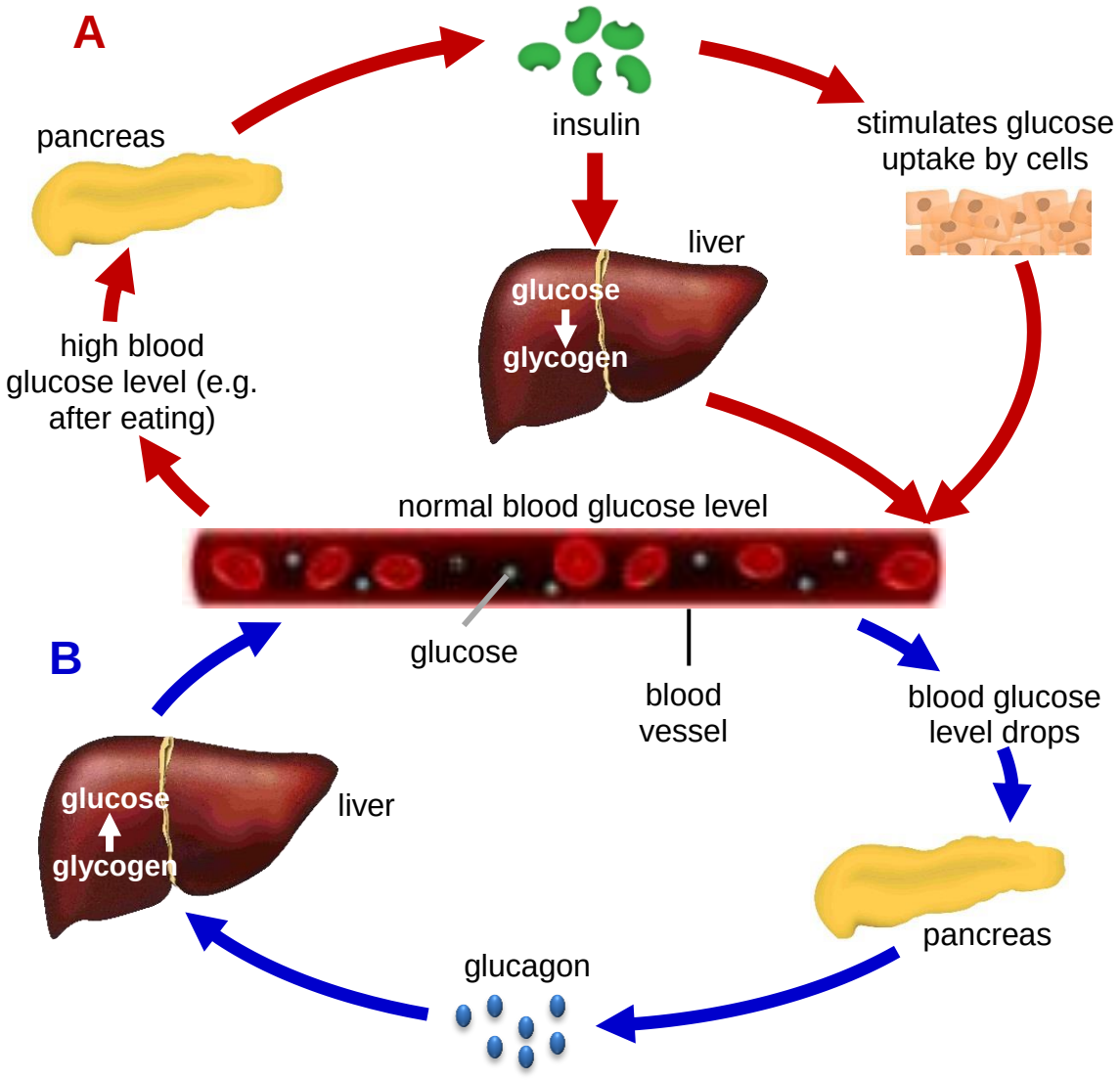


Figure 12: Regulation of blood glucose by the liver and pancreas

Negative feedback in the regulation of thyroxin levels

The basal metabolic rate (BMR) is the rate at which the body's cells use energy when at rest. Basic vital functions need to be maintained.

The hormone**, thyroxin**, produced in the thyroid gland:

- stimulates the body to increase the metabolic rate when required
- plays a vital role in the functioning of the heart and digestive system
- is important in skeletal and brain development
- is involved in maintenance of muscle tone

Iodine is an essential element needed in the production of thyroxin. A good source of iodine in our daily diet is sea salt or iodised table salt.

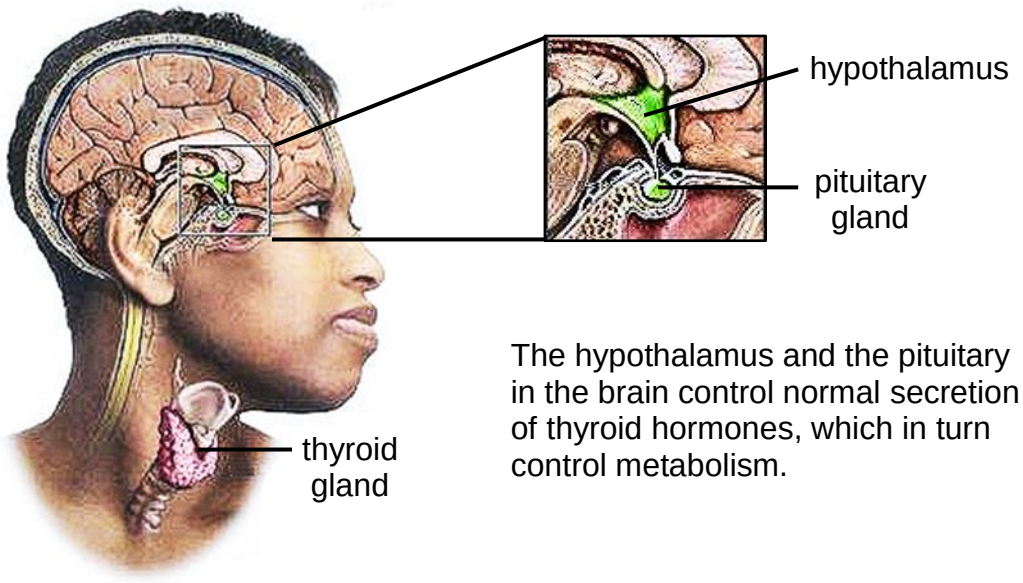


Figure 13: Location of thyroid gland in the neck and the connection to the pituitary gland

Two glands are involved in the control of thyroxin levels:

- pituitary gland – which releases thyroid stimulating hormone (TSH)
- thyroid gland – which releases thyroxin

Homeostatic regulation of thyroxin levels is illustrated in Figure 14 and detailed in Table 10.

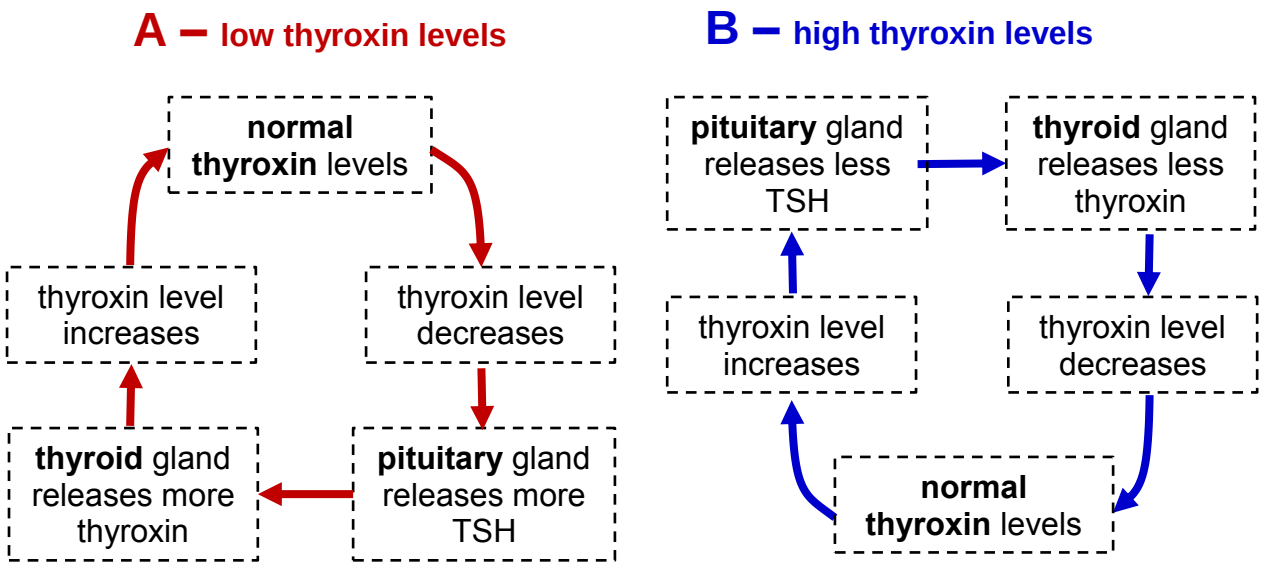


Figure 14: Flow diagram showing regulation of thyroxin levels
(A – low levels, B – high levels)

Table 10: Homeostatic control of thyroxin

A – low thyroxin level	B – high thyroxin level
When levels of thyroxin that fall **below normal**, this is detected by the **pituitary** gland.	When levels of thyroxin increase above normal, this is detected by the **pituitary** gland which is then inhibited.
This causes the pituitary gland to **secrete** more **TSH**.	**Less TSH** is secreted from the pituitary gland.
TSH is **transported** via the bloodstream to the **thyroid gland** which stimulates **increased** secretion of **thyroxin.**	**Lower** secretions of **TSH** result in the thyroid gland releasing **less thyroxin**.
The level of thyroxin is increased back to normal.	The level of thyroxin is decreased back to normal.

If we apply this to the negative feedback mechanism that restores thyroxin levels when it is **too low**, the appropriate steps can be made specific as follows:

Step 1: The thyroxin level in the blood decreases

Step 2: The pituitary is stimulated

Step 3: Pituitary gland increases its secretion of TSH

Step 4: TSH is transported by the blood to the thyroid gland

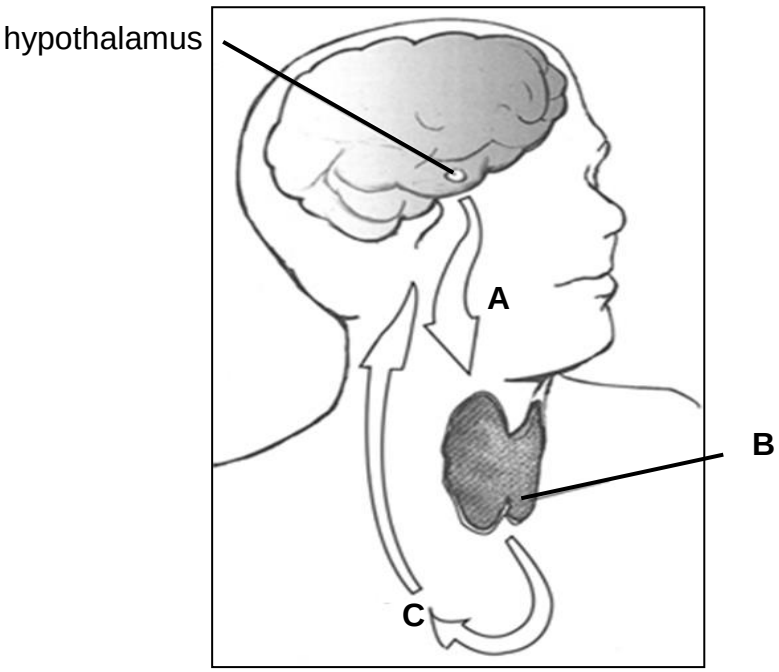
Step 5: TSH stimulates the thyroid gland to increase its secretion of thyroxin

Step 6: The thyroxin level in the blood increases

Step 7: Thyroxin levels return to normal

Activity 3: A negative feedback mechanism

The diagram below represents the interaction between two important endocrine glands. The hypothalamus is found at the base of the brain while the gland labelled B is present towards the front of the neck.



1. Provide a label for gland **B**. (1)
2. Name hormone **C**. (1)
3. State one function of hormone **A**. (1)
4. Describe the negative feedback mechanism that operates when the level of hormone C is higher than normal in the blood. (5)

(8)

Endocrine system disorders

In certain situations, hormone secretions are disrupted, and this affects homeostasis. Endocrine glands can either secrete too little (**hyposecretion**) or too much (**hypersecretion**) hormone. If this continues, a person would be diagnosed with an endocrine disorder.

Pituitary gland disorders

Table 11: Pituitary gland disorders

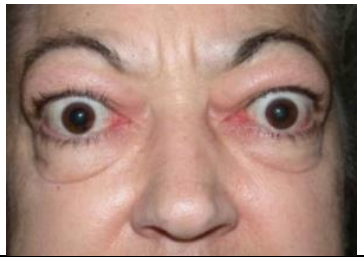
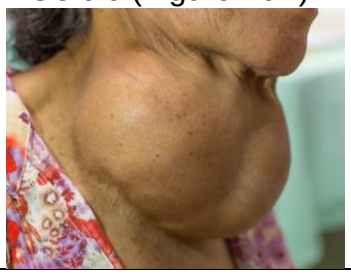
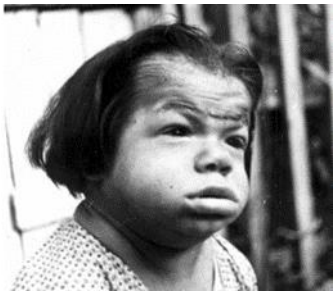
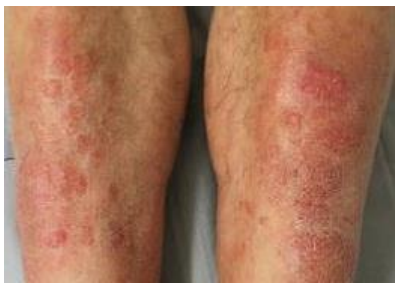
	Acromegaly	**Dwarfism**	**Gigantism** (Figure 15)
	hypersecretion of GH	**hypo**secretion of GH	**hyper**secretion of GH
Cause	too much GH secreted **after puberty**	too little GH produced during childhood	too much GH secreted during childhood
Symptoms	• enlargement of the hands and feet • additionally: enlargement of the forehead, jaw and nose	• well-proportioned but of short stature • retarded growth and delayed puberty.	• long bones and connective tissue grow very fast • person may grow up to 2,1 to 2,5 m tall • heart and other organs also enlarge, causing high blood pressure

Figure 15: Gigantism

Thyroid gland disorders

The continued production of too much thyroxin is known as hyperthyroidism (hyper = high). Continued low levels of thyroxin leads to hypothyroidism (hypo=low).

Table 12: Thyroid gland disorders

	Hyperthyroidism	
Examples	**Graves' disease** (Figure 16A) 	**Goitre** (Figure 16B) 
Causes	**autoimmune disease** – which occurs when the immune system attacks the thyroid and causes it to overproduce the hormone thyroxin	goitre – condition linked to elevated thyroid activity
Symptoms	• bulging eyes • weight loss • fast metabolism	• increased metabolic rate • increased cardio-vascular activity • increased anxiety • swollen thyroid gland in neck
	hypothyroidism	
Examples	**Cretinism** (Figure 16C) 	**Myxoedema** (Figure 16D) 
Cause	• caused by lack of thyroxin from birth	• caused by underactive thyroid gland in adulthood
Symptom	• physical, mental retardation	• mental, physical tiredness • low metabolic rate • increase in dermal fat • roughening of skin

Pancreas disorders – e.g.: Diabetes

A person with continued (chronic) high glucose levels is said to be **hyperglycaemic**. Diabetes mellitus is a disease associated with high blood glucose levels.

The long-term effect of diabetes is damage to all the blood vessels which eventually leads to circulatory problems and multiple organ damage. Wounds on the skin do not heal well. The eyes are negatively affected, leading to poor vision and eventually blindness.

- **Type 1** diabetics might inject insulin as a treatment. There are sophisticated insulin pumps available which are directly attached to the patient and are effective in controlling glucose levels.
- **Type 2** diabetics can in most instances control their sugar levels by watching their diet, losing excess weight and exercising.

Table 13: Representation of non-diabetic and both Type 1 and Type 2 diabetics

Non-diabetic	Type 1 Diabetic	Type 2 Diabetic
Normal blood glucose levels: 80-100 mg/ml of blood	**Type 1** diabetes – pancreas **not producing** the hormone, **insulin**, necessary for controlling the glucose levels in humans	**Type 2** diabetes – insulin is available, but the body is unable to control the glucose levels

Table 13 and Figures 17A to 17B illustrate the normal insulin glucose interaction, and what happens in a Type 1 or a Type 2 diabetic.

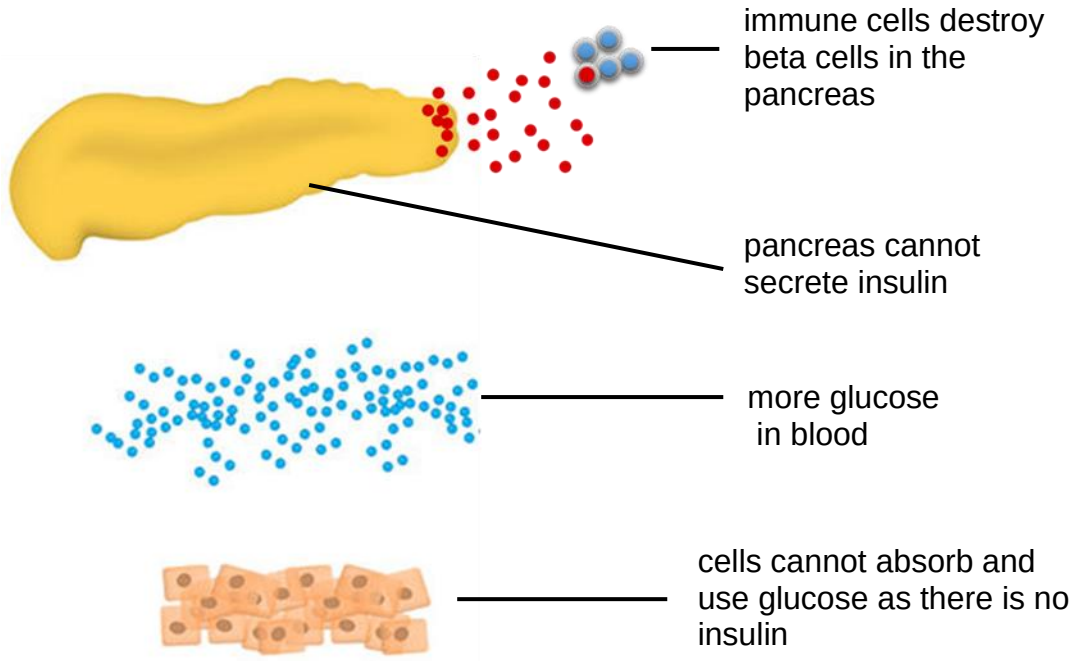


Figure 17A: Type 1 diabetic – no insulin

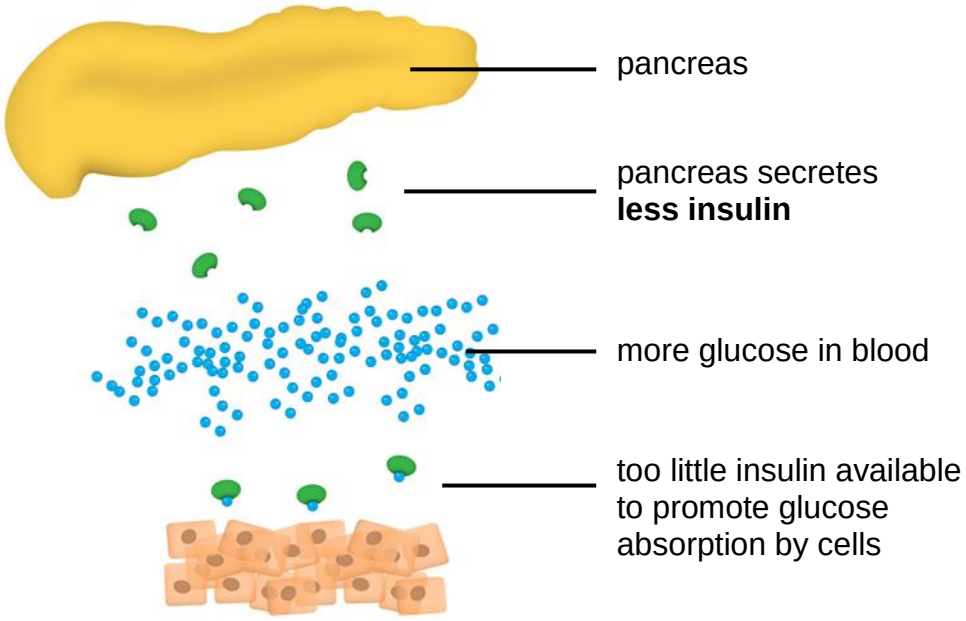


Figure 17B: Type 2 diabetic – less insulin produced

Activity 4: Research task on endocrine disorders

You will need to research an endocrine disorder caused by the hypersecretion or hyposecretion of an endocrine hormone. You will present your information in either a PowerPoint Presentation or a poster format. The following needs to be covered:

1. What hormone is involved with this disorder?
2. Where is the hormone produced?
3. What are the target organs/structures of the hormone?
4. How is the secretion of the hormone regulated/controlled?
5. What is the normal function of the hormone?
6. How does the hormone contribute to homeostasis?
7. What are the causes of hypersecretion or hyposecretion
8. What are the symptoms and effects of hypersecretion or hyposecretion?
9. What are the treatments for under or over activation of the hormone pathway?

Your teacher will provide you with a mark scheme. N.B.: Citation of at least 3 references.

Regulation of body temperature – THERMOREGULATION

Endotherms are animals that maintain a constant body temperature independent of the environment and primarily include the birds and mammals.

We as humans are **endothermic**. Our bodies can maintain a constant body temperature of approximately **36,8°C** even when outside temperatures are very high or very low.

It is vital that this happens to ensure that all metabolic functions continue. If body temperature were to drop below 36°C, metabolic processes will slow down and if it were to be raised above a safe level of 37,5°C, enzymes become denatured (cannot function effectively) and many body functions will be disabled.

The way in which the body manages to control its internal core temperature when external environmental conditions change is called **thermoregulation**. It is one of the important homeostatic mechanisms in the human body.

The human skin as thermoregulator

The human skin is well adapted for thermoregulation. It is the largest organ in the body (see Figure 18 below) and has **thermoreceptors** which respond to either hot (Ruffini's corpuscles) or cold (Krause's end bulb).

Heat can be lost from the body by **evaporation**, **radiation**, **conduction** and **convection.**

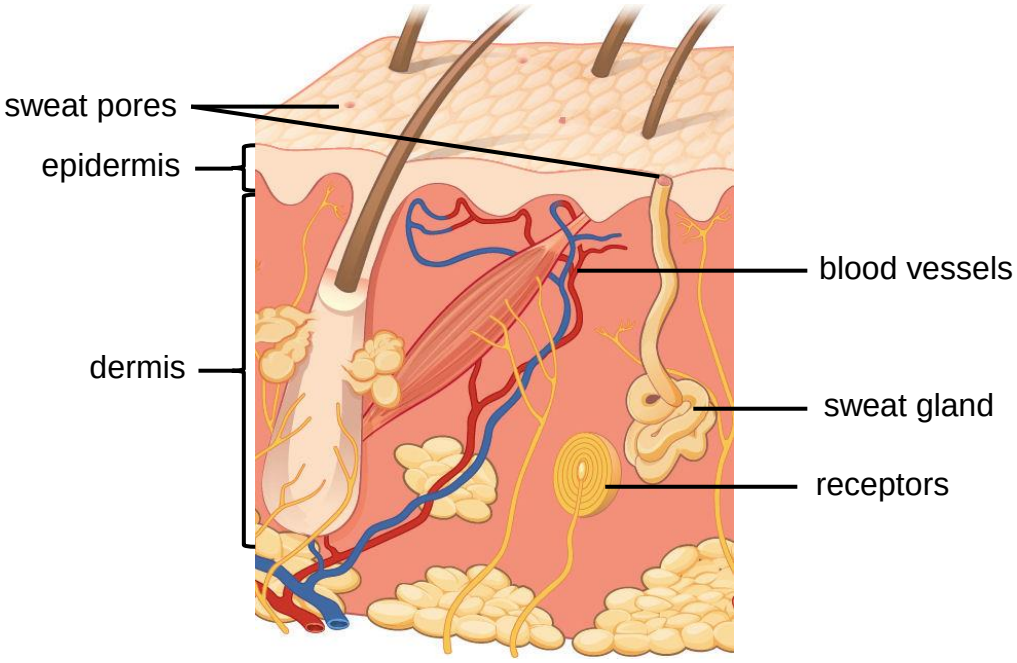


Figure 18: Cross section through human skin

The body's thermoreceptors transmit messages to the temperature regulating centre in the hypothalamus. Both conscious (fanning in hot weather and adding clothing in cold weather) and subconscious reactions (increased sweating in heat and shivering in cooler weather – see Figure 19) occur in response to the change in environmental temperature. These reactions enable the core body temperature to remain constant.

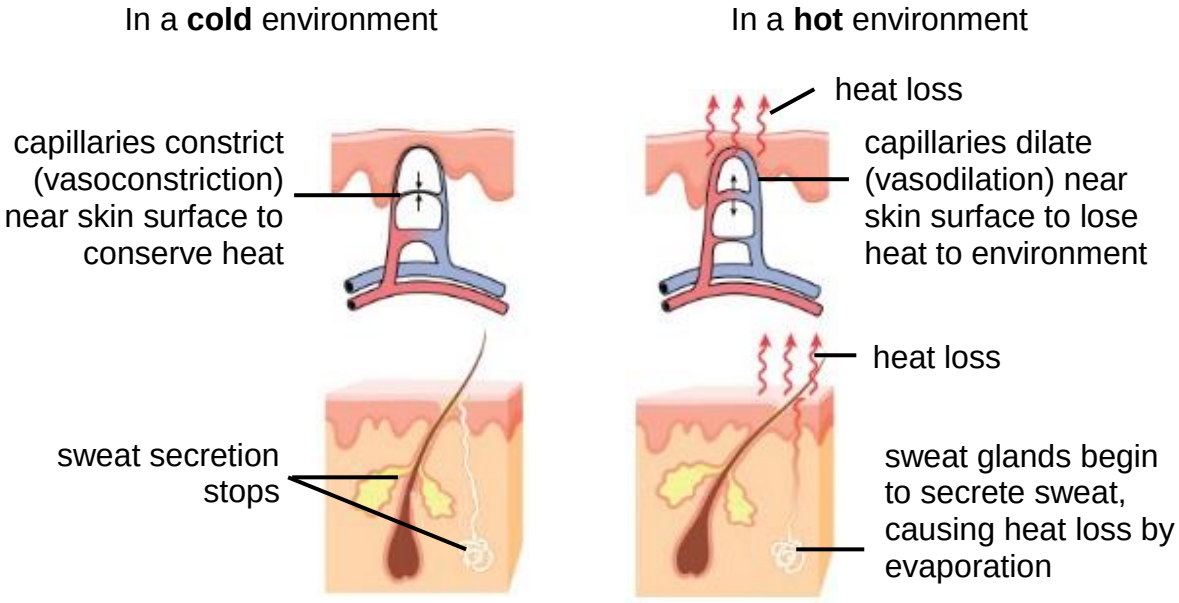


Figure 19: Homeostatic regulation of the body temperature

Conscious = behavioural = voluntary	subconscious = physiological = involuntary

Table 14 below details the process of thermoregulation in hot and cooler conditions.

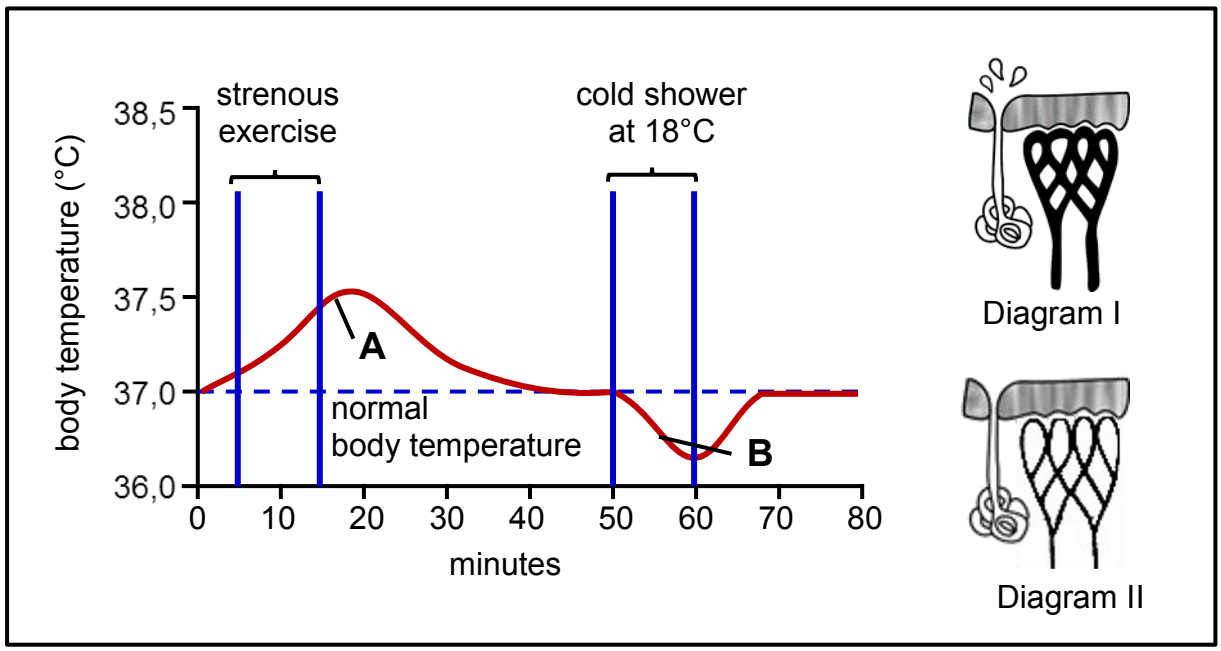
Table 14: Thermoregulation

Hot environment	**Cold environment**
• body temperature **increases** • warmed blood passes through the hypothalamus • impulses are sent to blood vessels in the skin and to sweat glands	• body temperature **decreases** • slightly colder blood passes through the hypothalamus • impulses are sent to blood vessels in the skin and to sweat glands
• **vasodilation** – blood vessels dilate and more blood flows closer to surface of the skin	• **vasoconstriction** – blood vessels become narrow and less blood flows close to surface of the skin
• more heat lost to outside air by **radiation** and **conduction**	• less heat is lost to outside air

• sweat glands activated and **sweating** occurs • sweat **evaporates** – this has a cooling effect on the skin	• sweat glands inactive; **no sweating occurs** • no evaporation of sweat
• surface blood capillaries lose heat to the environment and the **body cools down**	• heat is not lost as easily to the outside atmosphere and the body warms up
Extension: • The basal metabolic rate (BMR) also slows down and less body heat is produced.	*Extension:* • The **adrena**l and the **thyroid glands** release **adrenalin and thyroxin** respectively. Both these hormones **increase metabolic rate** and more **body heat** is **produced.** • The hypothalamus stimulates the **skeletal muscles** to contract. Involuntary **shivering** occurs, and heat is produced.

The human body's ability to maintain a constant core temperature of 36,8°C using the mechanism of thermoregulation ensures **homeostasis**.

Activity 5: Body temperature



1. Which part of the brain responds to the temperature changes that occur at A and B on the graph? (1)
2. What was the maximum temperature reached? (1)
3. For what period of time did the person engage in strenous exercise? (1)

4. Why should body temperature not be allowed to fluctuate too much? (2)

5. Which diagram (I or II) would represent the condition of the skin after 15 minutes? (1)

6. Explain your answer to question 5. (2)

(8)

The human endocrine system and homeostasis: End of topic exercises

Section A

Question 1

1.1 Various options are given as possible answers to the following questions. Choose the correct answer and write only the letter (A–D) next to the question number (1.1.1–1.1.5). For example, 1.1.6 D..

1.1.1 The outermost layer of the human skin is the

A hypodermis

B epidermis

C adipose

D dermis

1.1.2 Which of the following CORRECTLY represents the events involved in the secretion and action of ADH (antidiuretic hormone)?

	Water level in blood relative to normal	Amount of ADH produced relative to normal	Amount of water reabsorbed by kidneys
A	Increase	Increase	Decrease
B	Increase	Decrease	Increase
C	Decrease	Increase	Increase
D	Decrease	Decrease	Decrease

1.1.3 A worker spent about ten minutes in a walk-in freezer. Below are some of the changes that occurred in his body in response to the drop in external temperature.

(i) Blood vessels in the skin constrict
(ii) Brain reacts
(iii) Skin temperature changes
(iv) Temperature receptors in the skin detect changes

Which ONE is the correct sequence in which the changes occurred?

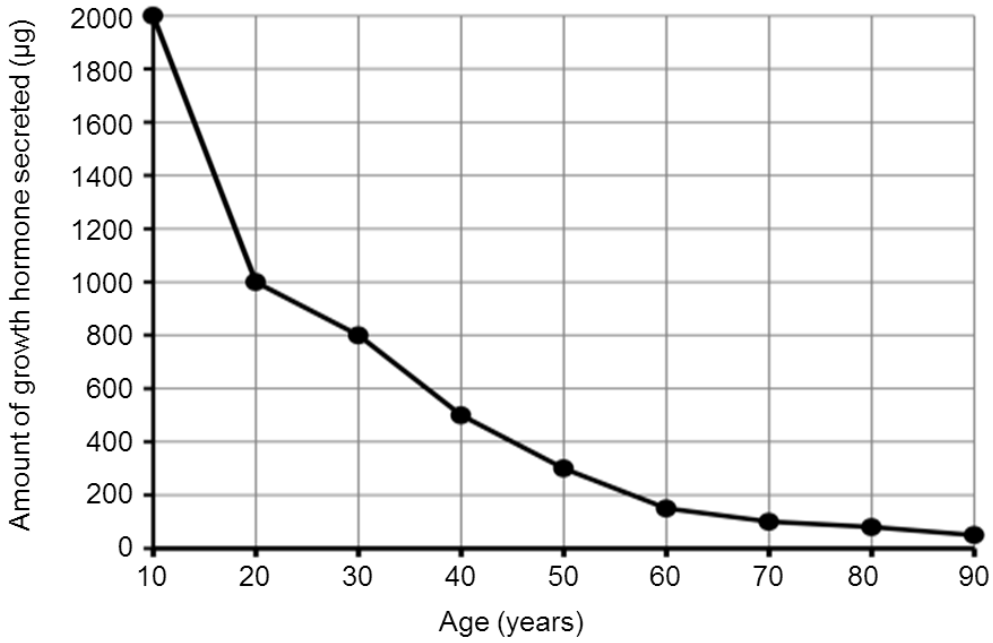
A (ii) → (i) → (iii) → (iv)

B (iii) → (i) → (iv) → (ii)

C (iv) → (ii) → (i) → (iii)

D (iv) → (i) → (ii) → (iii)

1.1.4 The graph below shows the relationship between the production of growth hormone and age



A general conclusion can be drawn from the results is that …

A growth hormone is not secreted after the age of 50 years
B the amount of growth hormone secreted decreases with age
C the amount of growth hormone secreted increases with age
D the amount of growth hormone secreted remains stable over time

1.1.5 Which ONE of the following hormones prepares the body to react to emergency situations?

A Insulin
B Aldosterone
C Adrenalin
D Growth hormone

(5 × 2 = 10)

1.2 Give the correct term for each of the following descriptions. Write only the term next to the question number.

1.2.1 The maintenance of a constant internal environment.
1.2.2 The maintenance of a constant body temperature.
1.2.3 Animals that control body temperature from within.
1.2.4 Widening of blood capillaries in the skin.
1.2.5 Method by which most heat is lost through sweating.

1.2.6 Control centre for temperature regulation in the brain.

1.2.7 A hormone that stimulates milk production in human females.

1.2.8 A disease that results from the bodies inability to produce insulin.

1.2.9 An enlarged thyroid gland that is caused by a deficiency of iodine.

1.2.10 The secretions that are produced in small quantities by the endocrine glands.

(10 × 1 = 10)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Carbon dioxide levels	A: medulla oblongata B: cerebellum
1.3.2 Vasodilation	A: 10°C B: 40°C
1.3.3 Increase the loss of heat in mammals	A: Sweating B: Shivering
1.3.4 Cells and tissue fluid	A: internal environment B: external environment
1.3.5 A gland that has a duct to carry its secretion to where it is needed	A: sweat glands B: pancreas

(5 × 2 = 10)

1.4 Complete the table below (10 × 1) = (10)

	Stimulus/variable	Receptor/s	Control centre	effector
osmoregulation	**1.4.1**	osmoreceptors	hypothalamus	**1.4.9**
salt concentration	salts e.g. Na^+ (high and low)	cells in glomeruli	**1.4.6**	kidneys
carbon dioxide concentration	CO_2 (high and low)	**1.4.4**	**1.4.7**	lungs
thyroxin	**1.4.2**	pituitary gland	thyroid gland	body cells
glucose	blood glucose (high and low)	**1.4.5**	pancreas	**1.4.10**
thermoregulation	**1.4.3**	thermo-receptors	**1.4.8**	skin

1.5 Read the following and answer the questions that follow:

South Africa's very own mountaineer and adventurer

Sibusiso Vilane, became a South African hero after summiting the Earth's highest mountain, Mount Everest, in 2003. He started training in mountaineering by climbing the peaks of the Drakensberg mountains.

Ex-President, Thabo Mbeki, said the following on the summit day "In this, he has shown the heights we can scale in life if we put our shoulder to the wheel. Sibusiso you have done us proud".

He continues to climb great peaks throughout the world and is actively involved in humanitarian work.

Mountaineers like Sibusiso Vilane put their bodies under severe physiological strain when climbing up to heights of 8000 metres. The higher the altitude the greater the stress on the human body. The availability of oxygen decreases and hypoxia (oxygen starvation) can set in. It literally takes your breath away. Average temperatures are well below freezing. Climbers can become disorientated, develop acute mountain sickness (AMS) and get frostbite on their extremities. Many climbers have died on Everest.

Athletes in extreme sports like this will try and acclimatize to these adverse conditions by preparing the body for the physiological challenges. The sherpas who assist climbers live at high altitudes all year around and their bodies have adapted well to the low oxygen levels and to the adverse cold.

This leaves us with words from one of Sibusiso Vilane's motivational speeches: "Every person has their own 'Everest' to climb".

1.5.1 With low oxygen levels what other atmospheric gas levels could become a problem in the system of climbers like Sibusiso? (1)

1.5.2 How are the levels of the gas that you have given as your answer in 1.5.1 detected? (1)

1.5.3 In a flow diagram show how their bodies will try and compensate and adapt to the levels of the gas in their system. (3)

1.5.4 The climbers will lose a lot of heat through radiation to the environment. What conscious measures would you suggest they take to reduce this loss? (1)

1.5.5 Suggest a way in which climbers could prepare their bodies for the challenges of high altitudes, i.e. how in their training could they acclimatize to the conditions on Everest? (1)

1.5.6 What is the term used when the oxygen availability in the blood decreases? (1)

1.5.7 During an expedition led by Sibusiso in 2016, to the highest peak in Africa, Mount Kilimanjaro, one of our other famous sportsmen, Gugu Zulu, a rally driver, tragically fell ill and died. It seemed that he developed the onset of flu while on the climb. The fact that Gugu was not 100% healthy would have worsened the impact of high altitude and cold. One of the symptoms of a flu is fever. Which homeostatic mechanism that has been covered in this section would have been affected and briefly explain how the normal levels had been altered by the flu? (2)

(10)

Section A: [50]

Section B

Question 2

2.1 Study the table below that shows the volume of urine produced by six different people on a hot day and on a cold day and answer the questions that follow.

Person	Volume of urine produced in cm^3	
	Hot day	**Cold Day**
1	430	890
2	350	1060
3	270	930
4	560	1280
5	400	680
6	390	1 160
Average		1 000

2.1.1 Calculate the average volume of urine in cm^3 produced on the hot day. Show all workings. (2)

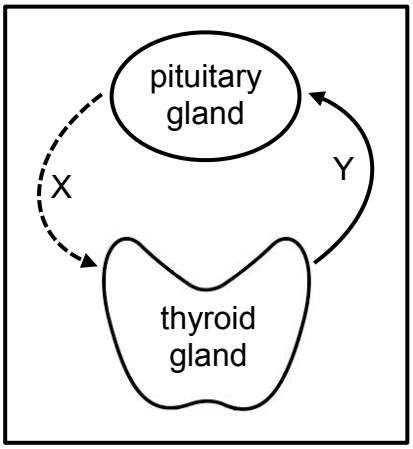
2.1.2 What can you deduce from the difference between the average volume of urine produced on the hot day and the average volume of urine produced on the cold day? (2)

2.1.3 Explain why, on a hot day, less water is lost from the body as urine. (2)

2.1.4 The composition (make-up) of urine depends on several factors. Name two factors that would affect the composition of urine. (2)

(8)

2.2 The diagram below represents a negative feedback mechanism. X and Y represent hormones secreted by the respective glands.



2.2.1 What is the role of any negative feedback mechanism in the human body? (1)

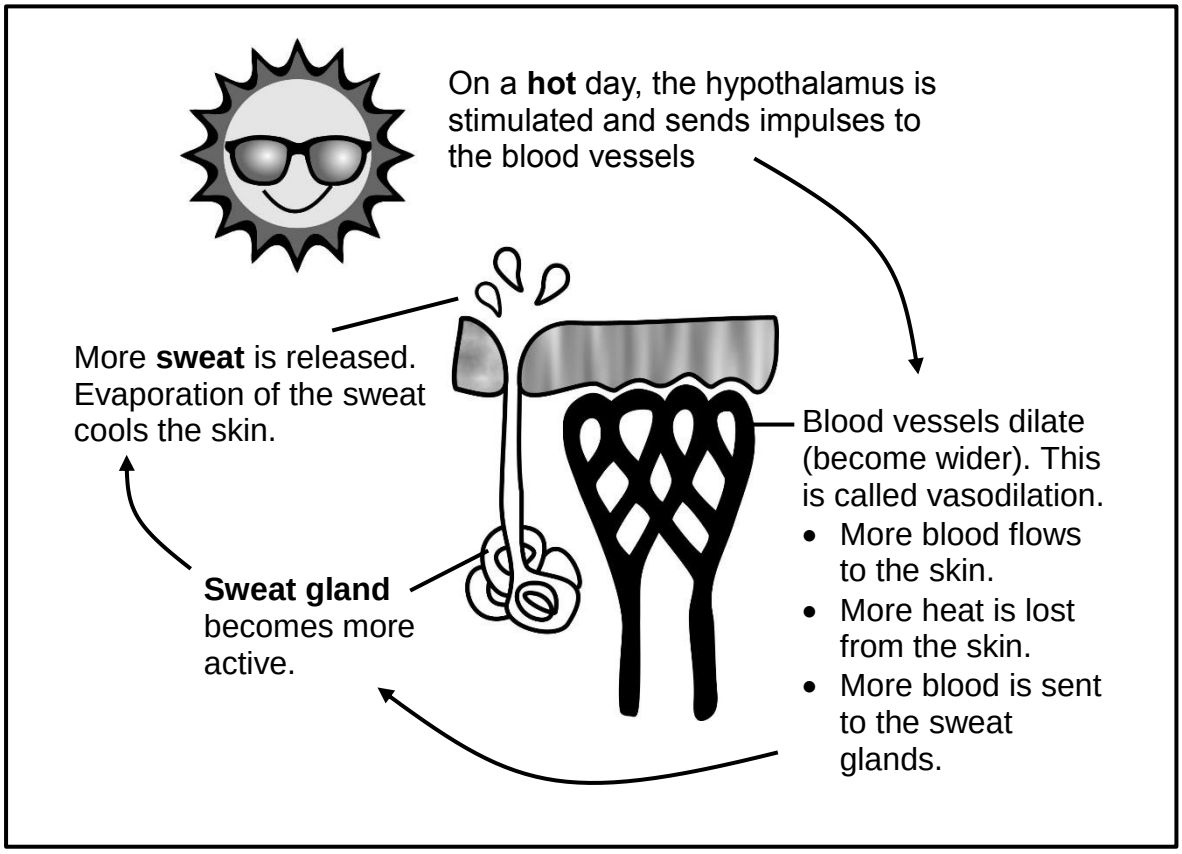
2.2.2 Identify hormone X. (1)

2.2.3 Explain the consequences for a person if hormone Y remained abnormally high for extended periods of time. (3)

(5)

2.3 Triathletes competing in the Iron Man series are sometimes on the road and in the water for a total of over 8 hours. They will get very hot and thirsty. They will sweat profusely and will drink fluids continually through the race. They often do not need to urinate. Which two mechanisms would these athletes use to regulate their body temperature and fluid loss during the race. (2)

2.4 The picture below shows how important the skin is in controlling the core body temperature in very warm conditions.



Using the information provided **draw** your own picture, alongside the one given, showing how the skin controls body temperature in cooler conditions.

(5)

[20]

Question 3

3.1 Type 2 diabetes is often linked to body mass index (BMI). The higher your BMI the greater your chances of developing Type 2 diabetes. The table below shows the results of an investigation into the BMI of women and their risk of developing diabetes (statistics from the American Diabetes Ass.)

BMI (mass÷height) (kg/m^2)	Relative risk of developing diabetes in females (%)
< 20	7,5
20 – 25	18,0
26 – 30	37,5
31 – 35	57,0
> 35	74,5

3.1.1 Draw a histogram using the data in the table. (5)

3.1.2 Which hormone is deficient in people with diabetes? (1)

3.1.3 In which organ is this hormone produced? (1)

3.1.4 Name another hormone that regulates the amount of glucose found in the blood. (1)

3.1.5 Write up your own conclusion from the data given in the table and from your histogram. (2)

(10)

3.2 Lerato carried out an investigation to determine the effect of exercise on skin temperature. She asked 100 learners in her school to participate in the investigation. The sample consisted of 100 girls of the same age. The investigation was done as follows:

- The learners were divided into two groups of 50 each (Group A and B).
- The skin temperature was measured for all the participants.
- Group A was asked to run around the sports field for 10 minutes.
- Group B was asked to remain seated on the benches next to the field for 10 minutes.

After 10 minutes the skin temperature of all participants was measured, and the average was calculated for each group (A and B).

3.2.1 In this investigation, identify the:

(a) independent variable (1)

(b) dependent variable (1)

3.2.2 State two steps that Lerato took into consideration during the planning of the investigation. (2)

3.2.3 What is the expected results for the participants in group A? (1)

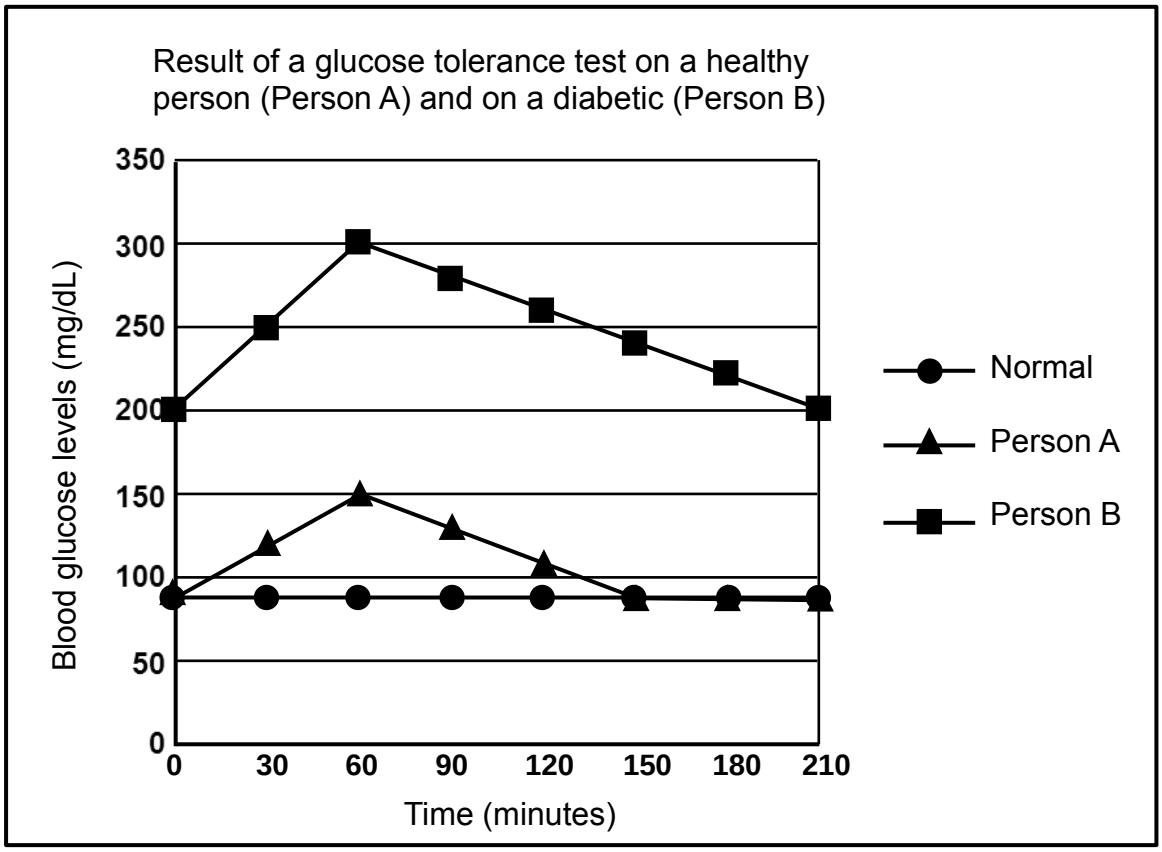
3.2.4 Name the one factor that Lerato kept constant during the investigation. (1)

3.2.5 Which of the two groups (A or B) will release more sweat? (1)

3.2.6 Explain why sweat production will increase in the group identified in question 3.2.5. (3)

(10)

3.3 The graph below shows a comparative glucose test on a healthy and a diabetic person. (In the glucose tolerance test the people being tested would have not eaten for at least 8 hours before the test. When they arrive at the hospital/clinic/doctor's rooms their blood is taken, and glucose levels are tested. They then drink a glucose solution and their blood is taken and tested every 30 minutes over at least a 3 hour period.)



3.3.1 What values does the graph accept as normal blood glucose levels? (1)

3.3.2 What is the difference in blood glucose levels at time 0 between person A and person B? (2)

3.3.3 What do you think happened in person A to cause the glucose levels to drop after 60 minutes? (2)

3.3.4 Name three lifestyle precautions should person B be taking? (3)

3.3.5 Besides lifestyle changes what treatment is available for diabetics to regulate their glucose levels? (2)

(10)

[30]

Section B: [50]

Total marks: [100]

8: Plant responses to the environment

CHAPTER 8: PLANT RESPONSES TO THE ENVIRONMENT

Introduction

Plants, just like any other living organism, are able to respond to changes in their environment. They are able to respond to stimuli such as water, sunlight, gravity, chemicals and touch. Plants use chemicals called **hormones** (also known as plant growth regulators) and these hormones affect how a plant grows, by stimulating plant cells to divide, enlarge, elongate and to stop growing.

In this chapter, we will deal with:

- plant hormones – auxins, gibberellins, abscisic acid
- the role of auxins in phototropism, geotropism, apical dominance and weed control

Key terminology

hormone	a chemical messenger produced in one part of the plant and has an effect on another part of the stem
tropism	growth or turning movement of a plant or part of a plant in response to external stimulus
phototropism	growth of part of a plant in response to the stimulus of light
geotropism	growth of a plant in response to gravity
unilateral light	light coming from one side or direction
herbicide	a substance that is toxic to plants and destroy unwanted vegetation (weeds)
apical bud	the growing point of the stem located at the tip of the stem
apical dominance	when auxins produced at the tip of the stem inhibit the growth of the branches closer to the tip of the stem

Auxins

Auxins are produced in the growing tips of stems and roots and in apical buds and are the main hormones that cause plants to grow. They stimulate or can prevent (inhibit) growth.

The main functions of auxins:

- apical dominance
- growth regulation (responsible for phototropism and geotropism)

Other functions include:

- cell division (mitosis)
- formation of adventitious roots in cuttings
- development of flowers and fruits
- abscission of leaves and ripe fruits (cause leaves and fruit to fall off)

Apical dominance

When the stem grows upward, auxins are produced at the tip of the stem. The auxins move downward and inhibit the growth of the lateral branches. This process is called **apical dominance**. Auxins thus promote apical dominance. As a result of apical dominance, growth of the lateral branches closer to the tip of the stem is inhibited by the auxin resulting in them being shorter than the lateral branches lower down the stem. This results in tapered growth of the stem (wider at the bottom but narrower at the top).

What happens when the tip is removed?

Once the tip of the stem is removed, auxins are removed and so the lateral branches begin to grow. This is useful in the fruit industry where plants are kept short with more lateral branches, resulting in more fruit being produced. In addition, fruit is closer to the ground and therefore easier to pick.

Remember: removal of the tip of the stem stops the apical dominance

Growth regulation (tropisms)

In plants, a response to an external stimulus is known as a **tropism**. When the movement of a plant is away from the stimulus, it is known as a **negative tropism**. When the movement of a plant is toward the stimulus, it is known as a **positive tropism**.

Plants can respond to many different stimuli. We focus on two:

- phototropism – a response to light
- geotropism – a response to gravity

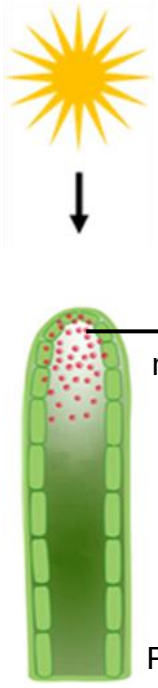
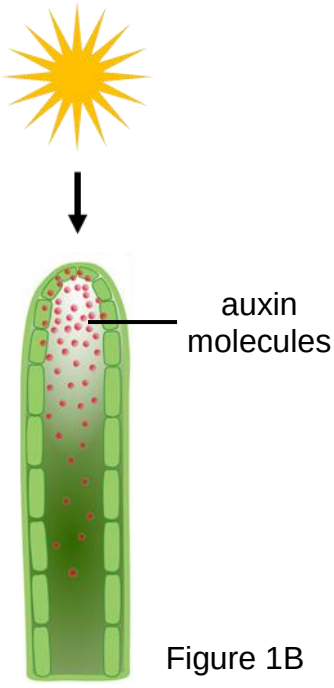
Phototropism

Phototropism is the growth of parts of a plant towards a light stimulus. When the stem of a plant is exposed to **unilateral light**, the stem will bend toward that light.

Role of auxins in phototropism

The role of auxins in phototropism is illustrated in Table 1 below.

Table 1: The role of auxins in phototropism

Direction of light stimulus	Effect of light on auxins	Observations
Shoot A – with sunlight directly overhead  Figure 1A	• Auxins produced at the tip of the stem / shoot • Auxins move downwards evenly • This distribution brings about equal growth on all sides of the stem	The stem / shoot A grows straight upward towards the light  Figure 1B

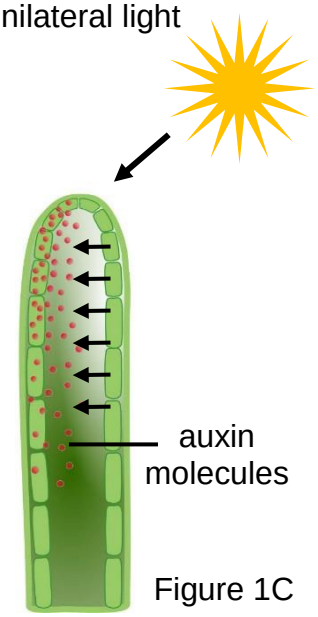
<table>
<tr>
<td>Shoot B – when the stem is exposed to unilateral light
 

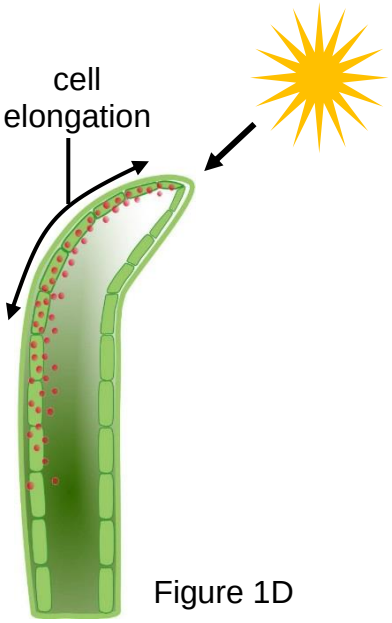
Figure 1C</td>
<td>• The auxin concentration will be high on the shaded side because light destroys auxins or auxins move away from the light
• More growth occurs on the dark side because auxins stimulate growth on the dark side</td>
<td>The stem / shoot B bends towards the light
 

Figure 1D</td>
</tr>
</table>

Figure 1: The role of auxin in phototropism

Stems are **positively phototropic** as they bend toward the light and roots are **negatively phototropic** as they grow away from the light.

Advantages of stems being positively phototropic:

- favourable position for leaves to receive sunlight needed for photosynthesis
- allows easy pollination of flowers
- allows easier seed dispersal

Activity 1: Phototropism

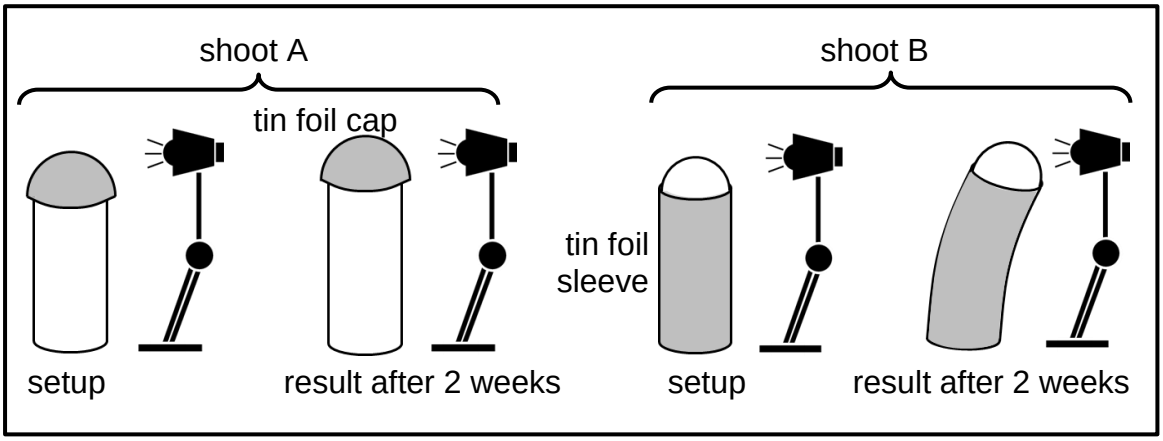
Lerato, a learner in Grade 12, is investigating how shoots respond to light. She used the following method.

Method

- Two shoots, labelled shoot A and shoot B were used.
- Both shoots were from the same plant species.
- The tip of shoot A was covered with a tin foil cap.
- The sides of shoot B were covered with a tin foil sleeve.

- Both shoots were exposed to unilateral light using two lamps.
- The lamps were placed at the same distance from the shoots.
- The apparatus was left for 2 weeks.
- After 2 weeks, she observed what happened to shoot A and shoot B.

The results of Lerato's investigation are shown in the diagram below.



1. Identify the

   a) independent variable (1)

   b) dependent variable (1)

2. State three planning steps that Lerato considered in this investigation. (3)

3. Explain the results observed on shoot B. (4)

4. How did Lerato ensure validity in this investigation? (4)

5. State three ways in which the reliability of the investigation can be improved. (3)

(16)

Geotropism

Geotropism is the growth movement of a plant in response to gravity.

When a pot plant is placed on its side and left to grow in a dark environment without any light, the stem will grow upwards and the roots will grow downwards. This response to gravity is known as geotropism.

It is illustrated in Figure 2 below.

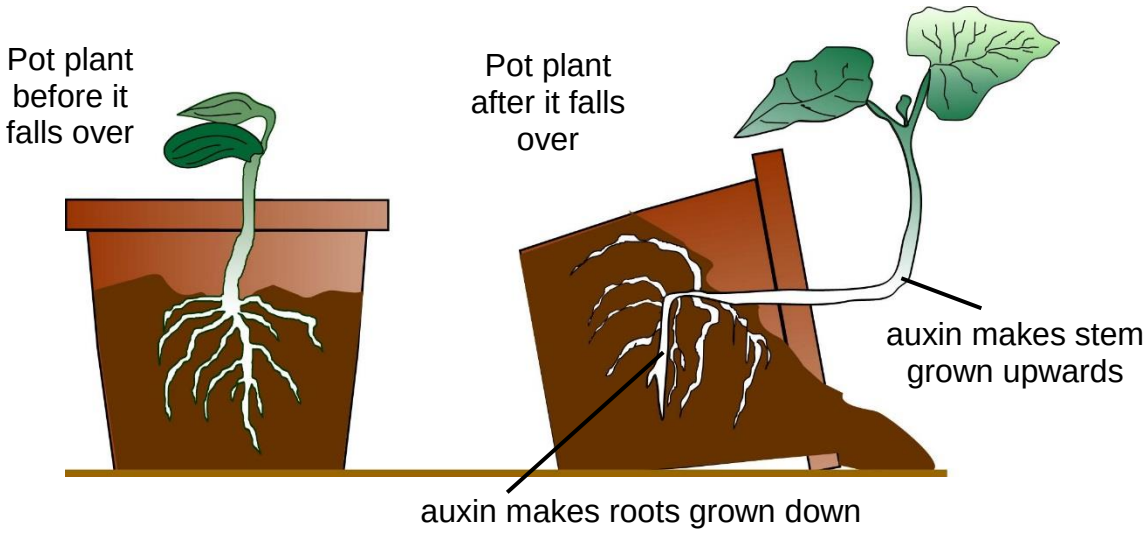


Figure 2: Positive and negative geotropism in a pot plant

In Figure 2 above, the roots are exhibiting **positive geotropism** as they are growing with gravity and the stems and leaves are exhibiting **negative geotropism** as they are growing against gravity.

Role of auxins in geotropism

When the pot plant is upright …

- auxin is produced at the tip of the roots and moves upwards evenly.
- The even distribution brings about equal growth on all sides of the root.
- As a result the root grows downward.
- When the pot plant is placed horizontally, the auxin concentration will be high on the lower side of the root because auxins are pulled down by gravity.
- More growth occurs on the upper side of the root because auxins on the lower side inhibit growth.
- As a result the root bends downwards.

NB: High concentration of auxins in root inhibit cell elongation whilst in the stem high concentration of auxins promote cell elongation.

Geotropism also occurs in germinating seeds (Figure 3); where the emerging young root starts to grow downward in response to gravity. Therefore no matter which way the seeds lands in the ground, the roots will always grow downward and the shoot will always grow upward toward the light.

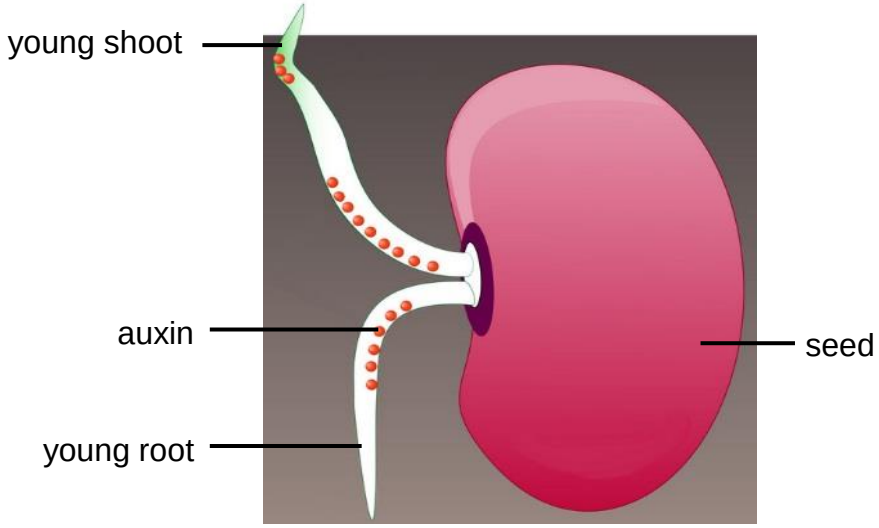


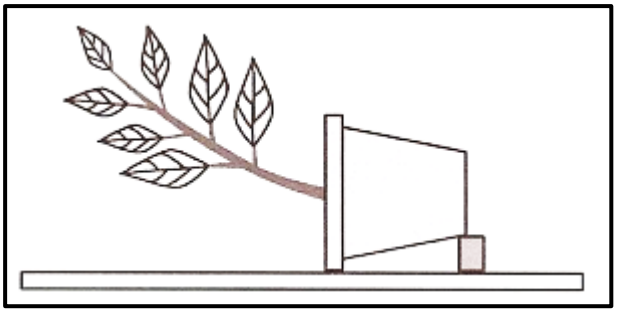
Figure 3: Geotropism in germinating seeds

Auxins have mass and are pulled down by gravity (Figure 3). As a result, the shoot and root both have a high concentration of auxins on the lower side. However, the effect of high concentrations of auxin on young roots and shoots is different.

- In the shoot high auxin concentration promotes cell elongation on the lower side. The shoot thus bends and grows upwards. It is **negatively geotropic**.
- In the young roots the lower part has high auxin concentration than the upper part. The lower part with more auxins is inhibited and does not grow fast. The upper part with no auxins grows faster. The root then grows downwards towards gravity. Roots are **positively geotropic**. Roots are then able to grow deep into the soil where the root hairs will absorb water and minerals.

Activity 2: Geotropism

The pot plant in the diagram below was placed onto its side in a dark cupboard. After 2 weeks, the stem had started to grow upwards.



1. Give the term used to describe this phenomenon. (1)
2. Define the phenomenon identified in question 1. (1)
3. Discuss the role of auxins in the phenomenon mentioned in question 1 in respect of the roots of the plant. (6)

(8)

Other plant hormones

Some other plant hormones include **gibberellins** and **abscisic acid**. Gibberellins initiate the germination of seeds, development of flowers and sprouting of buds. The main function of abscisic acid is to inhibit growth of apical buds. It also promotes seed dormancy.

The use of plant hormones in controlling weeds

Weeds are unwanted plants that grow in an area and compete with the other plants for space, nutrients, water and light. By doing this, weeds cause a decrease in crop productivity and yield (how much fruit a tree bears). **Herbicides** can be sprayed over crops or gardens to kill the unwanted weeds. However, these chemicals are often toxic to animals and humans and some plants.

An alternative to these toxic chemicals are plant hormones. Different plant species are sensitive to different levels of certain hormones, so weed killing can be a **selective process**. Most weeds have broad leaves and many cereal crops, such as maize and wheat, have narrow leaves. Therefore, if a plant hormone that only affects broad-leaved plants is used, the weeds will be killed and narrow-leaved commercial crops will survive.

Auxins sprayed on roots of weeds may inhibit root growth because high auxin concentration on roots has an inhibitory effect, causing the death of that particular weed.

Plant defence mechanisms

Plants represent the basis of the food chain as they are primary producers. This means, that plants are under constant attack from herbivores, insects and pathogens.

Chemical defences

The primary defence mechanism is the production of chemical compounds that poison herbivores and insects and protect plants against pathogens. These chemical compounds (e.g. tannins) can affect the feeding, growth and survival of herbivores, insects and pathogens.

Mechanical defences

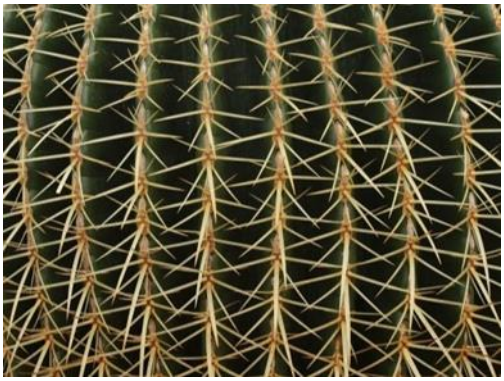
Other defences include the development of various external structures e.g. thorns that make it difficult for herbivores to eat the plant.

Examples of structures involved in mechanical defence in plants include thorns, prickles and spines.

Table 2 below show differences between thorns, prickles and spines.

Table 2: The differences between thorns, prickles and spines

 Figure 4A: Thorns	**Thorns** are modified branches or stems that form hard, pointed sharp edges that can pierce the skin or the roof of the mouth of a herbivore. Thorns make it difficult for larger herbivores to get their mouths to the leaves in between the thorns, without hurting themselves.
 Figure 4B: Prickles	**Prickles** are modified extensions of the cortex and epidermis of a plant that shape into a sharp, needle-like structure. These are often found on rose bushes.

 Figure 4C: Spines	**Spines** are modified leaves that have a cylindrically shaped hard and sharp point. These structures are often found on aloes and cacti. They are generally rather thin and are difficult to remove.

Enrichment

The following links show that plant hormones are chemical substances that accelerate, inhibit or otherwise affect growth.

http://www.untamedscience.com/biology/plants/phototropism/

Plant growth: Auxins and gibberellins: https://www.youtube.com/watch?v=EZ5tU45Ti_g

Plant hormones: https://www.youtube.com/watch?v=HR9KHW-e0pY

Phototropism time-lapse: https://www.youtube.com/watch?v=G4Mo9-JAeok

Geotropism: https://www.youtube.com/watch?v=57IXUG0CHSQ

Plant responses to the environment: End of topic exercises

Section A

Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write only the letter (A- D) next to the question number (1.1.1 – 1.1.5) on your answer sheet, for example 1.1.6 D

1.1.1 Which ONE of the following plant hormones is responsible for the germination of seeds?

A Growth hormone
B Abscisic acid
C Gibberellin
D Auxin

1.1.2 A gardener removes the apical buds from a rose bush in her garden regularly. As a result the rose bush will…

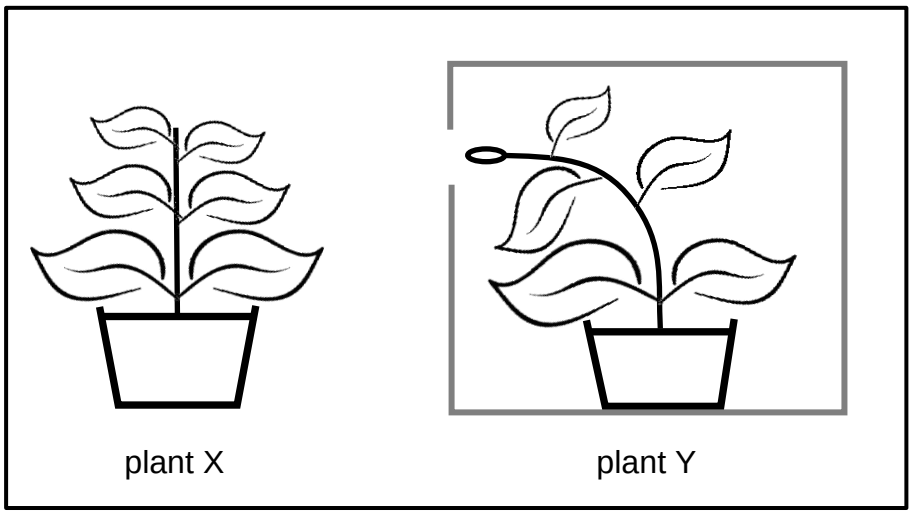
A produce more lateral branches.
B grow taller.
C remain the same size.
D produce fewer roses.

1.1.3 Which plant hormone promotes seed dormancy?

A Gibberellin
B Auxin
C Abscisic acid
D Growth hormone

Questions 1.1.4 and **1.1.5** are based on the information and diagrams below:

Two identical potted plants X and Y, of the same age and size were placed in the light, but plant Y was placed in a box with a hole on one side. The diagram below shows the plant after 5 days.



1.1.4 Which combination of the following statements is correct?

i) The shoots of both plants have grown towards moisture.

ii) The shoot of plant Y has grown more than the shoot of plant X

iii) The shoot of plant Y has grown against the force of gravity

iv) The shoot of plant Y has grown towards light from one side but the shoot of plant X grew in response to uniform light.

v) The shoots of both plants have grown in the direction of the force of gravity.

A (ii) and (iv)

B (i) and (ii)

C (iii) and (v)

D (i) and (v)

1.1.5 The reaction of plant Y is caused by growth hormones that…

A form only in the presence of light.

B cannot function in the dark.

C stimulate cell elongation on the shaded sides.

D Inhibits cell division of the lighted side.

(5 x 2) = (10)

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

1.2.1 The plant hormone that causes leaves to fall off trees in autumn.

1.2.2 The movement of a part of a plant in response to gravity.

1.2.3 A chemical substance that helps to coordinate the growth, metabolism or development of the plant.

1.2.4 Plant growth responses to external stimuli.

1.2.5 A substance containing plant hormones used to kill unwanted plants.

1.2.6 Animals that eat the leaves and twigs of trees.

1.2.7 A sheath that covers and protects the growing stem of grasses and cereals.

1.2.8 The plant hormone that promotes seed dormancy.

1.2.9 The response of a plant stem in reaction to light.

1.2.10 Inhibition of the growth of lateral buds by the auxins present in apical buds.

(10 x 1) = (10)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Plant defences	A: thorns B: chemicals
1.3.2 Chemicals used to kill weeds.	A: herbicides B: fungicides
1.3.3 Tropism involving movement of a plant in reaction to gravity.	A: phototropism B: hydrotropism
1.3.4 The young stem bearing leaves is called the…	A: shoot B: radicle
1.3.5 A stimulus coming from ONE direction only.	A: omnilateral B: unilateral

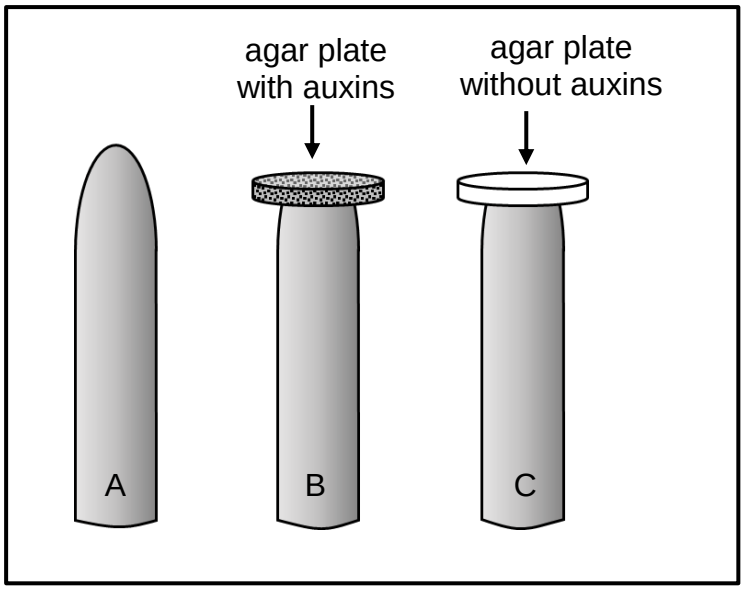
(5 x 2) = 10

1.4 Thobeka investigated the effect of auxins on the growth of three plant shoots (**A**, **B** and **C**). The plant shoots were treated as follows:

- Shoot **A** – Not treated in any way
- Shoot **B** – Tip removed and agar plate with auxins placed on top.
- Shoot **C** – Tip removed and agar plate without auxins placed on top.

All shoots were exposed to the same light conditions. Note: Agar is a jelly-

like substance that allows auxins to diffuse through it. The diagram below illustrates the set-up at the beginning of the investigation.



1.4.1 Identify the independent variable in this investigation. (1)

1.4.2 State two factors that must be kept constant in this investigation. (2)

1.4.3 Explain the results observed in:

a) Shoot **B** after a few days (3)

b) Shoot **C** after a few days (2)

1.4.4 Suggest two ways in which Thobeka could have improved the reliability of her investigation. (2)

(10)

1.5 A Grade 12 learner performed an investigation to determine the effect of light on the growth of plant shoots. The learner divided the plants that were used into three groups as follow:

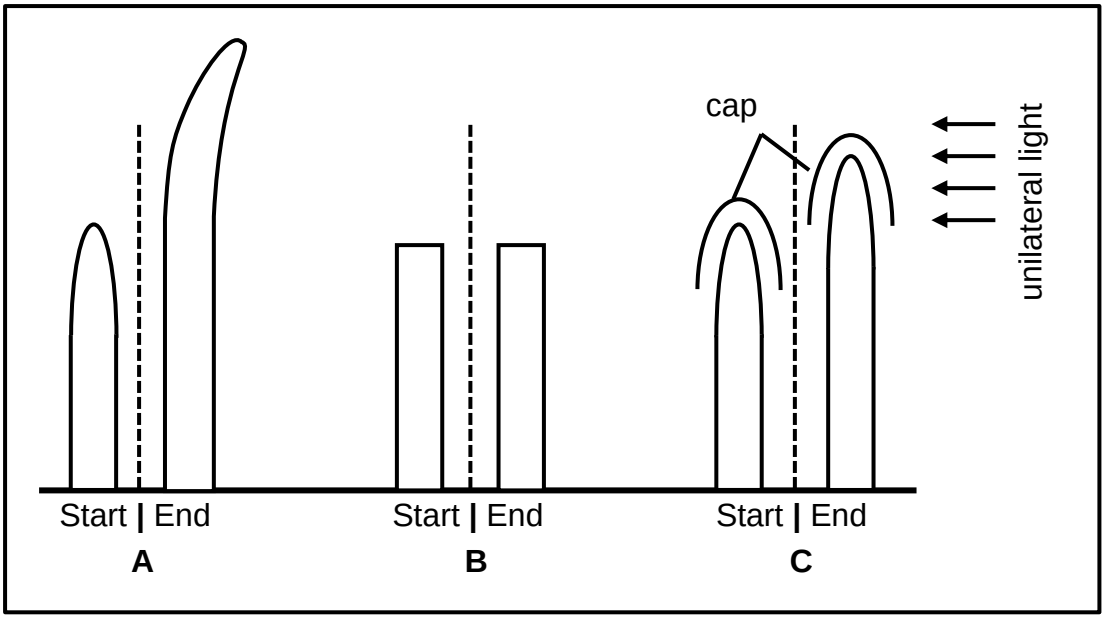
Group **A**: The tip of the shoot was intact.

Group **B**: The tip of the shoot was removed.

Group **C**: The tip of the shoot was covered by a cap that does not allow light to pass through.

The diagram in each group (**A**, **B** and **C**) below shows each shoot at the start of the investigation and next to each, the same shoot at the end of the investigation.

The arrows indicate the direction of light to which each of the shoots **A**, **B** and **C** were exposed.



1.5.1 Name the dependent variable in this investigation. (1)

1.5.2 Which plant hormone is being investigated in this experiment? (1)

1.5.3 State one factor that must be kept constant during this investigation. (1)

1.5.4 Explain the results observed in:

a) investigation A (3)

b) investigation C (3)

1.5.5 State one way in which the learner could improve the reliability. (1)

(10)

Section A: [50]

Section B

Question 2

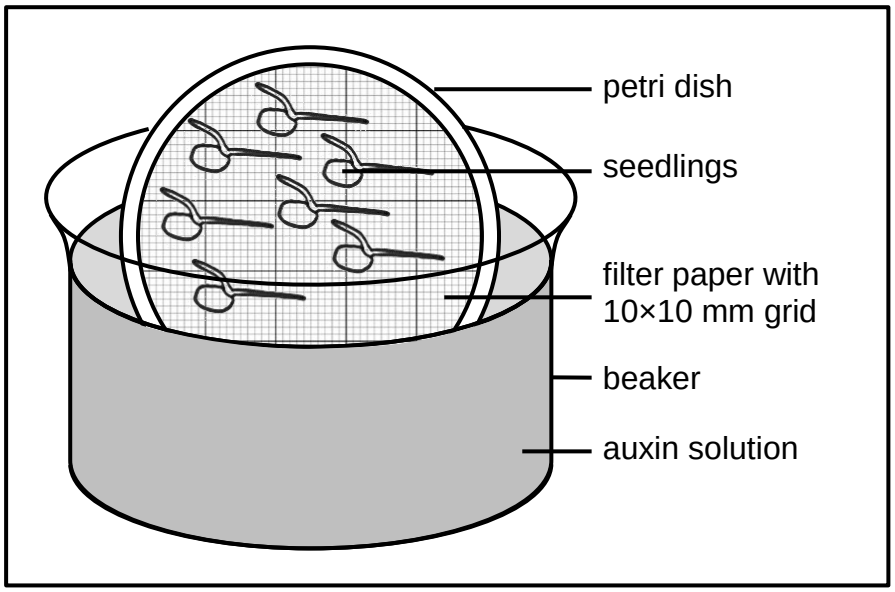
2.1 A group of Grade 12 learners investigated the influence of different concentrations of auxins on plumule growth. A plumule is a young stem that grows from a seed.

The procedure was as follows:

- 35 bean seeds were germinated.
- The seedlings were then divided into five groups of seven seedlings each.
- In each group the seven seedlings were attached with Prestik to filter paper on which a 10 mm x 10 mm grid was drawn.

- The filter paper with seedlings was then glued to the inside of a petri dish.
- Each of these five petri dishes was placed in a beaker containing a different concentration of auxins.

The diagram below shows the set-up of a single beaker.



- All five beakers were placed inside a dark cupboard for three days.
- After three days the increase in length of each plumule was measured.
- The average increase in length of the plumule in each beaker was calculated and recorded in the table below.

The table below shows the results of the investigation after three days.

Beaker number	Auxin concentration in parts per million (ppm)	Average increase in plumule length (mm)
1	0.1	1.5
2	1	3.2
3	10	4.8
4	50	2.3
5	100	0

2.1.1 For this investigation identify the:

a) independent variable (1)

b) dependent variable (1)

2.1.2 State the purpose of the grid that was placed inside each

petri dish. (1)

2.1.3 Explain why the beakers were placed in a dark cupboard. (2)

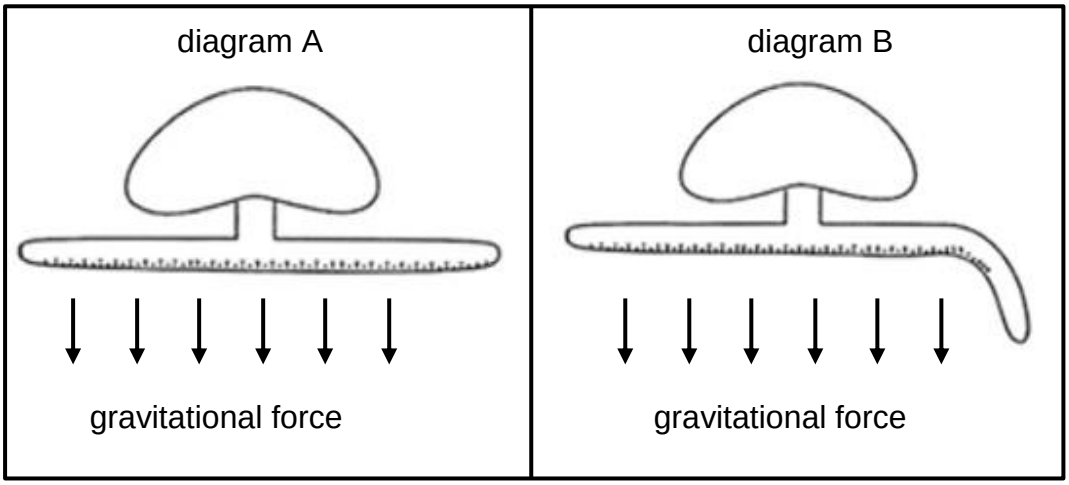
2.1.4 State one way in which the learners ensured the reliability of this investigation. (1)

2.1.5 State three factors, not indicated in the procedure, that should be kept constant during this investigation. (3)

2.1.6 State the conclusion that can be made from the results in the table. (2)

(11)

2.2 An experiment was conducted by a learner to investigate growth movements in plants. A seedling was placed horizontally in the dark as shown in diagram A. Diagram B shows the results after 5 days.



2.2.1 Give the term for the movement of part of a plant in response to a stimulus. (1)

2.2.2 Which plant growth hormone stimulates the growth movement shown in diagram B? (1)

2.2.3 Give any other two functions of the hormone mentioned in question 2.2.2. (2)

2.2.4 Does the accumulation of the hormone mentioned in question 2.2.2 inhibit or promote cell elongation in the growing tip of a stem? (1)

2.2.5 Explain why the part of the plant which showed a response as illustrated in the diagram B, will react as shown. (6)

(11)

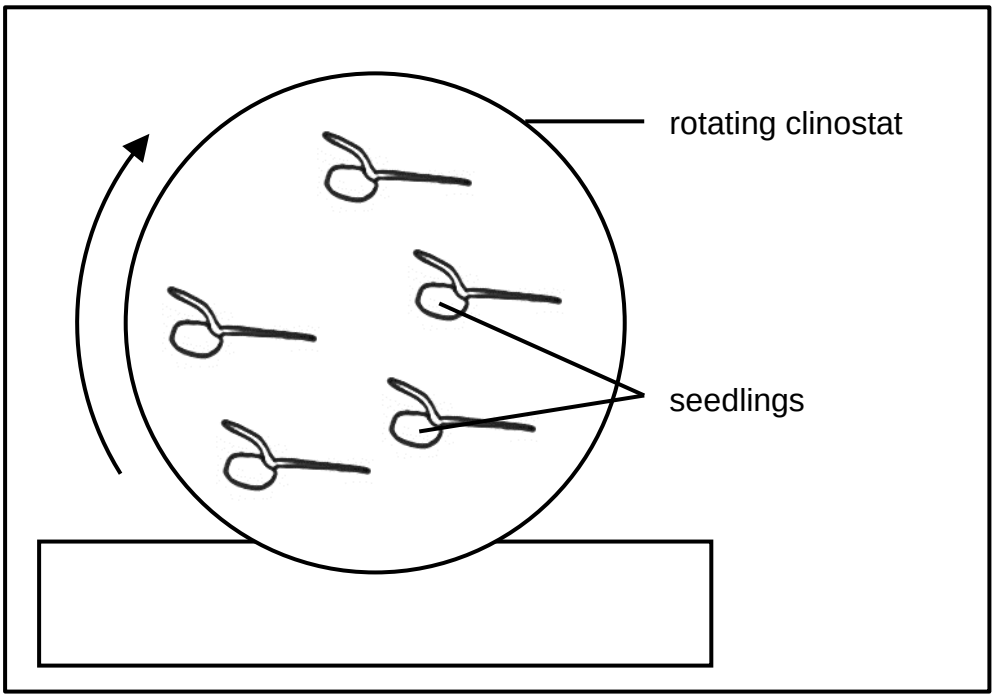
[22]

Question 3

3.1 A learner conducted an investigation to determine the effect of auxins and the effect of gravity on the root growth in pea seedlings. He used the following procedure:

- He germinated pea seeds for seven days.
- He then took a sample of 15 seedlings and divided them into 3 groups (A to C) of 5 seedlings each.
- In each group the 5 seedlings were placed **horizontally** on 3 different clinostats.

A clinostat is a device which has a disc that rotates at a constant speed. A diagram of a clinostat is shown below.



- He removed the root tips of all seedlings at the same length in group B.
- In groups A and B the clinostats were left stationary (no rotation).
- In group C the clinostat was allowed to rotate.
- All 3 clinostats were placed in a dark cupboard.

A summary of the learner's procedure is shown in the table below.

Group A	Group B	Group C
root tips present	no root tips	root tips present
stationary clinostat	stationary clinostat	rotating clinostat

After two days the direction of root growth was observed.

3.1.1 Which two groups were used to obtain information about:

a) The effect of auxins on root growth. (1)

b) The effect of gravity on root growth. (1)

3.1.2 Define the term *tropism.* (1)

3.1.3 Explain why the apparatus was placed in a dark cupboard. (2)

3.1.4 Describe the expected results for each of groups **B** and **C** in this investigation. (2)

3.1.5 Explain the expected results for group **A.** (3)

3.1.6 State three ways in which the learner ensured a high level of validity for this investigation. (3)

(13)

3.2 Weeds are problematic to farmers because they invade farm fields and outcompete crop plants for space. This reduces crop yield.

Farmers spray their fields with chemicals, known as herbicides, to kill the weeds. Some weeds, however, have evolved to be resistant to herbicides.

Scientists investigated the time it took for a species of weed to develop resistance to five types of herbicides. The results are shown in the table below.

Types of herbicide	**Time taken for weeds to develop resistance (years)**
2,4 – D	9
Dalapon	9
Picloran	25
Dicloflop	7
Trifluralin	26

3.2.1 Refer to the passage above and state how weeds act to reduce crop yield. (1)

3.2.2 Identify the:

a) independent variable (1)

b) dependent variable (1)

3.2.3 Name the herbicide:

a) to which the weeds developed resistance the fastest. (1)

b) that remained effective for the longest period of time. (1)

3.2.4 The scientists used the same weed species when investigating resistance to the different herbicides.

a) Describe how the scientists would have determined the resistance of the weeds to the herbicides. (2)

b) Explain how the use of the same weed species improved the validity of this investigation. (2)

3.2.5 Draw a bar graph to show the time taken for the evolution of resistance to the herbicides. (6)

(15)

[28]

Section B: [50]

Total marks: [100]


Strand
diversity
change
and
continuity

9: Evolution by natural selection

CHAPTER 9: EVOLUTION BY NATURAL SELECTION

Introduction

Topics for this unit:

- origin of ideas about origins
- theories of evolution
- Darwin's theory of evolution by natural selection
- formation of a new species
- artificial selection
- mechanisms of reproductive isolation
- evolution in present times

Key terminology

biological evolution	any genetic change in a population that is inherited over several generations
biological species	a group of organisms with similar characteristics that interbreed with one another to produce fertile offspring
population	a group of individuals of the same species occupying a particular habitat
punctuated equilibrium	evolution characterised by long periods of little or no change followed by short periods of rapid change
natural selection	mechanism of evolution - organisms survive if they have characteristics that make them suited to the environment
artificial selection	human-driven selective force, e.g. breeding of plants and animals to produce desirable traits
inbreeding	mating of individuals that are closely related
outbreeding	mating of individuals that are not closely related
speciation	the formation of a new species
geographic speciation	formation of a new species when the parent population separated by a geographical barrier
reproductive isolation	a mechanism that prevents two species from mating with one another and making fertile hybrids

Origin of ideas about origins

The theory of evolution has been developed over many years by many different scientists and is regarded as a scientific theory since various hypotheses relating to evolution have been tested and verified over time.

Theory vs Hypothesis

A **theory** is an explanation of something that has been observed in nature which can be supported by facts, generalisations, tested hypotheses, models and laws. A **hypothesis** is a possible solution to a problem.

The word **evolution** simply means change over time. Evolution is the process by which organisms develop over time from earlier forms. **Biological evolution** refers to any genetic change in a population that is inherited and becomes a characteristic of that population over several generations.

Evidence for evolution

Fossils	covered in Grade 10 • Different fossils are found in different rock layers with the oldest fossils in the oldest rock layers with transitional fossils present. • This systematic change through time is termed **descent with modification**. • The evidence shows characteristics that make organisms similar to one another largely from the study of fossils
Bio-geography	covered in Grade 10 • Biogeography is the study of where species are found and why they are found there. • There are many different collections of plants and animals in regions of the same line of latitude, with similar climates and conditions, suggesting such organisms have a shared ancestor.
Genetics	new concept for Grade 12 – see below • Species that are closely related have a greater genetic similarity to each other than distant species and therefore share a more recent common ancestor.
Other evidence	not studied in school – embryology, vestigial organs, comparative anatomy

Genetic evidence and variation

The study of genetics deals with the similarities in and differences of related organisms. Genetic evidence that organisms are closely related and are likely to have a common ancestor includes:

- identical DNA structure
- similar sequence of genes
- similar portions of DNA with no functions
- similar mutations (mitochondrial DNA)

Species that are closely related have a greater similarity to each other than more distantly related species.

There is also some degree of variation between individuals of the same species in a population. This variation may be caused by:

- **Crossing over** during Prophase I of meiosis involves an exchange of genetic material, leading to new combinations of maternal and paternal genetic materials in each new cell / gamete resulting from meiosis.
- **Random arrangement of maternal and paternal chromosomes** at the equator during metaphase allows different combinations of chromosomes / chromatids to go into each new cell / gamete resulting from meiosis, making them different.
- **Random fertilisation** between different egg cells and different sperm cells formed by meiosis result in offspring that are different from each other.
- **Random mating** between organisms within a species leads to a different set of offspring from each mating pair.
- A **mutation** changes the structure of a gene or chromosome and therefore the organism's genotype. Since the genotype influences the phenotype, it creates organisms with new, different characteristics from one generation to the next

Theories of evolution

The most significant advocates of the idea that species are not static, but have changed over time, were Jean Baptiste de Lamarck and Charles Darwin. Of these, Charles Darwin is best known, particularly as a result of his famous book called "The Origin of Species".

Lamarckism

Jean-Baptiste Lamarck was a naturalist and proposed that species were not fixed but that they change over time. During his investigations, he observed that:

- living species were different to those found in the fossil record
- domestication of wild plants and animals and selective breeding resulted in plants and animals changing
- cross breeding plants often led to new characteristics appearing in the offspring

Figure 1: Jean-Baptiste Lamarck

The Law of Use and Disuse

Lamarck suggested that animals changed over time in order to survive in a new environment. He argued that if a structure was used more often, that structure then became bigger in the following generations. Similarly, if a structure was not being used, then this structure would become smaller and might eventually disappear. He called this the **"law of use and disuse".**

The Law of Inheritance of Acquired Characteristics

Lamarck also explained that organisms could inherit these changed structures from their parents. This he called "**inheritance of acquired characteristics"**. Characteristics developed during the life of an individual (acquired characteristics) could be passed on to its offspring. A classic example that Lamarck used to explain his law of use and disuse was the elongation of the giraffe's neck (Figure 2). According to Lamarck, the original giraffes must have found themselves in an environment where, in order to reach food at the tops of trees, they continually needed to stretch

their necks. Over a lifetime, a giraffe could develop an elongated neck, allowing it to get more food. Parents could then pass on this elongated neck to their offspring.

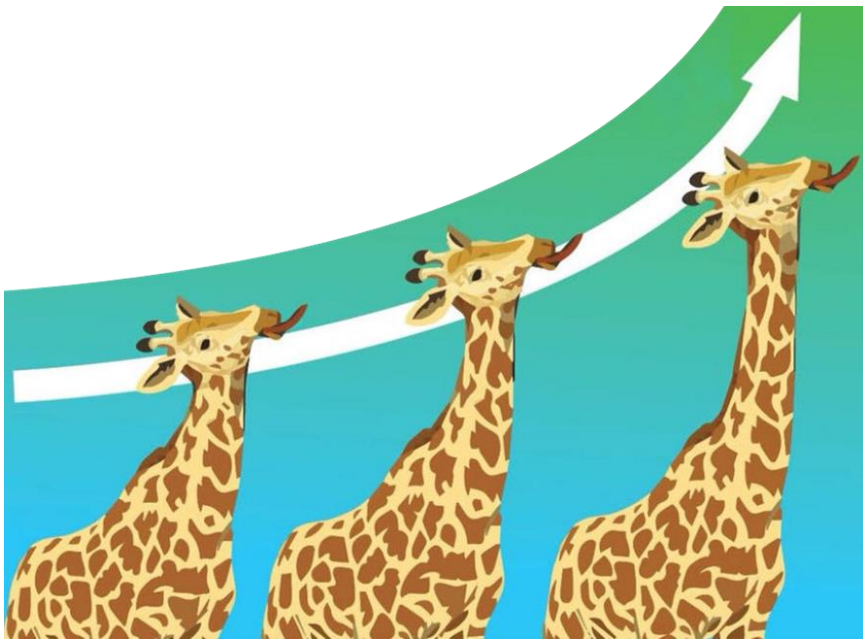


Figure 2: Elongation of a giraffe's neck over time according to Lamarck

Why Lamarck was wrong

Lamarck argued that traits acquired by parents could be passed on to offspring. He did, however, not provide any mechanisms of how this would happen, merely stating that the change happened because the organisms wanted or needed it. We now know that changes to organisms can only come about as a result of a genetic change which is then passed on to offspring.

For this reason, Lamarckism is not accepted today as an explanation for evolutionary change. His work did, however, set the groundwork for scientists like Charles Darwin.

Darwin's theory of evolution by natural selection

Charles Darwin's theory of evolution by natural selection is one of the basic concepts for understanding evolution and is based on the four main observations made by him while on his around-the-world trip on the ship, the HMS Beagle.

- Populations can produce far more offspring than needed.
- Sizes of most natural populations and resources remain relatively constant.

- There is a natural variation of characteristics among members of the same species.
- Some characteristics are inherited and are passed on to the next generation

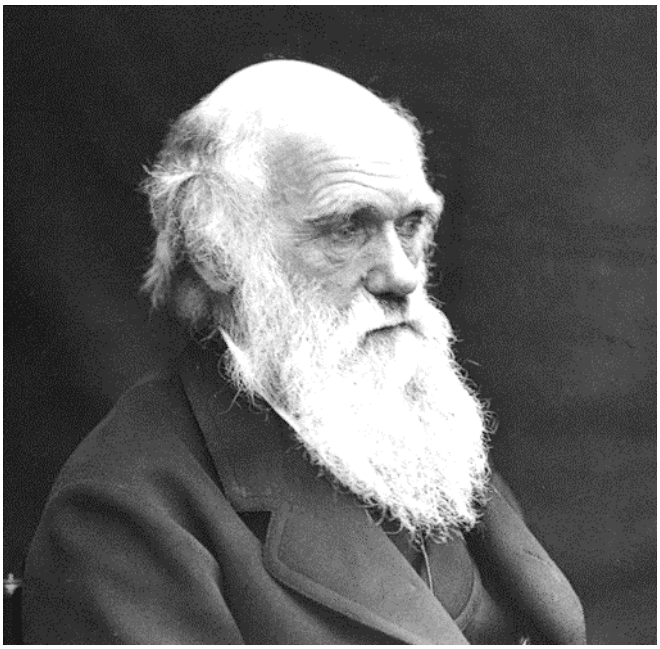


Figure 3: Charles Darwin

Based on his observations, Darwin came to three main conclusions:

- All organisms are involved in a struggle for survival and only those best suited to the environment would survive there.
- Organisms that survive are more likely to reproduce, and therefore pass on their useful characteristics to their offspring.
- Over many generations, reproduction between individuals with different genetic makeup changes the overall genetic composition of the population.

Evolution by natural selection

Natural selection is one of the mechanisms that explains how evolution takes place. Those organisms **best suited to a particular environment produce the most offspring**. This is commonly referred to as “survival of the fittest” – where “fittest” does not mean the strongest, but the best suited to the environment.

Some species are better equipped to face to changing conditions in their environment. Such changes include the type and availability of food and shelter, competition or predation.

Having favourable traits that are suitable to the changing environmental conditions may lead to the formation of new species (speciation). Natural selection always acts on variation already present in a population and the environment is the selective pressure for change.

How does natural selection work?

A generic explanation of natural selection is given in Table 1 below.

Table 1: Natural selection

1	There is a lot of variation among offspring as offspring differ from their parents (due to crossing over, random arrangement of chromosomes, etc.).
2	When the environment changes or there is competition (for food, space, etc.).
3	The offspring with characteristics or traits that make them better suited to the new environment or competition will be most likely to survive and reproduce.
4	The organisms without the desired characteristic or trait are less able to survive in the new environment or competition and so will die out.
5	This means that more offspring in the next generation will have the advantageous characteristic(s). The next generation will have a higher proportion of individuals with the new trait or characteristic.
6	These differences accumulate and eventually all individuals in a population have the new trait or characteristic.

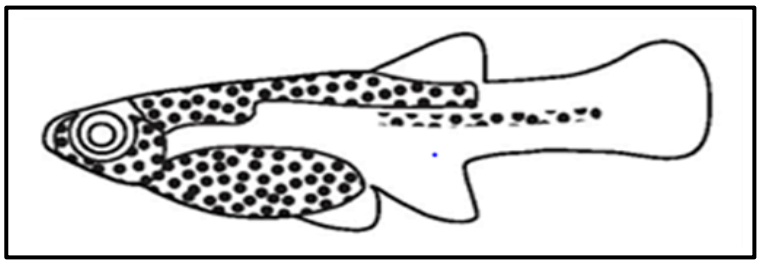
Activity 1: Natural selection

Question 1

A scientist used guppies (*Poecilia reticulata*) in an investigation to test Darwin's theory of natural selection. Male guppies have brightly coloured spots to attract females, but these spots also attract predators.

It was previously observed that males living in streams where there were many predatory fish tended to have fewer spots. This reduced their risk of being eaten.

Those males living in streams with fewer predators had more spots.



Guppy showing spots (adapted from www.decodedscience.org)

The **procedure** for the investigation was as follows:

- Equal numbers of male and female guppies were put into two ponds (pond 1 and pond 2).
- In pond 1, predatory fish that prey on guppies were introduced.
- In pond 2, predatory fish that do not feed on guppies were introduced.
- The guppies were allowed to breed for 20 months, representing several generations of guppies. (Guppies reproduce when they are about three months old.)

The **result** of the investigation:

The male guppies in pond 2 had significantly more spots than the male guppies in pond 1.

1.1 How could the validity of this investigation be increased? (2)

1.2 Identify the:

(a) independent variable (1)

(b) dependent variable (1)

1.3 Explain why the scientist included pond 2 in this investigation. (3)

1.4 Describe how Darwin's theory of natural selection can be used to explain why the guppies in pond 1 had fewer spots. (5)

Question 2

2.1. What type of characteristics does nature select during evolution? (1)

2.2 In nature, there is always a fight for survival due to competition, predation and adverse weather conditions. Suggest a collective term for all these factors. (1)

2.3 Why is the concept of natural selection so important? (2)

2.4 Why is natural selection not a random process? (2)

2.5 In a population of mice, half were light in colour and half were dark.

a) If an owl, hunts in the area at night, which mice have the more favourable characteristic? Explain your answer in terms of natural selection. (3)

b) If the predator was a snake that detects the body heat of its prey, which mice would probably have the more favourable variation? Explain your answer. (3)

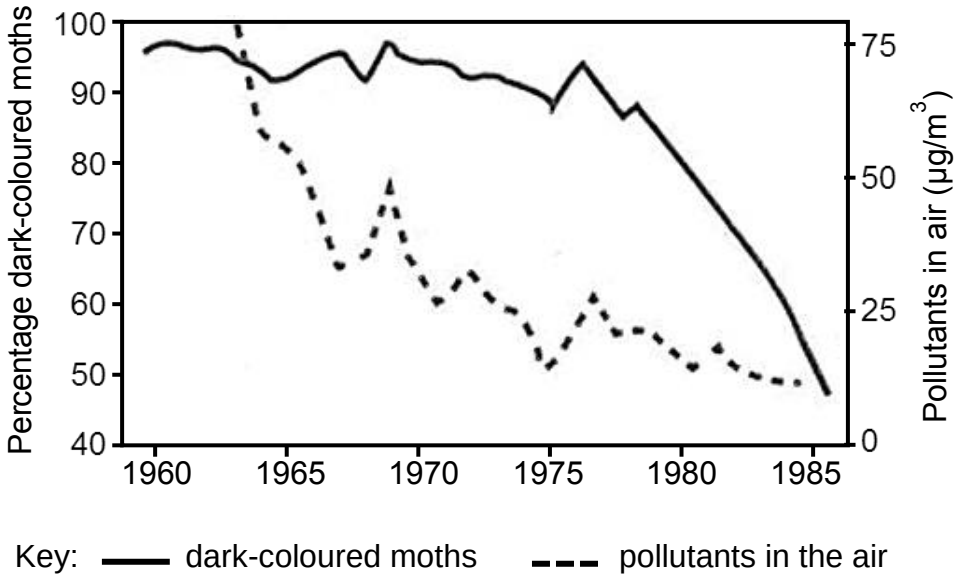
Question 3

Before the industrial revolution, light-coloured moths were far more common in England than dark-coloured moths. Trees were covered by a pale lichen which provided camouflage for the lighter moth. Dark moths were much more visible and were eaten by birds.

Due to pollution from factories in the 19th century, the environment changed. Lichen was killed off, and a black soot covered the bark on the trees. This provided good camouflage for the dark-coloured moths, but the light-coloured moths stood out from their background and were ready prey for birds.

The following is a graph showing the changes in the percentage of dark-coloured moths over a number of years.

Changes in the percentage of dark-coloured moths in relation to pollution over a period of time.



3.1 What is the general relationship between the dark-coloured moth population and the pollution from 1965 to 1985? (1)

3.2 Explain the relationship mentioned in question 3.1 (1)

3.3 Why did the population of the light-coloured moths decrease during the 19th century? (2)

3.4 Once the air pollution had decreased, what do you think happened to the population of the light-coloured moths? Give a reason for your answer. (2)

(30)

Punctuated equilibrium

Punctuated equilibrium refers to a form of evolution characterised by long periods of little or no change followed by short periods of rapid change. This concept was developed by Niles Eldredge and Stephen J. Gould in 1972.

Darwin had proposed that species evolve gradually with small changes over a period of time. This is called gradualism. In gradualism, the physical (phenotypic) characteristics of a population change gradually because of the accumulation of small genetic changes.

Eldredge and Gould noticed that in the fossil record, there were long periods of time where species did not change or changed very little. This was interspersed with periods of rapid change. Accordingly, new species were formed over a short period of time. The main evidence for this type of evolution was the absence of transitional fossils (the “missing-links”).

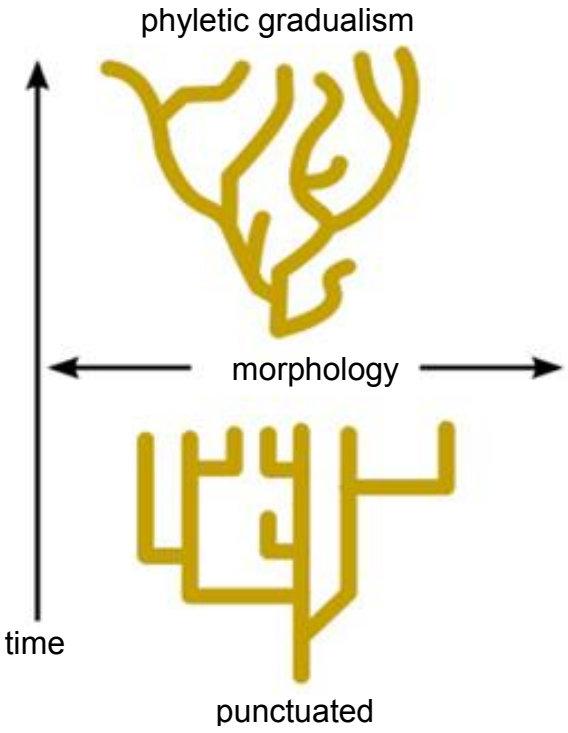


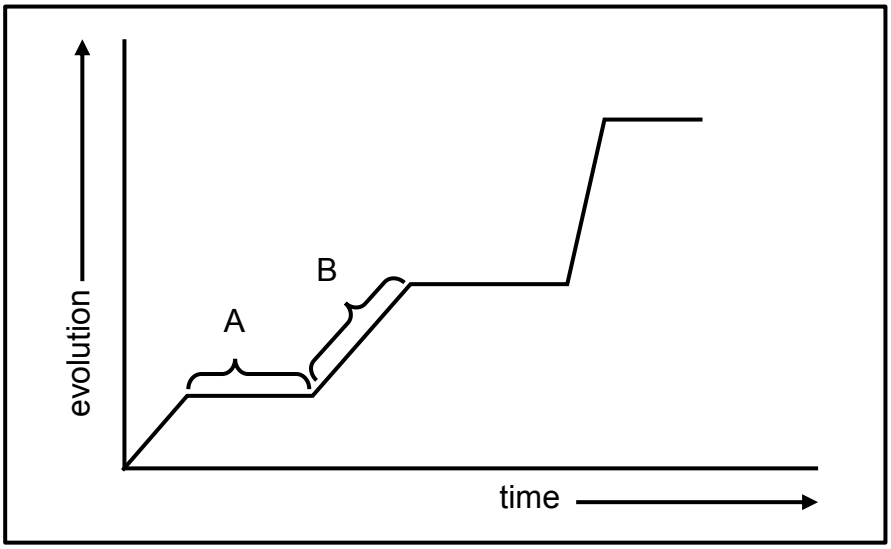
Figure 4: Punctuated equilibrium (Gould) versus gradualism (Darwin)

When a new species branched off from a parent species, changes occurred quickly, but thereafter, the organism changed very little.

In a fast-changing environment, species needed to change rapidly to adapt to the environment, failing which, they would become extinct.

Activity 2: Punctuated equilibrium

The graph below shows the speed at which evolution occurs in a species of butterfly.



1. Explain the trend in evolution represented by:
   a) phase A (2)
   b) phase B (2)
2. In view of the trend represented by A and B, what type of evolution is represented by the graph? (1)
3. Explain why the chances of speciation are great during phase B. (2)

(7)

Lamarckism vs Darwinism

Table 2 below outlines the differences between Lamarckism and Darwinism.

Table 2: Lamarckism vs Darwinism

	Lamarckism	**Darwinism**
make-up of a population	members of population are all the same	members have similar characteristics with a measure of variation
transformation of a species/population	individuals are able to transform during a life time	populations, not individuals, transform over time and only through genetic means
mechanism of change	individual chooses which traits to pass on to offspring changes are directed to meet survival	natural selection – the environment exercises selective pressure causing change variation exists regardless of organisms needs.

Activity 3: Theories of evolution

1. Jean Baptiste de Lamarck was a French naturalist who proposed his theory of evolution in 1809.

   a) Name the two ideas on which Lamarck's theory was based. (2)

   b) Why was his theory considered incorrect and therefore subsequently rejected? (1)

   c) Was Lamarck's work entirely without value because his theory had been rejected? (2)

2. Charles Darwin, a British naturalist, made his most important observations regarding evolution on the Galapagos islands.

   a) List four observations his evolutionary theory was based on. (4)

   b) Describe how Darwin's theory of Natural Selection would have explained the development of long necks in giraffes. (7)

   c) Tabulate two differences between the theories of Charles Darwin and Lamarck. (5)

3. Below are statements referring to the evolution of species. Decide if the statement applies to Darwin, Lamarck or to both scientists.

   a) Only the fittest individuals with the most advantageous characteristics survive in a changing environment. (1)

   b) All members are slightly different and these differences accumulate over time, changing their appearance. (1)

   c) A whale's hind limbs were severely reduced because they no longer used legs in the water. (1)

   d) Species acquire bigger and better structures by the increase in their use and pass these structures on to their offspring. (1)

(25)

Formation of a new species (Speciation)

The formation of a new species is called **speciation**. You have already learnt that variation in individuals is caused by sexual reproduction, genetic mutations, crossing over, random arrangement, etc. If enough of these variations occur and are kept within a **population**, the more likely it is that a species can change.

Biological species concept - a group of organisms with similar characteristics that *interbreed* with one another to produce fertile offspring.

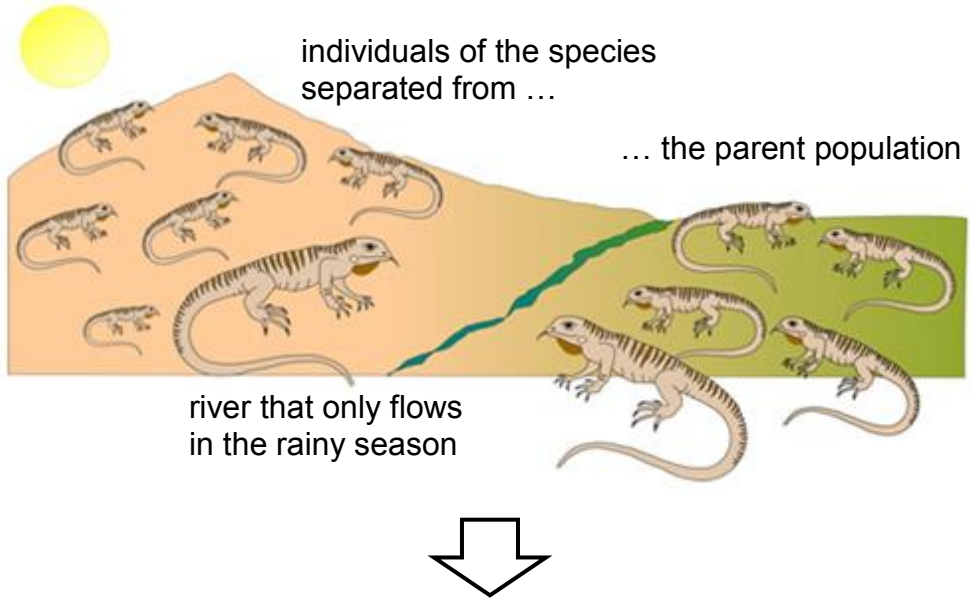
Every population has some sort of genetic variation and these variations are important as they increase a species chance of surviving in a changing environment (natural selection). **Geographic speciation** is one way speciation occurs.

Geographic speciation

Geographic speciation occurs when part of a population becomes isolated from the parent population due to physical barriers. Such barriers could be continental drift, oceans, rivers, mountains, or other natural disturbances such as volcanos or earthquakes.

The images below show how two new species can arise as a result of being separated, over a long period of time, due to a geographic barrier.

1. Early stage of separation (300 000 years ago)



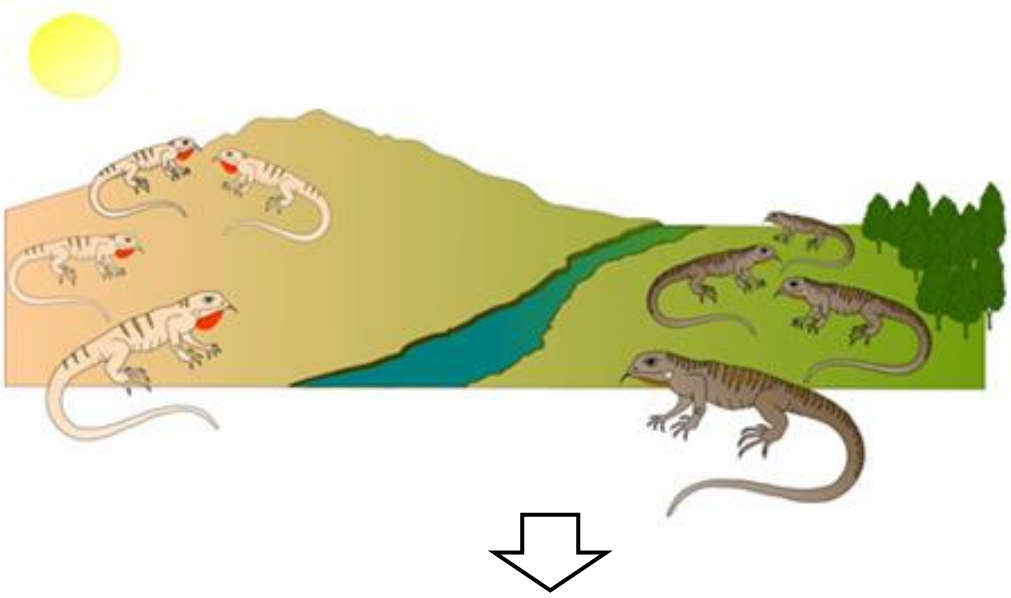
2. Later stage of complete isolation (150 000 years ago)

   Landscape features have altered over time: the river has widened, deepened and flows all year round, resulting in geographic isolation.

   As a result, the gene flow between the two populations stops. The two populations are exposed to different environmental conditions.

   Natural selection now takes place independently in each of the 2 populations –

they change genotypically and then phenotypically from each other.



3. Speciation has occurred (3000 years ago).

   Climate change over time has altered the landscape: the river had dried up enabling a meeting of the species.

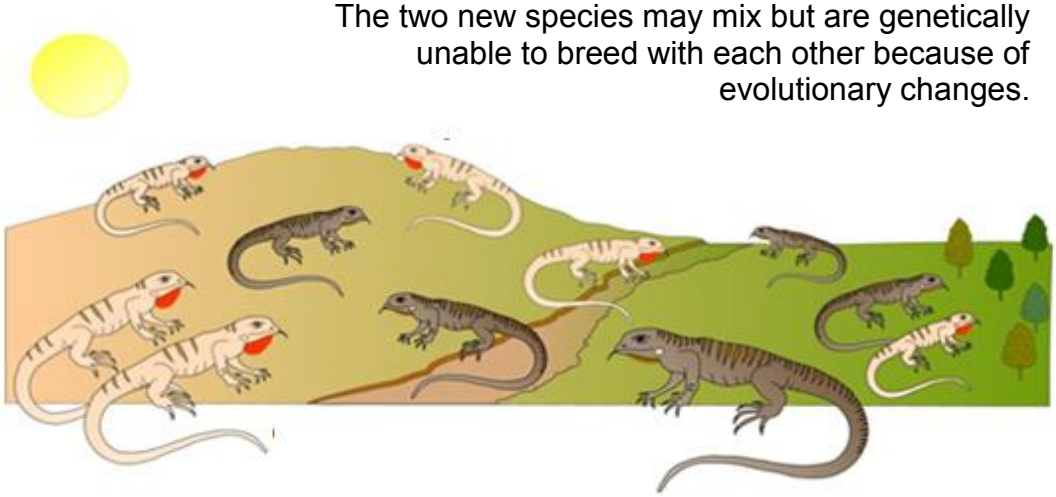


Figure 5: Process of geographic speciation in a population of lizards, separated by a river

Generic account of speciation

- A population is separated by a geographical barrier and splits into two populations.
- The two populations cannot mate and so gene flow between the two populations stops.

- The two populations are exposed to different environmental conditions and selective forces.
- Natural selection works independently on both populations simultaneously
- The two populations become different from the original population both genotypically and phenotypically.
- Even if the populations were to come together again, they would not interbreed with one another and therefore would have become different species.

Activity 4: Speciation

Question 1

1. Bontebok are antelope that are found in the Western Cape. Two main populations exist, one at the Bontebok National Park and the other at Table Mountain National Park. These two national parks are hundreds of kilometres apart. Scientists believe that due to geographical separation, speciation **may** occur.

    1.1 Define the term “speciation”. (2)

    1.2 Define the term ‘species’. (3)

    1.3 Name the type of speciation that may occur in the bontebok populations. (2)

2. For each of the statements below, state whether the statement is TRUE or FALSE. Where false, correct the statement so that it is true.

    2.1 Genetic barriers cause divided populations to remain the same. (2)

    2.2 Reproductive isolation prevents two or more populations from changing genes. (2)

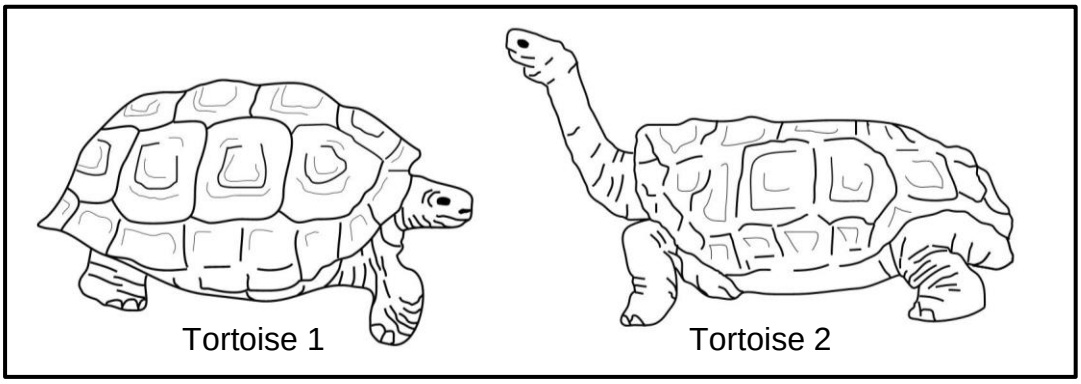
    2.3 Populations that become isolated by means of a geographic barrier will not differ from their ancestral species. (2)

    2.4 Competition, predation, climatic factors and disease are all selective forces / environmental pressures. (2)

Question 2

Darwin discovered two different species of tortoises on two different island in the Galapagos. One had a domed shell and short neck, the other had an elongated shell and a longer neck. The two islands had very different vegetation. One of the islands (island X) was rather barren, dry and arid. It had no grass but rather short tree-like cactus plants. On the other island (island Y), there were no cactus plants but it had a good supply of water and grass grew freely. The diagram below shows the two main

species of tortoise.



1.1 Which tortoise (1 or 2) would have been found on:

a) Island X (1)

b) Island Y (1)

1.2 Describe how the two tortoise species became different species. (5)

1.3 Scientists believe that the variation in populations lead to the formation of new species. List four sources of variation in populations. (4)

(26)

Cladogram of speciation

On a cladogram or phylogenetic tree (diagrams showing evolutionary relationships amongst organisms), one can easily see where a species has split into two different species. This is known as a speciation event (Figure 6).

Over time, some species have remained alive (they are extant) while others have died off (become extinct). Cladograms also show extinction events. If the lineage line does not reach the top of the tree, then the species became extinct. The longer the line of lineage, the more unchanged the species has remained.

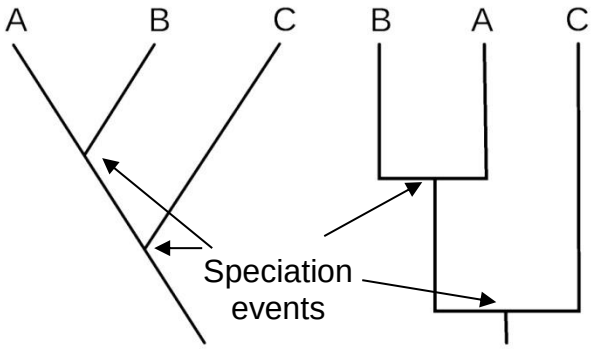


Figure 6: Cladogram showing speciation events

Artificial selection

Humans have long exploited the variation in wild and cultivated organisms to develop crops or new breeds of livestock, through a process called **artificial selection**.

Artificial selection is a human-driven selective force and occurs at a faster rate than natural selection. Favourable traits are artificially selected for by scientists and farmers and then bred out to produce offspring with those traits. Artificial selection mimics natural selection, with the exception that artificial selection is a much faster process and results in less variation than natural selection.

Artificial selection in a domesticated animal

All dog varieties (see Figure 7) originated from the Grey wolf, *Canis familaris*. The first few domesticated wolves would have been selected for traits such as tameness, submissiveness and ones that were easy to work with. Five ancient breeds of dog arose from inbreeding which gave rise to the large number of distinct dog breeds that we have today. The extremely large genetic variability in the ancestral species made it a perfect choice for domestication as different traits could be expressed under different selective pressures.

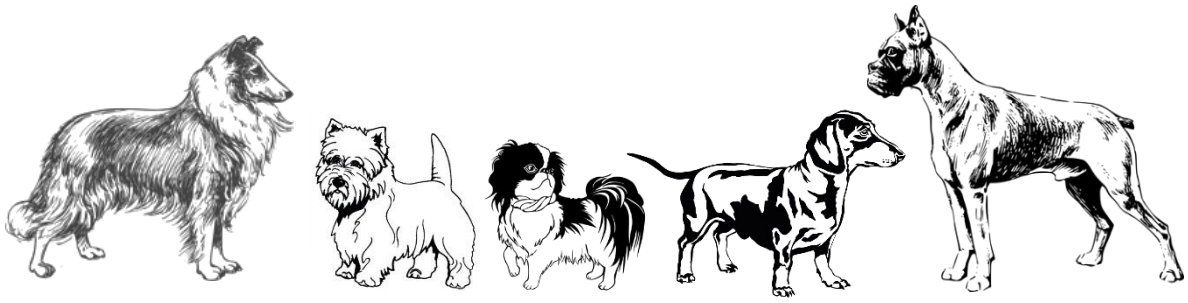


Figure 7: Domestic dogs

Pedigree dogs, born from two dogs of the same breed, sometimes suffer from deformations and can be vulnerable to diseases and parasites. This is due to their decreased genetic variation.

Mongrel dogs (“pavement specials” as they are commonly referred to in South Africa) are dogs that were outbreed and so their genetic variation is far greater than a pure-bred dog. This makes mongrel dogs quite robust (healthy) and they do not die very easily from natural diseases or parasites and they are very fertile.

Artificial selection in crops

Domestication in plants has resulted in wide variety of new species with large

phenotypic differences amongst species. Most of these crops are very dependent on humans for survival.

The domestication of maize (*Zea mays spp*) is one of the greatest success stories in agriculture. The modern day maize plant was bred from a multi-stemmed wild grass. Over the past thousand years, farmers selected and planted seeds from those maize plants that had bigger ears of corn and that required less space to grow. Over time, all the undesirable traits were bred out of the plant, leaving only the large ears of corn and less stems.

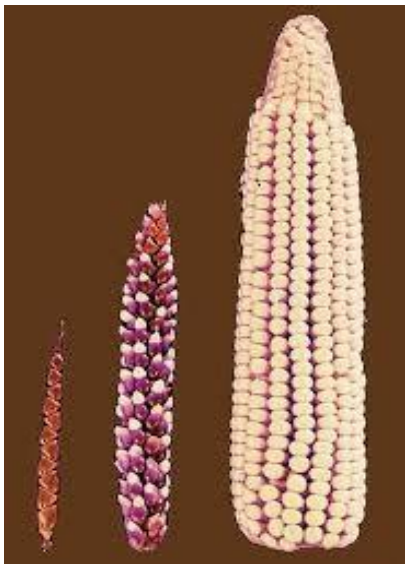


Figure 8: The evolution in the size of the ear of corn. The first image is the original size of the *Zea mays spp* and the one on the far right is the modern day maize.

The following characteristics were considered favourable traits in a maize plant:

- reduced seed coat
- retention of seeds on the cob so that seeds did not just fall off
- a tall plant with a single stalk and less stems
- large ear structure resulting in more food production

Differences between natural and artificial selection

For a long time, humans have been doing breeding experiments to develop organisms with a selected set of desirable characteristics, for example increased quality and quantity of milk produced by cows, or drought resistance and increased sugar content in sugar cane. This is achieved by **artificial selection**, which is a similar process to **natural selection**.

However, artificial selection differs from natural selection. Some of the differences are listed in Table 3 below.

Table 3: Difference between natural and artificial selection

Natural selection	Artificial selection
The **environment or nature** is the selective force	**Humans** represent the selective force
Selection is in response to **suitability to the environment**	Selection is in response to **satisfying human needs**
Occurs within **a species**	May involve **one or more species** (as in cross breeding)

Activity 5: Artificial selection and domestication

Question 1

1.1 List four ways in which artificial selection has been used in agriculture. (4)

1.2 Copy the table below and complete it showing the differences between artificial selection and natural selection. (9)

	Artificial selection	Natural Selection
Driven by...		
Rate of change...		
Amount of variation achieved		
End result		

1.3 Humans have been domesticating plants for years and today, most agricultural species come from domesticated varieties.

a) Define the term “domestication”. (2)

b) What was one of the first crops to be domesticated in the world? (1)

c) Name two characteristics that were selected for in the domestication of the crop mentioned in (b) above. (2).

Question 2

Decide if the statements below are TRUE or FALSE.

2.1 Cultivated plants show higher degrees of phenotypic variation than wild plants (1)

2.2 Natural selection is a random process. (1)

2.3 Artificial selection is similar to natural selection, except the process is driven by man and is a quicker process. (1)

2.4 The final product of artificial selection is the adaptation of populations of organisms to their environment. (1)

2.5 All hybrids are infertile. (1)

2.6 Artificial selection has been used by humans to speed up evolution. (1)

(24)

Mechanisms for reproductive isolation

Reproductive isolation is the mechanism that prevents two species from mating with one another and making fertile hybrids, even when not separated by a geographic barrier. Such mechanisms are used mostly to separate species that live in the same environment.

Strategy	Description
breeding at different times of the year	Different species will have different breeding seasons or, in the case of plants, will flower at different times of the year, in order to prevent cross-pollination.
species-specific courtship behaviour	Some animals have very specific courtship behaviours that do not attract individuals of other species, even if they are closely related species. Courtship behaviour is a physical or chemical signal that an organism is ready to mate. This can include anything from being brightly coloured, to singing elaborate mating songs or mating dances, to the secretion of pheromones in order to attract a mate.
adaptation to different pollinators (plants)	Many plants and their flowers are specifically adapted for specific pollinators. Some closely related species of plants have different characteristics such as flower shape, size, colour, reward type (nectar or pollen), scent and timing of flowering all play a role in attracted certain pollinators to them. Also, cross-pollination between the different species is prevented.
infertile offspring in cross-species hybrids	Even if two species are able to physically mate and produce offspring, they will still be reproductively isolated due to the fact the most hybrid offspring are infertile.

Evolution in present times

Evolution is always happening. Most of the time it is impossible to observe changes in populations and species because evolution happens very slowly – thus the theory of gradualism. However, there are some cases (e.g.: rapidly producing organisms such as viruses and bacteria) that allow scientists to study how species change in response to environmental factors. Pathogens (viruses and bacteria) evolve quickly because there is lots of natural variation amongst them and the fact that mutations occur most often in rapidly reproducing organisms.

Resistance to antibiotics in TB

Tuberculosis (TB) is a chronic bacterial infection caused by the bacterium *Mycobacterium tuberculosis.* Unfortunately, the incidence of this disease keeps increasing in South Africa.

Treatment is commonly in the form of antibiotics; however, some of the bacteria are naturally resistant to those antibiotics (see Figure 9).

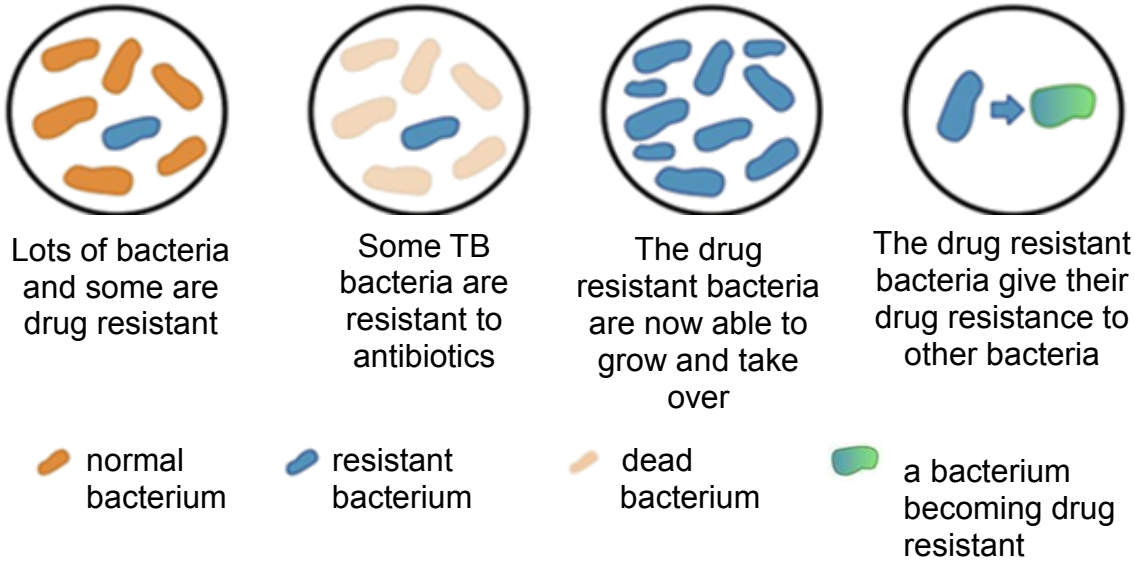


Figure 9: How antibiotic resistant happens.

TB has become more and more common in South Africa recently and this is primarily due to the fact that patients do not finish the full course of antibiotics and the naturally resistant bacteria then survive and reproduce. The patient will then develop TB again, except this time, most of the bacteria are now resistant to the previous antibiotic and so treatment will not help anymore. Patients would then have to be placed on stronger antibiotics to kill the resistant bacteria.

It became common practice to treat TB patients with multiple drugs at the same time. It was assumed that the bacteria would not develop resistance to multiple drugs at the same time. Unfortunately, this assumption was wrong. The TB bacterium became resistant to multiple drugs causing the emergence of multidrug-resistant bacteria. Multidrug-resistant bacteria now require a very aggressive treatment using five different drugs and very often patients with this type of TB do not survive.

Enrichment

Theory of evolution by natural selection:
https://www.youtube.com/watch?v=BcpB_986wyk

Natural selection: https://www.youtube.com/watch?v=7VM9YxmULuo

Natural selection – the peppered moth:
https://www.youtube.com/watch?v=Uf-mOCN7rUU

Evolution by natural selection: End of topic exercises

Section A

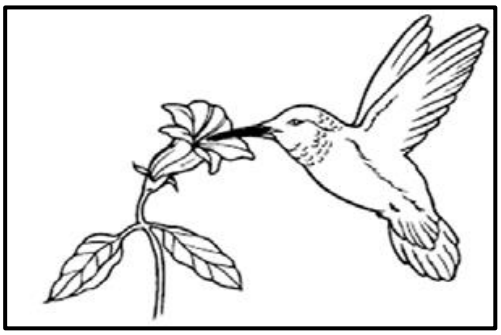
Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write the letter (A – D) next to the question number (1.1.1–1.1.5) for example 1.1.6 D.

1.1.1 The theory of evolution by natural selection was first described by …

A Gregor Mendel
B Watson and Crick
C Jean Baptiste de Lamarck
D Charles Darwin

1.1.2 The reason that Lamarck would have provided for the long beak of the hummingbird is that:



A all hummingbirds have the same beak length
B there is natural variation in beak length and some birds are therefore better suited to feed on nectar
C the more the hummingbird used its beak, the longer it grew
D hummingbirds with shorter beaks were more fit for survival

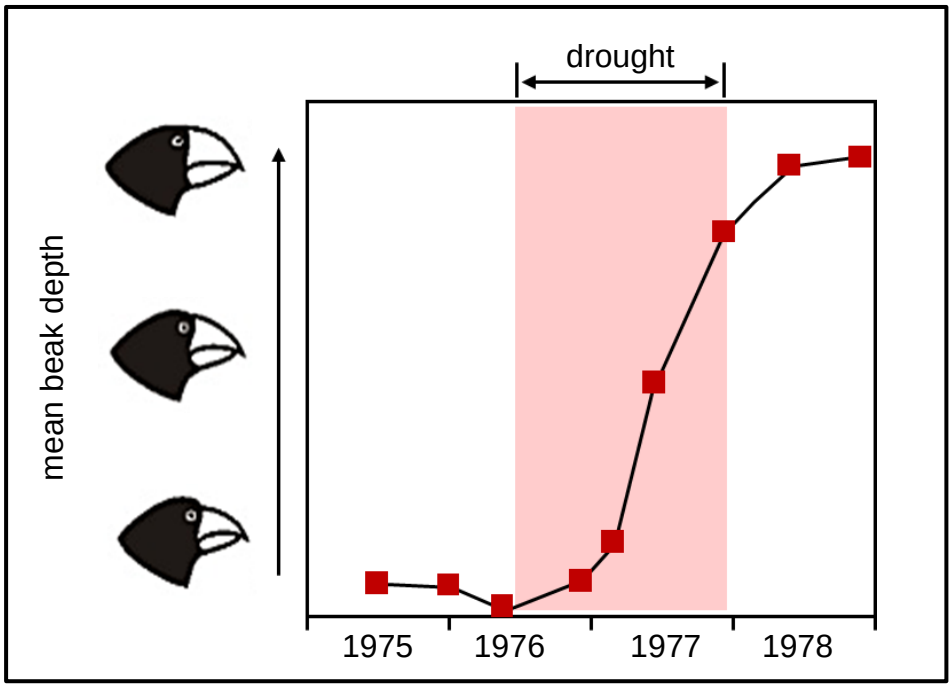
1.1.3 Lamarck's 'laws' of use and disuse and inheritance of acquired characteristics were:

A rejected, because only characteristics that benefit offspring can be inherited.
B not rejected, because evidence shows that acquired characteristics can be inherited

C rejected, because only characteristics that are coded for in the DNA can be inherited

D not rejected, because Darwin's theory supports Lamarck's

1.1.4 During an investigation, researchers measured the beak size of a certain species of finch on the Galapagos Islands. The type of food available before and after a drought was a factor in the study of the evolution of the beaks of finches.



Which factor is the dependent variable?

A the amount of rain

B the type of food available

C the beak size of finches

D the year

(4 x 2) = (8)

1.2 Give the correct biological term for each of the following descriptions. Write only the term next to the question number.

1.2.1 The permanent disappearance of a species from earth.

1.2.2 A tentative explanation of a phenomenon that can be tested.

1.2.3 The distribution of species in different parts of the world.

1.2.4 Variation that results in distinct phenotypes.

1.2.5 The explanation that species experience long periods without physical change, followed by short periods of rapid physical change.

1.2.6 An explanation for something that has been observed in nature and which can be supported by facts, laws and tested hypotheses.

1.2.7 Formation of a new species when a physical barrier has divided a population.

1.2.8 The breeding of plants and animals to produce desirable characteristics.

1.2.9 The process whereby organisms better suited to their environment survive and produce more offspring.

1.2.10 A group of similar organisms which interbreed successfully with each other to produce fertile offspring.

(10 x 1) = (10)

1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY, B ONLY, BOTH A AND** B or **NONE** of the items in Column II. Write **A only, B only, both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 The selection and breeding of organisms with desirable characteristics by humans	A: natural selection B: artificial selection
1.3.2 An example of discontinuous variation in humans	A: skin colour B: height
1.3.3 Example of a reproductive isolating mechanism	A: breeding at the same time of the year B: adaptation to different pollinators
1.3.4 A group of similar organisms that can interbreed to produce fertile offspring	A: species B: genus
1.3.5 Desired characteristics are passed on from parent to offspring	A: artificial selection B: natural selection

(5 x 2) = (10)

1.4 Since 1972, biologists Peter and Rosemary Grant from Princeton University in the USA have studied finch populations in the Galapagos. The table below shows their data collected on one island (Daphne Major), for a period of 7 years. They studied one finch population on Daphne Major.

Year	1974	1975	1976	1977	1978	1979	1980
rainfall (mm)	-	-	130	20	130	70	50
number of finches	1100	1300	1100	200	350	300	250
small seeds (mg/m^2)	-	800	600	90	300	70	50

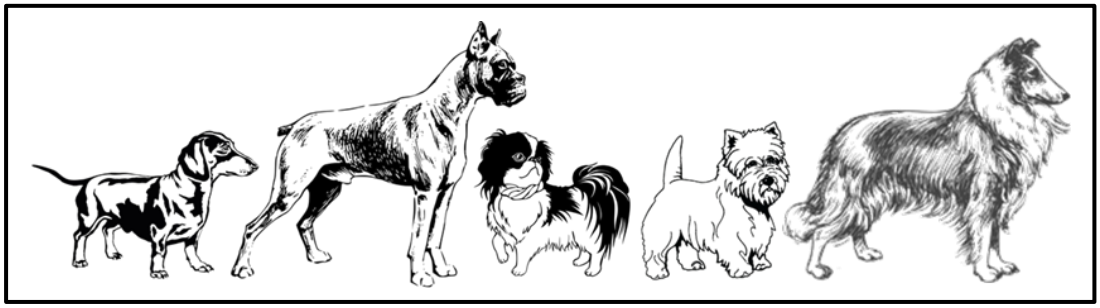
1.4.1 In which year were the largest drop in rainfall, number of seeds and number of finches recorded? (1)

1.4.2 Explain how the three events mentioned in question 1.4.1 are related to each other. (3)

1.4.3 When the number of finches decreased, there were still plenty of large seeds on the island. What does this tell you about the seed-eating habits of the finches that died? (1)

(5)

1.5 Many dog breeds exist today as shown in the diagram below.



(a) Explain why all breeds of domestic dogs belong to the same species. (2)

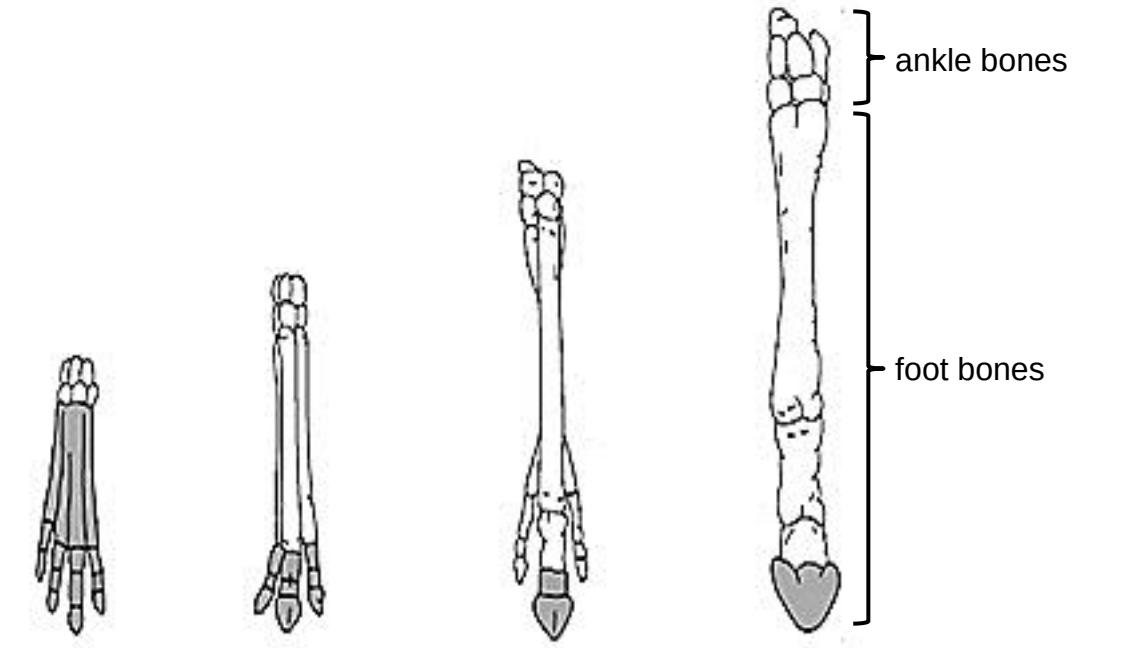
(b) Describe how artificial selection has led to different breeds of domestic dogs. (3)

(5)

1.6 This question applies to the diagram on the next page.

The ancestor of the modern horse had very differently shaped foot bones.

Scientists believed that the structure of the foot bones evolved as the environment changed from swampy areas with soft mud to drier and harder soil. This allowed the animals to move effectively in each habitat.



Key: the shaded bones are the ones that touched the ground

1.6.1 Describe two changes to the bones that have taken place over the past 50 million years. (2)

1.6.2 Eohippus lived in swampy areas with soft mud. Explain one advantage to Eohippus of the arrangement of bones in its feet. (2)

1.6.3 The changes in the arrangement of the foot bones of horses support Darwin's theory of evolution by natural selection. Explain how the arrangement of the foot bones of Eohippus could have evolved into the arrangement of the foot bones of Equus. (6)

(10)

Section A: [48]

Section B

Question 2

2.1 An investigation was conducted by a scientist to determine if two plant populations, Population 1 and Population 2, belonged to the same species. The scientist collected seeds from each of the populations.

The procedure followed was:

- He planted 20 seeds from Population 1 and 20 seeds from Population 2 in two separate plots close to each other.
- The stamens of all the flowers of Population 1 were removed.
- Pollen from the flowers of Population 2 was used to pollinate the flowers of Population 1.
- The scientist harvested the seeds of the plants in Population 1.
- He grew these seeds under ideal conditions in a laboratory.

Result: None of the seeds germinated.

2.1.1 Explain the advantage of removing the stamens from the flowers of Population 1. (2)

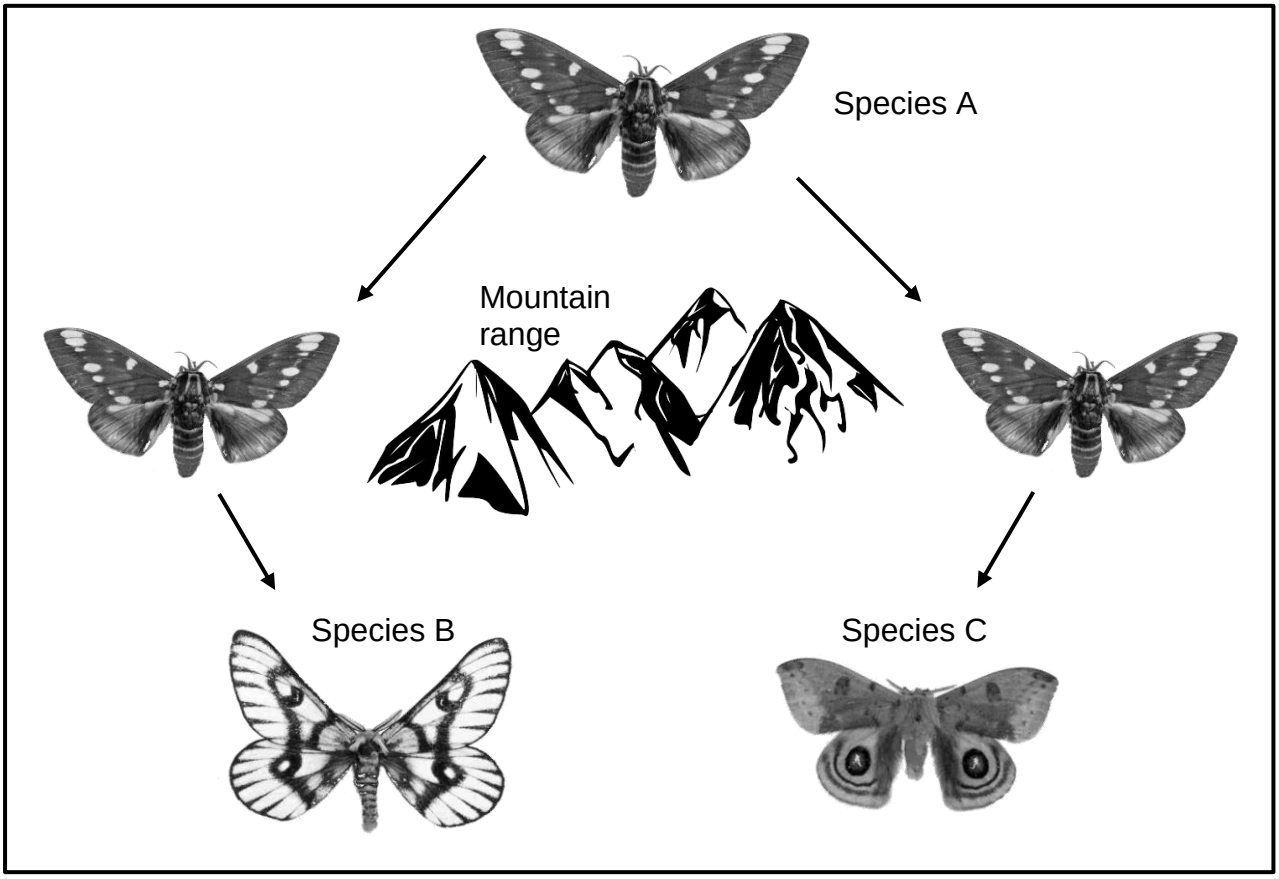
2.1.2 What evidence indicates that the two populations do not belong to the same species? (1)

2.1.3 State two factors that the scientist would have kept constant in the laboratory. (2)

2.1.4 State one way in which the scientist could have increased the reliability of his results. (1)

(6)

2.2 Study the diagram below of the moth species that originally belonged to a single population but was later separated by a mountain into two groups.



2.2.1 Name the process which is illustrated in the diagram above. (1)

2.2.2 Explain the importance of the process you identified in question 2.2.1 above. (2)

2.2.3 Why is species A the ancestor of species B and C? (2)

2.2.4 Explain the above illustrated process in relation to the three species indicated in the diagram. (6)

(11)

2.3 Tabulate two differences between natural selection and artificial selection. (3)

2.4 Study the extract below which describes the evolution of the snake.

> How snakes lost their limbs has long been a mystery to scientists: New research on a 90-million-year-old snake fossil suggests that snakes evolved to live and hunt in burrows as many snakes still do today.
>
> It is generally accepted that snakes and lizards are closely related, although very few transitional fossils have been found to support this generalisation.
>
> (adapted from https://www.ed.ac.uk/news/2015/snakes-271115)

a) Explain one characteristic that you would expect a transitional snake fossil to have. (1)

b) Describe how would Jean Baptiste de Lamarck have explained the loss of limbs in snakes? (4)

(5)

[25]

Question 3

3.1 Lizards of a certain species on an island are usually brown in colour. A mutation in one gene for body colour results in red or black lizards. Black lizards camouflage well against the dark rocks and warm up faster on cold days which will give them energy to avoid predators.

Scientists investigated the relationship between the colour of lizards in a population and their survival rate on an island.

They conducted the investigation as follows:

- They selected a group of lizards of a certain species in a habitat.
- They recorded the percentage of each colour (brown, red or black) in the selected group.
- They repeated the investigation over a period of 30 generations of offspring.

The results of the investigation are shown in the table below.

Colour of lizards	Percentage (%) of each colour In the population			
	Initial population	10th generation	20th generation	30th generation
Brown	80	80	70	40
Red	10	0	0	0
Black	10	20	30	60

(adapted from https//hhmi.org/bioInteractive)

3.1.1 State the:

a) independent variable (1)

b) dependent variable (1)

3.1.2 Explain the effect of the mutation on the survival of red lizards. (2)

3.1.3 Explain why the scientists had to conduct this investigation over 30 generations. (2)

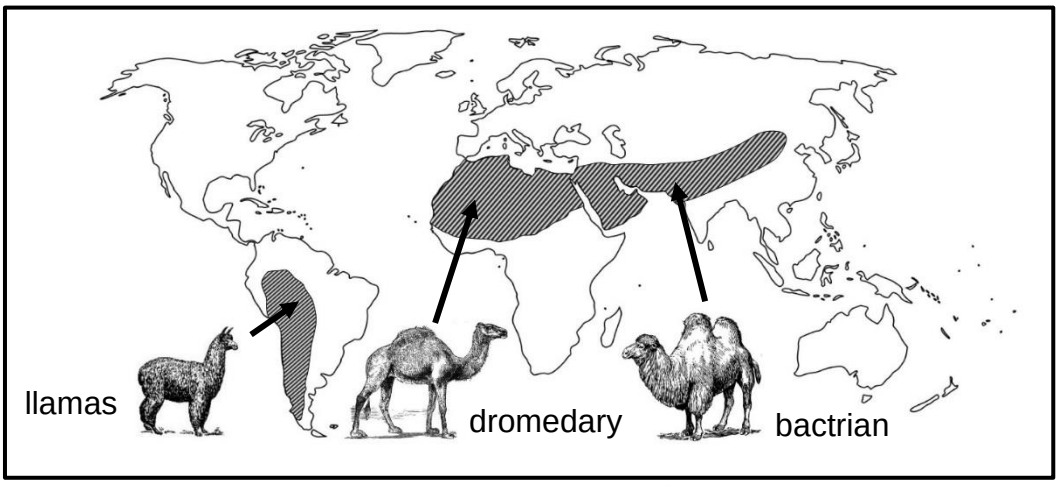
3.1.4 State two ways in which the scientists could have improved the validity of the investigation. (2)

3.1.5 Use the theory of natural selection to explain the higher percentage of black lizards in the population of the 30th generation. (6)

3.1.6 Draw a bar graph to compare the percentage of the brown and the black lizards in the initial population and the 30th generation. (6)

(20)

3.2 The diagram shows the distribution of various camels on the different continents. The arrows indicate the current distribution of the animals.



(adapted from http://www.ck12.org)

Explain how speciation of camels may have occurred. (6)

[26]

Section B: [51] - Total Marks: [99]

10: Human evolution

CHAPTER 10: HUMAN EVOLUTION

Introduction

In this chapter we consider the origins and evolutionary development of modern human beings. This includes:

- Interpretation of a phylogenetic tree to show **our place in the Animal Kingdom**
- We will look at the **characteristics that humans share with African apes**
- We also consider that which makes us, as **human beings, different from the apes / other primates.**
- Fossil, genetic and cultural **evidence that support the idea of common ancestors for living hominids**
- We explore the **'Out of Africa' hypothesis** – the scientific understanding that modern human beings (*Homo sapiens*) evolved in Africa and from there populated the rest of the world.
- We consider the **importance of the Cradle of Humankind** (and that of other fossil sites in South Africa and Africa) to an understanding of human evolution.
- Lastly, we briefly consider some **alternatives to evolution**.

Key terminology

hominids	Hominids are a biological group that includes modern humans, our early human ancestors, chimpanzees and bonobos, gorillas and orangutans, sometimes collectively referred to as apes.
hominins	Hominins are a sub-group of the hominids, and includes only modern humans and early human ancestors.
homo	This is a Latin term meaning 'human'.
Homo sapiens	*Homo sapiens* means 'wise human'. All humans living today belong to the same species of *Homo sapiens*.
primates	A biological grouping that includes lemurs, baboons, chimpanzees, apes, and humans. Primates share a number of characteristics as will be detailed shortly.
phylogenetic diagram	A branching diagram or "tree" showing the evolutionary relationships among various biological species

Our Place in the Animal Kingdom

So where exactly do scientists place us?

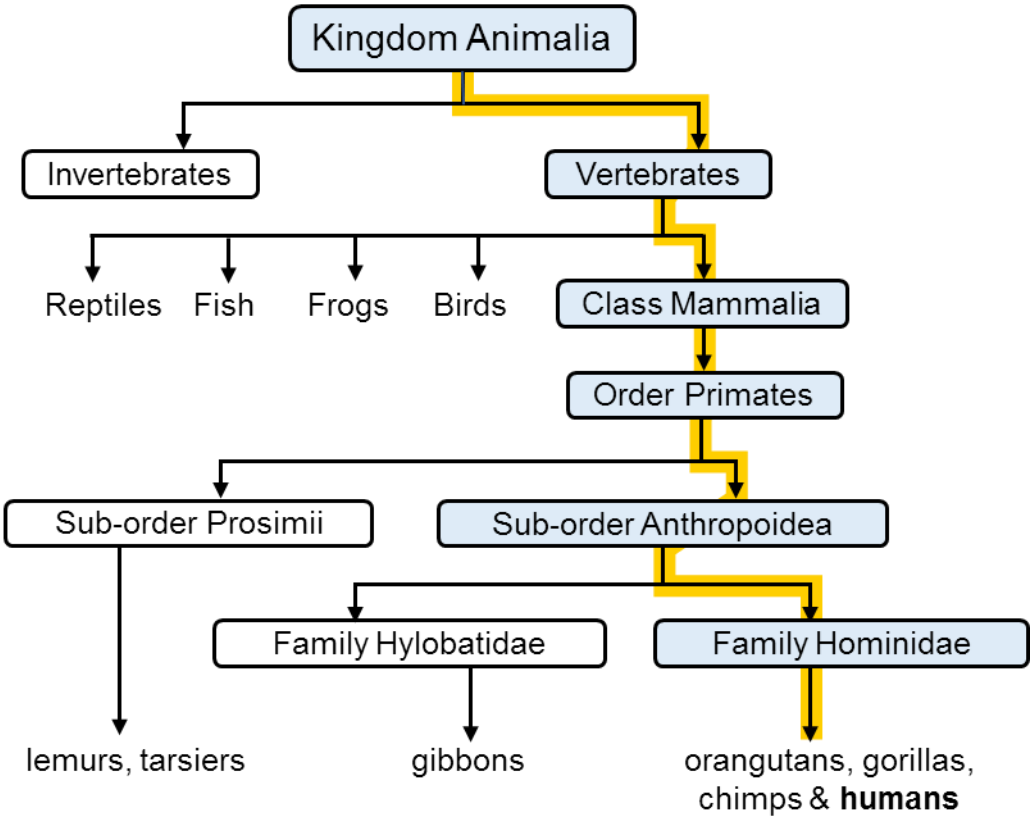


Figure 1: Evolutionary path of humans and other primates

Biological Classification

Modern humans – given the scientific name *Homo sapiens* (homo: man, sapiens: wise) – are considered part of the animal kingdom, the Kingdom Animalia (see Figure 1). Within this kingdom, the Linnaean classification is as follows:

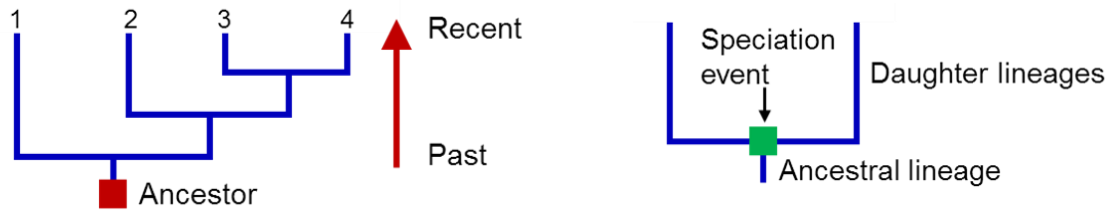
- Kingdom: *Animalia*
- Class: *Mammalia* (mammals give birth to live young and feed them on milk)
- Order: *Primates* (with opposable thumbs on a hand with five fingers, finger nails, not claws, two eyes facing forward, etc.)
- Family: *Hominidae* (humans, chimpanzees, gorillas, and orangutans)
- Genus: *Homo*
- Species: *sapiens*

Interpretation of a phylogenetic tree to show our place in the Animal Kingdom

The evolutionary relationships of ancestral species and their descendants can be illustrated using a branching **phylogenetic tree**. A phylogenetic tree indicates which ancestors gave rise to which descendants.

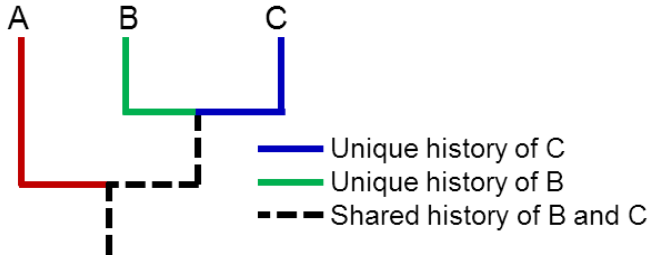
To help interpret this (and other) phylogenetic diagram, the following pointers:

- The root of the phylogenetic diagram represents the ancestor, and the tips of the branches, the descendants of that ancestor (see below, left). To move upwards is to move forward in time.



- Speciation is represented as a branching of the tree, as a single ancestral lineage gives rise to two or more daughter lines (see above, right).

- Each lineage has a part of its history that is unique and parts that are shared with other lineages, as illustrated below …



- And each lineage has ancestors that are unique to that lineage and common ancestors that are shared with other lineages (see below).

Belonging to the same **Family Hominidae** suggests that humans, chimpanzees, gorillas and orangutans share a common ancestor. Indeed, studies show that

humans share a common ancestor with chimpanzees that lived approximately 6 million years ago. This is illustrated in the phylogenetic diagram (Figure 2) below.

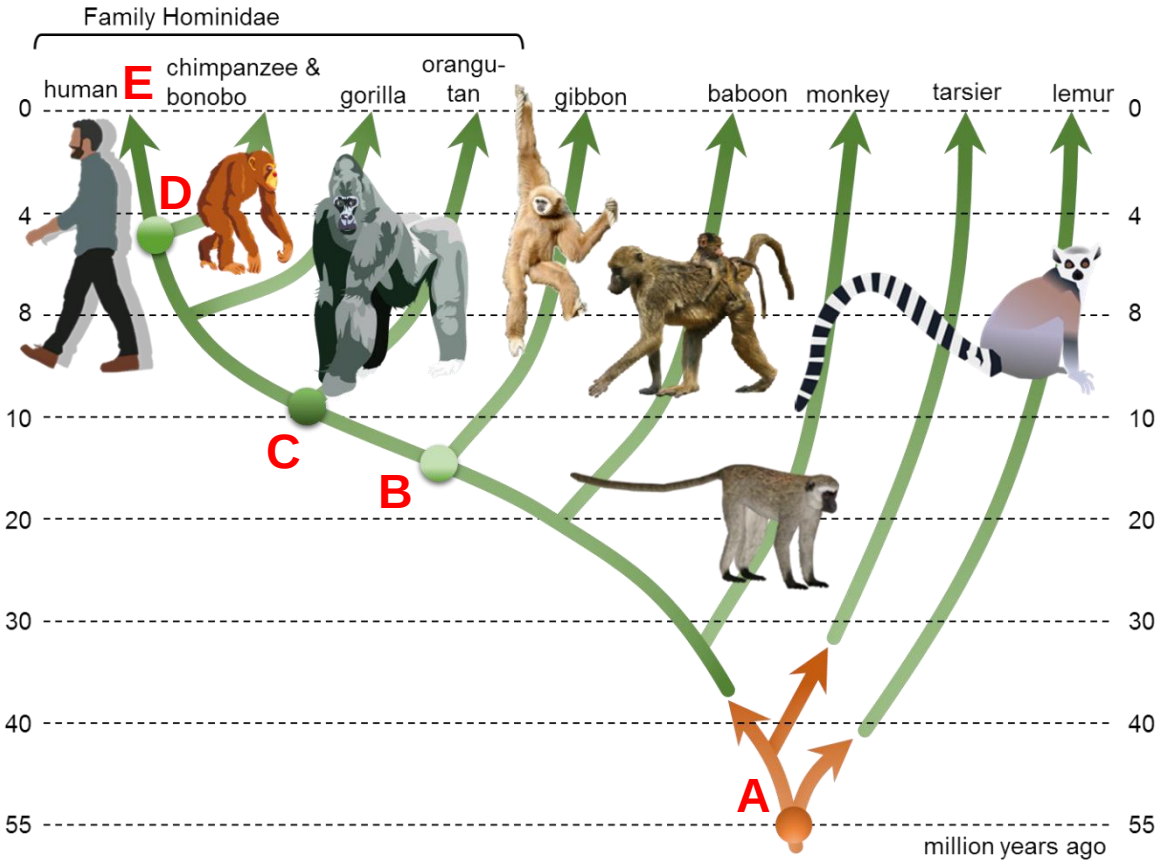


Figure 2: Phylogenetic tree for primates.

Note the place of the Family Hominidae in the tree, and the relationships between the various primates, humans included.

Study the diagram: on the left, and right, we have a time line, in million of years, beginning at 55 million years ago (in the past), and ending with the present (0 years).

It illustrates the evolution of various primates from a common ancestor (marked **A**), who lived 55 million years ago. Markers **B**, **C** and **D** point to speciation events that lead eventually, at marker **E**, to the emergence of the modern human.

- Marker **B** indicates a speciation event that led to the evolution of gibbons as a separate species from the other primates.
- Marker **C** represents the common ancestor for the Family Hominidae that includes humans, chimpanzees and bonobos, gorillas and orangutans. This common ancestor lived approximately 10 million years ago.
- Marker **D** represents the common ancestor of humans and chimpanzees. This ancestor lived approximately 5 – 6 million years ago. This indicates that of all primates, humans and chimpanzees are the most closely related.

- The line from **D** to **E** represents the unique history of humans, and we will explore that in some detail later in this chapter.
- The line from **C** backwards to **A** represents the shared history of the Family Hominidae, and from **D** backwards to shared history of humans and chimpanzees.

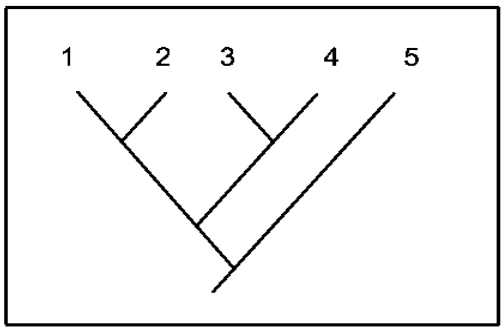
Once we have considered the major phases of hominin evolution, we will examine some phylogenetic diagrams that focus on expanding the part of the branch from D to E in the diagram above.

The phylogenetic tree shows us the place of the Family Hominidae within the Order Primates and the larger Kingdom Animalia. Our focus now will be specifically on the Family Hominidae, exploring the relationships between humans and other hominids.

Family Hominidae: https://www.youtube.com/watch?v=dUKV02uYEu0

Activity 1: Phylogenetic trees

1. To what Order and what Family do modern humans belong? (2)
2. Name two species that belong to the same Family humans belong to. (2)
3. According to the phylogenetic tree in Figure 2, when did the most recent common ancestor for humans and gorillas exist? (1)
4. Distinguish hominids from hominins. (4)
5. Study the phylogenetic tree below.



Which ONE of the following is a reasonable conclusion based on the phylogenetic tree?

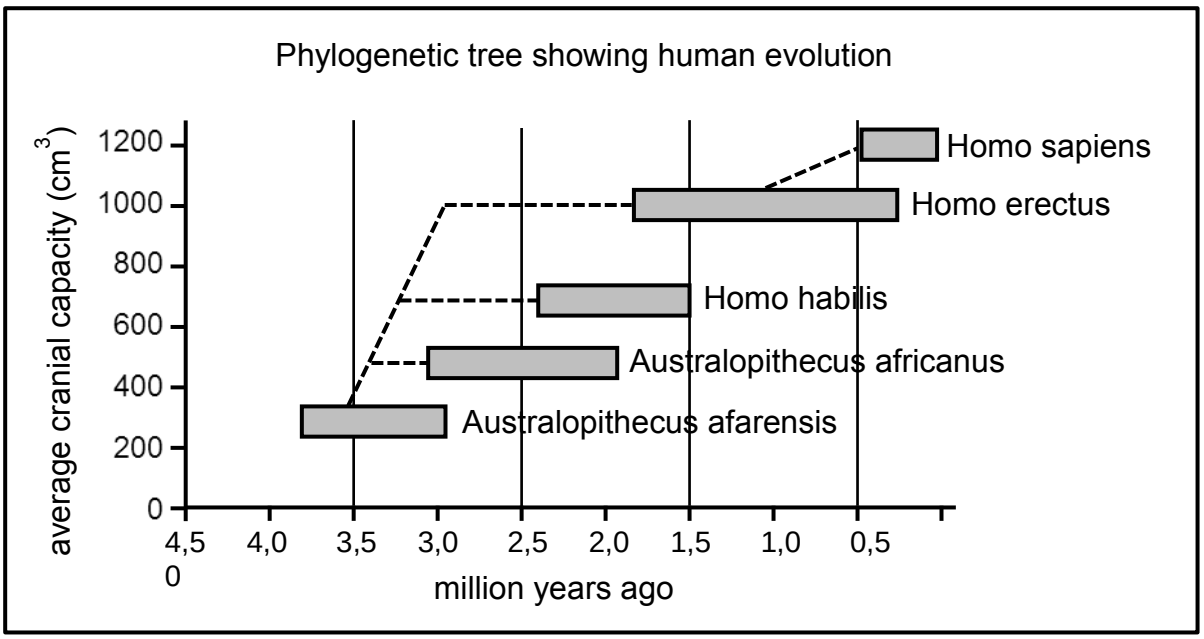
A **1** and **2** belong to the same species

B **3** is more closely related to **4** than to **5**

C **1** and **5** do not have a common ancestor

D The DNA of 1 will be more similar to **4** than to **2** (2)

6. Study the phylogenetic tree below and answer the questions that follow.



a) Define a phylogenetic tree. (2)

b) Which organism is considered to be the common ancestor of all species shown above? (1)

c) Which organism has the biggest cranial capacity? (1)

d) Name TWO species that lived between 1,5 and 2 million years ago. (2)

e) Calculate the time difference between the evolution of *Homo erectus* and *Homo sapiens*. (Show your working.) (3)

f) Which organism – *Homo erectus* or *Homo habilis* − is more closely related to modern day humans? (1)

(21)

Characteristics that humans share with African apes

To trace the evolutionary development of modern humans from an ancestor shared by all hominids, it is helpful to consider their anatomical similarities, and of course, their differences. The differences point to the existence of different species, while the similarities point to a possible common ancestor.

Key terminology

arboreal	living primarily in trees
opposable thumb	a thumb that can be placed opposite the fingers of the same hand

sexual dimorphism	distinct differences in size or appearance between the sexes of an animal in addition to the sexual organs themselves
bipedalism	ability to walk on two legs
quadrupedalism	use of four limbs for locomotion (quadrupeds)
diurnal	active during the day rather than at night.
foramen magnum	hole in the base of skull through which the spinal cord passes
cranial ridge	ridge running across the top of the skull that served to attach large jaw muscles to the head
prognathous	protruding (projecting forward) upper / lower jaw

Similarities that humans share with African Apes

Hominids (members of the Family Hominidae, including humans) share a number of characteristics. Scientists argue that these arose from their adaptation to arboreal living (life spent mostly in trees). The main similarities are given in Figure 3 below.

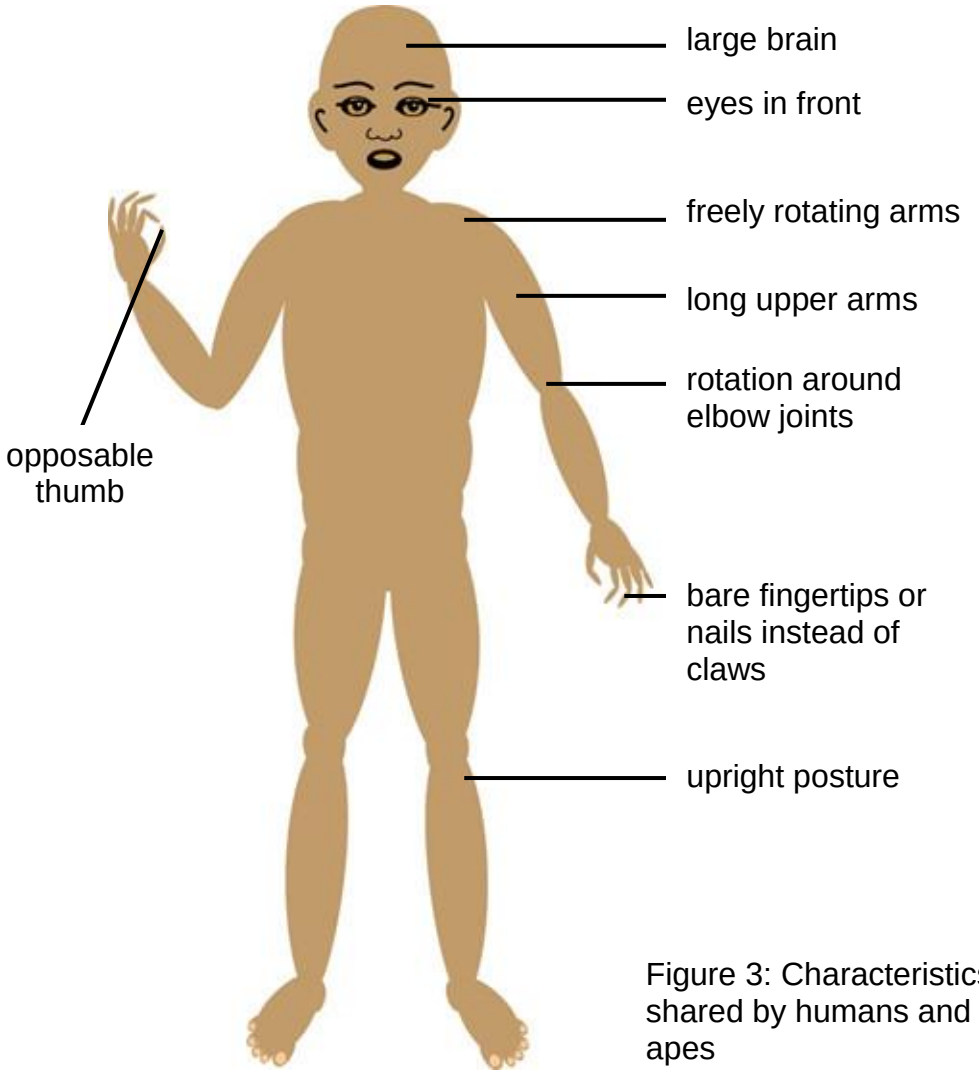


Figure 3: Characteristics shared by humans and African apes

- **Large brains**: relative to their body size, hominids have larger brains than other species in the Animal Kingdom. This allows them to process and store information.

- **Two eyes in the front of the head** (Figure 4): this provides good binocular vision as both eyes work together. The eyes have cones for colour vision that gives greater clarity.

Figure 4: the eyes of a chimpanzee in the front of the head.

- **Freely rotating arms**: arms can be lifted above the head to swing from branch to branch, or to pick fruit hanging relatively high above the ground.

- **Long upper arms / front limbs**: apes are normally quadrupeds, and this requires longer front limbs. Longer front limbs also make it easier to grasp and swing from branches.

- **Rotation around elbow joints**: this allows the limb to extend or flex to grasp and reach for objects. It also enables the flexing and rotation of the wrists.

- **Bare fingertips or nails instead of claws**: Digits (finger and toes) have soft, broad and very sensitive pads. The flat finger nails or toe nails protect these pads.

- **Opposable thumb**: the thumbs of hominids are positioned so that it can oppose other digits, enabling the hand to grip an object. See Figure 5 below.

- **Upright posture**: the back limbs of hominids are generally stronger than their front limbs, enabling them to stand erect (upright) and use their hands for grasping; standing erect also gives a better view of surroundings and exposure of genitals to attract the opposite sex (Figure 6).

- **Sexual dimorphism** (Figure 7) – this refers to differences between males and females of the same species. Humans and apes are sexually dimorphic. This is linked to competition.

Figure 5:
opposable thumb

Figure 6:
upright posture

Figure 7:
sexual dimorphism

Hominids share some other characteristics as well. They …

- **lack a tail** (that other primates – baboons, monkeys, etc. use for balancing or sometimes as an extra limb), and
- are **diurnal** – active during the day rather than at night

Note: Scientists hypothesise that humans and modern apes share a common ancestor. They do NOT believe that a chimpanzee is our direct ancestor.

Anatomical differences between African apes and humans

Many of the anatomical differences between modern humans and other apes are related to habitual bipedalism. All apes are capable of upright posture and at times walking on two feet (gibbon in Figure 8 below). Usually however, the other apes are knuckle-walkers, moving or scampering (run with quick light steps) on all four limbs.

A **B** **C**

Figure 8: Modes of walking: **A** – a chimpanzee walking on all four legs, **B** - a man walking upright on two legs and **C** - a gibbon scampering on two legs.

Advantages of bipedalism

Humans can also crawl on all fours but tend to stand erect and walk on two legs in an upright position. This is known as bipedalism. The trend in human evolution has been towards bipedalism.

Bipedalism brings with it a number of significant advantages.

- Hands are free to pick or carry food, to use tools and handle weapons
- Standing upright, with eyes higher off the ground, gives a better, wider view of surroundings, a timelier warning of approaching predators or of potential prey.
- Movement becomes easier and more energy-efficient.
- A more vertical posture reduces the body's exposure to sunlight when in an open area (60% less than for quadrupeds). It also raises a large percentage of the body away from the hot ground, where it is exposed to cooling breezes.
- In courtship behaviour, the male sex organ is readily displayed.

Anatomical differences as a result of bipedalism

- The **position of the foramen magnum** – the hole in the base of the skull where the spinal cord leaves / enters the skull – has changed position. As human evolution has progressed, Quadrupeds have the foramen magnum is in a backward position. Humans, walking upright have it in a forward position (Figure 9 below). As a result, humans have their skull balanced on top of the spinal column, hence allowing bipedalism.

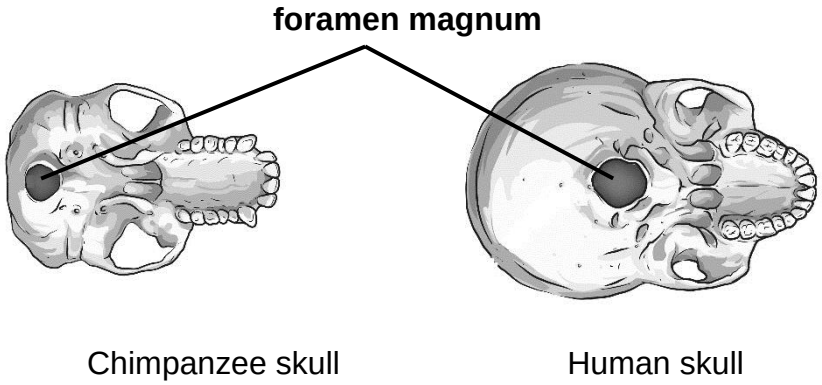


Figure 9: Position of the foramen magnum in chimpanzee and human skulls

- The **curvature (shape) of the spine** – as shown in the Figures 10A and B:

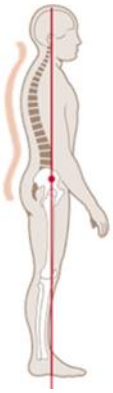


Figure 10A: the human spine is curved so the upper body (and the centre of gravity – the red line) is directly above the pelvis when standing erect – a more curved spine (S-shaped spine)

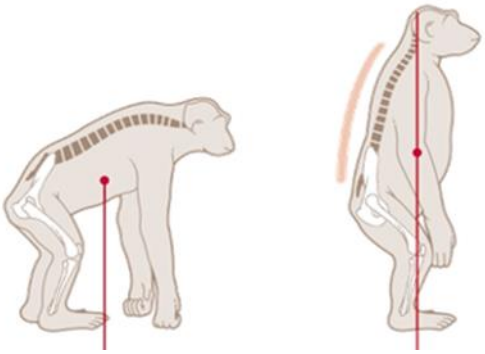


Figure 10B: The chimpanzee's spine is much less curved. As a result, when standing erect, the ape's weight pulls it forward, making an upright stance unsteady – a less curved spine (C-shaped spine)

- The **shape of the pelvic girdle** (see Figures 11 and 12 below):

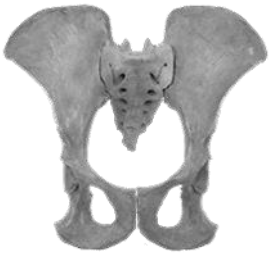


Figure 11A: a chimpanzee pelvis, long and narrow, is adapted to quadrupedal knuckle walking, providing greater rigidity.

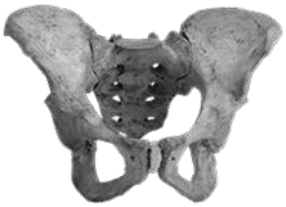


Figure 11B: The human pelvis (short and wide) is better able to support the vertically stacked human organs.

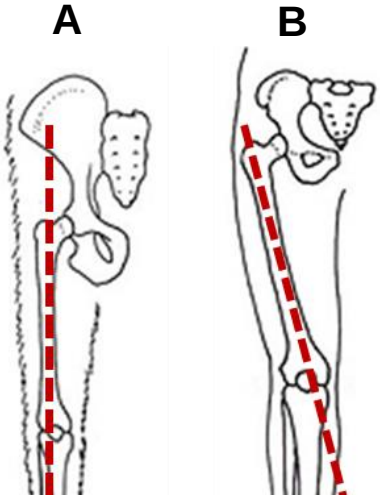


Figure 12: Hip socket and femur angle for chimpanzees (**A**) and humans (**B**). In humans, the shape of the pelvis means the femur is angled inwards for maximum load bearing. This also makes it easier to walk bipedally, placing one foot in front of the other.

Other anatomical differences include: the brain, brow ridges, jaws, teeth, palate shape and cranial ridge.

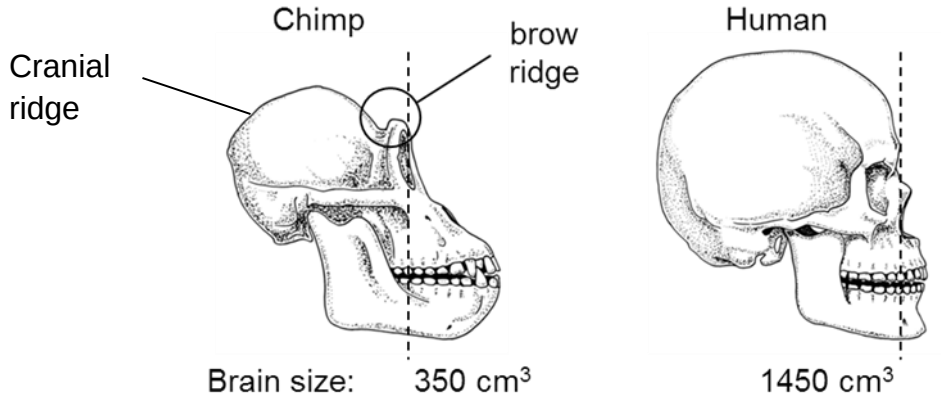


Figure 13: Anatomical differences between the skull of a chimpanzee and human

- **Brain / cranium size** (see Figure 13) – as early humans evolved, the brain grew in size and complexity. Over the course of human evolution, brain size tripled. Humans have a larger brain (cranium size) than chimpanzees (apes)

- **Brow ridges**: (as illustrated in Figure 13):
    - chimpanzees have a well-developed brow ridge above the eye socket.
    - In humans, the brow ridges are very small or non-existent. As the human cranium increased in size, the forehead flattened and became more vertical. As a result, the human brow ridge slowly became smaller and smaller.

- **Jaws, teeth and palate shape**

  As human beings evolved, their diet changed too. The mainly vegetarian diet gave way to a more varied one, including the meat of animals they caught. Once they learnt to control fire and cook their food (making it softer and easier to chew), the jaws, teeth and palate shape changed, as shown in Figure 14.

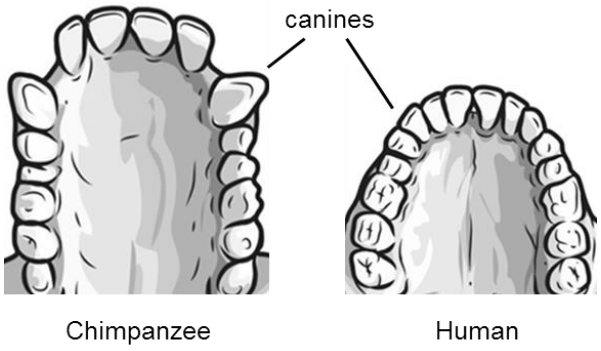


Figure 14: the palate shape and size of canines for chimpanzees and humans

- **Palate shape**:
    - a chimpanzee / ape palate is long, and rectangular
    - the human palate is smaller, almost semi-circular
- **Canines** (sometimes called ‘pointed tooth’, or eye tooth) as illustrated:
    - The canines for chimpanzees are quite large and pointed.
    - Human canines are small. Eating softer, cooked foods, the need for large canines and strong jaws to tear and chew food slowly disappeared, leading to the reduction in size we see today.
- **Jaws:** as is clear from Figure 14 above
    - the jaws of chimpanzees and apes protrude forward beyond a vertical line through the eye. We use the term prognathous to describe this. Thus, chimpanzees have more protruding jaws, they have prognathous jaws.
    - By comparison, humans have relatively small jaws that are less protruding, less prognathous.

- **Cranial ridge** – a ridge running across the top of the cranium as shown in Figure 15 below.

  A cranial ridge serves as attachment for the muscles involved with chewing. Adult animals who rely on powerful biting and the clenching of their teeth have a very large cranial ridge.

  In the evolutionary development of modern humans, with a change in diet to cooked foods that were easier to chew, their jaws became much smaller and they no longer needed large jaw muscles. And so, the cranial ridge became redundant and disappeared.

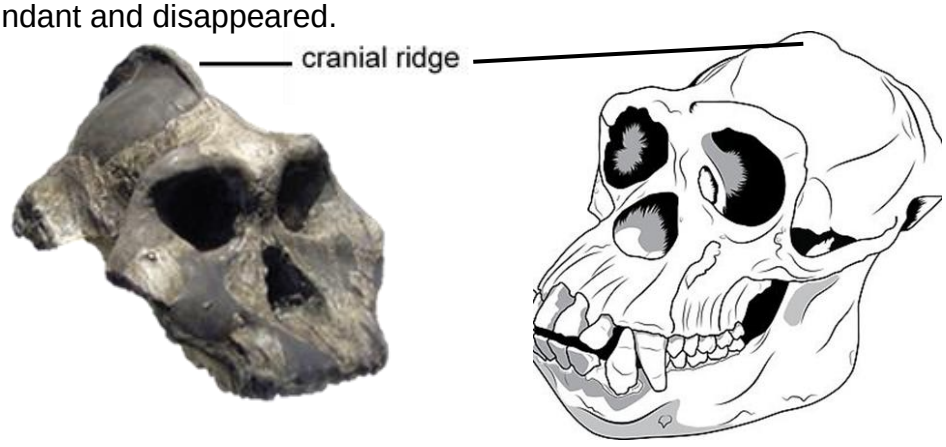


Figure 15: Cranial ridge on a *Paranthropus* skull and on a gorilla skull

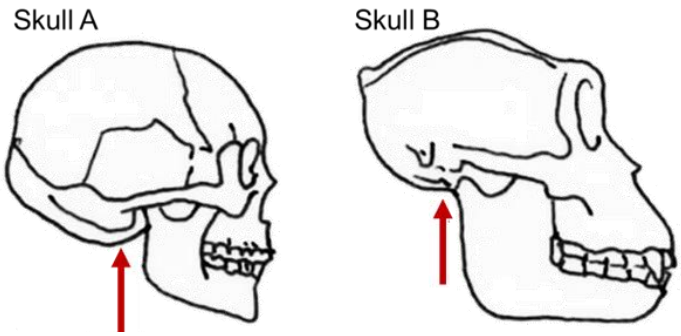
Table 1: Summary of differences between modern humans and African apes.

Feature	Humans (*Homo sapiens*)	African apes
cranium	large cranium / brain	small cranium / brain
brow ridges	not well developed	well developed, prominent
spine	more curved (S-shaped)	less curved (C-shaped)
pelvic girdle	short and wide	long and narrow
canines	small	large
arrangement of teeth	small gaps between teeth	big gaps between teeth
palate shape	small, semi-circular	long, rectangular
jaws	small, less prognathous	large, more prognathous
cranial ridges	none	across top of cranium
foramen magnum	in a forward position	in a backward position

Activity 2: Anatomical differences and similarities between African apes and modern humans

1. Name five characteristics that all hominids share, and name three differences between humans and chimpanzees. (8)
2. Explain the meaning of the term ‘opposable thumb’ in your own words. (2)
3. Explain bipedalism in your own words. Is bipedalism simply the ability to stand on two feet? (3)
4. Name four advantages of bipedalism. (4)
5. Explain the meaning of binocular vision and depth perception. (4)
6. Use a sketch to illustrate the meaning of the term ‘prognathous’. (3)
7. Draw a labelled diagram to illustrate the evolution of the palate shape and teeth from chimpanzee to modern human. The diagram should include at least three visible differences. (6)
8. The diagram shows the skulls of two different primate species.

   The arrows point to the position of a crucial part of the skull. Answer the questions below.



a) What part of the skull are the arrows pointing to in both cases? (1)

b) Which species, A or B, is more likely to be a quadruped? Explain. (3)

c) Tabulate 4 directly observable differences between the two skulls. (5)

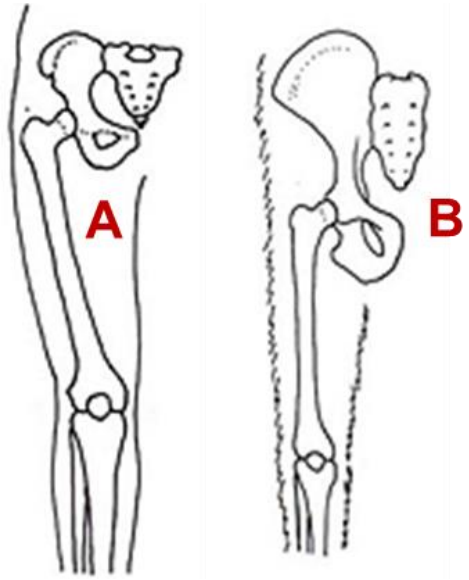
d) Explain how the change in the skulls pictured above might indicate a change in intelligence. (3)

9. The diagram below gives parts of the skeletons of a human and an ape.

a) Which letter, A or B, best represents a bipedal organism? (1)

b) Explain how the shape of the pelvis contributes to bipedalism. (2)

c) Which other characteristic shown in the diagram below contributes to bipedalism? (2)



(47)

Lines of evidence that support the idea of common ancestors for living hominids including humans

Here we focus on the progressive evolution of the above characteristics from the ape-like beings to the humans, using fossil, genetic and cultural evidence to support the idea of common ancestors for living hominids including humans. Before studying the major phases of human (hominin) evolution, some terminology, associated with human evolution must be explained first.

Fossil evidence

Key terminology

hominin	The group consisting of modern and early humans
pithecus	Greek word of 'ape'
genus	Biological classification ranking between family and species, consisting of structurally or phylogenetically related species
species	A group of organisms that are genetically similar, can interbreed and produce fertile offspring
For all entries below, the first name: *Ardipithecus*, *Australopithecus* and *Homo* refers to the genus, the second name, e.g. *ramidus*, refers to the species.	
Ardipithecus ramidus	Ardipithecus – *ardi* means 'ground', or 'floor', and *ramidus* means 'root': the name refers to the closeness of this species to the roots / origins of humanity
Australophitecus	*Australis* is the Latin for 'southern', thus southern ape.
A. afarensis	*afarensis* – from Afar, a location in Ethiopia
A. africanus	*africanus* – from Africa (thus southern ape of Africa)
A. *sediba*	*Sediba* – Sotho word, meaning 'natural spring' or 'well'
A. *robustus*	*robustus* – meaning robust, strong, sturdy, heavy set.
Homo	Latin word for human
H. *habilis*	*habilis* – meaning skilful, or handy
H. *erectus*	*erectus* – meaning erect, walking upright
H. *sapiens*	*Sapiens* – wise, thus H. sapiens the wise human (a reference to the large brain)
H. *ergaster**	*ergaster* – the Greek word for 'work', thus working man
H. *heidelbergensis** **H. *neanderthalensis****	The names of these species are derived from two towns in Europe where these species were first discovered
H. *naledi**	*naledi* – meaning star.

The major phases of hominin evolution

Human evolution was driven in part by climate change. Climate has always been variable and organisms could adapt to slow changes. More rapid changes however, with a scarcity of resources, placed enormous pressure on all organisms to adapt.

Hominins (humans) survived, and flourished, because of their ability to walk upright, their larger brain's ability to communicate, to problem-solve, and to make tools.

Here we trace the development of hominins from the genus Ardipithecus that lived about 5 million years ago, to *Homo sapiens*, the only hominin species currently living. This development is traced in Figure 16 below.

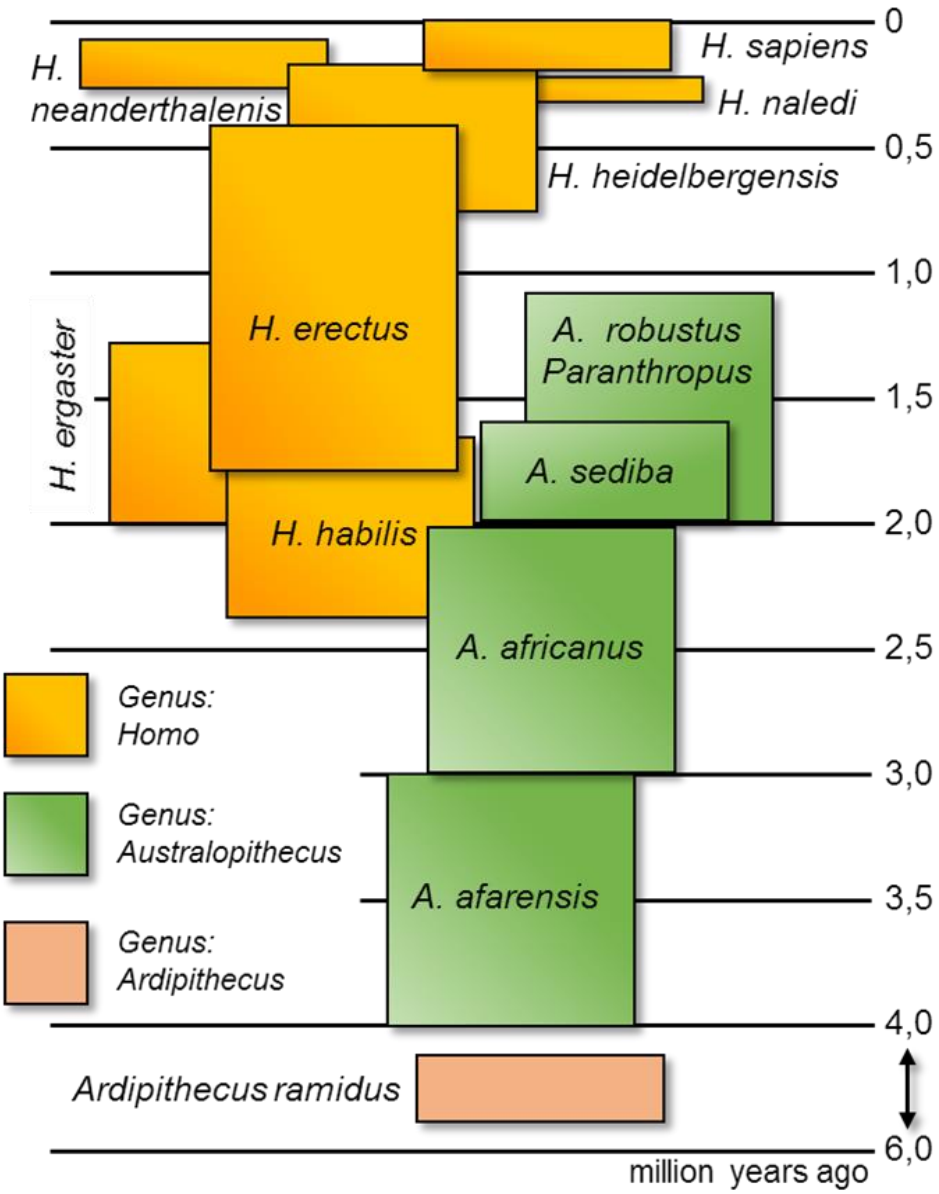


Figure 16: The evolution of modern humans – timeframes for the existence of various hominin species and genera

Understanding human evolution is complex – there is no straight and continuous line from one species to the next. We only look at a few fossil 'snapshots' that suggest the evolutionary foundations of modern humans.

Genus: *Ardipithecus* (Table 2 and 3) – the earliest hominin species (Figure 17)

- A small hominin, weighing about 50 kg; 17 fossils found; an intermediate between apes and humans

Figure 17: *Ardipithecus ramidus*

Table 2: Ardipithecus - stats

Species	When existed	Fossil site (year)	Discovered by
A. ramidus	5 – 4 mya	Ethiopia (1993)	Tim White

Table 3: *Ardipithecus ramidus* characteristics

Height	1,2 m tall, with a weight of about 50 kg
Brain size	300 – 350 mL, the same size as adult chimpanzee
Foramen magnum	a forward position
Brow ridges	large / heavy, as in Figure 17 above
Jaws	very protruding, prognathous
Canines	smaller than for chimpanzee
Pelvis	Adapted for bipedal walking and for climbing trees

Genus: *Australopithecus* (Figure 18, Table 4 and 5)

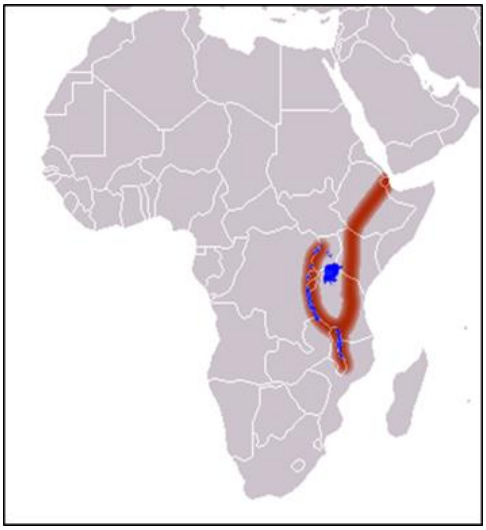


Figure 18: The Rift Valley in East Africa.

Fossils for this genus have been discovered only in Africa, specifically along the Rift Valley and in South Africa.

Australopithecines lived approximately 4 to 1,6 million years ago.

Table 4: *Australopithecus* - statistics

Species	When existed	Fossil site (year)	Discovered by
A. afarensis	3,9 – 2,8 mya	Ethiopia (1974) Kenya and Tanzania	Donald Johansen
A. africanus	3,2 – 2 mya	Taung (1924); Sterkfontein	Raymond Dart
A. sediba	2,0 – 1,6 mya	Malapa Cave (2009)	Lee Berger

Famous specimen

- *A. afarensis*:

  Lucy, discovered 1974, lived 3,2 mya – well adapted for arboreal living, but had ability to walk upright with proper bipedalism

  Laetoli footprints, discovered in 1976 by Mary Leakey – clear evidence for bipedalism (Figure 19)

Figure 19: Laetoli footprints

- *A. africanus*: (Figure 20)

  Taung child, discovered 1924 by R. Dart – not initially accepted as hominin

  Mrs Ples, lived 2 mya – discovered by Robert Broom at Sterkfontein caves

  Little Foot, lived 3,9 – 4,2 mya – a complete skeleton, found in 1997 by Ron Clarke

- *A. sediba*: (Figure 20)

  Karabo, discovered by Lee Berger – a possible ancestor to the genus *Homo*

Figure 20: Fossils of (from left to right): Taung child, Mrs Ples and Karabo

Table 5: *Australopithecus* – characteristics

	A. afarensis	***A. africanus***	***A. sediba***
Height	110 – 150 cm	110 – 135 cm	120 – 130 cm
Brain size	375 – 550 mL	420 – 620 mL	420 mL
Foramen magnum	forward position	forward position	forward position
Brow ridges	large / heavy	present, smaller than *A. afarensis*	present, smaller than *A. africanus*
Cranial ridge	none	none	none
Jaws	very prognathous	prognathous	less prognathous
Canines	large, pointed	not very long	not very long
Pelvis	intermediate – bidpedal & tree climbing	fully adapted for bipedal walking	fully adapted for bipedal walking

- ***Australopithecus robustus*** (dated 2,0 – 1,2 mya)
  Fossils from this particular species have been found only in South Africa. The classification as *Australopithecus* is uncertain, and the species, together with another similar species (*A. boisei*) from Tanzania, are now identify as of the genus *Paranthropus*.

Genus: *Homo* (2,2 mya to present) (Figure 21 and Tables 6 and 7)

- The genus *Homo* consists of the one still-living species, *Homo sapiens* – that all modern humans belong to, and between 15 – 20 extinct species, including *Homo habilis*, *Homo erectus* and *Homo naledi*.
- The most significant difference between this genus and *Australopithecus* – a much larger brain (about 30% larger)(see Figure 22 below)

Table 6: *Homo* stats (Figure 21)

Species	**When existed**	**Fossil site (year)**	**Discovered by**
Homo habilis	2,2 – 1,6 mya	Olduvai, Tanzania (1960)	Louis & Mary Leakey
Homo erectus	2 – 0,4 mya	Java, Indonesia (1891) also in SA and Kenya	Eugene Dubois
Homo sapiens	0,2 mya to present	Omo, Ethiopia (2005)	Richard Leakey

Figure 21: Fossil of (from left to right): *Homo habilis*, *Homo erectus*, and *Homo sapiens*.

Table 7: Characteristics of the three *Homo* species

	Homo habilis	*Homo erectus*	*Homo sapiens*
Height	110 – 130 cm	160 – 180 cm	160 – 180 cm
Brain size	650 mL	900 – 1000 mL	1200 – 1800 mL
Foramen magnum	forward position	forward position	forward position
Brow ridges	present, but not pronounced	distinct, but small	none (see Figure 21 above)
Cranial ridge	none	small	none
Jaws	less prognathous	less prognathous	not prognathous
Canines	small	small, short	small teeth
Pelvis	fully adapted for bipedal walking	fully adapted for bipedal walking	fully adapted for bipedal walking

Phylogenetic trees of hominin evolution

We conclude this section by a short review of another example of a phylogenetic tree

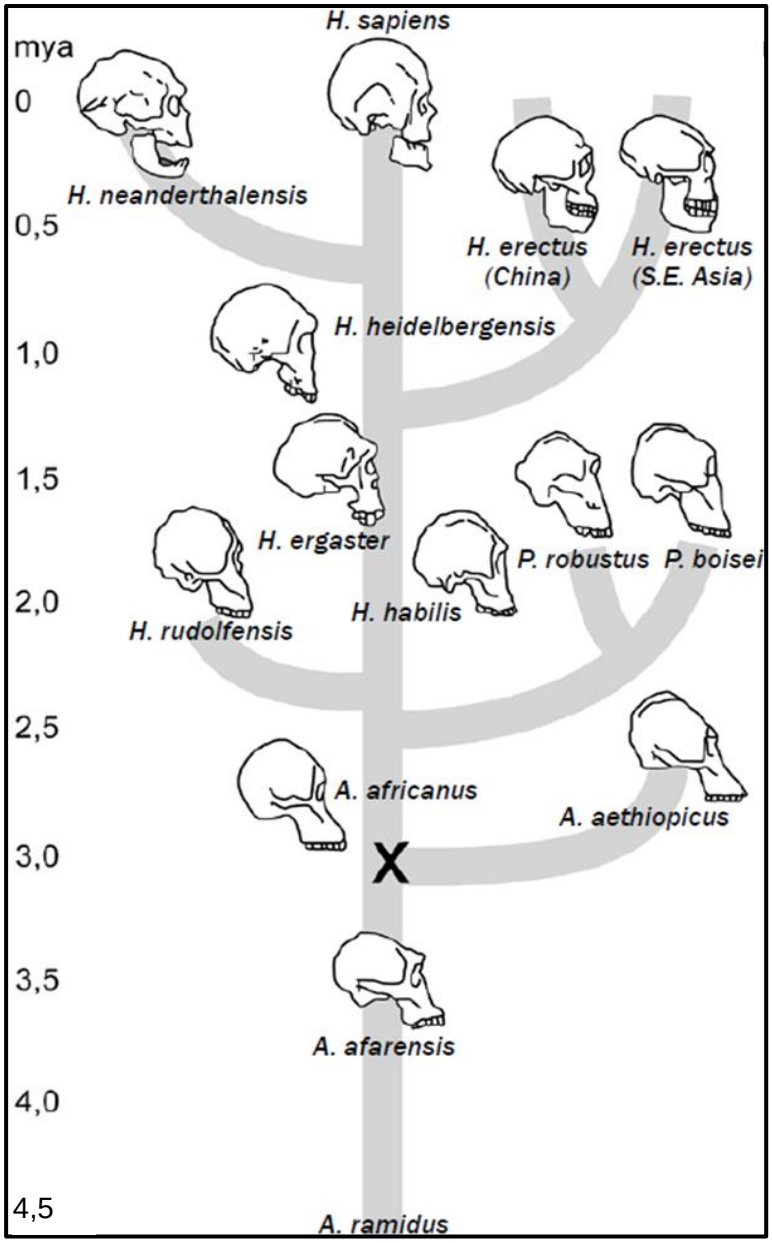


Figure 22: Phylogenetic tree of human evolution

This phylogenetic tree shows aspects of the evolution of *Homo sapiens*. It shows very clearly that a number of evolutionary branches, e.g. *H. rudolfensis, P. robustus*, etc., became extinct, and more or less when this extinction happened.

The diagram might suggest that there is a single evolutionary line of development from *Ardipithecus ramidus*, through *A. afarensis, A. africanus, H. Habilis, H. ergaster*, and *H heidelbergensis* to *H. sapiens.* However, the process of evolution leads to a branching pattern of relationships among organisms, not a linear progression.

As the late evolutionary biologist Stephen J. Gould put it, “evolution is a bush, not a ladder.”

Genetic evidence to support common ancestry for living hominids, including humans

Studies comparing the nuclear DNA shared by humans and apes reveal that:

- The genetic difference between modern-day humans is very small. There is on average only a 0,1% difference – they share 99,9% of the same genes.
- Between humans and apes there is a slightly larger genetic difference, but they still share the large majority of their genes: between 96,9 and 98,8%
- Studies show that, of the African apes, the chimpanzee is the closest relative of humans. Chimps and humans share 98,8% of the same genes – there is a 1,2% difference (10 – 12 times larger than the difference between humans).

The analysis of mitochondrial DNA (mtDNA) and the differences that exist between the mtDNA of two different species enables scientist to determine how long ago the species separated. Based on such analysis, the following relationship diagram may be drawn (see Figure 23 below)

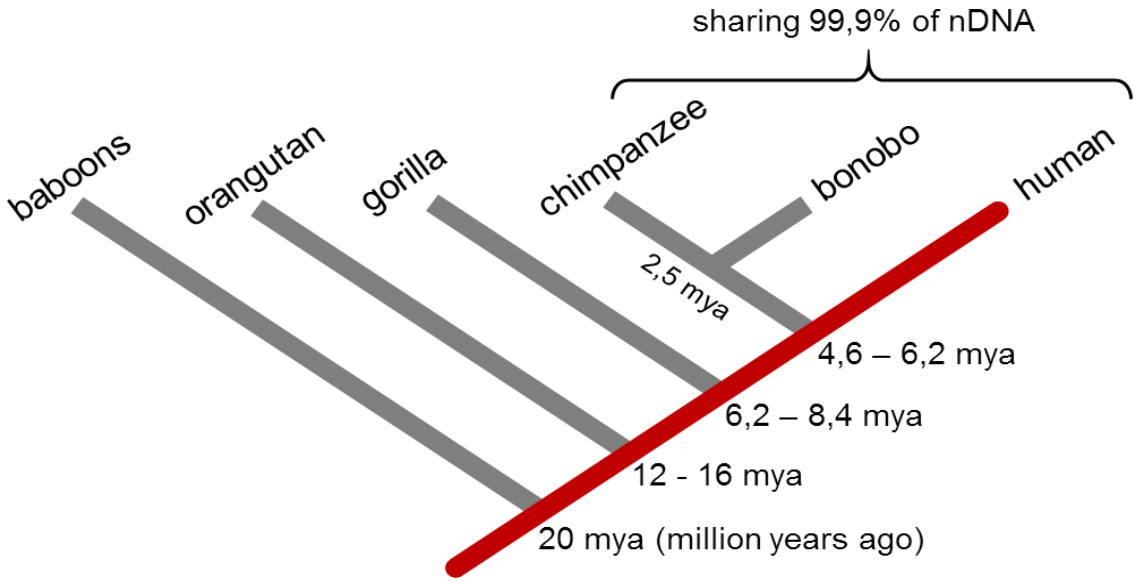


Figure 23: Diagram of relationships based on mtDNA comparisons

The study of genetics has proved invaluable in gaining a better understanding of human evolution and of the origins of hominids. Given the amount of genetic material shared between humans and other hominids (the apes), they must have had a common ape-like ancestor who lived approximately 5 – 6 million years ago.

Cultural evidence

A very important aspect of human evolution, separating humans from other hominids, is the development and use of tools.

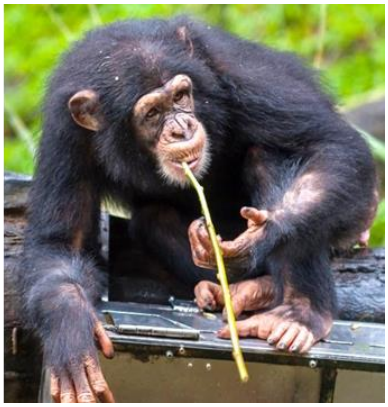


Figure 24: A monkey using a stone to crack a nut; chimpanzee using a stick to get at fruit in a box

The use of tools is not exclusive to humans, as illustrated in the images above. (see Figure 24). Chimpanzees have been observed in the wild using simple tools, e.g. using a piece of grass or a stick to fish for termites or, using a stone to crack open nuts.

The **manufacturing** of tools is unique to humans – belonging to the genus *Homo*. The type of tool, and the gradual development of more sophisticated tools, is illustrated in the diagram below (Figure 25).

- **Oldowan tools** (from Olduvai Gorge where these tools were first found).

  These are the earliest tools, from about 2,6 mya (million years ago), and are associated with *Homo habilis*. They consisted of sharp flakes chipped off a larger core – probably not sharp enough yet to cut raw meat.

- **Hand axe**: These tools appear around 1,7 mya, and have been found at sites in Kenya and South Africa. They are mostly associated with *Homo erectus.*

- **Flakes**: About 250 000 years ago, early humans began to make smaller, sharper, knife-like tools and scrapers. These tools, and all further development, is associated with *Homo sapiens*.

- About 40 – 50 000 years ago, longer **blade-like tools** appeared. About 20 000 years ago, humans began to make spears with stone (or bone) tips attached to a shaft. They also made tools with **microliths** (small stone chips) fastened to a shaft with animal sinew.

- About 5000 years ago, this stone industry came to an end, and was replaced by copper, bronze, tin and eventually iron in tool-making.

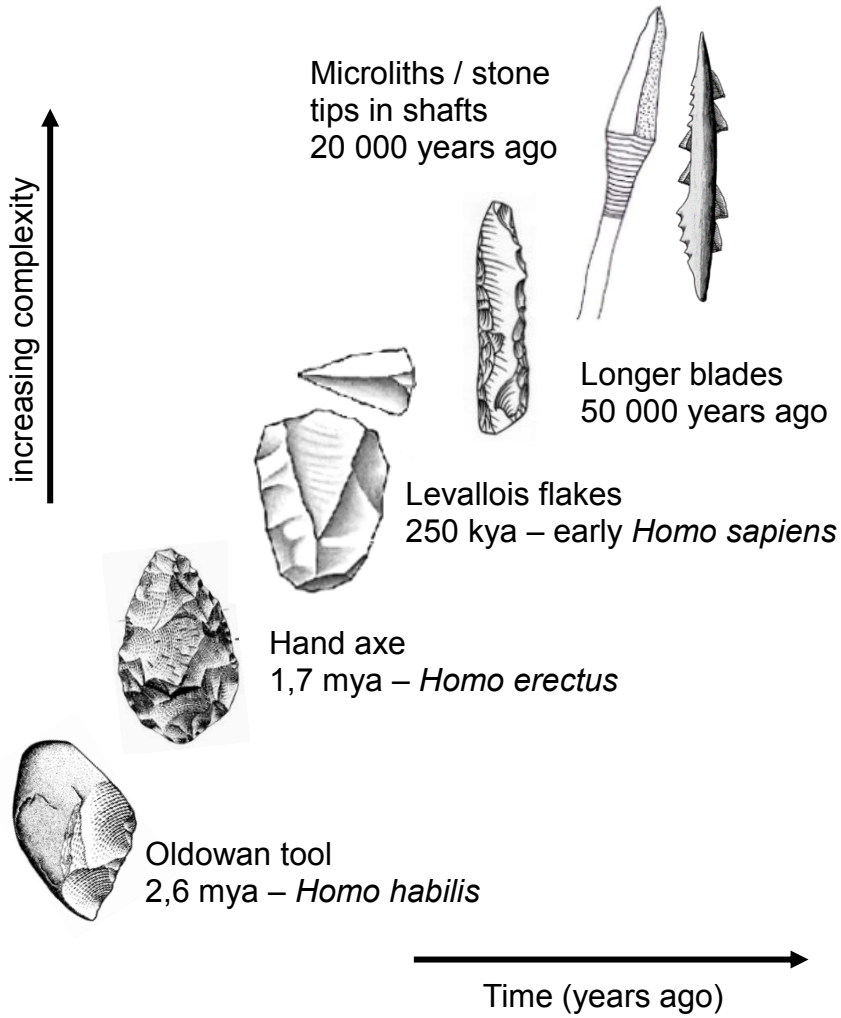


Figure 25: A brief history of early human tool making

Two other aspects of culture had a significant impact on human evolution.

- The first is the control of fire (being able to make a fire) to provide warmth, to allow for the cooking of food, and contribute to social cohesion.

- Art also contributed. The earliest known art dates from about 100 000 years ago, and the earliest cave paintings (see Figure 26 below), of which we have an abundance in South Africa, were made some 40 000 years ago.

  The purpose of art? Some speculate that art bonded individuals, sustained relationships for greater reproductive success, and was an attempt at spiritual development.

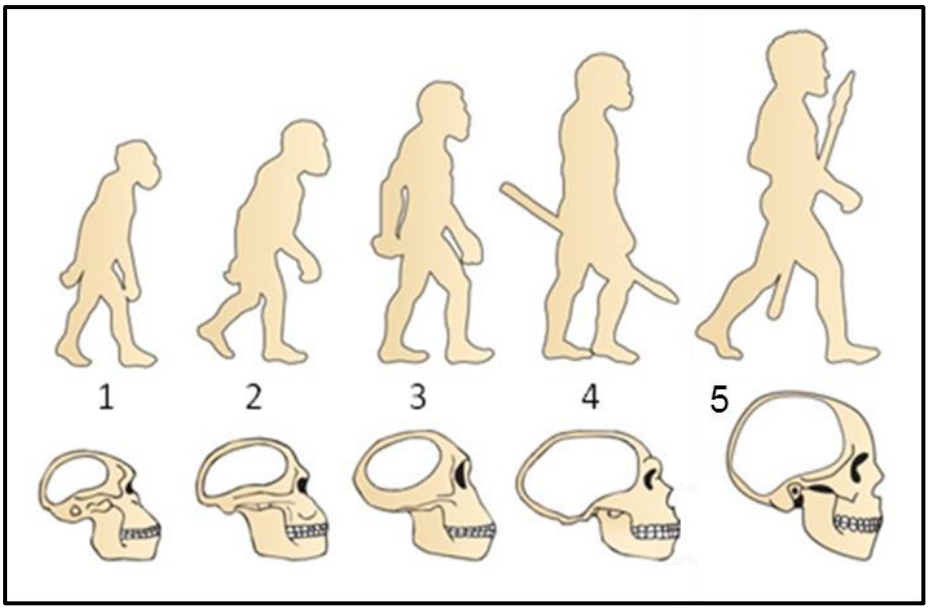
Figure 26: San / !Kung rock paintings – the eland (right) was of great spiritual significance to the San people and often featured in their rites of passage

Activity 3: Fossil evidence

1. Explain why our understanding of the sequence of human evolution based on fossil evidence might change in the future. (2)
2. The image below is of Mrs. Ples.
   a) Name three ape-like features of this skull. (3)

   b) What clues are there in the image to the brain size of Mrs. Ples. (2)
   c) Where was Mrs. Ples found, and by whom? (2)
   d) What species did Mrs. Ples belong to, and when did this species live? (2)
   e) The species Mrs. Ples belonged to is extinct. What does this mean? (1)
3. Which genus of early human lived on Earth for the longest time span? How does this relate to the time span for the other two genera considered? (3)
4. Name three Australopithecine species that lived. For each species, give the timeframe in which they lived, an example / specimen of the species, and where, when and by whom the specimen were found. (12)
5. If asked to decide whether a complete skull with jaw-bones was that of *Ardipithecus* or *Australopithecus*, what four features would you examine? (8)

6. Study the skulls shown in the image below.



a) Identify the species represented. Species include: *H. habilis*, *A. afarensis, A. robustus, H. sapiens, H. erectus.* (5)

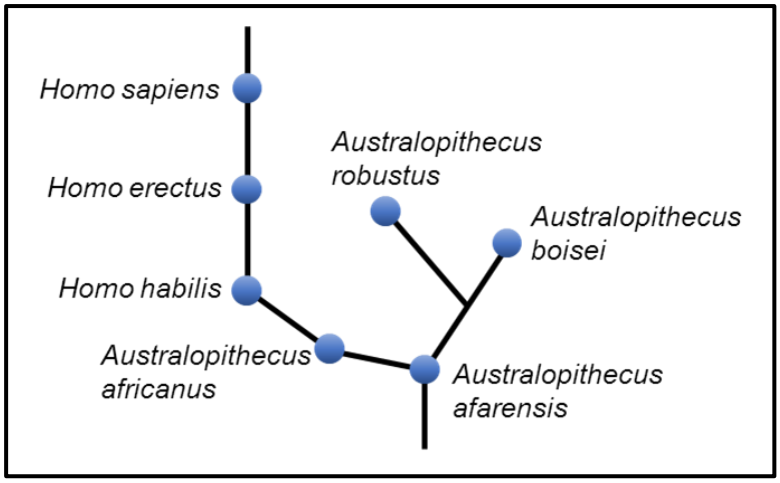
b) List four characteristics of the skull and brain size that you used to make your selection. (4)

7. Draw a line graph to show the development of brain size from *Ardipithecus* through to *Homo sapiens*. Use the following data.

Species	Time frame (mya)	Brain size (mL)
Ardipithecus ramidus	5	350
Australopithecus afarensis	3,4	460
A. afarensis	2,6	520
A. sediba	1,9	420
Homo habilis	2	650
H. erectus	1,2	950
H. sapiens	0,2	1500

What conclusion/s can you draw from the graph? (8)

8. The diagram below shows possible relationships between members of the family Hominidae. Study the diagram, then answer the questions that follow.



a) What is the name given to this type of diagram? (1)

b) How many genera, and how many species, are represented? (2)

c) Explain why *A. robustus* and *A. boisei* are more closely related than *A. boisei* and *A. afarensis*. (2)

(57)

‘Out of Africa’ hypothesis

The ‘**Out of Africa’** hypothesis states that all modern humans originated in Africa, and then migrated out of Africa to the rest of the world.

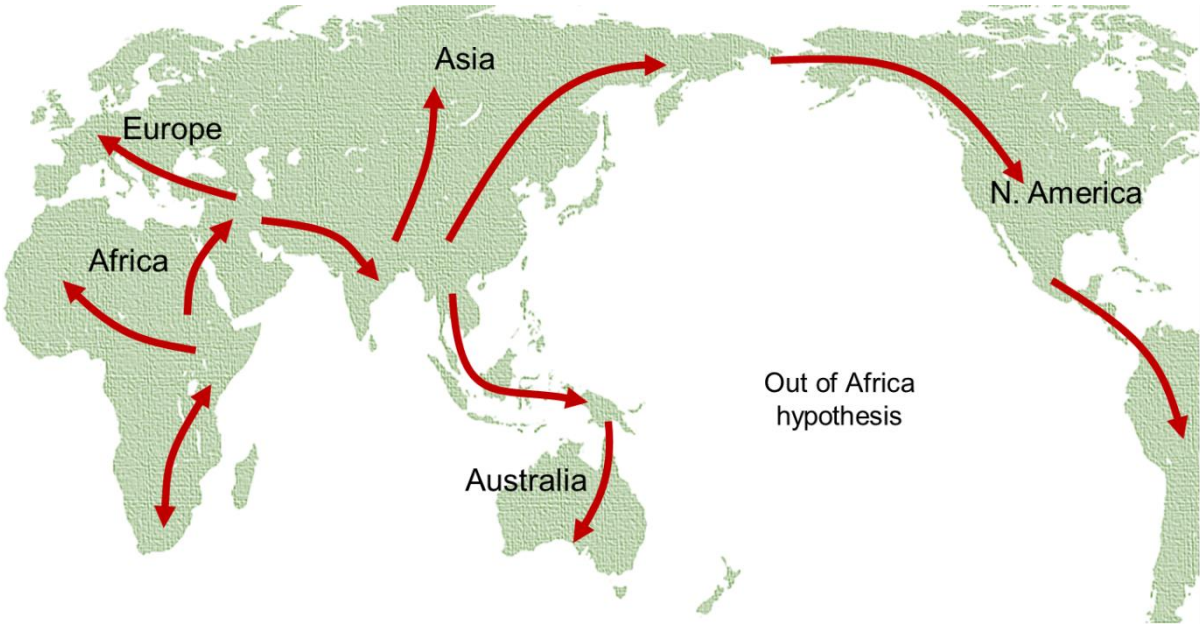


Figure 27: Migration out of Africa into the rest of the world.

- Approximately 150 – 200 000 years ago, ancestors of *Homo sapiens* (such as *Homo erectus*) evolved into *Homo sapiens* in eastern and southern Africa.
- About 70 000 years ago, these modern humans spread out, into Europe, Asia and across the world as illustrated in the map above (Figure 27).

Out of Africa hypothesis is supported by:

- genetic evidence
- the fossil record

Genetic evidence (mitochondrial DNA studies)

Using our current understanding of DNA, its structures and properties, scientists have analysed human DNA to explore the relationships between humans across the world.

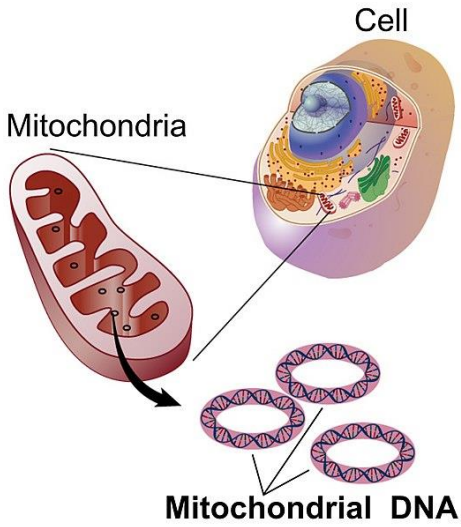


Figure 28: Mitochondrial DNA found inside mitochondria within a cell

Geneticists use mitochondrial DNA (mtDNA – Figure 28) to study human origins and migrations since mtDNA is passed unchanged from mother to offspring. However, during a person's life, ***mutations*** (changes) to the mtDNA do occur.

Scientists can determine the rate at which such mutations (or markers) take place, and can then use them as a type of molecular clock to determine the age of a particular maternal mtDNA lineage. From the studies, we can conclude:

- African populations of *Homo sapiens* have the greatest number of mtDNA markers and are thus the oldest.
- The most recent common ancestor whose genetic marker is found in all living humans, must have lived in eastern Africa approximately 150 000 years ago.

Based on markers in non-African populations, scientists believe that modern humans moved out of Africa about 60 – 70 000 years ago. It would have been an ideal time.

Due to an ice age, the sea levels on the Red Sea would have been quite low, allowing *Homo sapiens* to cross first into the Middle East, then to Eurasia, Europe and Australia, and about 20 000 years ago into North America.

The fossil record

The fossil record uncovered in Africa thus far points unambiguously to the fact that modern humans originated and evolved in eastern and southern Africa.

Before examining this record in some detail, studying the major phases of hominid evolution, we take a look at the main lines of evidence that emerge from that fossil record. Based on the fossil record, we can state that …

- Fossils from the earliest hominin species, *Ardipithecines* and A*ustralopithecines,* have been ***found only in Africa*** and not anywhere else.
- Fossils for the earliest species of the genus *Homo*, *Homo habilis*, have also ***only been found in Africa***.
- Fossil evidence for *Homo erectus* indicates this species lived in eastern and southern Africa between 1,9 – 1,4 million years ago. The earliest finds in **Africa** are the **oldest fossils** of *Homo erectus* discovered anywhere in the world.
- Finally, ***Homo sapiens* emerged in Africa**. The oldest *Homo sapiens* fossils were discovered in 2005 near Ethiopia's Omo River and are dated to between 195 000 and 160 000 years ago.

Fossil sites in South Africa

There are many different fossil Hominid sites found in South Africa; but we will only focus on the Cradle of Humankind.

- The Cradle of humankind includes different sites (see Figure 29 below). These sites have yielded more hominin fossils than any other site.
- The Cradle of Humankind is situated in Gauteng Province, north-west of Johannesburg which includes 15 different sites

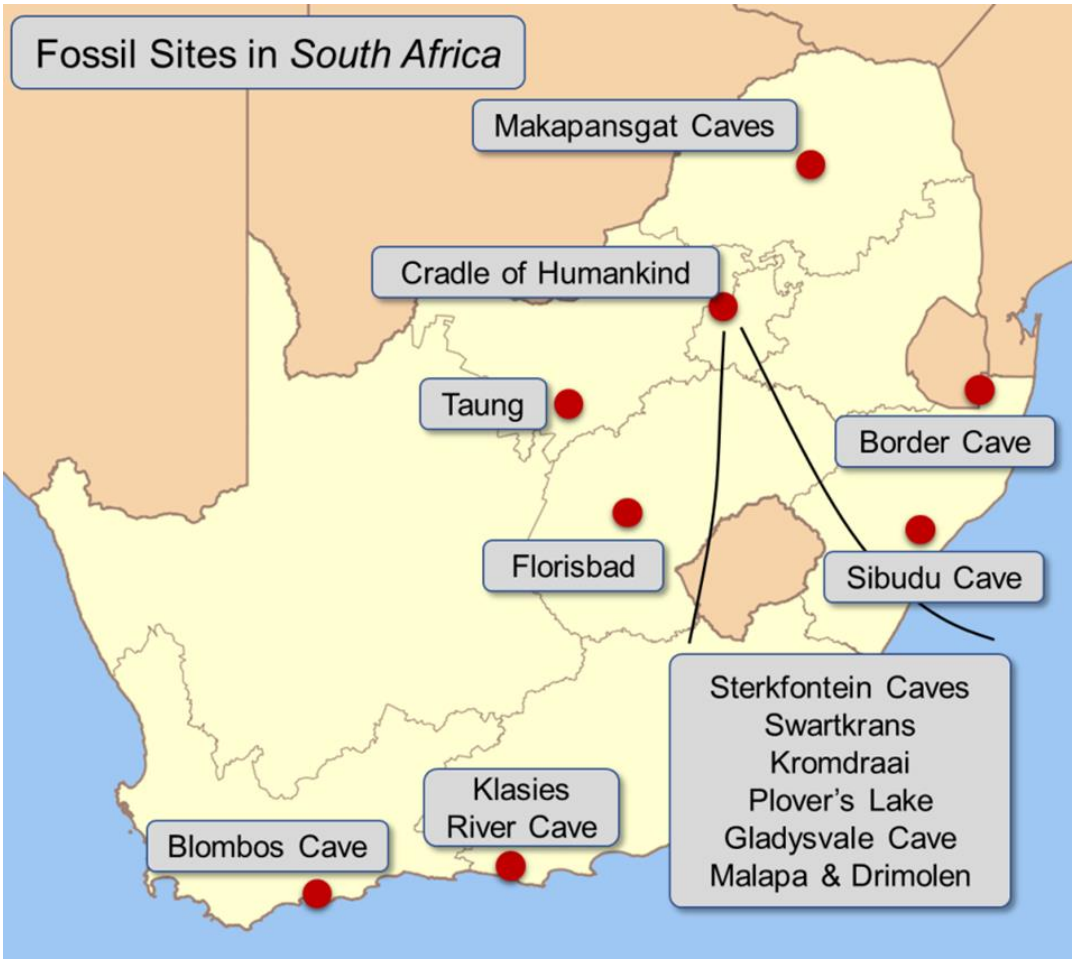


Figure 29: Important fossil sites in South Africa

The discussion will only focus on 5 of the 15 sites:

1. **Sterkfontein** caves: First hominin discovery in 1936, and since then, about 500 hominin fossils have been found there. This represents almost 40% of all hominin fossils found world-wide. Famous fossils:

    - In 1947, Robert Broom (Figure 30) discovered **Mrs Ples**, the most complete skull of the species *Australopithecus africanus*.

    - In 1997, Ron Clarke (Figure 30), working with Stephen Motsumi and Nkwane Molefe, discovered **Little Foot**, about 4,2 – 3,9 million years old – the oldest fossil remains from the Cradle of Humankind.

    - In 2013, Lee Berger and his team excavated about 1550 fossils (at least 15 individuals) of ***Homo naledi***, a species of hominin not known previously.

Figure 30: Eminent SA palaeontologists (from left to right) – Raymond Dart, Robert Broom, Ron Clarke.

2. **Swartkrans** – largest sample of *Paranthropus robustus* fossils anywhere, with numerous *homo* fossils as well. The oldest fossils date from 2,1 – 1,9 mya.
3. **Kromdraai** – in 1938, the first discovery of *Paranthropus robustus*, identified by Robert Broom. 29 hominin specimen, dated 2 – 1,8 mya have been found there, with stone tools from around 1 mya.
4. **Malapa** – Karabo (*Homo sediba*), dated 2 mya – a transitional species linking *A. afarensis* and the earliest form of the genus *Homo*.
5. **Other sites**: Drimolen, Plover's Lake, and Gladysvale.

The importance of the Cradle of Humankind

The Cradle of Humankind is a world's heritage site for these reasons:

- ***Australopithecus africanus***
  - The first adult skull was found at Sterkfontein in 1936. A virtually complete skeleton (Little Foot) was found there in 1997.
  - The fossils found at Sterkfontein are spread over a longer timeframe than elsewhere (1 million years from 3 – 2 million years ago). The species is only found in South Africa.
  - It is an early ancestor of the genus *Homo*.

- ***Paranthropus robustus***
  - Found at Kromdraai in 1938, and subsequently at Swartkrans. This species has only been found in South Africa.
  - *Lived* in the same time period as *Homo habilis*, and fossils of these two species have been found together at the Cradle of humankind. Could this point to a speciation event occurring at the Cradle of Humankind?

- ***Homo erectus***
    - The first fossils were found by Robert Broom at Swartkrans. At Sterkfontein, there is the first and only association of the *Homo erectus* with early stone tools such as the hand axe.

Other South African sites

- **Taung** (North-West Province): Taung child discovered here. It was the first ever specimen of *Australopithecus africanus*, and suggested that hominin originated not in Asia, as previously thought, but in Africa.

- **Makapansgat Valley** (near Mokopane, Limpopo Province): Research at Makapansgat was initiated by Raymond Dart in 1947.

- **Florisbad**: In 1932, T. Dreyer discovered a reasonably complete skull, 260 000 years old, near Florisbad. The skull shows features linking it to both *H. heidelbergensis* and to early *Homo sapiens* – probably a transitional fossil.

- Other South Africa sites include the **Border Cave** in the Lebombo Mountains, the **Blombos Cave** and the **Klasies River Cave** along the Cape coastline.

Other African fossil sites

The Great Rift Valley is a 2000 km long geological feature across Ethiopia, Kenya and Tanzania. There are numerous fossil sites in the Rift Valley.

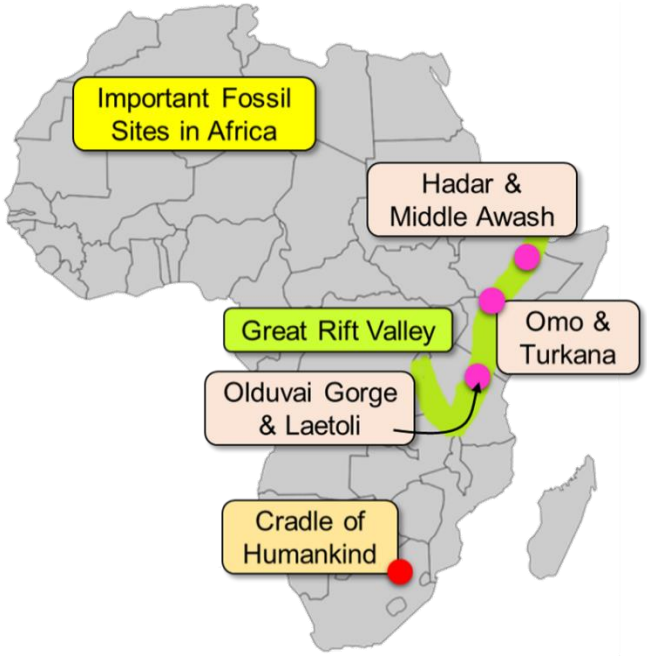


Figure 31: Location of the Rift Valley in East Africa.

- **Ethiopia** (**Hadar** and **Middle Awash**)
    - In 1974, Donald Johansen discovered the first specimen of the species *Australopithecus afarensis* at Hadar. Over 360 other skeletons have been found there since.
    - *Homo habilis* fossils and Oldowan tools were also found there.
    - A large number of fossils of the species *Ardipithecus ramidus* was found at Middle Awash in the Afar Depression in Ethiopia by Tim White in 1994.
- **Kenya** (**Turkana** and **Omo**)
    - The most complete skeleton of the *Homo erectus* (the Turkana boy, dated 1,6 – 1,5 million years ago) was found at Turkana in 1984, by Richard Leakey.
    - Richard also discovered the Omo fossils, remains of modern *Homo sapiens* from about 195 000 years ago.
- **Tanzania** (**Olduvai Gorge** and **Laetoli**)
    - Louis and Mary Leakey discovered fossils of *Homo habilis* (dated to between 2,1 – 1,5 million years ago) here in 1960.
    - Mary Leakey discovered fossils – about 1,75 million years old – of *Paranthropus boisei* (Nutcracker man) in 1959. In 1976, she found 3,5 million year old hominin footprints at Laetoli, evidence that our early hominin ancestors walked with a bipedal, free-striding gait.

Activity 4: Out of Africa hypothesis

1. State the ‘Out of Africa’ hypothesis. (3)
2. Explain why we speak of an ‘Out of Africa’ *hypothesis*, not theory. (4)
3. What evidence is there to support the ‘Out of Africa’ hypothesis? (9)
4. What is mitochondrial DNA? (3)
5. What factors make mtDNA a useful tool in the exploration of human evolution? (4)
6. In your own words, describe the importance of the Cradle of Humankind. (4)
7. List two sites in South Africa, but not part of the Cradle of Humankind, where important fossils remains were discovered. Provide some detail of the fossils found. (4)

(31)

Alternatives to evolution

Evolution is a well-established scientific theory based on real-world observation. Nevertheless, various alternative explanation are proposed. These include:

Creationism

Creationists believe that all life was created individually by a supreme being using supernatural powers. They do not believe that an existing species evolved from an earlier species.

Intelligent Design

Proponents of intelligent design do not accept stages of natural selection since nothing can evolve out of something simple to become more complex. The complexity of things points to an intelligent cause.

Theistic Evolution

Theistic evolutionists believe in a divine being that created the material world through the natural processes that we refer to as evolution. Evolution is simply the tool that the supreme being uses to create the diversity and complexity of life around us. For theists, science and religion can co-exist.

Literalism

Literalists interpret their scriptural texts literally. Christian literalists take the creation accounts in the Book of Genesis literally. Literalists embrace a very narrow, more restricted version of creationism.

Human evolution: End of topic exercises

Section A

Question 1

1.1 Various options are provided as possible answers to the following questions. Choose the correct answer and write the letter (A–D) next to the question number (1.1.1–1.1.5) for example 1.1.6 D.

1.1.1 A possible explanation for an observation that can be tested is known as a

A fact
B law
C theory
D hypothesis

1.1.2 The most dramatic change in the evolution of *Homo sapiens* is traced in

A loss of body hair
B shortening of the jaws
C shorter legs
D the increase in brain size

1.1.3 How were the first modern humans (*Homo sapiens*) different from any of the other hominid species?

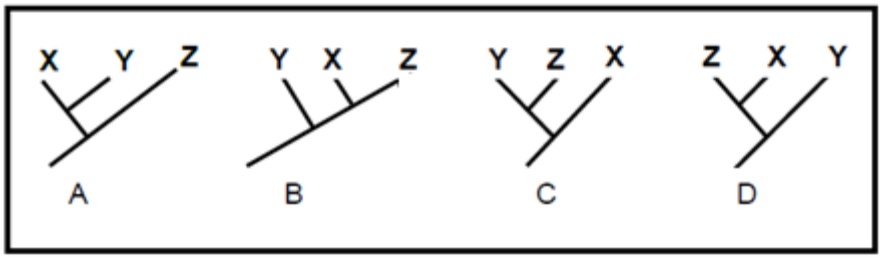
A They lived outside Africa
B They lived longer in Africa than any of the other hominids
C They used tools
D They used symbolic thought, represented in language and art.

1.1.4 Which one of the following serves as evidence of cultural evolution in early *Homo* species?

A The size of a *Homo erectus* cranium relative to a *Homo sapiens* cranium.
B The presence of ancient stone tools
C Male and female skeletons in the same area
D Animal fossils mixed with hominin fossils.

1.1.5 Three related species, X, Y and Z, share a common ancestor. Species Y and Z share the most recent common ancestor.

Which phylogenetic tree most accurately represents their evolutionary relationship?



(5 × 2) = (10)

1.2 Give the correct term / phrase for each of the following descriptions. Write only the term next to the question number.

1.2.1 Living primarily in tree
1.2.2 The type of vision shared by apes and humans that allows for depth perception
1.2.3 The family to which humans belong
1.2.4 The hypothesis which supports migration of human ancestors from the point of origin
1.2.5 The ability of an organism to walk on two feet
1.2.6 Having a face with protruding jaws
1.2.7 The first hominin that used stone tools sharp enough for cutting meat
1.2.8 The genus to which modern humans belong
1.2.9 The permanent disappearance of a species from Earth
1.2.10 Genetic material used to trace female ancestry

(10 × 1) = (10)

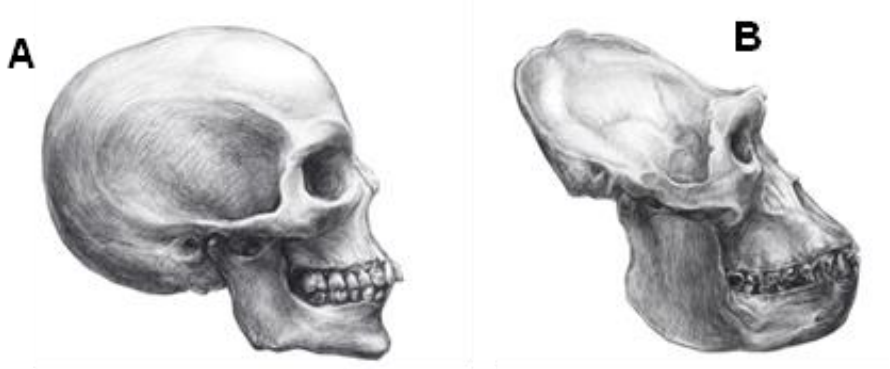
1.3 Indicate whether each of the descriptions in Column I applies to **A ONLY**, **B ONLY**, **BOTH A AND B** or **NONE** of the items in Column II. Write **A only**, **B only**, **both A and B** or **none** next to the question number.

Column I	Column II
1.3.1 Found in apes and humans	A: claws B: nails and an opposable thumb
1.3.2 Fossils found in South Africa	A: Mrs Ples B: Lucy

1.3.3 Fossil evidence found in Ethiopia	A: *Ardipithecus ramidus* B: *Australopithecus africanus*
1.3.4 Study of fossils	A: fossilisation B: palaentology
1.3.5 Discovered the fossil called 'Little Foot'	A: Raymond Dart B: Ronald Clarke

(5 × 2) = (10)

1.4 The diagram shows the skulls of two organisms; a human and a gorilla. Study the diagrams (drawn to scale) and answer the questions that follow.



1.4.1 Which diagram (A or B), represents the skull of a gorilla? (1)

1.4.2 Which organism (A or B), is bipedal for most of its adult life? (1)

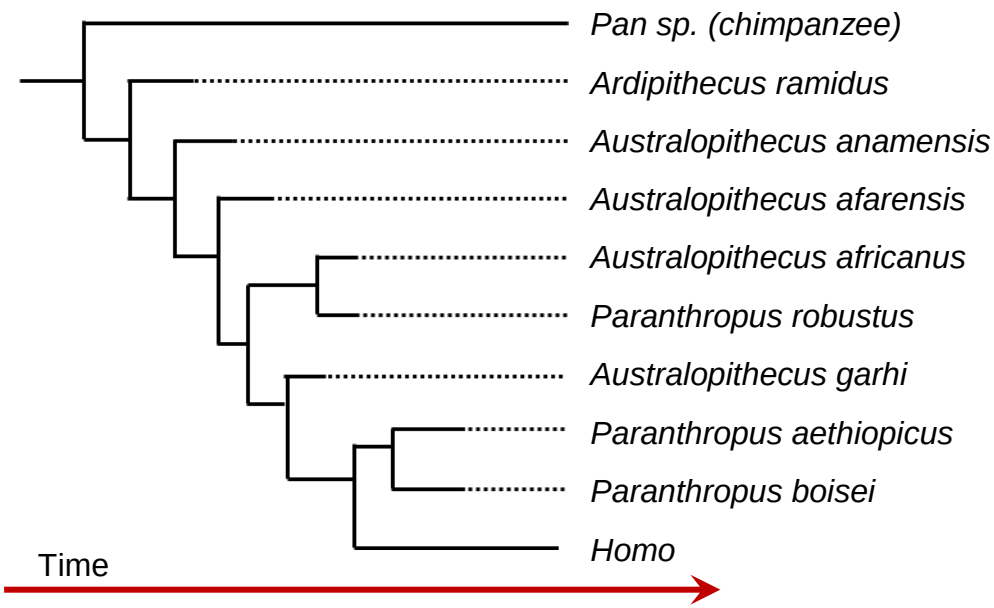
1.4.3 Name and explain two possible advantages of bipedalism for an organism. (4)

1.4.4 Tabulate two observable differences between the skull of organism A and B (5)

1.4.5 Name one similarity between organism A and B which is a characteristic of primates. (1)

(12)

1.5 The diagram below shows possible evolutionary relationships between hominids. A dotted line indicates the species is extinct.



1.5.1 What is this type of diagram called? (1)

1.5.2 List the different hominin genera shown in the diagram. (4)

1.5.3 According to this diagram, which …

a) genus is most recently evolved? (1)

b) genus of hominin is the oldest? (1)

c) hominin species shares a common ancestor with *Australopithecus africanus*? (1)

1.5.4 Give two examples of an *Australopithecus africanus* fossil found in South Africa. (2)

1.5.5 Name two *Homo* species, besides *Homo sapiens*, that have been found in Africa. (2)

(12)

Section A: [54]

Section B

Question 2

2.1 Read the following passage, then answer the questions based on it.

Australopithecus sediba

According to those who discovered the fossil remains of *Australopithecus sediba,* this species shared many characteristics with *Australopithecus africanus*, from which it descended. The species however also reveals a number of early *Homo* features, more so that any other *Australopithecus* species. This suggests that *A. sediba* is possibly ancestral to *Homo*, though it may also be an evolutionary dead end.

Like other species from the genus *Australopithecus*, *A. sediba* had a relatively small brain size. The length of the legs, arms adapted for climbing trees, and details of the teeth also resemble earlier Australopithecines. On the other hand, the species' hand with the precision grip of a toolmaker, and its facial features closely resemble those of early Homo species. Remarkably, *A. sediba* had a more human-like pattern of movement than a fossil attributed to *Homo habilis*.

The pelvic structure of *A. sediba* suggests this species walked upright on a regular basis. The legs and feet however point to a previously unknown way of walking upright. With each step, *Australopithecus sediba* turned its foot inward with its weight focused on the outer edge of the foot.

(adapted from Australopithecus Sediba, https://factsanddetails.com/world/cat56/2215.html)

2.1.1 Who discovered *Australopithecus sediba*, and where? (2)

2.1.2 *A. sediba* is described as having a relatively small brain size. What was the average brain size for this species? (1)

2.1.3 Define the term 'transitional fossil'. (2)

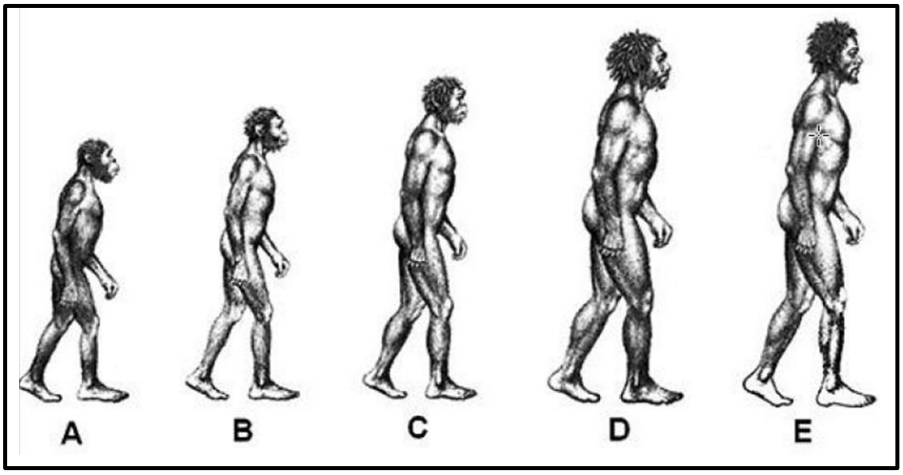
2.1.4 *A. sediba* is described as possibly an "evolutionary dead end". What is an evolutionary dead end? (3)

2.1.5 According to the passage, *Australopithecus sediba* had a previously unknown way of walking upright. What does this suggest for the evolution of bipedalism? (2)

2.1.6 What is the difference between bipedalism and standing upright? Use examples to explain. (5)

(15)

2.2



The diagram above shows the progression of human evolution. Study the diagram of some early hominin A, B, C, D and E which represent *Homo erectus*, *Homo sapiens*, *Australopithecus*, *Homo habilis* and *Homo neanderthalensis*, in no particular order.

2.2.1 Identify each of the above hominid members (A – E) correctly from the list given above. (5)

2.2.2 Mention any three common characteristics which are shared by the members represented in the above diagram. (3)

2.2.3 Name the family the above group belongs to, and the collective name for these members (2)

2.2.4 Supply any three characteristics that make the organism, labelled E different from other primates. (3)

(13)

[28]

Question 3

3.1

3.1.1 A larger brain size is often associated with a greater intelligence. Accordingly, *Homo neanderthalensis*, with a larger brain than *Homo sapiens*, should have been more intelligent, and thus better able to adapt to climate changes. Yet *H. neanderthalensis* is extinct, while *H. sapiens* flourishes. What other factor related to the brain could explain this? (2)

3.1.2 Explain the relationship between the decrease in the jaw size of evolving hominin species and their increasing brain size. (3)

(5)

3.2 Scientists use fossils as evidence for human evolution. The brain volume of some extinct primates has been estimated from their fossils and have been

compared to the brain volumes of living primates. The results are shown in the table below (figures in brackets give mid-point of existence).

Hominid	Period of Existence (million years ago)	Average Brain Volume (mL)
Ardipithecus ramidus	5,8 to 4,4 (5,1)	400
Australopithecus afarensis	4 to 2,7 (3,4)	450
Australopithecus africanus	3 to 2 (2,5)	450
Homo habilis	2,2 to 1,6 (1,9)	750
Homo erectus	2 to 0,4 (1,2)	1 000
Homo neanderthalensis	0,3 to 0,23 (0,27)	1 500
Homo sapiens	0,2 to present (0,1)	1 400
Modern apes	0,2 to present (0,1)	500

3.2.1 Apart from fossil evidence, give two other types of evidence for human evolution? In each case, give a brief explanation of how the evidence is used to support the notion of human evolution. (4)

3.2.2 The brain of an organism is not preserved as fossil. How do experts determine the average brain volume of extinct species? (2)

3.2.3 Calculate the difference in brain volume (in mL) between the two living primates. Show all calculations. (3)

3.2.4 Draw a line graph to show the evolution of brain size across all hominin species listed in the table. Use the mid-point of the period of existence on one axis. Once the points have been plotted, interpret the graph. (8)

(17)

[22]

Section B: [50]

Total marks: [104]

A FINAL WORD: ASSESSMENTS

The purpose of an assessment is to give an indication of your mastery of a subject. During the year, *informal assessments* allow you to be aware of your strengths and weaknesses, and to identify the areas in which you may need additional help. *Formal assessments* allow your parents and teachers to be aware of your progress.

Assessments will measure your understanding of the *content*, *concepts* and *skills* needed to pass Grade 12.

Informal daily assessments

These occur during the daily lessons, as you check your homework and classwork, answer questions posed by your teacher or work through questions in a group. This is where you will be able to become aware of areas that you are struggling in and take action through extra studying or consulting with peers or your teachers.

Formal school-based assessments

In Grade 12, your final mark is made up in the following way:

Formal Tests (× 1), June and trial exams Practicals (× 2) and Project / Assignment	25%
Final Exam (external)	75%

Because school-based assessments only count 25% they are often neglected. But remember, *they help to prepare you as best as possible* for your final exam.

Assessment Content

Knowing science	40%	Recalling *learned* information – details, facts, formulas, terms and definitions or procedures.
Understanding science	25%	This will test your ability to expand upon given information, either by interpreting, giving an example, classifying or summarising, or comparing different concepts or objects.
Applying your knowledge	20%	This refers largely to your *practical skills* and your ability to follow procedures or given methods, and use your knowledge of theory to draw conclusions from your results
Analysis and evaluation	15%	Here you your given knowledge one step further to *solve non-routine problems* or *evaluate a new procedure* based upon your background knowledge. You could also be asked to *integrate pieces of information* to create a new idea.

Examples of useful verbs and what is required of you

Analyse - Separate, examine and interpret

Calculate - Used when a numerical answer is required. In general, you should show your working, especially where two or more steps are involved

Classify - Group things based on common characteristics

Compare - Point out or show both *similarities and differences* between things, concepts or phenomena

Define - Give a clear meaning

Describe - State in words (using diagrams where appropriate) the main points of a structure / process / phenomenon / investigation

Determine - To calculate something, or to discover the answer by examining evidence

Differentiate - Use differences to qualify categories

Mention - Refer to relevant points

Name - State something; *alternative keywords: give, identify, mention*

State - Write down information without discussion

Suggest - Offer an explanation or a solution

Tabulate - Draw a table and indicate the answers as direct pairs

Exam format

Each exam paper is 150 marks and written over 2 ½ hours. Your two exam papers will be broken up in this way:

- *Section A* – short answer questions, such as multiple choice, terminology, statements and response to data. (50 marks)
- *Section B* – two longer questions broken up into subsections. (50 marks)

Content per exam

- ***Paper 1***
  - DNA: Code of Life (18%)
  - Meiosis (14%)
  - Genetics and Inheritance (32%)
  - Evolution (36%)

- ***Paper 2***
    - Reproduction in vertebrates (5%)
    - Human reproduction (27%)
    - Responding to the environment – humans (36%)
    - Responding to the environment – plants (23%)

Tips and suggestions for examinations

Writing exams can be a source of stress. Here are some ideas to get the most out of your *learning time* (pre-exam) and *writing time* (in-exam)

- **Be sure to plan thoroughly**. Don't leave your studying to the last minute, and try not to procrastinate during your learning time. Prepare a study time table – allow yourself enough time over the period of 4 weeks – focus on at least 3-4 topics per week.
- **Get yourself a study buddy** - you will be able to assist one another on difficult concepts/skills
- **Pay careful attention to your theory**. Remember that 40% of your exam will be based on that directly.
- **Spend time working through past exam papers and test papers** to familiarise yourself with the basic format. Time yourself during these practices so that you do not work too slowly.
- **Set yourself a goal** beforehand to work towards.
- Before the exam, be sure to **get enough sleep and eat a decent meal**.
- During your exam, consider the marks of each question. You have **150 minutes and 150 marks** so it is 1 mark per minute. It will benefit you if you *try to work slightly faster than this during Section A* to give yourself more time in Section B.
- **Read each question fully** before starting to answer it. Additionally, for Section B, *plan your answers as far as possible*, even if just with key word, before beginning to write.
- **Write neatly and be sure to number** your questions according to the question paper.

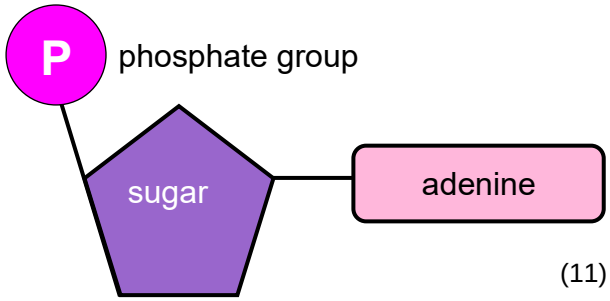
We wish you every success as you prepare!

ANSWERS TO ACTIVITIES

Chapter 1: DNA – the code of life

Activity 1: DNA

1. 1 – adenine ✓, 2 – deoxyribose sugar ✓, 3 – hydrogen bonds ✓
2. 10 ✓
3. Nucleus ✓ and mitochondria ✓
4. Double helix ✓
5. ✓ for structure,
   ✓×3 - for correct labels



(11)

Activity 2: DNA replication

1. DNA replication ✓
2. DNA replication ensures that identical cells, with the same number and type of chromosomes, can be produced during cell division. ✓
3. 1 – deoxyribose sugar ✓, 2 – phosphate ✓ , 3 – nucleotide ✓ , 4 - thymine ✓
4. The process of DNA replication
   - Double helix DNA unwinds as the weak hydrogen bonds between the nitrogenous bases break ✓
   - The two DNA strands separate from each other (DNA unzips) and each original DNA strand serves as a template to form a new strand ✓
   - Free DNA nucleotides from the nucleoplasm attach to the original strand ✓
   - The nucleotides attach to their complementary bases (A to T and G to C) ✓
   - Each DNA molecule now consists of one original strand and one new strand ✓
   - The result is two genetically identical DNA molecules; the entire process is controlled by enzymes ✓
5. Mitochondrial DNA in mitochondria or chloroplastic DNA in chloroplasts ✓

(13)

Activity 3: DNA profiling

1. Suspect 2 ✓

2. 3 of the DNA bands match the evidence from the crime scene while none of the other suspects match. ✓
3. Any one of … ✓
    - identification of relatives such as paternity testing or tracing siblings
    - testing for genetic disorders
    - to determine matching tissues for organ transplants
    - research into variation in populations
4. Any two of …. ✓✓
    - DNA samples may be planted or a person could be framed with the use of false evidence
    - Human error can lead to false results
    - Only a small amount of DNA is analysed so it may not be unique to one individual
    - Testing standards may not be followed in various private labs
    - Invasion of privacy and revealing personal information (5)

Activity 4: Protein synthesis

1. Translation of protein synthesis ✓
2. a) ribosome ✓ , b) mRNA ✓ , c) peptide ✓
3. a) C – tRNA ✓ , b) D – amino acid ✓
4. Transcription ✓
    - section of DNA double helix unwinds as the weak hydrogen bonds between the nitrogenous bases of DNA break
    - DNA unzips (in this section of DNA), and one strand acts as a template
    - This DNA template is used to form a complementary strand of messenger RNA (mRNA) ✓
    - This is done using free RNA nucleotides in the nucleoplasm ✓
    - The mRNA now contains the code for the protein which will be formed ✓
    - Three adjacent nitrogenous bases on the mRNA are known as codons. These code for a particular amino acid. ✓
    - mRNA moves out of the nucleus through a nuclear pore into the cytoplasm, where it attaches onto a ribosome. ✓

(12)

Activity 5: Codons and amino acids

1. 2 ✓
2. CUC ✓
3. a) TGG ✓ ; b) aspartate ✓

(4)

Chapter 2: Meiosis

Activity 1: Meiosis I and Meiosis II

1.1 A ✓✓ 1.2 C ✓✓ 1.3 C ✓✓ 1.4 B ✓✓

1.5.1 B ✓✓ 1.5.2 C ✓✓ 1.6 D ✓✓

(14)

2.1 A only ✓✓ 2.2 B only ✓✓ 2.3 Both A and B ✓✓ 2.4 B only ✓✓
2.5 B only ✓✓ 2.6 Both A and B ✓✓ 2.7 None ✓✓

(14)

3.1 Meiosis ✓ 3.2 Anaphase I ✓

3.3 2 – centromere ✓ , 3 – centriole ✓

3.4 crossing over ✓

3.5 Results from the swopping of genetic material during Prophase I which brings about genetic variation ✓

(6)

4.1 Metaphase II ✓

4.2 Single chromosomes are lined up at the equator ✓ in two cells ✓

4.3 Crossing over between the maternal and paternal chromosomes results in genetic variation (different gene combinations) ✓

4.4 No ✓

4.5 Only 2 chromosomes – in humans, there would be 23 ✓

4.6 Anther ✓ and ovule ✓

(8)

5. Meiosis ✓ is vital so that sexual reproduction ✓ can occur. This is due to the fact that the chromosome number is halved ✓ (diploid to haploid ✓). This allows haploid male and female gametes to fuse ✓ to form a diploid zygote which has the correct ✓ diploid number. It also allows genetic variation ✓ so that the offspring has a unique genetic makeup. In this way a better adapted ✓ offspring could be formed which could lead to evolution.

(8)

(50)

Chapter 3: Reproductive strategies in vertebrates

Activity 1: Fertilisation

1. External fertilisation ✓
2. The fish are close to each other when they release their gametes ✓ . Many egg and sperm cells are released to maximise the chances of fertilisation ✓ .
3. Oviparous / Ovipary ✓
4. The eggs are already in water ✓ , no desiccation (drying-out) will occur ✓ .
5. The chances of fertilisation are reduced as gametes have to meet in water ✓ . To overcome this challenge, many gametes are produced and released shortly after each other and while the parents are close to each other to maximise the chances of fertilisation ✓ .

   Offspring do not have a large degree of protection from the external environment and are easily predated upon ✓ . To overcome this challenge, parents can offer parental care and defend eggs and juveniles. Offspring are also precocially developed and well-suited for their environment meaning that they can fend for themselves ✓ . (10)

Activity 2: Amniotic egg

1. 1 – Amnion ✓ ; 2 – chorion ✓
2. Temperature regulation; limits mechanical injury; prevents dehydration of the embryo ✓✓ - any two
3. The bladder ✓
4. The foetus is directly connected to the mother via the umbilical cord to the placenta. Through these structures, the foetus can receive nourishment (replacing the function of yolk sac) ✓ and release nitrogenous waste to the mother's body (replacing the function of the allantois) ✓
5. The outer shell is porous to allow gaseous exchange but prevents the desiccation of the embryo as it limits water loss ✓ . The chorion allows gaseous exchange to take place through the porous egg shell ✓ . The amnion cushions the developing embryo from mechanical injury ✓ and helps regulate temperature ✓ and prevents dehydration ✓ . (12)

Activity 3: Parental care

1. a) B ✓ & D ✓ b) A ✓ & C ✓
2. a) Parental care for precocially developed young would be less intensive as these young are already mobile at birth and can feed and fend for themselves ✓ .

Parental care for altricial young however would require a greater degree of parental care as these young cannot feed themselves ✓ as their bodies are still under-developed ✓ . Parents would need to feed and protect these young until they reach a more developed state ✓ .

b) The bodies of precocial young are well developed. Precocially developed young's eyes are open, they have down feathers or fur and can move soon after birth ✓ . The bodies of altricially developed young however are not as well developed as their eyes are closed, bodies are naked and have very limited movement ✓ .

c) In precocial ovoviviparous species' eggs, more yolk is found to assist in the development of a well-developed body. This also sustains the young for a longer incubatory period ✓ . In altricial ovoviviparous species' eggs, less yolk is found and the offspring are born sooner, thus being under-developed ✓ .

3.

	Precocial development	**Altricial development**
Development of the body	well developed	under developed
Eyes after birth	open	closed
Presence of fur / feathers	have fur / feathers	usually naked
Parental care required	low degree of parental care required	high degree of parental care required.
Mobility	young can move soon after birth.	young usually have limited capability to move freely.
Yolk amount in egg	greater quantity	lower quantity

✓ - for tabulating answer

✓ - 2 marks per correct development – one for precocial, and one for altricial development

(19)

Chapter 4: Human reproduction

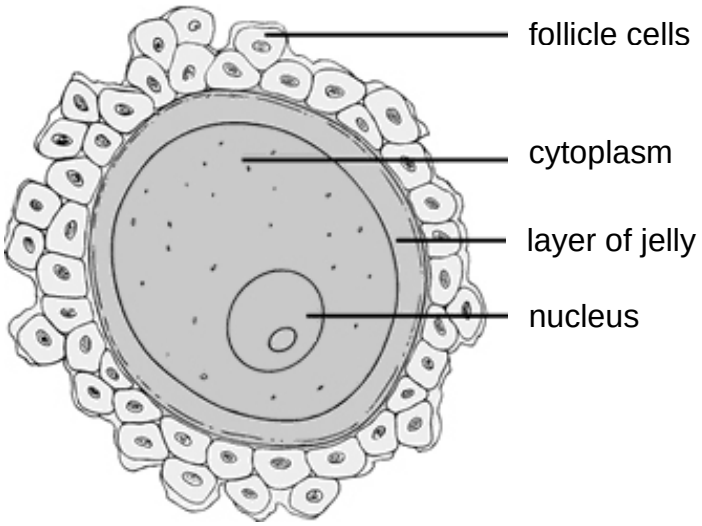
Activity 1: Reproductive systems

1. A – urethra ✓, B – vas deferens ✓, C – prostate gland ✓, D – testes ✓, E – uterus ✓, F – fallopian tube ✓, G - ovary ✓, H – vagina ✓
2. a) Protects the sperm cell from the acidic environment of the vagina or provides a fluid medium in which sperm cells can swim/ increases mobility of sperm ✓

   b) place for the foetus to develop ✓; maintains pregnancy ✓; assists in child birth✓; implantation of the blastocyst ✓; protects the foetus ✓; passage for sperm cells ✓ (any one)
3. serves as a birth canal ✓; allows for passage of blood ✓ / endometrial lining / amniotic fluid / placenta; facilitates sexual intercourse ✓ / receives semen; secretes acid which prevents infections ✓ (any two)
4. to keep the testes at a temperature that is lower than body temperature ✓, optimum temperature for sperm production which is necessary for the production of healthy sperm and so that healthy sperm can survive. ✓

Activity 2: Gametogenesis

1. In males meiosis occurs in the testes ✓ and in females meiosis occurs in the ovaries ✓.
2. Gametogenesis is the process in which cells undergo meiosis to form gametes ✓.
3. Gametogenesis in males is called spermatogenesis ✓ and in females it is known as oogenesis ✓.
4. Structure of ovum ✓



1 mark for title, one for actual drawing, 3 marks for any 3 correct labels.

5.

- acrosome ✓ – contains enzymes to penetrate the ovum ✓
- head ✓ – contains the nucleus with the male genetic information ✓
- middle portion ✓ – contains many mitochondria to provide energy for the sperm cell to swim ✓
- tail ✓ – propels the sperm cell forward / allows the sperm to swim ✓

Activity 3: Hormones

1. Day 14 (13 or 15 is accepted) ✓
2. The level of oestrogen decreases sharply or the level of luteinising hormone increases ✓
3. a) Graafian follicle ✓
   b) corpus luteum ✓
4. a) The follicles have developed into the Graafian follicle secreting more oestrogen ✓ to make the endometrial wall thicker / more vascular
   b) Increased levels of oestrogen stimulate the pituitary gland to release more LH ✓ so that ovulation can occur ✓
5. a) pregnancy has resulted or the woman is pregnant ✓
   b) no pregnancy or leads to menstruation ✓

Activity 4: Menstrual cycle

1. oestrogen / follicle stimulating hormone ✓
2. the lining of the endometrium thickens during this period stimulated by the increased level of oestrogen or the follicle develops during this period stimulated by increased levels of FSH (✓✓)
3. corpus luteum has not disintegrated, it continues to secrete progesterone so the endometrial lining remains thickened (✓✓✓)

Activity 5: Fertilisation and development of the embryo

1. A – jelly coating ✓, B – cell membrane ✓, C – cytoplasm ✓, D – head ✓, E – acrosome ✓, F – nucleus ✓, G – middle part (neck) ✓
2. a) G ✓ b) E ✓ c) D ✓
3. The zygote undergoes mitosis ✓ until a ball of cells is formed called the morula ✓. The morula continues to divide and forms a mass of cells with a hollow cavity ✓ called a blastocyst ✓. The outer membrane of the blastocyst forms the chorionic villi which attaches it to the endometrium ✓.
4. Gestation is the period of development inside the uterus between fertilisation and birth ✓

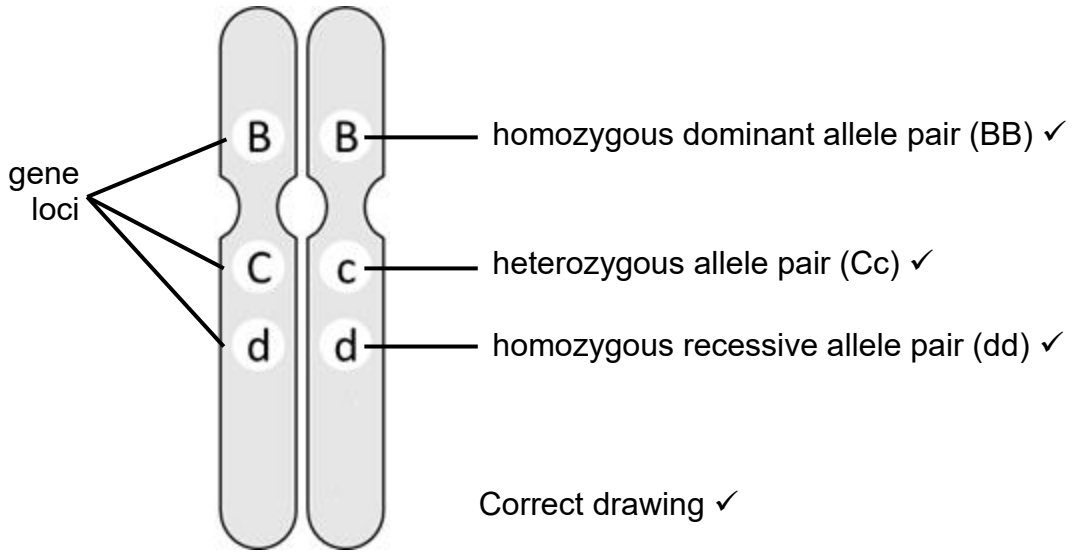
Chapter 5: Genetics and inheritance

Activity 1: Traits, genes and alleles

1. a) B ✓ b) A ✓ c) C ✓ d) D and A ✓
2. Genes code for proteins ✓✓
3. Any of the alternative forms of a gene ✓ that may occur at a specific locus ✓
4. a) homozygous ✓
   b) heterozygous ✓
5. Homologous chromosomes are two chromosomes ✓ , one from the mother and one from the father ✓ , that have the same length, overall appearance, and genes, although the alleles may differ ✓
6. As letters ✓ , uppercase for dominant and lowercase for recessive alleles
7.

Genotype	Phenotype	Alleles
homozygous dominant	Tall ✓	T / T ✓
homozygous recessive ✓	short	t / t
heterozygous ✓	Tall ✓	T / t ✓

8. **Homologous chromosomes** ✓



(25)

Activity 2: Monohybrid crosses with complete dominance

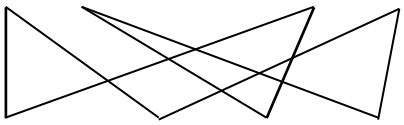
1.

P_1	Phenotype	Yellow seeds	x	Green seeds	✓
	Genotype	YY	x	yy	✓

Meiosis

	G/gametes	Y Y	x	y y	✓

Fertilisation



F_1	Genotype	Yy	Yy	Yy	Yy	✓
	Phenotype	All (100%) Yellow seeds				✓

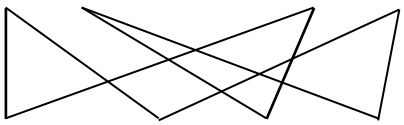
P_1 and F_1 ✓ Meiosis and Fertilisation ✓ (Any 6)

P_2/F_1	Phenotype	Yellow seeds	x	Yellow seeds	✓
	Genotype	Yy	x	Yy	✓

Meiosis

	G/gametes	Y y	x	Y y	✓

Fertilisation



F_1	Genotype	YY	Yy	Yy	yy	✓
	Phenotype	Yellow seeds	Yellow seeds	Yellow seeds	Green seeds	✓

Genotypic Ratio : 1YY: 2Yy: 1yy (1:2:1)

Phenotypic Ratio: 3 Yellow seeds: 1 Green seeds (3:1)

P_1 and F_1 ✓ Meiosis and Fertilisation ✓ (any 6)

2. Tongue rolling is dominant, and both parents were heterozygous (**Rr**) ✓ . If both parents have the recessive allele for non-rolling tongue and the child received both recessive alleles ✓, one from father (r), and one from mother (r), then then it creates a genotype for non-rolling tongue (**rr**). ✓

(15)

Activity 3: Monohybrid cross with incomplete dominance

1.

P_1 Phenotype Grey x Grey ✓

Genotype BW x BW ✓

Meiosis

G/gametes B W x B W

Fertilisation

Gametes	B	W
B	BB	BW
W	BW	WW

1 mark for gametes ✓

F_1 Genotype BB BW BW WW ✓

Phenotype Black Grey Grey White ✓

Genotypic Ratio: 1BB: 2BW: 1WW (1:2:1)

P_1 and F_1 ✓ Meiosis and Fertilisation ✓ (any 6)

2.1

P_1 Phenotype Sipho high cholesterol levels x Andiswa high cholesterol levels ✓

Genotype HL x HL ✓

Meiosis

G/gametes H L x H L

Fertilisation

Gametes	H	L
H	HH	HL
L	HL	LL

✓ - for gametes

F_1 Genotype HH HL HL LL ✓

Phenotype Very High, High, High, Low ✓

(Cholesterol levels)

50% ✓* of their children will have high but not extreme cholesterol levels

P_1 and F_1 ✓ Meiosis and Fertilisation ✓ (*1 compulsory + any 6)

2.2 a) 25% ✓

b) 25% ✓ (15)

Activity 4: Sex-linked diseases

1.

P_1 Phenotype: Normal father x Normal mother ✓

Genotype X^HY x X^HX^h ✓

Meiosis

Gametes	X^H	Y
X^H	X^HX^H	X^HY
X^h	X^HX^h	X^hY

Fertilisation

F_1 Genotype X^HX^H ; X^HX^h ; X^HY ; X^hY ✓

Phenotype 50% Normal female; 25% Normal male ;

25% Affected male ✓

P_1 and F_1 ✓

Meiosis and Fertilisation ✓ (any 6)

2. The allele for the trait is carried on the X-chromosome ✓ . The Y-chromosome does not carry the allele for the trait ✓ . Males only have one X-chromosome ✓ . A male only needs one recessive allele ✓ to be affected, whereas for a female to be affected both alleles must be recessive ✓ . (any 4)

3.1 The gene ✓ for this disorder is located on the autosome (chromosome number 7) and not on the sex chromosomes / gonosomes ✓ .

3.2

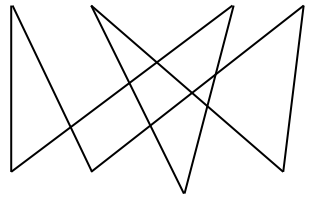
P_1 Phenotype: Normal parent x Normal parent ✓

Genotype Bb x BB ✓

Meiosis

Gametes B b x B B

Fertilisation



F_1 Genotype BB; BB; Bb; Bb ✓

Phenotype Normal Normal ✓

P_1 and F_1 ✓

Meiosis and Fertilisation ✓

0% chance to have a child with cystic fibrosis ✓ * Compulsory mark

Compulsory 1 + any 5

3.3 To determine their chances of having a child with the disorder ✓ to help them to make an informed decision ✓ on whether to have children or not.

(20)

Activity 5: Monohybrid crosses using blood types

1.

P_1 Phenotype: Father - Blood group **AB**

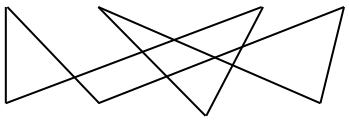
x Mother - Blood group **A** ✓

Genotype I^AI^B x $\mathbf{I^Ai}$ ✓

Meiosis

Gametes $\mathbf{I^A}$ $\mathbf{I^B}$ x $\mathbf{I^A}$ $\mathbf{i}$

Fertilisation



F_1 Genotype $\mathbf{I^AI^A}$; $\mathbf{I^Ai}$; $\mathbf{I^AI^B}$; $\mathbf{I^Bi}$ ✓

Phenotype Blood group **A, A, AB and B** ✓

P_1 and F_1 ✓

Meiosis and Fertilisation ✓

Hence the man with blood group AB cannot be the father of that child ✓ . * Compulsory mark

(Compulsory 1 + any 5)

2. a) I^A ✓ , I^B ✓ , i ✓

b) 2 ✓

c) Any individual inherits one allele from each parent ✓

d) I^A ✓ , I^B ✓

e) Each child has an equal ✓ , i.e. a 25% chance, of having any blood group ✓ – A, B, AB, or O

(15)

Activity 6: Dihybrid crosses

1.1 Dihybrid ✓ crossing

1.2 a) short ✓ ears; b) pointed ✓ lip; c) EEll or Eell ✓

1.3 EL ✓ and El ✓

1.4 Due to random arrangement of chromosomes at the equator ✓ during meiosis ✓ any one of the two alleles of a characteristic can sort with any two of another characteristic

The alleles of different genes move independently ✓ of each other into the gametes ✓

They can therefore appear in the gametes in different combinations: LE, Le, lE, le ✓ (any 4)

2.1 Andrew has short fingers while Susan has normal fingers ✓ . Andrew has straight hair while Susan has curly hair ✓

2.2 Bh ✓ , bh ✓ (14)

Activity 7: Pedigrees

1.1 2 ✓ 1.2 ($\frac{1}{7}$ x 100) ✓ = 14,3% ✓

1.3 a) X^DX^d ✓ b) X^dX^d ✓

1.4 100% ✓

2.1 Because they were normal they must each have one dominant allele ✓ and in order for their children to be affected each parent must have one recessive allele ✓

2.2 **NN** ✓ or **Nn** ✓

2.3 The father ✓ would have been affected ✓ if it was sex-linked in order for the daughter to be affected ✓

3.1 10 ✓

3.2 a) Dd ✓ b) Dd ✓

3.3 a) homozygous ✓ b) heterozygous ✓

3.4 Individual 2 is the grandmother ✓ of individual 12 or

Individual 12 is the grandson ✓ of individual 2.

(19)

Activity 8: Genetic engineering

1. They learnt that what one <u>thinks</u> ✓ will happen is not likely to happen <u>in reality</u>. ✓
2. Genetic engineering is <u>expensive</u> ✓ so only rich countries can use it. ✓
3. **Short term**

   - greater yield ✓ therefore better food security. ✓
   - enhanced nutrient content ✓ e.g. vitamin A in rice.
   - easier to grow ✓ as the crop is less likely to get a disease and can grow in harsh conditions. ✓ (any 2 + 2)

   Long term

   - possible health ✓ issues due to excessive use of herbicides ✓ or allergic to 'new' gene.
   - loss of biodiversity. ✓
   - using genetic engineering for experiments ✓ which push the limits of ethics and morality ✓ e.g. human genes in mice. (any 1 + 1)
4. If a human gene is incorporated into a vegetable (tomatoes/peppers) and you eat it ✓, you are actually also eating a very small part of a human cell ✓.
5. Recombinant DNA technology ✓
6. BAD ✓: "Playing God with nature" in this way could lead to psychological and social problems. ✓ or GOOD: Could feel special ✓ because you were created by a unique scientific experiment ✓

(15)

Chapter 6: Human responses to the environment

Activity 1: The central nervous system

1. A – cerebrum ✓, B – corpus callosum ✓, C – cerebellum ✓
2. a) C - cerebellum ✓; b) A ✓ - cerebrum ✓
3. a) controls breathing, peristalsis, heart beat and swallowing ✓
   transmits impulses from the spinal cord to the brain ✓
   controls less important reflexes such as blinking, coughing, sneezing, vasodilation, vasoconstriction and salivating ✓ – any two

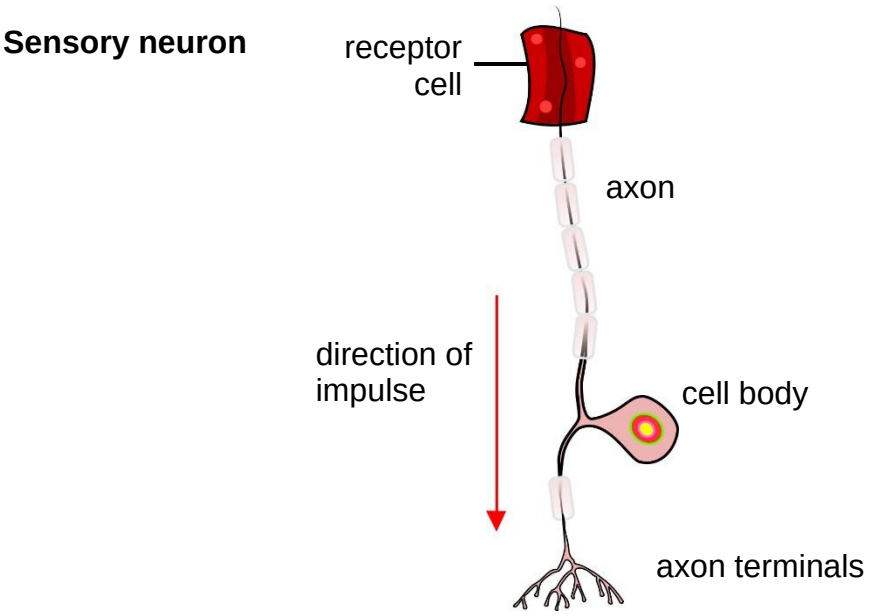
   b) control centre for things such as hunger, thirst, sleep, body temperature and emotions (✓ - any two)
4. The spinal cord is protected by vertebrae with cartilage discs between them to act as shock absorbers ✓, by membranes called meninges ✓, and cerebrospinal fluid ✓ – any two
5. The medulla oblongata would be affected. This could lead to problems with .. breathing ✓, heartbeat ✓, digestion ✓, communication between the brain and the spinal cord ✓. (any two)

(15)

Activity 2: Neuron structure

1. motor neuron ✓
2. A – dendrite ✓, B – nucleus ✓, C – axon ✓, D – myelin sheath ✓, E – cell membrane ✓
3. a) transmits impulses away from the cell body ✓
   b) speeds up the transmission of impulses ✓
4. Dendrites receive the impulse and move them towards the cell body ✓. They pass through the cell body and are transmitted down the axon.
5. Mark allocation: correct type of neuron – title: a sensory neuron ✓
   correct direction of impulse ✓
   any two correct labels ✓✓
   (see diagram on next page)

(13)



Activity 3: Reflex arc

1. a) E ✓; b) A ✓; c) C ✓
2. a) The receptor detects the stimulus, in this case a pin prick, and generates impulses ✓.

   b) transmits impulses from the central nervous system to the effector to bring about a response ✓.
3. The spinal cord shortens the reaction time by sending impulses directly to the effector ✓. The brain delays the reaction ✓ as impulses must travel further, which could cause injury or even death ✓.
4. a) The receptor would detect the stimulus and generate impulses ✓, however the impulses would not reach the central nervous system ✓ because the sensory neuron is cut ✓. The sensation would not be felt and the body would not be able to respond ✓.

   b) The receptor would detect the stimulus and generate impulses ✓ which will reach the central nervous system ✓. The sensation will be felt but the body will not be able to respond ✓ because the motor neuron is cut so impulses cannot reach the effector ✓.

(16)

Activity 4: Practical investigation on reaction times

1. a) gender ✓ b) reaction time ✓
2. Each trial was repeated five times for each of the participants. ✓
   Relatively large sample size was taken ✓
3. Same group of learners used ✓
   Same person dropping the ruler ✓
   Same meter ruler ✓
   Same time of day ✓

4. Boys have faster reaction time than girls. ✓✓ **OR** Girls have lower reaction times than boys. ✓✓ **OR** Both girls and boys have the same reaction time. ✓✓

(8)

Activity 5: The human eye

1. C – pupil ✓, D – iris ✓, H – suspensory ligaments ✓
2. The cornea is transparent to allow light to enter ✓ and it is curved to allow for refraction of light ✓.
3. E – contains rods and cones which are the receptors sensitive to light. These allow for an image to form ✓.

   G – pigments absorb excess light to prevent reflection ✓; blood vessels supply oxygen and nutrients ✓ (any one)
4. a) F ✓ b) A ✓
5. pupillary mechanism ✓

   the circular muscles of the iris contract ✓

   the radial muscles of the iris relax ✓

   the pupil constricts ✓

   the amount of light entering the eye is reduced ✓

(14)

Activity 6: Accommodation

1. a) C ✓ b) B ✓
2. a) short-sightedness ✓ b) concave lens ✓
3. accommodation

   ciliary muscles contract while the suspensory ligaments become slack ✓; tension on the lens decreases ✓; the lens becomes more convex (bulgy) ✓; this causes light rays to bend more ✓; a clear image is formed on the retina ✓

(9)

Activity 7: Case study on visual defects

1. The person is able to see near objects ✓ but cannot see objects more than 6 metres away clearly ✓
2. Concave lenses ✓
3. The protein found in the lens forms clumps that cloud the lens ✓.
4. She would eventually become totally blind ✓.
5. Kayise's near-sightedness is caused by a lens that cannot adjust adequately to focus the incoming light (is no longer supple) ✓, and is cloudy ✓. During surgery, the lens is removed and replaced with an artificial lens ✓. As a result, Kayise could see clearly without glasses ✓.
6. Light rays enter through the cornea but are not able to be refracted through the lens correctly ✓. The clouding prevents the refraction of light ✓ and the light rays are not focused onto the yellow spot ✓, which leads to vision becoming blurry.

7. Long-sightedness / astigmatism (✓ - any one)

(13)

Activity 8: The human ear

1. a) Eustachian tube ✓; b) round window ✓; c) cochlea ✓
2. ossicles ✓; transmits vibrations from the tympanic membrane to the inner ear ✓; amplify the vibrations ✓
3. a) crista ✓
   b) they detect changes ✓ in speed and direction of the body ✓

(9)

Activity 9: Balance, hearing and defects

1. a) B ✓ b) C ✓
2. The stirrup cannot vibrate ✓ and the vibrations will not be transmitted to the inner ear ✓. The organ of Corti will not be stimulated ✓ resulting in hearing loss.
3. a) E – tympanic membrane ✓, or B – ossicles ✓
   b) C – the cochlea ✓
4. A virus or inflammation of the inner ear disrupts the transmission of sensory information from the ear to the brain ✓. This may result in dizziness, difficulties with balance, with hearing, and lead to a ringing in the ears (tinnitus) ✓.

(10)

Chapter 7: The human endocrine system and homeostasis

Activity 1: Endocrine glands and their hormones

A – hypothalamus ✓; ADH ✓

B – pituitary gland ✓; GH ✓, TSH ✓, FSH ✓, LH ✓, prolactin ✓ – any four for a total of 20 marks for Activity 1.

C – thyroid gland ✓; thyroxin ✓

D – adrenal gland ✓; adrenalin ✓ and aldosterone ✓

E – pancreas ✓; glucagon ✓, insulin ✓

F – ovaries ✓; oestrogen ✓ and progesterone ✓

G – testes ✓; testosterone ✓

(20)

Activity 2: Effects of a certain hormone

1. Adrenalin ✓
2. On top of each kidney ✓
3. Less blood flow to the gut ✓, as it is not involved in responding to the emergency ✓. Blood flow is redirected to organs involved in responding to the emergency ✓ such as: skeletal muscles to improve muscle tone ✓ or heart muscle, for the heart to beat faster so as to increase the transport of oxygen and glucose needed for increased respiration ✓.
4. Pupil ✓
5. The pupil dilates ✓ to allow more light to enter the eye ✓ for clear vision ✓ during the emergency situation.

(10)

Activity 3: A negative feedback mechanism

1. Thyroid gland ✓
2. Thyroxin ✓
3. Stimulate the thyroid gland ✓
4. High levels of thyroxin are detected ✓ by the pituitary gland which leads to a decrease ✓ in the secretion of TSH. Thyroid activity is slowed down ✓ / less thyroxin is produced. Thyroxin levels drop to normal ✓.

(8)

Activity 4: Research task on endocrine disorders

Answers will depend on the hormone you choose to investigate. Your teacher will provide you with a mark scheme. A possible rubric (mark scheme) is given here:

Component	Learners mark	Possible mark
Hormone? Where produced? Target area/organ/s		5
Regulation of hormone		5
Normal function of hormone (homeostatic level)		5
Cause of disease (hyper/hypo)		5
Symptoms/Effects		5
Treatment		5
References (at least 3 and correctly cited)		5
Presentation skills (Quality of PowerPoint or poster)		10
Knowledge in answering questions		5
TOTAL		50

Activity 5: Body temperature

1. Hypothalamus ✓
2. 37,5°C ✓
3. 10 minutes
4. Most human activity is controlled by enzymes ✓ and enzymes require optimum temperatures to function ✓
5. Diagram I ✓
6. Blood vessels dilated to bring more blood to the surface ✓ and so more heat will be lost ✓ OR Increased sweat production ✓ which will cool down the body ✓

Chapter 8: Plant responses to the environment

Activity 1: Phototropism

1. a) Position of the tin foil on the shoot ✓

   b) Shoot growth ✓
2. Lerato decided on …
   the duration of the investigation ✓
   the plant species to use ✓
   the method of recording the results ✓
   the apparatus to use ✓ (any three - mark first three only)
3. Since the tip of shoot B was not covered ✓, the auxins produced at the tip moved to the shaded side ✓. This stimulated cell elongation on the shaded side ✓. The shaded side grew faster and bent towards the light source ✓.
4. Lerato ensured the validity of the investigation …
   by using the same plant species ✓
   by placing the shoots the same distance from the lamp ✓
   by ensuring that the shoots were both exposed to unilateral light ✓
   by ensuring that both shoots were exposed to the light for the same length of time ✓
5. The reliability of the investigation can be improved by …
   repeating the investigation ✓
   increasing the number of shoots used for each setup ✓
   increasing the period of the investigation ✓

(16)

Activity 2: Geotropism

1. Geotropism ✓
2. Geotropism is the growth of a plant in response to gravity ✓.
3. The role of auxins in geotropism
   - When the root is placed horizontally, the auxin concentration will be high on the lower side of the root ✓
   - gravity attracts auxins ✓
   - More growth occurs on the upper side of the root ✓
   - because auxins on the lower side inhibit growth ✓
   - As a result the upper side of the root grows faster ✓
   - causing the root to bend downwards ✓

(8)

Chapter 9: Evolution by natural selection

Activity 1: Natural selection

Question 1

1.1 By ensuring that both ponds in an experiment have identical ✓ environmental conditions ✓ ; by ensuring that there were equal numbers ✓ of predatory fish in both ponds ✓ (any one correct answer)

1.2 a) the type of predators ✓

b) average number of spots on each male guppy ✓

1.3 as a control ✓ , to compare the results between the ponds

to ensure that any changes that occurred ✓ were due to the presence of predators ✓ and not other environmental factors.

1.4 there is variation ✓ amongst the male guppies

some have more spots ✓ while others have fewer spots ✓

the ones that have more spots attract predators ✓ and are eaten ✓ by the predators.

the ones with fewer spots survived ✓ and reproduced to pass the gene for fewer spots on to the next generation ✓ (any five)

Question 2

2.1 Those that will benefit an organism and make it more successful ✓

2.2 Selective forces ✓

2.3 It provides a mechanism for evolution ✓ , explaining that animals are able to change to a changing environment and that these small changes over time can result in a new species being formed ✓ that is different to ancestral species.

2.4 The environment actively selects ✓ which organisms are best suited to their environment ✓ . The ways by which variation arises in a population may be random but natural selection is a very selective process.

2.5 a) The dark coloured mice ✓ – they will be difficult to spot in the dark ✓ as they will be well camoflauged at night ✓ in their surroundings

b) The light coloured mice ✓ – lighter colours absorb less heat than darker colours ✓ . Darker coloured mice will absorb more heat and therefore will be more “visible” to the snake ✓ .

Question 3

3.1 Direct relationship ✓

3.2 As the air pollution decreased over time, the percentage of dark coloured moths

also decreased ✓

3.3 The pollution caused a black ash to cover the lichen on the birch trees which made the light coloured moths more visible to predators ✓ and therefore the population numbers would decrease as predation increased ✓ .

3.4 The light coloured moth population would have increases since lower pollution levels resulted in less ash on the birch trees, allowing the lichen to grow again ✓ . Lighter coloured moths are more difficult to see on a light background and so would not be predated upon ✓.

(30)

Activity 2: Punctuated equilibrium

1. a) No evolutionary change takes place in phase A ✓ – the species is in equilibrium with its environment ✓.

   b) Phase B points to an accelerated evolutionary change ✓ due to rapid environmental changes ✓.

2. Punctuated equilibrium ✓

3. During phase B, species with advantageous characteristics, i.e. suitable to the new environment, survive and reproduce. ✓ Species that do not have advantageous characteristics die out. Thus the chances of speciation during phase B are much greater than during phase A .

(7)

Activity 3: Theories of evolution

1. a) The more a part was used, the larger and more dominant the trait became – the Law of Use and Disuse ✓ .

   Acquired changes were passed down to offspring – Law of Inheritance of Acquired characteristics ✓

   b) Lamarck's ideas were rejected since he suggested that the acquired characteristic which an organism gained through its life experience was transferred to it's offspring, which is not possible, since the acquired characteristic does not bring any change to an individuals set of genes ✓ .

   c) No ✓ , it laid the foundation that traits could be passed on to offspring and he attempted to explain how and why species had changed from those in the fossil record ✓ .

2. a) four observations
   - Populations can produce far more offspring than needed ✓
   - Sizes of most natural population and resources remain relatively constant ✓ .
   - Natural variation of characteristics among members of the same species

are evident ✓

- Some characteristics are inherited and so are passed on to the next generation ✓

b)

Organisms produce a large number of offspring ✓ .

There is a lot of variation among offspring as offspring differ from their parents in minor random ways – for example, in the length of their necks ✓ .

The offspring with traits / characteristics that make them better suited to the environment – i.e. with long necks to get to food sources others can't get to – will be most likely to survive and reproduce ✓ .

The organisms without the trait are less able to get to the food and so will die ✓ .

This means that more offspring in the next generation will have longer necks, a helpful difference. The next generation will have a higher proportion of individuals with the new trait – long necks ✓ .

These differences – the long necks – accumulate and eventually all individuals in a population have the new trait ✓

Over time, together with other minor changes, this process leads to an entirely new species and evolution by natural selection will have take place ✓ .

c) any two …

Lamarckism	**Darwinism**
Members of a population are all the same ✓	Natural variation within the same population ✓
Individuals are able to transform during a life time ✓	Populations transform over time and only through genetic means ✓
Individual chooses which traits to pass on to offspring; changes are directed to meet survival ✓	Natural selection – the environment is the selective pressure causing change ✓

3. a) Darwin b) Both c) Lamarck d) Lamarck

✓ - for each correct answer

(25)

Activity 4: Speciation

Question 1

1.1 the formation of a new species ✓ ✓

1.2 A group of organisms ✓ that are closely related to each other ✓ , and are able to interbreed and produce viable offspring ✓

1.3 Allopatric speciation or geographic speciation ✓ ✓

2.1 False – causes populations to diverge ✓ ✓

2.2 True ✓ ✓

2.3 False – they will differ from ancestral species ✓ ✓

2.4 True ✓ ✓

Question 2

1.1 a) Tortoise 2 ✓

b) Tortoise 1 ✓

1.2

- The ancestral tortoise population was separated by a geographic barrier (the ocean) as they were found on the mainland and an islands ✓
- There was no gene flow between the populations ✓
- Each population was exposed to different climatic conditions and different vegetation types, so that natural selection occurs independently in both populations ✓
- The individuals in the populations become very different to each other both in their genes (genotypically) and their appearance (phenotypically) ✓
- Even if the populations were to mix again, they will not be able to reproduce with one another ✓ , since they are now two different species.

1.3 crossing over during Prophase I of meiosis ✓ ; the random arrangement of maternal and paternal chromosomes ✓ ; random fertilisation of egg cells ✓ ; random mating ✓

(26)

Activity 5: Artificial selection and domestication

Question 1

1.1 any four, one mark ✓ each

- produce disease resistant crops
- improve yield of crops
- adapt old crops to grow in adverse conditions
- develop special breeds for particular purposes
- enhance nutritional value and flavour of crops

1.2 one mark for table, one each per correct answer.

	Artificial selection	**Natural Selection**
Driven by...	man ✓	nature ✓
Rate of change...	faster ✓	slower ✓
Amount of variation achieved	less ✓	more ✓
End result	improved crops and livestock ✓	suitable to changed environment ✓

1.3 a) the selecting and breeding of organisms ✓ with desirable characteristics ✓

b) maize (*Zea mays*) ✓

c) any two: reduced covering of the seed ✓ ; retention of seeds (kernels) on the cob ✓ ; erect habit with a single stalk ✓ ; larger ear structure ✓

Question 2

2.1 True 2.2 False 2.3 True 2.4 False 2.5 False

2.6 False - one mark ✓ per correct answer

(24)

Chapter 10: Human evolution

Activity 1: Phylogenetic trees

1. The Order Primates ✓ and the Family Hominidae ✓
2. Gorillas, chimpanzees, orangutans, bonobos ✓✓ any two
3. About 10 million years ago ✓
4. Hominids are members of the Family Hominidae ✓ and include humans and early humans, chimpanzees, bonobos, gorillas and orangutans ✓ .

   Hominins form a sub-group (tribe) within the Family Hominidae ✓ , and include only modern humans and early human ancestors ✓ .
5. B ✓✓
6. a) a branching diagram or "tree" ✓ showing the evolutionary relationships among various biological species ✓ .

   b) *Australopithecus afarensis* ✓

   c) *Homo sapiens* ✓

   d) *Homo habilis* ✓ , *Australopithecus africanus* ✓ and *Homo erectus* ✓ (any two)

   e) *Homo sapiens*: emerges around 0,5 mya ✓ ; *Homo erectus* emerged around 1,8 mya ✓ . Time difference = 1,8 – 0,5 = 1,3 million years ago ✓ .

   f) *Homo erectus* ✓ (21)

Activity 2: Anatomical differences and similarities between African apes and modern humans

1. Shared characteristics: Large brain, eyes in front of head, opposable thumbs, bare fingertips / nails instead of claws, upright posture, freely rotating arms, sexual dimorphism ✓ for any five

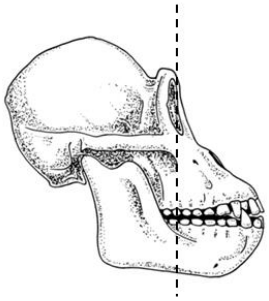
   Differences (human vs chimpanzee): Forward vs backward position of foramen magnum, curved vs straighter spine, short, wide vs long, narrow pelvis, no vs prominent brow ridges, C-shaped or semi-circular vs long, rectangular palate, small vs large canines, orthognathic vs prognathous jaws ✓ for any three .
2. The thumb is opposable if it can touch and exert pressure on the finger pad of another finger ✓ on the same hand ✓ .
3. Bipedalism or habitual bipedalism is the ability to stand erect and walk comfortably on two feet ✓ , placing one foot in front of the other, slight apart ✓ . It is more than simply standing on two feet ✓ – many animals can do that for a short period.
4. ✓ for any four: Hands are free to pick or carry food, to use tools or weapons; Standing upright, with eyes higher off the ground, gives a better and wider view

of surroundings, a timelier warning of approaching predators or of potential prey; Movement becomes easier and more energy-efficient; A more vertical posture reduces the body's exposure to sunlight when in an open area; In courtship behaviour, the male sex organ is readily displayed.

5. Binocular vision: having two eyes ✓ in the front of the head ✓ to view an object. Depth perception is a function of the brain ✓ that interprets what the eyes see and recognises shape, distance, etc. ✓ – this is known as stereoscopic vision.

6. prognathous means protruding, as in sketch, the jaws of the chimpanzee skull extend far beyond the vertical line running through the eye-socket.

   ✓ - for sketch, ✓✓ - showing jaws protruding



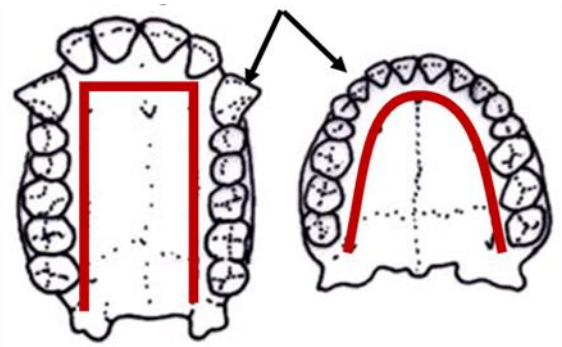
7. Diagram illustrating the evolution of palate shape ✓✓✓

   change in canines ✓

   Smaller human teeth ✓

   Changing palate shape ✓

Canines – humans canines differ



Changing palate shape

Humans have smaller teeth generally

Chimpanzee vs human palate

8. a) foramen magnum ✓

   b) Species B ✓ . When walking as quadruped, on all fours, the back is almost horizontal ✓ . To look forward comfortably, the spine needs to go into the skull towards the back of the base ✓ .

   c) ✓ - for table, each observable difference – any four

	Skull A (human)	**Skull B (gorilla)**
Brain size	large	Much smaller
Jaws	Orthognathous / flat face	Prognathous
Teeth	Small, small canines	Large, large canines

Cranial ridge	none	Present
Brow ridge	none	prominent

d) The larger the cranium ✓ , the larger the brain is can house / accommodate ✓ . A larger brain suggests greater intelligence ✓ .

9. a) A ✓

b) The pelvis is A is shorter and wider (more cup-shaped) than the pelvis in B ✓ . It is better able to support the weight of vertically stacked organs ✓ , as in a human.

c) The shape of the pelvis in A and the direction of the hip socket angle the femur inwards ✓ for maximum load bearing and an efficient, comfortable bipedal gait ✓ .

(47)

Activity 3: Fossil evidence

1. While numerous fossils have been found, most have only been discovered in the last 50 years or so. Every fossil find requires study and interpretation, to find out how it fits into the overall picture ✓ . This is not an easy task, particularly if you have few pieces of the puzzle ✓ . New discoveries can change our understanding radically, as has happened in the past already.
2. a) Brow ridge , strongly projecting upper jaw bone , smaller cranium / brain size ✓ - for any three

   b) the size of the cranium ✓ ✓

   c) by Robert Broom ✓ , in 1947, near Sterkfontein ✓

   d) *Australopithecus africanus* ✓ , lived in Africa between 3,2 and 2 million years ago ✓

   e) Extinct means to no longer exist. No member of the species is still alive ✓ .
3. The genus *Australopithecus* lived on Earth between 4 and 1,2 million years ago – a total of 2,8 million years ✓ , much longer than the genus *Homo* (about 2,2 million years) ✓ , and very much longer than the *Homo sapiens* species (200 000 years) ✓ . The genus *Ardipithecus* probably lived for about 1,5 million years.
4. *Australopithecus afarensis* ✓ : 3,9 – 2,8 million years ago ✓ , Lucy – discovered 1974 ✓ , by Donald Johansen at Hadar, Ethiopia ✓

   Australopithecus africanus ✓ : 3,2 – 2 million years ago ✓ , Taung child – discovered by Raymond Dart in 1924 ✓ , at Taung, North West Province, South Africa ✓ .

   Australopithecus sediba ✓ : 2 – 1,7 million years ago ✓ , Karabo – discovered in 2009 ✓ , by Lee Berger, at Malapa, South Africa ✓ .
5. Cranium size / brain size ✓ : *Ardipithecus* had a smaller brain size (350 mL as against 435 – 530 mL) ✓

   The position of the foramen magnum ✓ : for *Ardipithecus*, it would not be as forward as for *Australopithecus* ✓ .

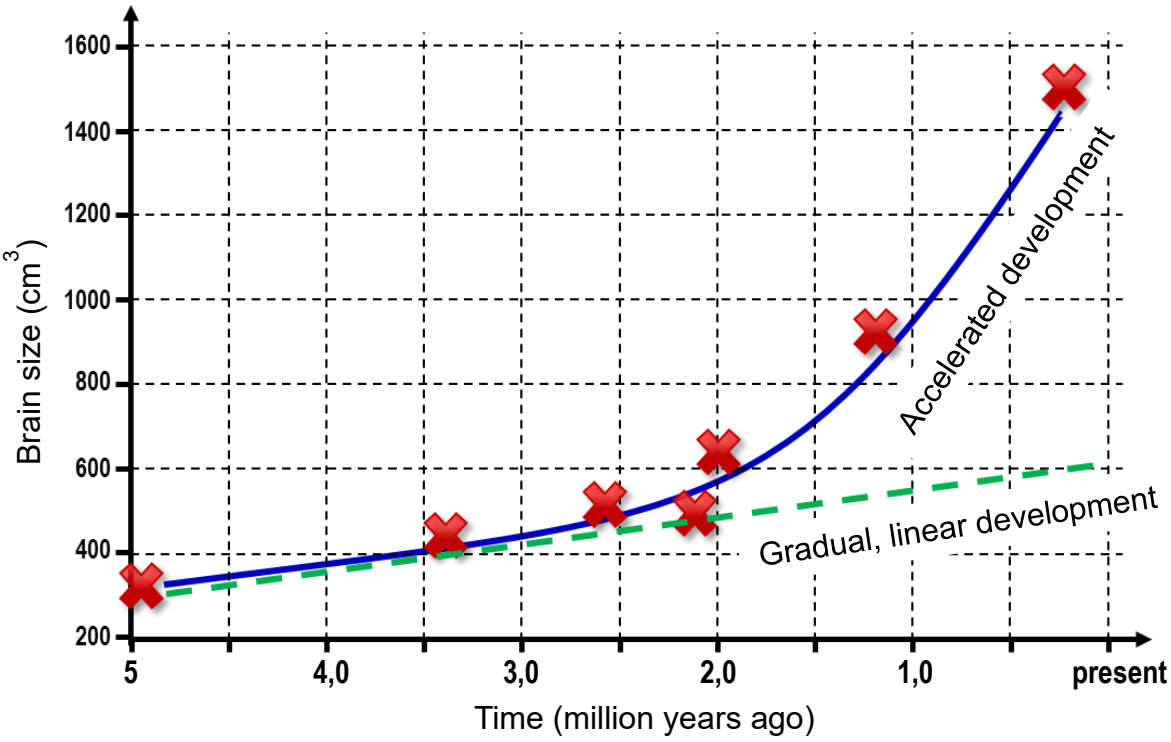
Considering the dentition, examine palate shape, and the size of canines ✓ .
Australopithecus would have a slightly rounder arch ✓ .

The size of the canines ✓ : larger in *Ardipithecus* than in *Australopithecus* ✓

6. a) 1 – *A. afarensis*, 2 – *A. robustus*, 3 – *H. habilis*, 4 – *H. erectus*, 5 – *H. sapiens* – one mark ✓ for each correct specification

b) Brain size: the larger the brain, the further the species in the stage of evolution, generally speaking; brow ridges / the shape of the forehead / how prognathous the jaw is / the size of the jaw – one mark ✓ for each correct specification

7.



Conclusion: the initial brain size development is slow, and then speeds up exponentially as one approaches the present. ✓ ✓

(this is clearly illustrated by the two lines of best fit drawn through the scatter plots: the line representing a gradual, more linear brain size development, and the line showing accelerated development)

✓✓ - for correctly drawn graph – scatter plot, position of dots/crosses
✓✓ - for correct labelling, axes

8. a) phylogenetic tree ✓

b) two genera *Australopithecus, Homo* ✓ and seven species ✓

c) *A.robustus* and *A. boisei* share a more recent common ancestor ✓✓

(57)

Activity 4: Out of Africa hypothesis

1. All modern humans (*Homo sapiens*) ✓ originated in Africa ✓ and migrated to other parts of the world ✓

2. It is a hypothesis, since it relies on currently available fossil evidence that has been studied and from which relationships etc. are inferred ✓ . Fossil evidence yet to be discovered can contradict the presently generally accepted Out of Africa hypothesis ✓ . This has happened a few times in the past. Some scientists argue for a multi-regional origin ✓ . A theory is more definitive than a hypothesis ✓ , hence the Out of Africa hypothesis, not theory.

3. Genetic evidence ✓ – mitochondrial DNA is inherited from the mother ✓ . Analysis of mutations / markers on the mtDNA shows the oldest female ancestors ✓ were living in Africa ✓ , and that all currently living humans are descended from her ✓ .

   Fossil evidence ✓ – the fossils for *Ardipithecus*, for *Australopithecus* and for *Homo habilis*, have been found only in Africa ✓ . The oldest *Homo erectus* fossil ✓ and the oldest *Homo sapiens* fossil ✓ have also been found in Africa.

4. Mitochondrial DNA is the small circular chromosome ✓ found inside mitochondria ✓ . The mitochondria, and thus mitochondrial DNA, are passed only from mother to offspring through the egg cell ✓ .

5. Scientists look for mutations in the mtDNA ✓ . The mutations (called markers) occur at a steady and known rate ✓ . Those with the greatest number of markers are the oldest human populations (all from Africa) ✓ . Comparing markers allows scientists also to determined when populations separated from each other ✓ .

6. The importance of the Cradle of Humankind derives from the abundance of hominin fossil (40% of all world-wide) ✓ found here. The fossil species found only here ✓ : *Australopithecus africanus, Paranthropus* ✓ . The first African fossils of *Homo erectus* were found here ✓ .

7. Makapansgat Valley ✓ : this cave complex has a significant fossil record, and 40 individuals of the species *A. africanus* that is only found in South Africa ✓ .

   Florisbad ✓ : an almost complete skull of an early *Homo sapiens* (or of *H. heidelbergensis*) – with a cranial volume of 1400 mL – was found there ✓ .

(31)

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Chapter 1: DNA – The code of life

1. GMMDC construction
2. Designua, Shutterstock 781948435
3. Mind the Gap, Life Sciences, Grade 12, Figure 1.1
4. 4A: Adapted – Udaix, Shutterstock 108604994; 4B: Mind the Gap, Life Sciences, Grade 12, Figure 1.2
5. 5A and 5B – GMMDC construction
   Activity 1: GMMDC construction – adapted from DBE Life Sciences Past Paper, 2017, Paper 2
6. Mind the Gap, Life Sciences, Grade 12, Figure 1.2
7. 7A to 7E: GMMDC construction
   Activity 2: GMMDC construction – adapted from DBE Life Sciences Past Paper, 2016, September Paper 2
8. GMMDC construction
   Activity 3: GMMDC construction – adapted from DBE Life Sciences Past Paper, 2016, September Paper 2
9. GMMDC construction
10. GMMDC construction
11. GMMDC construction
12. GMMDC construction
    Activity 4: adapted from DBE Life Sciences Past Paper, 2017, Paper 2

Chapter 2: Meiosis

Key terminology diagrams: GMMDC construction,

1. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
2. GMMDC construction
3. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
4. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
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6. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
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8. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
9. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
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11. GMMDC construction
12. GMMDC construction – adapted from Dreamy Girl, Shutterstock, 566585809
    Activity 1: Mind the Gap, Life Sciences, Grade 12, Figures 2.4 and 2.7
13. Mind the Gap, Life Sciences, Grade 12, Figure 2.10
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15. GMMDC construction

Chapter 3: Reproductive strategies in vertebrates

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   Activity 2: GMMDC construction
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Chapter 4: Human reproduction

1. GMMDC construction
2. GMMDC construction
3. GMMDC construction
4. GMMDC construction

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12. Steve Cymro, Shutterstock, 332191181
13. GMMDC construction

Chapter 5: Genetics and inheritance

Table 1 diagrams: GMMDC constructions
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   Activity 1: GMMDC construction
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   Table 2 diagrams: Mariana Ruiz, Wikipedia, CC0
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    Activity 7: GMMDC constructions
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16. Studio BKK, Shutterstock, 1120881782
17. NordNordWest, Wikipedia, CC0

Chapter 6: Human responses to the environment

1. GMMDC construction
2. GMMDC construction
3. GMMDC construction
4. CNX OpenStax, Wikipedia, CC BY 4.0
   Activity 1: GMMDC construction – adapted from dumielauxepices.net
5. GMMDC construction
6. 6A, 6B, 6C – GMMDC constructions
7. Joshya, Shutterstock, 203105053 – adapted
   Activity 2: GMMDC construction
8. GMMDC construction
   Activity 3: GMMDC construction
9. Designua, Shutterstock, 685689190 – adapted
10. GMMDC construction
11. A and B: Mind the Gap, Life Sciences, Grade 12, 6.8 and 6.9 – adapted
12. A and B: Mind the Gap, Life Sciences, Grade 12, 6.10 and 6.11 – adapted
13. A and B: Гуменюк И.С, Wikipedia, CC BY SA 4.0 – adapted
14. A and B: Gumenyuk, I.S., Wikipedia, CC BY-SA 4.0 – adapted
15. A and B: BruceBlaus, Wikipedia, CC BY-SA 4.0 – adapted
16. A and B: BruceBlaus, Wikipedia, CC BY-SA 4.0 – adapted
    Activity 6: Lookafteryoureyes.org – CC BY-SA 4.0 – adapted
    DBE, Life Sciences Past Paper, September 2017, Paper 2
17. Adapted from Divers Alert Network, Anatomy of the Ear
18. GMMDC construction
19. GMMDC construction
20. GMMDC construction
21. Blamb, Shutterstock, 23857687 – adapted GMMDC
22. GMMDC construction – with Blamb, Shutterstock, 23857687
23. GMMDC construction – adapted from Sakurra, Shutterstock, 737695282, and Alila Medical Media, Shutterstock, 98133092
24. GMMDC construction
25. A and B: GMMDC construction

26. GMMDC construction
27. Maxx-Studio, Shutterstock, 699866578
28. Family Hearing, Wikipedia, CC BY-SA 4.0
    Activity 9: GMMDC construction

Chapter 7: The human endocrine system and homeostatis

1. Aldona Griskeviciene, Shutterstock, 1088531576
2. Aldona Griskeviciene, Shutterstock, 1088531576
3. Mind the Gap, Life Sciences, Grade 12, 7.1 – adapted
4. GMMDC construction – adapted from BruceBlaus, Wikipedia, CC BY 3.0 and MEpedia, CC BY-SA 4.0
   Table 2 diagrams: adapted from Tefi, Shutterstock, 323959508; Vecton, Shutterstock, 661087420; Tefi, Shutterstock, 67846957
5. Designua, Shutterstock, 189761837
6. A and B: Tefi, Shutterstock, 67846957; Tefi, Shutterstock, 323959508 – adapted
   Activity 1: Double Brain, Shutterstock, 686764972
7. GMMDC construction
8. GMMDC construction – adapted from Mind the Gap, Life Sciences, Grade 12, 8.2
9. GMMDC construction – adapted from Mind the Gap, Life Sciences, Grade 12, 8.3
10. GMMDC construction – adapted from Mind the Gap, Life Sciences, Grade 12
11. Alila Medical Media, Shutterstock, 147789425
12. GMMDC construction – adapted from Designua, Shutterstock, 281113787
13. Claire Moore, Wikipedia, CC0
14. GMMDC construction – adapted from Mind the Gap, Life Sciences, Grade 12, Section 7.2.2
15. Earl, Flickr.com, CC BY-NC-SA 2.0
16. A: Designua, Shutterstock, 292833791; B: Karen Bunjean, Shutterstock, 655176013; C: Healthcop – Cretinism; D: pcds.org, CC BY-NC-SA 3.0
17. A and B: GMMDC constructions – adapted from Joshya, Shutterstock, 182603222
18. CNX OpenStax, Wikipedia, CC BY 3.0
19. GMMDC construction – adapted from Blamb, Shutterstock, 327769451

Chapter 8: Plant responses to the environment

1. A, B and C: GMMDC constructions
   Activity 1: GMMDC construction
2. GMMDC construction – adapted from Disqus, Biology Notes for IGCSE.
3. Designua, Shutterstock, 387248392
   Activity 2: GMMDC construction
4. A: Manthri, Anusha, Shutterstock, 1179337225; B: Fabrizio Only, Shutterstock, 60095335; C: Pixabay, CC0

Chapter 9: Evolution by natural selection

1. Charles Thevenin, Wikipedia, CC0
2. GMMDC construction – adapted from Linnean Learning – Twitter, CC BY-SA 3.0
3. Leonard Darwin, Wikipedia, CC0
4. Chavez, Miguel, Wikipedia, CC0
5. GMMDC construction
6. GMMDC construction
7. GMMDC construction – adapted from Wikipedia, CC0
8. John Doebley, Wikipedia, CC BY 2.5
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Chapter 10: Human evolution

1. GMMDC construction
2. GMMDC construction – in order, left to right: Pixabay, CC0; DataBase Center for Life Sciences, CC BY 4.0; Aspen Photo, Shutterstock, 170032571; CC0; Dutch Designs, CC0; Pixabay CC0
3. GMMDC construction

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5. Africa Studio, Shutterstock, 357498392
6. Eric Isselee, Shutterstock, 30906931
7. Eric Gevaert, Shutterstock, 11497138
8. A: Mariait, Shutterstock, 264973217; B: YWD, Walking man png, CC0; C: Eric Isselee, Shutterstock, 51124108
9. NoPainNoGain, Shutterstock, 342125462
10. A and B: Bastian Groscurth, Shutterstock, 463116554
11. A and B: adapted from Henry vandyke Carter, Wikipedia, CC0; Kenan Taylor, Milne Publishing, CC BY-SA 3.0
12. A and B: Helen Beare, Australian Museum, CC BY-NC-SA 4.0
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14. Adapted from Beth Blaxland, Fran Dorey, Australian Museum, CC BY-SA 4.0
15. Nrkpan, Wikipedia, CC BY-SA 3.0
    Activity 2: Mind the Gap, Life Sciences, Grade 12, 10.9
16. GMMDC construction
17. Tiia Monto, Wikipedia, CC BY-SA 3.0
18. En rouge, Wikipedia, CC BY-SA 3.0
19. D. Pietras, Wikipedia, CC BY-SA 4.0; GMMDC construction
20. José-Manuel Benito Alvarez, Wikipedia, CC0; adapted – J. Braga, Wikipedia, CC BY-SA 4.0; Brett Eloff, Wikipedia, CC BY-SA 4.0
21. José-Manuel Benito Alvarez, Wikipedia, CC0; Thomas Roche, Wikipedia, CC BY-SA 2.0; Fran Dorey, Australian Museum, CC BY-NC-SA 3.0
22. Mind the Gap, Life Sciences, Grade 12, 10.10
23. GMMDC construction
24. David Bokuchava, Shutterstock, 1007000509; Vincent St. Thomas, Shutterstock, 235455565
25. GMMDC construction – adapted from José-Manuel Benito Alvarez, Wikipedia, CC BY-SA 2.5 and CC0; Adam Benton, filthymonkeymen.com, “Human ancestors used tools earlier than previously thought”, CC BY-SA 3.0.
26. EcoPrint, Shutterstock, 104024036 and 695073016
    Activity 3: Usagi-P, Shutterstock, 290914883
27. GMMDC construction – adapted from Crates, Wikipedia, CC BY-SA 4.0
28. National Human Genome Research Institute, Wikipedia, CC0
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31. GMMDC construction – adapted using Andreas 06, Wikipedia, CC0.