INTEGRATED SCIENCES

STUDENT'S BOOK

FOR TTCs

3

OPTIONS: Languages Education (LE)

&

Social Studies Education (SSE)

FOREWORD

Dear Student- teacher,

Rwanda Basic Education Board is honoured to present to you this Integrated Science book for Year Three of Languages Education **(LE)** and Social Studies Education **(SSE)** Options which serves as a guide to competence-based teaching and learning to ensure consistency and coherence in the learning of Biology subject. The Rwandan educational philosophy is to ensure that you achieve full potential at every level of education which will prepare you to be well integrated in society and exploit employment opportunities.

The government of Rwanda emphasizes the importance of aligning teaching and learning materials with the syllabus to facilitate your learning process. Many factors influence what you learn, how well you learn and the competences you acquire. Those factors include the instructional materials available among others. Special attention was paid to the activities that facilitate the learning process in which you can develop your ideas and make new discoveries during concrete activities carried out individually or with peers.

In competence-based curriculum, learning is considered as a process of active building and developing knowledge and meanings by the learner where concepts are mainly introduced by an activity, a situation or a scenario that helps the learner to construct knowledge, develop skills and acquire positive attitudes and values. For effective use of this textbook, your role is to:

- Work on given activities including laboratory experiments which lead to the development of skills;
- Share relevant information with other learners through presentations, discussions, group work and other active learning techniques such as role play, case studies, investigation and research in the library, from the internet or from your community;
- Participate and take responsibility for your own learning;
- Draw conclusions based on the findings from the learning activities.

I wish to sincerely extend my appreciation to the people who contributed towards the development of this book, particularly REB staff who organized the whole process from its inception. Special gratitude goes to teachers, illustrators and designers who diligently worked to successful completion of this book.

Dr. MBARUSHIMANA Nelson

Director General of Rwanda Basic Education Board

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I owe gratitude to different Universities and schools in Rwanda that allowed their staff to work with REB in the in-house textbooks production project. I wish to extend my sincere gratitude to lecturers, teachers, tutors, illustrators, designers and all other individuals whose efforts in one way or the other contributed to the success of writing of this textbook.

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Joan MURUNGI,

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UNIT 1

BASIC BIOCHEMISTRY OF LIFE

Key Unit Competence:

Explain the cellular respiration and photosynthesis

Introductory activity 1

Observe the person in the picture below who is making physical exercise and attempt the following questions:

i) Where is the energy used by the person in the picture come from?

ii) Why do all living organisms need a continuous supply of energy?

iii) Identify the process exhibited by the person on the picture that consumes too much energy if compared with another one who is at rest.

iv) How is the energy produced in our body? Does energy being produced in our body serve for our various activities? If yes, how?

All living organisms require a continuous supply of energy to stay alive, either from the absorption of light energy or from chemical potential energy (energy stored in nutrient molecules). The process of photosynthesis transfers light energy to chemical potential energy, and so almost all life on Earth depends on photosynthesis, either directly or indirectly. Photosynthesis supplies living organisms with two essential requirements: an energy supply and usable carbon compounds.

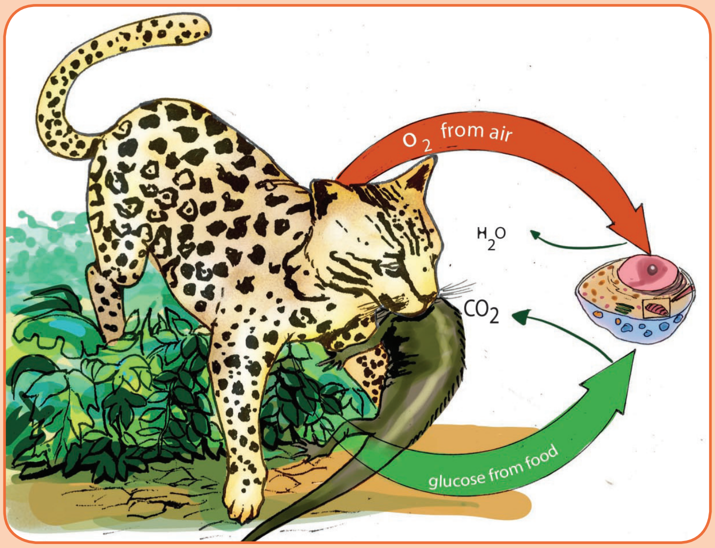
All biological macromolecules such as carbohydrates, lipids, proteins and nucleic acids contain carbon. All living organisms therefore need a source of carbon. Organisms that can use an inorganic carbon source in the form of carbon dioxide are called **autotrophs**. Those needing a ready-made organic supply of carbon are **heterotrophs**.

Organic molecules can be used by living organisms in two ways. They can serve as 'building bricks' for making other organic molecules that are essential to the organism, and they can represent chemical potential energy that can be released by breaking down the molecules in respiration. This energy can then be used for all forms of work. **Heterotrophs** depend on **autotrophs** for both materials and energy.

1.1. Cellular respiration

Activity 1.1

1. When an ocelot breathes, it acquires oxygen, and when it feeds on a lizard, it acquires glucose. Both molecules enter its bloodstream and are carried to the body's cells, where there is a specific biological process which uses both oxygen and glucose.



2. Which biological process is represented in the figure above? Where does that process take place in the organism? In a eukaryotic cell?

i) Where does the biological process mentioned above take place in the cell?

ii) Write the chemical equation of that biological process.

iii) The equation written in (iii) above is described in four steps. Conduct research from the library textbooks or search engine to explain:

- How is pyruvate formed from sugar/glucose?
- What is the role of Coenzyme A in the link reaction?
- What is the role of reduced NAD^+ and FAD in the Krebs cycle?
- What is the final acceptor of protons and electrons in the respiratory chain?

2. Yeast, sugar, water and flour are the main components in bread making

a) Why do bakers add yeast to flour and water when making bread?

b) When yeast is added to grape juice at room temperature, vigorous bubbling occurs. What gas produces the bubbles?

c) What type of beverage is produced by this process?

d) What is the name of this process?

Cellular respiration is a set of metabolic reactions and processes that take place in the cells of organisms to convert biochemical energy from nutrients into adenosine triphosphate (ATP), and then release waste products.

Cellular respiration is the complex process in which cells make adenosine triphosphate (ATP) by breaking down organic molecules. The energy stored in ATP can then be used to drive processes requiring energy, including biosynthesis, locomotion or transportation of molecules across cell membranes. The main fuel for most cells is carbohydrate, usually glucose which is used by most of the cells as respiratory substrate. Some other cells are able to break down fatty acids, glycerol and amino acids.

There are two types of cellular respiration, aerobic and anaerobic. Aerobic respiration is more efficient and can be utilized in the presence of oxygen, while anaerobic respiration does not require oxygen. Many organisms (or cells) will use aerobic respiration primarily, however, if there is a limited oxygen supply, they can utilize anaerobic respiration for survival.

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,H_2O + 6\,CO_2 + 32\,ATP$$

The breakdown of glucose can be divided into four stages: glycolysis, the link reaction, the Krebs cycle and oxidative phosphorylation.

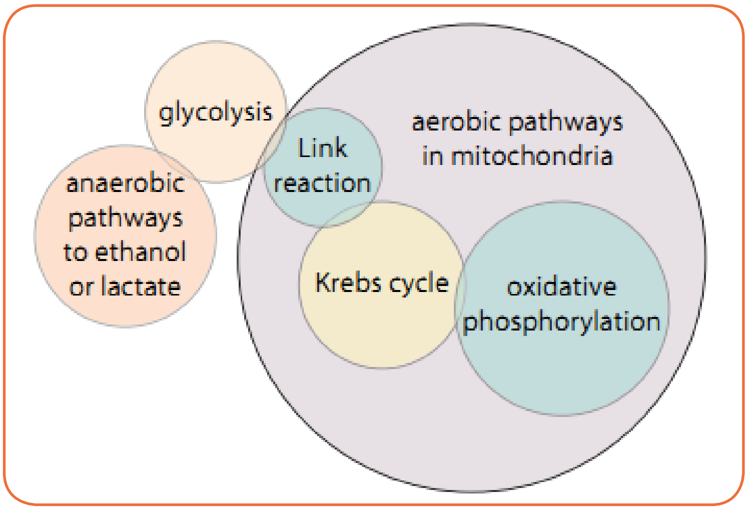


Figure 1.1. The sequence of events in respiration

1.1.1. Glycolysis

Glycolysis is the splitting, or lysis, of glucose. It is a multi-step process in which a glucose molecule with six carbon atoms is eventually split into two molecules of pyruvate, each with three carbon atoms. Energy from ATP is needed in the first steps, but energy is released in later steps, when it can be used to make ATP. There is a net gain of two ATP molecules per molecule of glucose broken down. Glycolysis takes place in the cytoplasm of a cell.

In the first stage, phosphorylation, glucose is phosphorylated using ATP. Glucose is energy-rich but does not react easily. To tap the bond energy of glucose, energy must first be used to make the reaction easier. Two ATP molecules are used for each molecule of glucose to make first glucose phosphate, then fructose phosphate, then fructose bisphosphate, which breaks down to produce two molecules of triose phosphate.

Hydrogen is then removed from triose phosphate and transferred to the carrier molecule NAD (nicotinamide adenine dinucleotide). Two molecules of reduced NAD are produced for each molecule of glucose entering glycolysis.

The hydrogens carried by reduced NAD can easily be transferred to other molecules and are used in oxidative phosphorylation to generate ATP.

The end-product of glycolysis, pyruvate, still contains a great deal of chemical potential energy. When free oxygen is available, some of this energy can be released via the Krebs cycle and oxidative phosphorylation. However, the pyruvate first enters the link reaction, which takes place in the mitochondria.

1.1.2. Link reaction

Pyruvate passes by active transport from the cytoplasm, through the outer and inner membranes of a mitochondrion and into the mitochondrial matrix. Here it is decarboxylated (this means that carbon dioxide is removed), dehydrogenated (hydrogen is removed) and combined with coenzyme A (CoA) to give acetyl coenzyme A. This is known as the link reaction

Coenzyme A is a complex molecule composed of a nucleoside (adenine plus ribose) with a vitamin (pantothenic acid), and acts as a carrier of acetyl groups to the Krebs cycle. The hydrogen removed from pyruvate is transferred to NAD.

Fatty acids from fat metabolism may also be used to produce acetyl coenzyme A. Fatty acids are broken down in the mitochondrion in a cycle of reactions in which each turn of the cycle shortens the fatty acid chain by a two-carbon acetyl unit. Each of these can react with coenzyme A to produce acetyl coenzyme A, which, like that produced from pyruvate, now enters the Krebs cycle.

1.1.3. The Krebs cycle

The **Krebs cycle** (also known as the citric acid cycle or tricarboxylic acid cycle) was discovered in 1937 by Hans Krebs.

The Krebs cycle is a closed pathway of enzyme-controlled reactions.

- Acetyl coenzyme A combines with a four-carbon compound (oxaloacetate) to form a six-carbon compound (citrate).
- The citrate is decarboxylated and dehydrogenated in a series of steps, to yield carbon dioxide, which is given off as a waste gas and hydrogens which are accepted by the carriers NAD and FAD.
- Oxaloacetate is regenerated to combine with another acetyl coenzyme A. For each turn of the cycle, two carbon dioxide molecules are produced, one FAD and three NAD molecules are reduced, and one ATP molecule is generated via an intermediate compound.

Although part of aerobic respiration, the reactions of the Krebs cycle make no use of molecular oxygen.

However, oxygen is necessary for the final stage of aerobic respiration, which is called oxidative phosphorylation. The most important contribution of the Krebs cycle to the cell's energetics is the release of hydrogens, which can be used in oxidative phosphorylation to provide energy to make ATP.

1.1.4. Oxidative phosphorylation and the electron transport chain

In the final stage of aerobic respiration, **oxidative phosphorylation**, the energy for the phosphorylation of ADP to ATP comes from the activity of the **electron transport chain**. Oxidative phosphorylation takes place in the inner mitochondrial membrane.

Reduced NAD and reduced FAD are passed to the electron transport chain. Here, the hydrogens are removed from the two hydrogen carriers and each is split into its constituent proton (H^+) and electron (e^-). The energetic electron is transferred to the first of a series of electron carriers.

Most of the carriers are associated with membrane proteins, of which there are four types. A functional unit, called a respiratory complex, consists of one of each of these proteins, arranged in such a way that electrons can be passed from one to another down an energy gradient.

As an electron moves from one carrier at a higher energy level to another one at a lower level, energy is released. Some of this energy is used to move protons from the matrix of the mitochondrion into the space between the inner and outer membranes of the mitochondrial envelope. This produces a higher concentration of protons in the intermembrane space than in the matrix, setting up a concentration gradient.

Now, protons pass back into the mitochondrial matrix through protein channels in the inner membrane, moving down their concentration gradient. Associated with each channel is the enzyme ATP synthase. As the protons pass through the channel, their electrical potential energy is used to synthesise ATP in the process called **chemiosmosis**.

Finally, oxygen has a role to play as the final electron acceptor. In the mitochondrial matrix, an electron and a proton are transferred to oxygen, reducing it to water. The process of aerobic respiration is complete.

The sequence of events in respiration and their sites are shown in **Figure 1.1**. The balance sheet of ATP used and synthesised for each molecule of glucose entering the respiration pathway is shown in **Table 1.1.**

Theoretically, three molecules of ATP can be produced from each molecule of reduced NAD, and two molecules of ATP from each molecule of reduced FAD. However, this yield cannot be achieved unless ADP and Pi are available inside the mitochondrion. About 25% of the total energy yield of electron transfer is used to transport ADP into the mitochondrion and ATP into the cytoplasm.

Hence, each reduced NAD molecule entering the chain produces on average two and a half molecules of ATP, and each reduced FAD produces one and a half molecules of ATP. The number of ATP molecules actually produced varies in different tissues and different circumstances, largely dependent on how much energy is used to move substances into and out of the mitochondria.

Table1.1: Balance sheet of ATP used and synthesized for each molecule of glucose entering in respiration

	ATP used	ATP made	Net gain in ATP
Glycolysis	-2	4	+2
Link reaction	0	0	0
Krebs cycle	0	2	+2
Oxidative phosphorylation	0	28	+28
Total	-2	34	+32

Efficiency of aerobic and anaerobic respiration

Without oxygen, pyruvate (pyruvic acid) is not metabolized by cellular respiration but undergoes a process of fermentation. The pyruvate is not transported into the mitochondrion, but remains in the cytoplasm, where it is converted to waste products that may be removed from the cell. This serves the purpose of oxidizing the electron carriers so that they can perform glycolysis again and removing the excess pyruvate. Fermentation oxidizes NADH to NAD+ so it can be re-used in glycolysis.

In the absence of oxygen, fermentation prevents the build-up of NADH in the cytoplasm and provides NAD+ for glycolysis. This waste product varies depending on the organism. In skeletal muscles, the waste product is lactic acid. This type of fermentation is called lactic acid fermentation. In yeast and plants, the waste products are ethanol and carbon dioxide. This type of fermentation is known as alcoholic or ethanol fermentation. The ATP generated in this process is made by substrate-level phosphorylation, which does not require oxygen.

Fermentation is less efficient at using the energy from glucose since only 2 ATP are produced per glucose, compared to the 38 ATP per glucose produced by aerobic respiration. This is because the waste products of fermentation still contain plenty of energy. Glycolytic ATP, however, is created more quickly.

Applications of anaerobic respiration

Some food products and drinks are produced by using anaerobic microorganisms:

- Production of beer
- Production of wine

- Production of yoghurt
- Production of cheese
- Production of bread

In the bread-making process, it is the yeast that undergoes cellular respiration. Anaerobic respiration also known as **fermentation** helps to produce beer and wine and happens without the presence of oxygen. During bread production, yeast starts off respiring aerobically, creating carbon dioxide and water and helping the dough rise. After the oxygen runs out, anaerobic respiration begins, although the alcohol produced during this process, ethanol, is lost through evaporation when the bread is exposed to high temperatures during baking.

Yeast is crucial to making those soft, puffy loaves of bread and creating the deep, craggy holes popular to traditional European breads, such as baguettes. Yeast works as a leavening agent in bread, changing the sugars in dough into gas, which creates the bubbles in the loaves. The longer the yeast is allowed to work in the bread, this is the rising period of bread making and the more flavorful the bread. However, because yeast will eventually switch from aerobic to anaerobic respiration, the yeast will run out of nutrition of oxygen. When the bread is left to rise too long, the dough will slowly start to deflate.

To speed up the rising process, increase the sugar content, as well as add in small amounts of vinegar, which encourages cellular respiration or fermentation in the yeast. When you bake the bread after it has risen sufficiently, the cellular respiration process stops, and the bubbles produced during the process are preserved, making the holes in the bread.

The complete oxidation of glucose produces the energy estimated at 686 Kcal. Under the condition that exists inside most of the cells, the production of a standard amount of ATP from ADP absorbs about 7.3 Kcal. Glucose molecule can theoretically generate up to 38 ATP molecules in aerobic respiration. The efficiency of aerobic respiration (EAER) is calculated as follows:

$$\text{Efficiency of aerobic respiration} = \frac{\text{Energy required to make ATP} \times 100}{\text{Energy released by oxidation of glucose}}$$

$$= \frac{38\ \text{ATP} \times 7.3\ \text{Kcal} \times 100}{686\ \text{Kcal}} = 40\%$$

This result indicates that the efficiency of aerobic respiration equals 40%. The remainder of the energy (around 60%) is lost from the cell as heat.

Due to the fact that anaerobic respiration produces only 2 ATP, the efficiency of anaerobic respiration is less than that of aerobic respiration.

It is calculated as follows:

$$\text{Efficiency of anaerobic respiration} = \frac{\text{Energy required to make ATP x 100}}{\text{Energy released by oxidation of glucose}}$$

$$= \frac{\text{2 ATP x 7.3 Kcal x 100}}{\text{686 Kcal}} = 2\%$$

Oxygen debt

Standing still, the person absorbs oxygen at the resting rate of 0.2 dm^3min^{-1}. (This is a measure of the person's metabolic rate). When exercise begins, more oxygen is needed to support aerobic respiration in the person's muscles, increasing the overall demand to 2.5 dm^3min^{-1}. However, it takes four minutes for the heart and lungs to meet this demand, and during this time lactic fermentation occurs in the muscles. Thus the person builds up an oxygen deficit. For the next three minutes, enough oxygen is supplied. When exercise stops, the person continues to breathe deeply and absorb oxygen at a higher rate than when at rest. This post-exercise uptake of extra oxygen, which is 'paying back' the oxygen deficit, is called the oxygen debt. The oxygen is needed for:

- Conversion of lactate to glycogen in the liver
- Re oxygenation of haemoglobin in the blood
- A high metabolic rate, as many organs are operating at above resting levels.

The presence of the lactic acid is sometimes described as an ' **oxygen debt'**. This is because significant quantities of lactic acid can only be removed reasonably quickly by combining with oxygen. However, the lactic acid was only formed due to lack of sufficient oxygen to release the required energy to the muscle tissue via aerobic respiration. Lactic acid can accumulate in muscle tissue that continues to be over-worked. Eventually, so much lactic acid can build-up that the muscle ceases working until the oxygen supply that it needs has been replenished. To repay such an oxygen debt, the body must take in more oxygen in order to get rid of the additional unwanted waste product lactic acid.

Muscle cramps

A muscle cramp is an involuntarily and forcibly contracted muscle that does not relax. Muscle cramps can occur in any muscle; cramps of the leg muscles and feet are particularly common.

Almost everyone experiences a muscle cramp at some time in their life. There are a variety of types and causes of muscle cramps. Muscle cramps may occur during exercise, at rest, or at night, depending upon the exact cause.

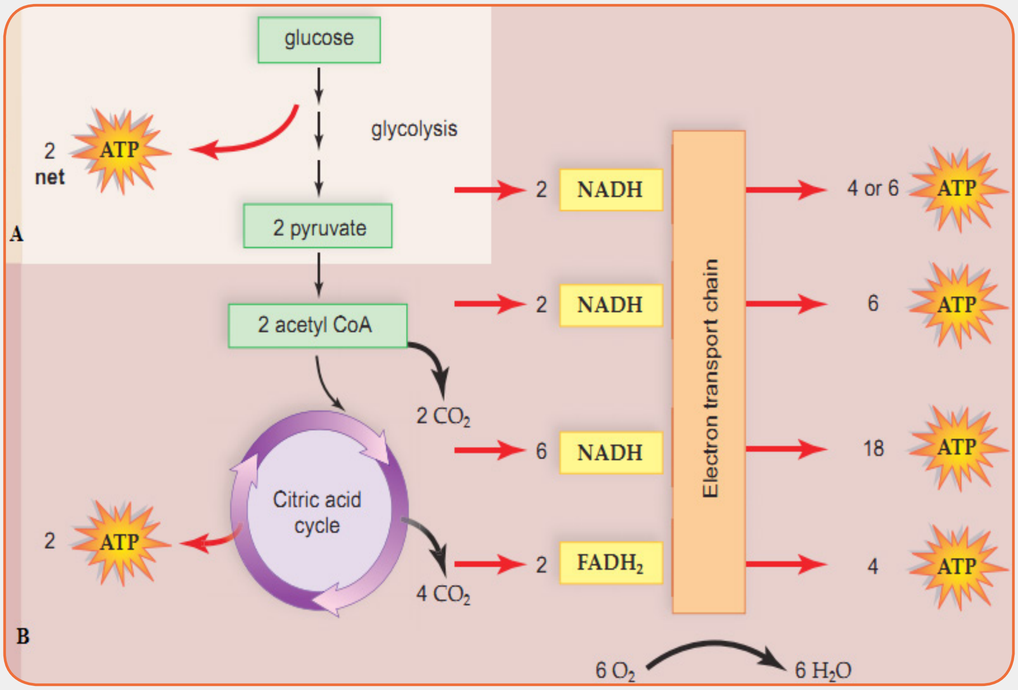
Overuse of a muscle, dehydration, muscle strain or simply holding a position for a prolonged period can cause a muscle cramp. In many cases, however, the cause isn't known.

Although most muscle cramps are harmless, some may be related to an underlying medical condition, such as:

- Inadequate blood supply. Narrowing of the arteries that deliver blood to your legs (arteriosclerosis of the extremities) can produce cramp-like pain in your legs and feet while you're exercising. These cramps usually go away soon after you stop exercising.
- Nerve compression. Compression of nerves in your spine (lumbar stenosis) also can produce cramp-like pain in your legs. The pain usually worsens the longer you walk. Walking in a slightly flexed position such as you would use when pushing a shopping cart ahead of you may improve or delay the onset of your symptoms.
- Mineral depletion. Too little potassium, calcium or magnesium in your diet can contribute to leg cramps. Diuretics or medications often prescribed for high blood pressure also can deplete these minerals.

Application activity 1.1

The figure below accounts the energy yield per glucose molecule breakdown during cellular respiration in different cell organelles. Study it carefully and answer questions that follow:



i) Where do the process labeled **A** and **B** take place in the cell?

ii) Account for the total energy yield (ATP) per glucose molecule breakdown during cellular respiration.

iii) What are the uses of energy produced during cellular respiration?

iv) What would happen to the total energy yield if glucose molecule increases or decrease?

v) A student-teacher regularly runs 3 km each afternoon at a slow, leisurely pace. One day, student–teacher runs 1 km as fast as she/he can. Afterward, student-teacher is winded and feels pain in her chest and leg muscles. What is responsible for her symptoms?

1.2. Photosynthesis

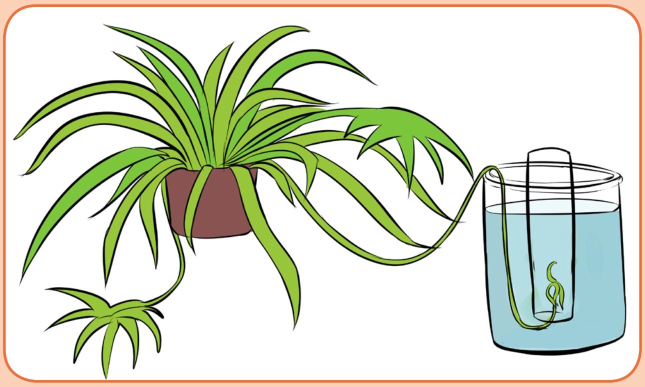
Activity 1.2

Leaves and photosynthesis

Materials: test tubes, 500-mL beaker, potted houseplant with runners, such as a spider plant, or a water plant (e.g., Elodea); wood splint; secured Bunsen burner.

Procedure / protocol:

- Fill a 500-mL beaker with 400 mL of water.
- Fill a test tube with water and, without spilling, turn it upsidedown into the water in the beaker. If an air bubble remains in the test tube, repeat the procedure until there is no bubble or until the bubble is as small as possible.
- Place the other test tube in the beaker repeating the steps above.
- Carefully place a spider-plant runner or sprig of a water plant into one of the test tubes, as shown in the setup below and leave the other test tube filled with water only.



Leave the apparatus in bright sunlight or under a spotlight until there is almost no water left in the tube containing the plant. Observe the test tubes every 15 min over several hours.

i) What happened to the glowing splint when it was lowered into the test tube? Write the observation.

ii) What gas collected in the test tube?

iii) How do you know that the gas came from the plant?

iv) In which step does the gas mentioned above is produced?

1.2.1. Autotrophic nutrition

Autotrophic nutrition is a process by which living organisms make their own food. This process is carried out by photoautotrophs like green plants, green algae and green bacteria; and chemoautotrophs. Living organisms which make their own food are called autotrophs, while others, including humans, which cannot make their own food but depend on autotrophs, are called **heterotrophs**.

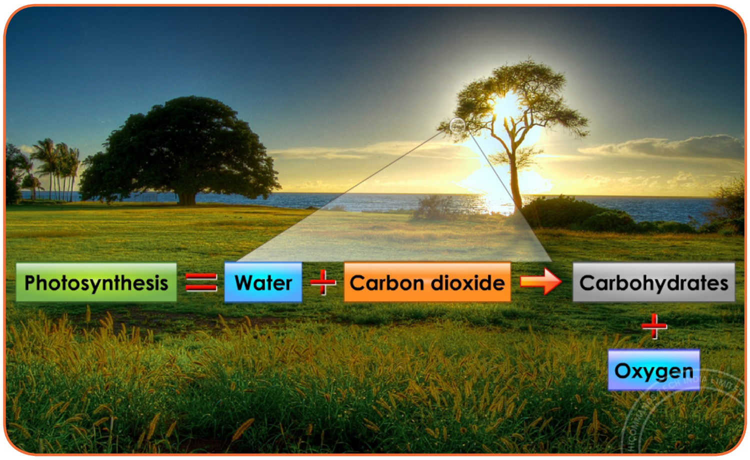


Figure 1.2: Photoautotrophism

a. Types of autotrophic nutrition

There are two types of autotrophic nutrition such as **chemoautotrophic** and **photoautotrophic** nutrition.

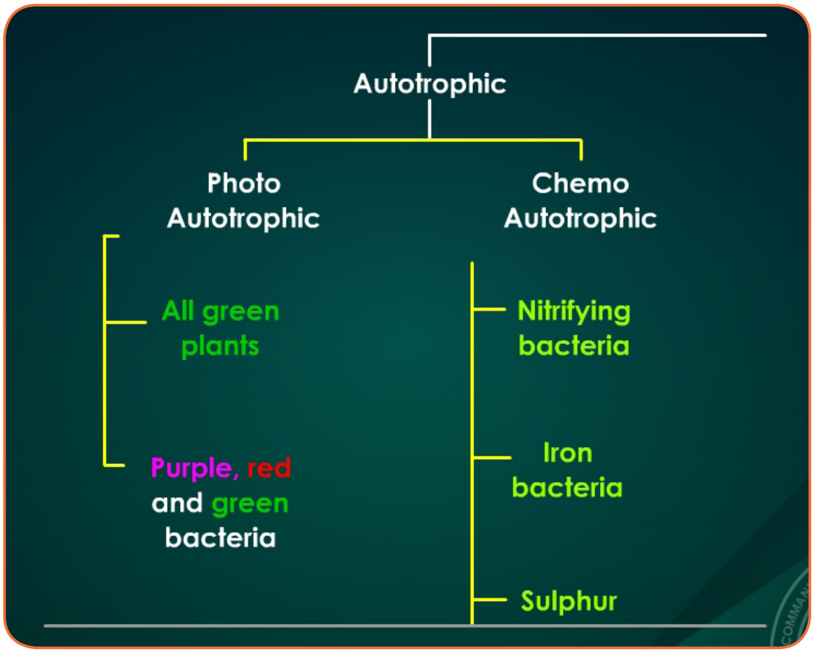


Figure 1.3: Types of autotrophic nutrition

a. 1 Chemoautotrophic nutrition

It is an autotrophic nutrition where organisms (mainly bacteria) get energy from oxidation of chemicals, mainly inorganic substances like hydrogen sulphide and ammonia.

$$H_2S + O_2 \longrightarrow 2H_2O + 2S + E.$$

$$(NH_4)_2CO_3 + 3O_2 \longrightarrow 2HNO_2 + CO_2 + 3H_2O + E.$$

a.2 Photoautotrophic nutrition

It is an autotrophic nutrition where organisms get energy from sunlight and convert it into sugars. Green plants and some bacteria like green Sulphur bacteria can make their own food from simple inorganic substances by a process called photosynthesis. Photosynthesis is a process by which, autotrophs make their own food by using inorganic substances in presence of light energy and chlorophyll.

$$6CO_2 + 6H_2S \xrightarrow{\text{Light and bacteriochlorophylly}} C_6H_{12}O_6 + 6S$$ (Green Sulphur bacteria)

$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ H_2O + 6\ CO_2$$ (Green plants)

In eukaryotes, photosynthesis takes place in chloroplasts. A chloroplast contains many sets of disc like sacs called thylakoids, which are arranged in stacks known as grana. Each granum looks like a stack of coins where each coin being a thylakoid. In the thylakoid, proteins are organized with the chlorophyll and other pigments into clusters known as photosystems. The photosystems are the light-collecting units of the chloroplast.

The function of thylakoids is to hold the chlorophyll molecules in a suitable position for trapping the maximum amount of light. A typical chloroplast contains approximatively 60 grana, each consisting of about 50 thylakoids. The space outside the thylakoid membranes are made by watery matrix called stroma. The stroma contains enzymes responsible for photosynthesis.

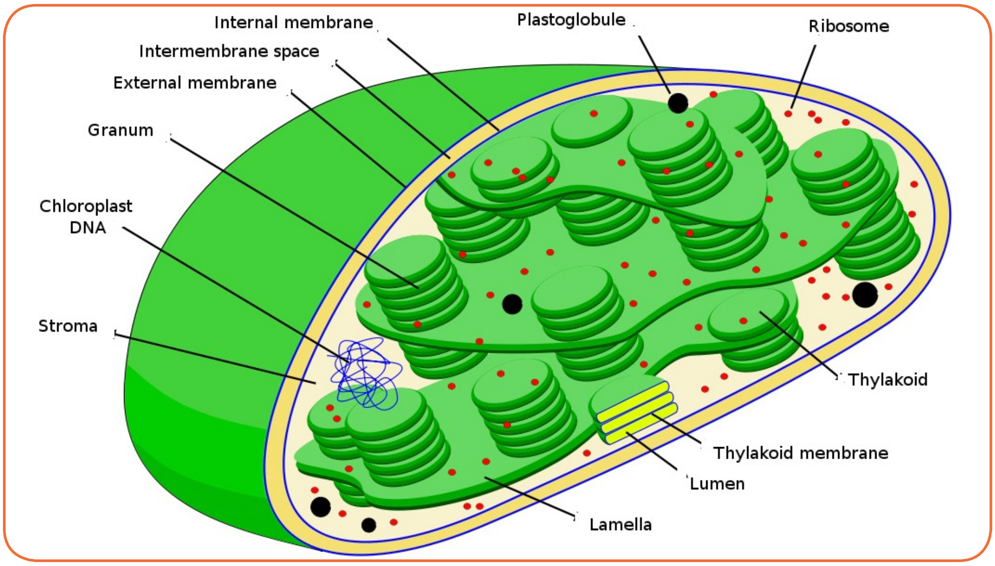


Figure 1.4: Structure of a chloroplast

Note: Photosynthetic prokaryotes have no chloroplasts, but thylakoids often occur as extensions of the plasma membrane and are arranged around the periphery of the prokaryotic cell.

b. Chlorophyll

It is a sunlight- absorbing pigment, and it actually gets its green color because it absorbs bleue and red wavelengths of light.

Structure of chlorophyll

The chlorophyll molecule is made of atoms of Carbon and Nitrogen joined in a complex porphyrin ring containing an atom of Magnesium in the center of the ring. The chlorophyll also has long hydrophobic carbon tail of 20 carbon atoms (phytol) which hold it in the thylakoid membrane. In short, the chlorophyll consists of a porphyrin ring and a phytol tail.

The chlorophyll **a** differs from the chlorophyll **b** in that: the porphyrin of the chlorophyll a has the methyl group (-CH_3) as a functional group, which is replaced by an aldehyde group (-CHO) for chlorophyll b.

The difference between the chlorophyll a and the chlorophyll b shifts the wavelength of light absorbed and reflected by chlorophyll b, so that the chlorophyll b is yellow-green, whereas the chlorophyll a is bright-green.

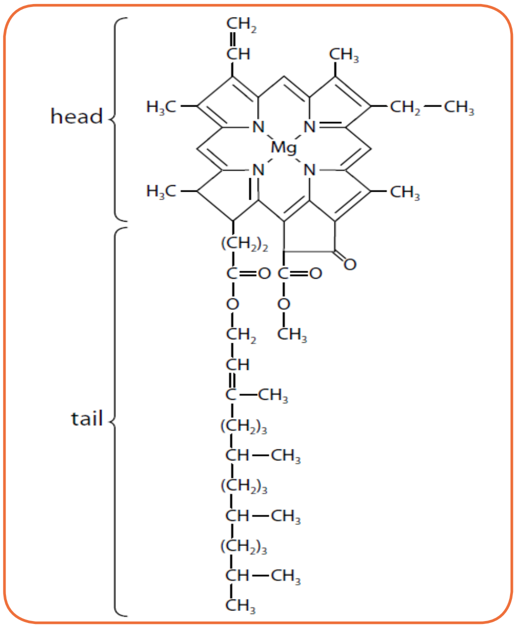


Figure 1.5: Structure of a chlorophyll a

Adaptations for photosynthesis

By considering both external and internal structures of the leaf, we can recognize several adaptations for photosynthesis.

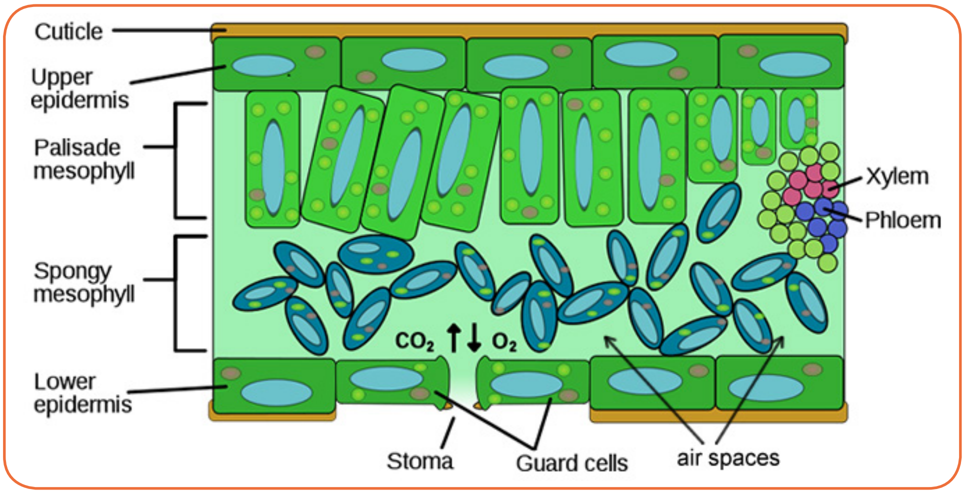


Figure 1.6: Internal structure of the leaf and its adaptations to photosynthesis

Parts of the leaf	Its adaptation for photosynthesis
Transparent cuticle	It allows absorbing much light. It prevents excessive water from the plant
Upper epidermis	It is made by thin and transparent cells for absorption of much light. They act as barriers to pathogens.
Palisade mesophyll	Its cells are packed with many chloroplasts, so it is the main site for photosynthesis
Spongy mesophyll	It is relatively less packed by chloroplasts, and it contains air spaces which allow gaseous exchange: CO_2 in cells, and O_2 from cells during photosynthesis.
Vascular bundle	It consists of leaf veins: Xylem which brings water and minerals to leaves, phloem which transports sugars and amino acids away to other parts.
Lower epidermis	It is the site for gaseous exchange in and out of the leaf, and it prevents excessive water loss through stomata.
Stomata	Surrounded by guard cells, which allow stomata to open: water moves out during transpiration, CO_2 diffuses in and Oxygen diffuses out during photosynthesis.

Note: when stomata are opened, the rate of photosynthesis may be 10 to 20 times as fast as the maximum rate of respiration. If the stomata are closed, photosynthesis still can continue, using CO_2 produced during cell respiration. The equilibrium can be reached between photosynthesis and cell respiration.

Photosynthesis uses CO_2 from respiration, and respiration uses Oxygen from photosynthesis. However, the rate of photosynthesis under these circumstances will be much slower than when an external source of CO_2 is available. The stomata cannot remain closed indefinitely, they have to be open in order to maintain transpiration of the plant.

1.2.2. Mechanism of photosynthesis

The process of photosynthesis occurs through two main stages such as:

- The light-dependent reactions: which take place in thylakoids, and
- The light-independent reactions (Calvin cycle): which take place in stroma.

A. The light-dependent reactions

They require light energy and occur in thylakoids. They produce Oxygen gas and convert ADP and NADP+ into ATP and NADPH.

The light-dependent reactions involve the following steps:

a. Absorption and action spectra

In addition to water and CO_2, photosynthesis requires light and chlorophyll. The chlorophyll pigment is found in the chloroplasts. The light that our eyes perceive as white light is a mixture of different wavelengths. Most of them are visible to our eyes and make up the visible spectrum. Our eyes see different wavelengths of visible spectrum as different colors (violet, blue, green, yellow, orange and red) except indigo which is not visible to our eyes. Plants absorb the light energy by using molecules called pigments such as: **chlorophyll a, chlorophyll b, carotene** (orange) and **xanthophyll** (yellow) but chlorophyll a is the principle pigment in photosynthesis.

The chlorophyll absorbs light very well in blue-violet and red regions of visible spectrum. However, chlorophyll does not absorb well the green light; instead it allows the green light to be reflected. That is why young leaves and other parts of the plants containing large amount of chlorophyll appear green.

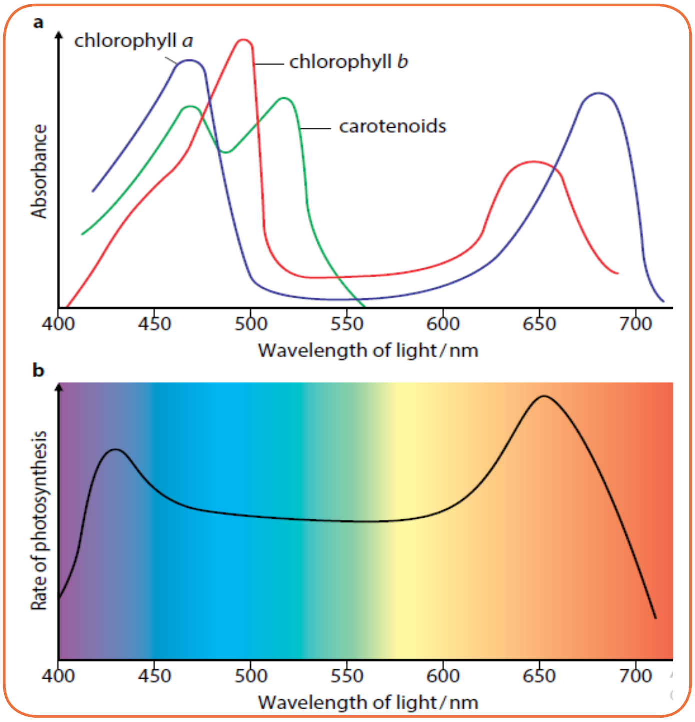


Figure 1.7: Light absorption by leaf pigment

The chlorophyll a as a principle and abundant pigment, it is directly involved in light reactions of photosynthesis. Other pigments (chlorophyll b, carotene, xanthophyll and phaeophytin) are accessory pigments. They absorb light colours that chlorophyll a cannot absorb, and this enables plants to capture more energy from light.

The amount of energy that the pigment can absorb from the light depends on its intensity and its wavelengths. So, the greater the intensity of light, the greater amount of energy will be absorbed by the pigment in a given time.

Photosynthesis begins when the chlorophyll a in photosystem II absorbs light at different wavelengths of light.

- When the light energy hits the chlorophyll a, the light energy is absorbed by its electrons, by raising their energy level.
- These *electrons with high potential energy* (electrons with sufficient quantum energy) are passed to the electron-transport chain.
- Excited electrons are taken up by an electron acceptor ($NADP^+$: oxidized Nicotinamide Adenine Dinucleotide Phosphate), and pass along electron transfer chain from photosystem II to the photosystem I. (Note: The photosystems are the light-collecting units of the chloroplast).

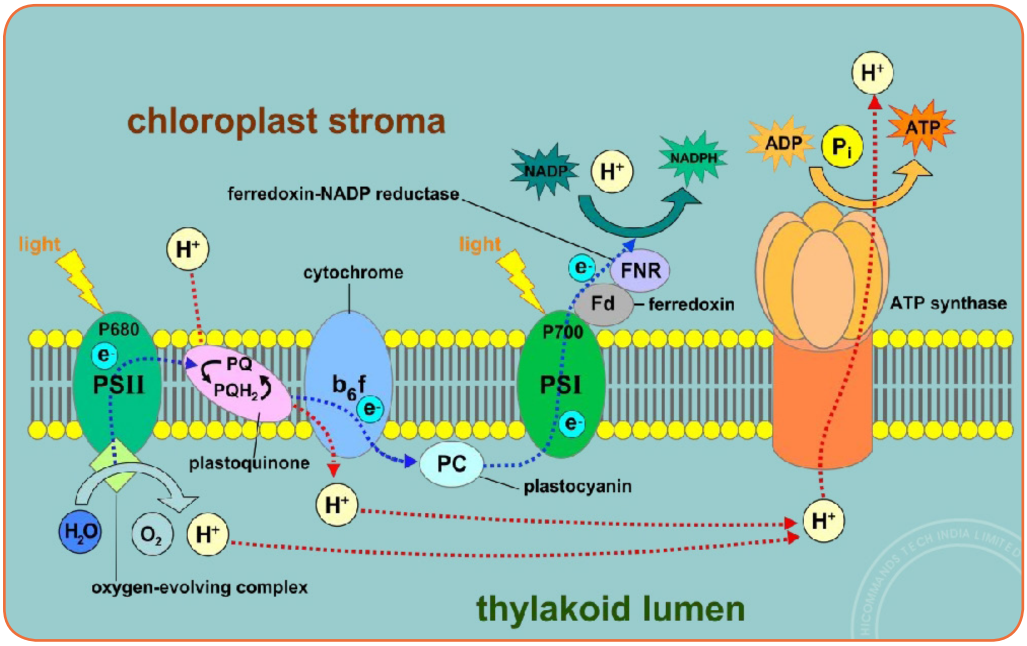


Figure1.8: Electron transport chain

b. Enzymes in thylakoids and light absorbed by photosystem II

Enzymes in thylakoids and light absorbed by photosystem II are used to break down a water molecule into energized electrons, hydrogen ions H^+, and Oxygen.

$$H_2O \xrightarrow{\text{Enzymes and light}} 2H^+ + \frac{1}{2}O_2 + 2e^-$$

- Oxygen produced is released to be used by living things in respiration.
- Electrons and H^+ from photolysis of water are used to reduce NADP+ to NADPH (Reduced Nicotinamide Adenine Dinucleotide Phosphate).

- The light-dependent reactions also allow generation of ATP (Adenosine Triphosphate) by adding inorganic phosphate to ADP$^+$ (Adenosine Diphosphate):

$$\mathbf{ADP + P_i \xrightarrow{Energy} ATP}$$

Generally, the light-dependent reactions use light energy, ADP, Pi, NADP+ and water to produce ATP, NADPH and Oxygen. Or simply:

$$12H_2O + 12NADP^+ + 18ADP^+ + 18P_i \xrightarrow{\text{Light and chlorophyll}} 6O_2 + 12NADPH_2 + 18ATP$$

Both ATP and NADPH are energy carriers which provide energy to sugars (energy containing sugars) in Light-independent reactions.

c. Photophosphorylation

The fixation of Pi to ADP+ to form ATP is called photophosphorylation**.** Photophosphorylation can be done into two processes: cyclic photophosphorylation, and non-cyclic photophosphorylation.

Cyclic photophosphorylation

It involves only photosystem I and not photosystem II. There is no production of NADPH and no release of Oxygen. When the light hits the chlorophyll in PSI, the light-excited electron leaves the molecule.

This light-excited electron is taken up by an electron acceptor which passes it along an electron transfer chain (a series of electron carriers) until it returns to the chlorophyll molecule that it left (cyclic process). As an excited electron moves along an electron transfer chain, it loses energy which will be used for the synthesis of ATP from ADP+ and inorganic phosphate in the process called **chemiosmosis**. Electron carriers can vary, but the principle includes the cytochromes.

Non-cyclic photophosphorylation

It is the main route of ATP synthesis. It is done in the following steps:

- When the photosystem II (in chlorophyll) absorbs light, an electron is excited to a higher energy level and captured by the primary electron acceptor.
- Enzymes extract electrons from a water molecule replacing each electron that the chlorophyll molecule lost when absorbed light energy. This reaction dissociates a water molecule into hydrogen ions ($2H^+$) and Oxygen which is released for animals' respiration.
- Excited electron moves from the primary electron acceptor of photosystem

II to photosystem I, via an electron transport chain.

- When excited electron moves from the primary electron acceptor of photosystem II to photosystem I, via an electron transport chain its energy level lowers. The energy removed is used to synthesize ATP from ADP and P_i in a process called: Non-cyclic phosphorylation.
- The hydrogen ions ($2H^+$) produced from dissociation of water molecule combines with $NADP^+$ to form $NADPH_2$.
- Both ATP and $NADPH_2$ will be used in the light-independent reactions (Calvin cycle) for synthesis of sugars.

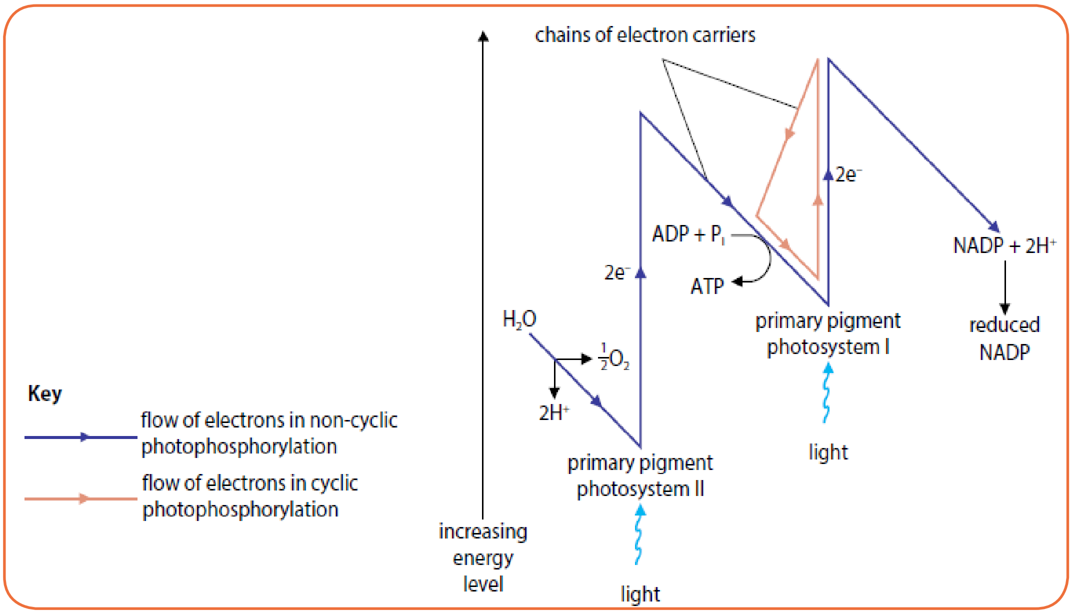


Figure 1.9: Chain of electron carriers

The significance of the cyclic phosphorylation

Non-cyclic photophosphorylation produces ATP and NADPH in equal quantities, but the Calvin cycle consumes more ATP than NADPH. The concentration of NADPH in a chloroplast may determine which pathway (cyclic versus non-cyclic) electrons pass through.

If a chloroplast runs low on ATP for the Calvin cycle, NADPH will accumulate as the cycle slows down. The rise of NADPH may stimulate a shift from non-cyclic (which produces ATP only) to cyclic electron pathway until ATP supply catches with the demand.

Table 1.2: Comparison between Non-cyclic and cyclic photophosphorylation

	Cyclic photophosphorylation	Non-cyclic photophosphorylation
Pathway of excited electrons	Cyclic pathway	Non-cyclic pathway
Source of electrons (1st electron acceptor)	Photosystem I	water
Destination of electron (Last electron acceptor)	Photosystem I	$NADP^+$
Photosystem involved	Photosystem I only	Photosystem II and Photosystem I
Products	ATP only	ATP, NADPH and Oxygen

B. The light-independent reactions (Calvin cycle)

The light-independent reactions occur in stroma, and consist of reducing CO_2 into sugars by using ATP and NADPH both coming from light-dependent reactions in thylakoids. The Calvin cycle involves three main stages such as:

- Carbon fixation in form of CO_2.
- Carbon reduction from CO_2 to glucose.
- Regeneration of RuBP.

a) Carbon fixation (Carboxylation) in form of CO_2

The Calvin cycle begins with a 5-Carbon sugar phosphate called Riburose-1, 5 biphosphate (RuBP) which fixes the CO_2 from air. This reaction is catalyzed by an enzyme called RuBPcarboxylase-oxygenase (RUBISCO), which makes up about 30% of the total protein of the leaf, so it is probably one of the most common proteins on the Earth.

The combination of RuBP and CO_2 results in a theoretic 6-carbon compound which is highly unstable. It immediately splits into two molecules of 3-carbon known as phosphoglyceric acid (PGA) or glycerate 3-phosphate, or 3-phosphoglycelate.

b) Carbon reduction from CO_2 to glucose

With energy from ATP and reducing power from NADPH, the phosphoglyceric acid is reduced into 3carbon molecules known as glyceraldehyde-3-phosphate or phosphoglyceraldehyde (PGAL).

Each molecule of PGA receives an additional phosphate group from ATP, becoming 1, 3-biphosphoglycerate, and a pair of electrons and H^+ from NADPH reduces the carboxyl group of 3-phosphoglycerate to the aldehyde group of PGAL which stores more potential energy.

ATP gives one phosphate group becoming ADP^+, and NADPH gives H^+ and electrons to become $NADP^+$. Both ADP^+ and $NADP^+$ will be used again in light-dependent reactions.

With 6 turns of Calvin cycle, the plant cell fixes $6CO_2$ molecules which are used to synthesize 2 molecules of PGAL which leave the cycle and combine to make one molecule of glucose or fructose. This glucose can be converted into:

- Sucrose: when Oxygen combined with fructose. It is a form by which carbohydrates are transported in plants.
- Polysaccharides like starch for energy storage, and cellulose for structural support.
- Amino acids when combined with nitrates,
- Nucleic acids when Oxygen combined with phosphates, and
- Lipids.

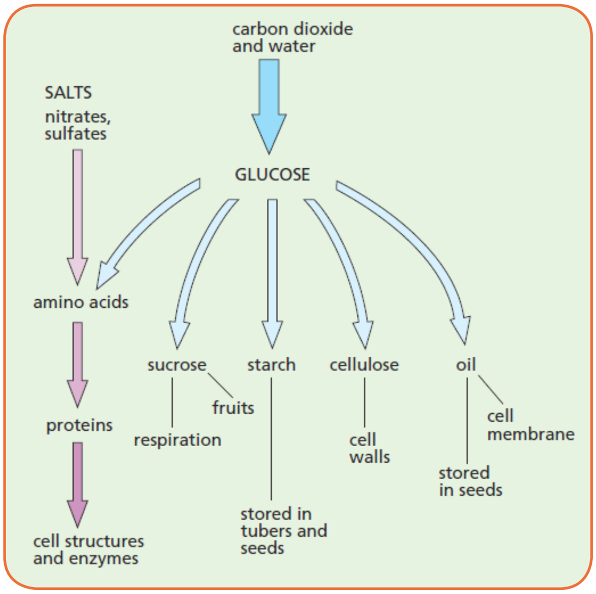


Figure 1.10: Conversion of glucose into other organic substances

c) Regeneration of RuBP

The remaining ten 3-carbon molecules (PGAL) are converted back into six 5-carbon molecules, ready to fix other CO_2 molecules for the next cycle. The light-independent reactions can be summarized as:

$$12NADPH + 18ATP + 6CO_2 \rightarrow C_2H_{12}O_6 + 12NADP^+ + 18ADP^+ + 18P_i + 6H_2O$$

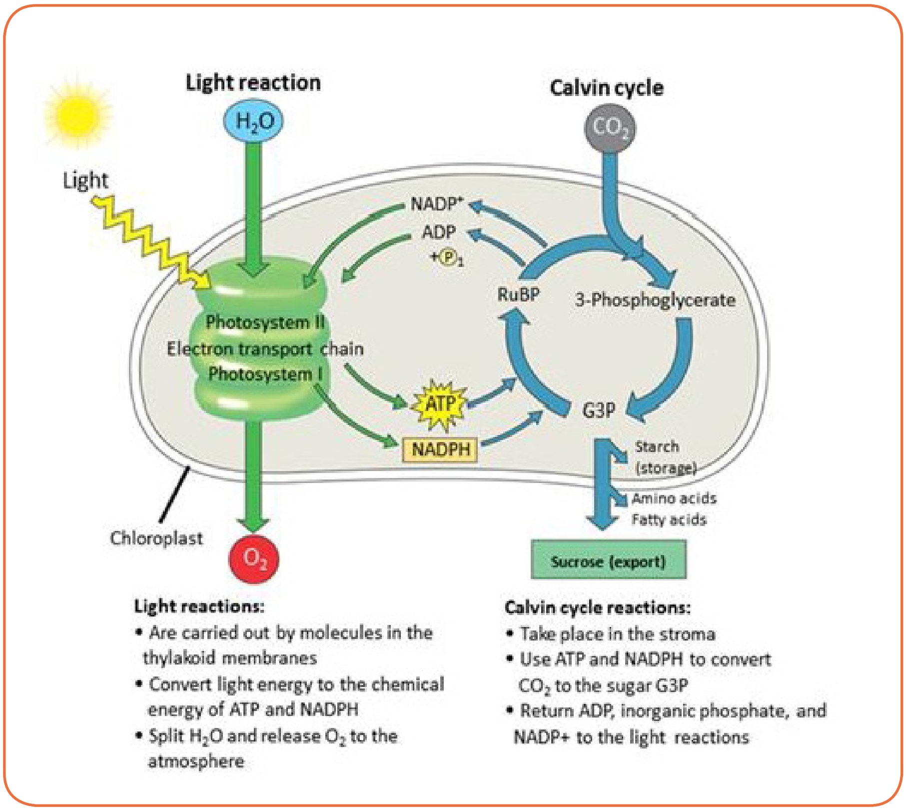


Figure 1.11: Light reaction and Calvin cycle

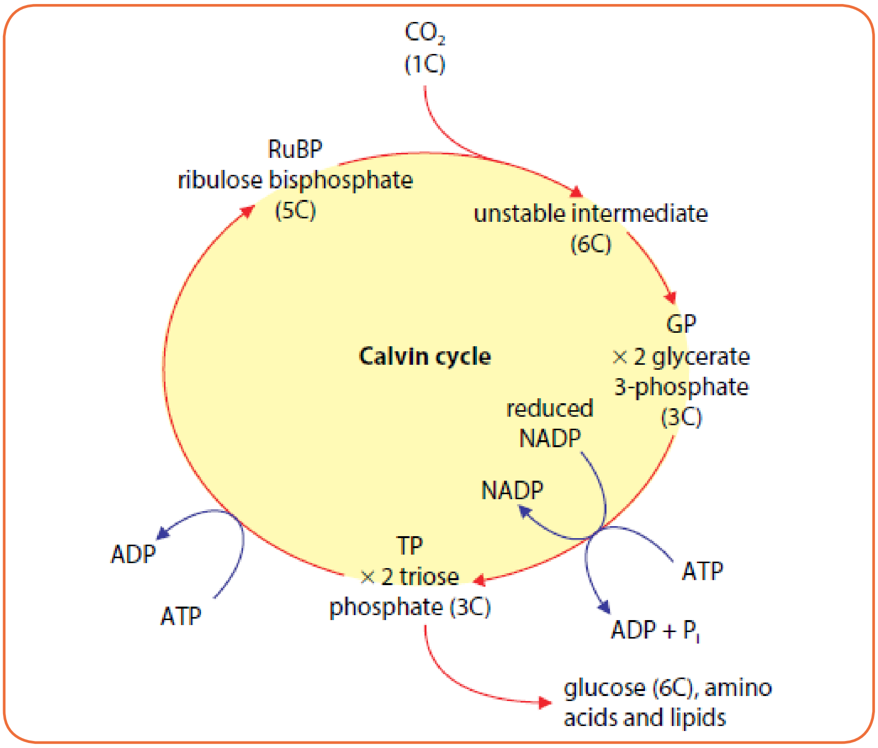


Figure 1.12: Calvin cycle

Other carbon dioxide fixation pathways (C4 CAM)

The most common pathway combines one molecule of CO_2 with a 5-carbon sugar called ribulose biphosphate (RuBP). The enzyme which catalyzes this reaction (nicknamed "Rubisco") is the most abundant enzyme on earth! The resulting 6-carbon molecule is unstable, so it immediately splits into two 3-carbon molecules. The 3 carbon compound which is the first stable molecule of this pathway gives this largest group of plants the name "**C-3 plants**".

Dry air, hot temperatures, and bright sunlight slow the C-3 pathway for carbon fixation. This is because **stomata**, which normally allow CO_2 to enter and O_2 to leave, must close to prevent loss of water vapor. Closed stomata lead to a shortage of CO_2. Two alternative pathways for carbon fixation demonstrate biochemical adaptations to differing environments. Plants such as **corn** solve the problem by using a separate compartment to fix CO_2.

Here CO_2 combines with a 3-carbon molecule, resulting in a 4-carbon molecule. Because the first stable organic molecule has four carbons, this adaptation has the name **C-4**. Shuttled away from the initial fixation site, the 4-carbon molecule is actually broken back down into CO_2, and when enough accumulates, Rubisco fixes it a second time!

In some temperate plants such as wheat, rice, potato and bean only Calvin cycle occurs. Such plants are called C-3 plants. While in some other plants dual carboxylation takes place: (1) carboxylation of phosphoenol pyruvate (PEP) and (2) carboxylation of RuBP. Such plants are called C-4 plants e.g. maize, sugar cane and sorghum. In these, the first product formed during carbon dioxide fixation is a four carbon compound oxalo acetic acid (OAA). C-4 plants have special type of leaf anatomy called **Kranz** Anatomy. They have special large cells around vascular bundles called **bundle sheath cells**. These are characterized by having large number of chloroplasts, thick walls and no intercellular spaces. The shape, size and arrangement of thylakoids in chloroplasts are also different in bundle sheath cell as compared to mesophyll cell chloroplasts.

The pathway followed by C-4 plants is called **C-4 cycle** or **Hatch and Slack pathway**. This was discovered by Hatch and Slack in sugar cane. The primary CO_2 acceptor is a 3-carbon molecule phosphoenol pyruvate (PEP). The reaction is catalyzed by **PEP carboxylase** or **PEP case** in mesophyll cell chloroplast. It forms 4-carbon compounds like OAA, malic acid or aspartate, which are transported to the bundle sheath cells. In bundle sheath cells, these acids are broken down to release CO_2 and 3-carbon molecule. The 3-carbon molecule is transported back to mesophyll cells and converted to PEP again, while CO2 enters into C-3 cycle to form sugars. C-4 plants are more efficient than C-3 plants as in C-4 plants, photosynthesis can occur at low concentration CO_2 and photorespiration is negligible or absent.

Cacti and succulent (water-storing) plants such as the jade plant avoid water loss by fixing CO_2 only at night. These plants close their stomata during the day and open them only in the cooler and more humid nighttime hours. Leaf structure differs slightly from that of C-4 plants, but the fixation pathways are similar. The family of plants in which this pathway was discovered gives the pathway its name, **Crassulacean Acid Metabolism**, or **CAM**. All carbon fixation pathways lead to the Calvin cycle to build sugar.

The CAM pathway is similar to the C4 pathway in that carbon dioxide is first incorporated into organic intermediates before it enters the Calvin cycle. **The difference is that in C4 plants, the initial steps of carbon fixation are separated structurally from the Calvin cycle whereas in CAM plants, the two steps occur at separate times.**

The CAM pathway and the C4 pathway compared

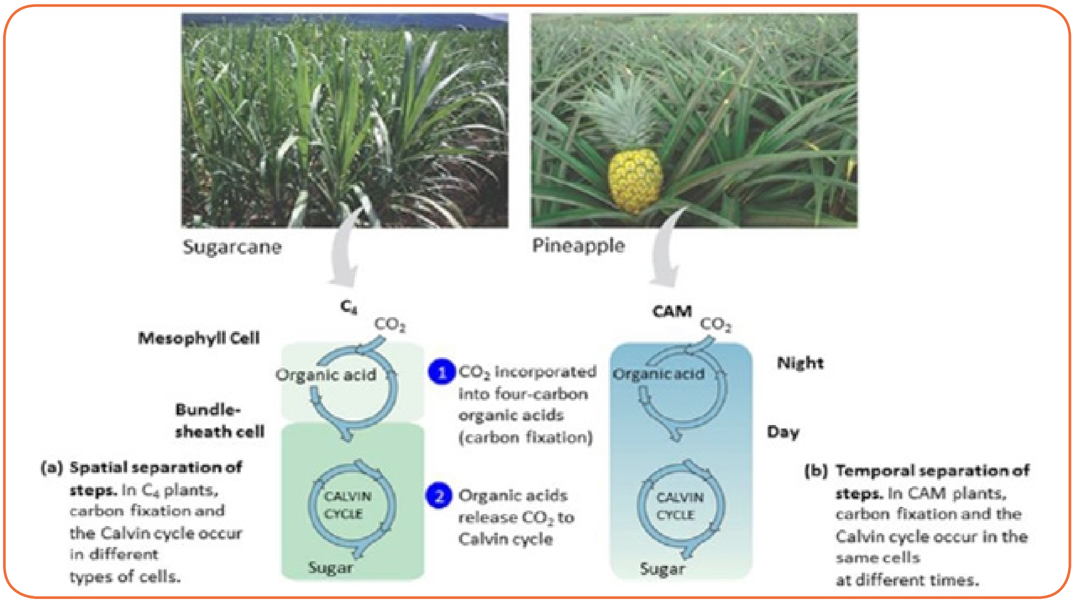


Figure 1.13: The C4 and CAM pathways compared

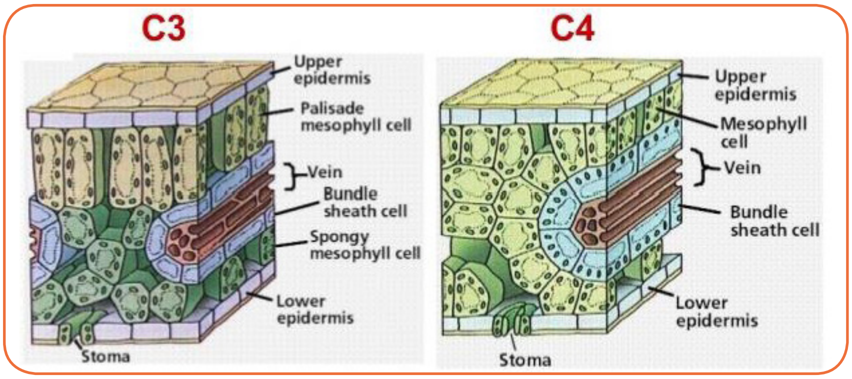


Figure 1.14: C3 leaf anatomy and the C4 leaf anatomy compared

The table 1.3: Comparison between C3 and C4 plants

	C3 Plants	C4 Plants
Perform the Calvin cycle	Yes	Yes
Primary CO_2 acceptor	RuBP	PEP
First product of CO_2 fixation	PGA	Oxaloacetate
CO2 fixing enzyme	RUBISCO	PEP carboxylase (This enzyme adds CO_2 to phosphoenolpyruvate (PEP), forming the four-carbon product oxaloacetate.
Affinity of carboxylase for CO_2	Moderate	High
Photorespiration	Extensive	Minimal
Classes of chloroplasts	One	Two
Leaf anatomy, photosynthetic cells	Mesophyll	Mesophyll and Bundle sheath

Photorespiration

In most plants, initial fixation of carbon occurs via Rubisco, the Calvin cycle enzyme that adds CO_2 to ribulose biphosphate. Such plants are called C3 plants because the first organic product is a three carbon organic compound, PGA. These plants produce less food when their stomata close on hot and dry days.

The declining level of CO_2 in the leaf starves the Calvin cycle. Making matter worse, Rubisco can accept O_2 in place of CO_2. As O_2 concentration overtakes CO_2 concentration within the air space, Rubisco adds O_2 instead of CO_2. The product splits and one piece, a two-carbon compound is exported from the chloroplast. Mitochondria then break the two-carbon molecule into CO_2.

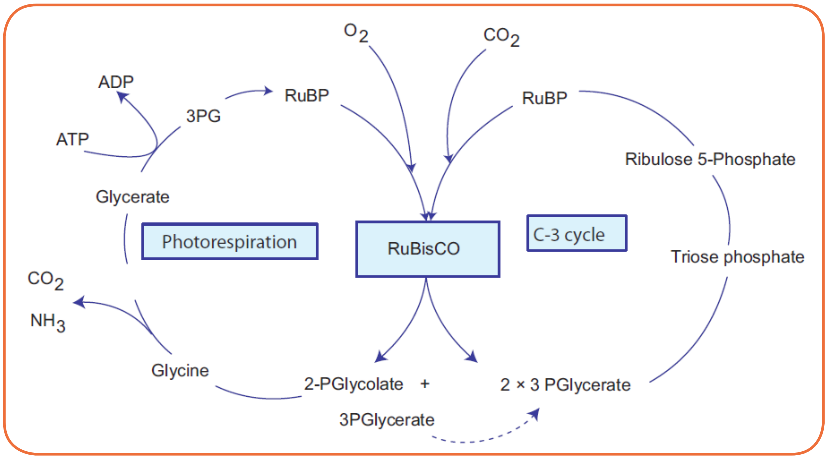


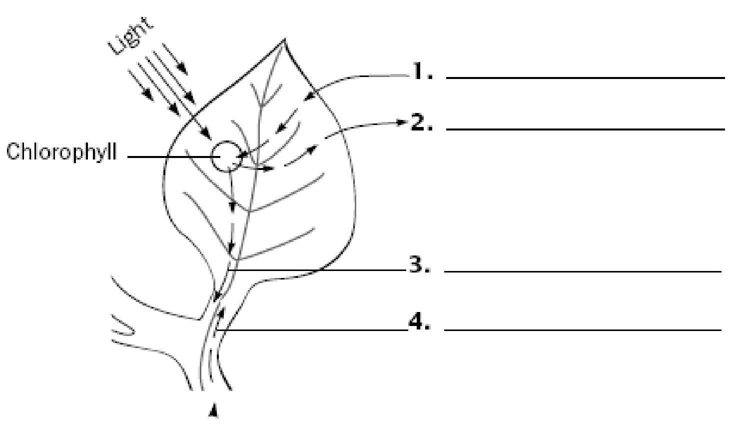
Figure 1.15: Photorespiration and C-3 cycle

The process is called photorespiration because it occurs in presence of light (photo) and consumes O_2 (respiration). However, unlike normal cellular respiration, photorespiration generates no ATP, and unlike photosynthesis, photorespiration generates no food. In fact, photorespiration decreases photosynthetic output by using material from the Calvin cycle.

Application activity 1.2

The diagram below illustrates photosynthesis process. Write each of the following terms on the correct numbered line. Then answer the questions that follow.

Carbon Dioxide Glucose Oxygen Water



i) In photosynthesis, establish an equation of substrate with substances produced

ii) What would happen if substance labeled in 1 and 4 are absent? Justify your answer.

iii) Explain how photosynthesis and respiration are interdependent?

1.3. Factors affecting the rate ofphotosynthesis

Activity 1.3

1. When beans are grown under banana trees, the farmers record poor harvest. Explain why?
2. Make a research to find out how each of the following factors can affect the rate of photosynthesis: Temperature – Light intensity – Concentration of CO2 – Amount of water

The photosynthesis rate varies with the species but also varies within individuals for a same species; this varies under the influence of certain external factors which are: the temperature, CO_2 concentration in the atmosphere, light intensity and soil humidity.

a. Temperature

Photosynthesis is an enzyme-controlled process. At very low temperatures the rate of photosynthesis is slow because the enzymes are inactive. As temperature increases, the rate of photosynthesis increases because the enzymes become more active. Rate of photosynthesis is optimum at (35-40) °C. Beyond 40°C the rate of photosynthesis decreases and eventually stops since the enzymes become denatured.

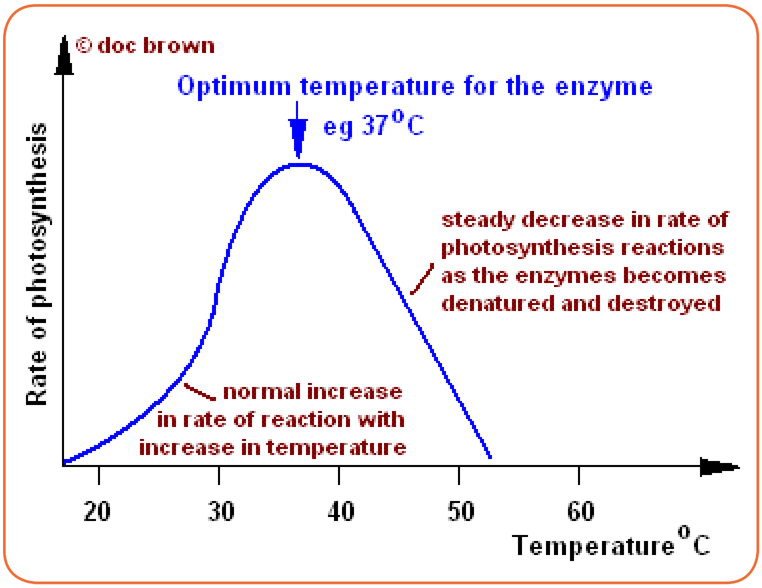


Figure 1.16: Effect of temperature on the rate of photosynthesis

b. CO_2 concentration in the atmosphere

While the concentration of carbon (IV) oxide in the atmosphere is fairly constant at 0.03%, an increase in carbon (IV) oxide concentration translates into an increase in the rate of photosynthesis upto a certain point when the rate of photosynthesis becomes constant. At this point, other factors such as light intensity, water and temperature become limiting factors.

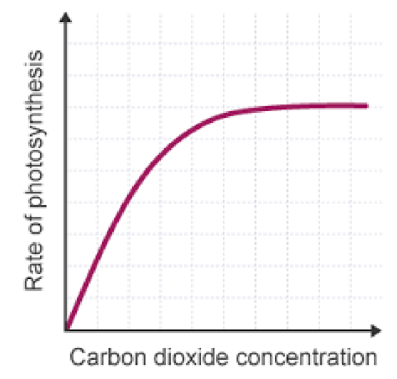


Figure 1.17: Effect of carbon dioxide on the rate of photosynthesis

The photosynthetic rate is zero in place lacking CO_2, it increases with the increase concentration of CO_2 in the atmosphere and reaches an optimum ranging between 5 and 8%CO_2 concentration.

c. Light intensity

The rate at of photosynthesis increases with an increase in light intensity up to a certain level. Beyond the optimum light intensity, the rate of photosynthesis becomes constant. To this effect, plants photosynthesize faster on bright and sunny days than on dull cloudy days.

Light quality/wavelength also affects the rate of photosynthesis. Most plants require red and blue wavelengths of light for photosynthesis. Light duration also affects photosynthesis rate

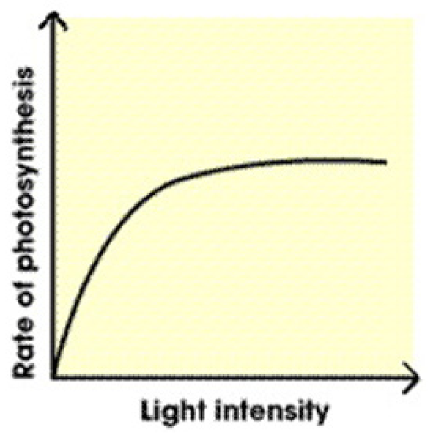


Figure 1.18: Effect of light intensity on the rate of photosynthesis

The photosynthesis rate is low during night, it increases when the light intensity increases but the optimum varies according to the plants.

d. Availability of water for the plant

The photosynthesis rate is low when the soil is dry, it increases when the content of water increases for the terrestrial plants, and for the aquatic plants it remains constant as long as they are fixed in water.

Note: The limiting factors work together to influence the rate of photosynthesis

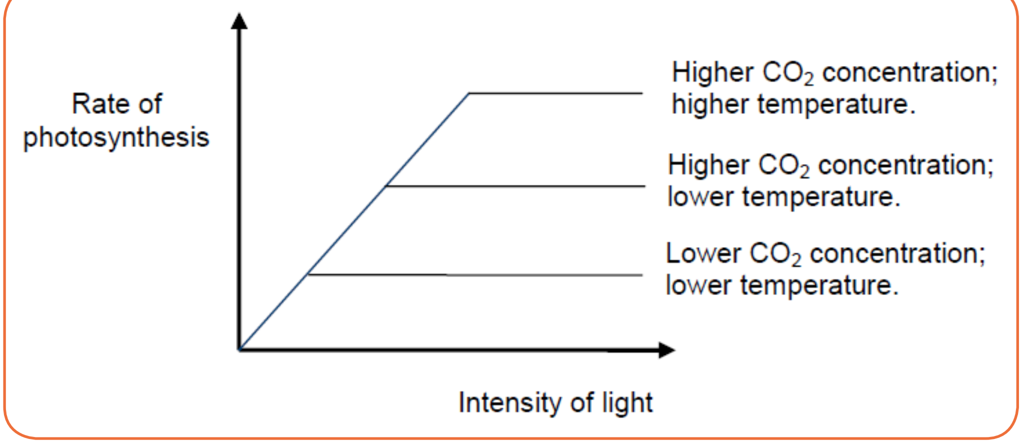


Figure 1.19: Effect of combined limiting factors on the rate of photosynthesis

Application activity 1.3

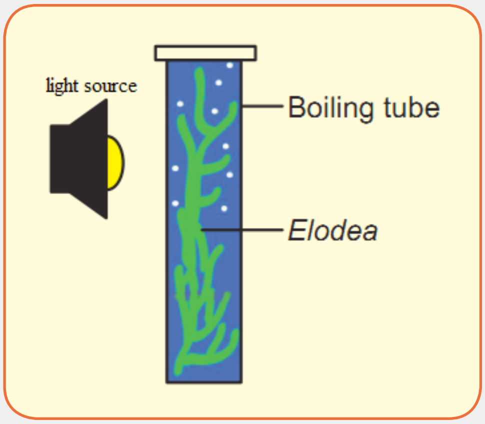
Factors affecting rate of photosynthesis.

Materials Required:

Elodea plant, glass rod, sodium bicarbonate.

Procedure:

Take a fresh, healthy twig of **Elodea** plant with one end intact and tie it gently to a glass rod. Put the glass rod with plant in a boiling tube containing water and add 1mg/mL sodium bicarbonate and keep it in moderate light condition. Note the numbers of bubbles escaping from cut end per minute. Again add same amount of sodium bicarbonate and note the number of bubbles escaping from cut end per minute. Do you find number of bubbles increasing? Repeat this step until bubbles escaping per minute do not increase. Then take set up under high light intensity and note the numbers of bubbles.

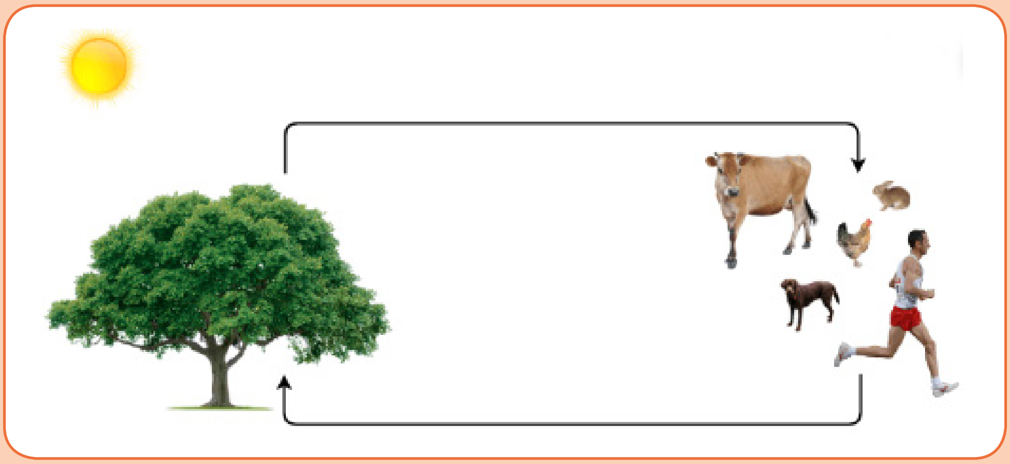


1. What is the observation made when the mass of sodium bicarbonate was increased?
2. What is your observation if the set up is under high light intensity?

1.4. Importance of photosynthesis

Activity 1.4

The following diagram shows the link that exists between plant and animals. Observe the diagram and use it to answer the related questions.



i) What do the animals receive from the plant and what do the plants receive from the animal on the diagram above?

ii) Discuss how the relation between plants and animals are interdependent?

iii) Suggest the role of aquatic plants to aquatic life of animals.

Autotrophic nutrition is a process by which living organisms (autotrophs: photoautotrophs and chemoautotrophs) make their own food. The autotrophism is very essential as it allows production of Oxygen and food for not only themselves but also for heterotrophs. The roles of autotrophic nutrition include:

a. Independence of green plants from other living organisms

This importance relates to their capacity for synthesizing organic molecules from glucose produced by CO_2 and water, this completely make them independents of the other living organisms to the nutrition point of view.

b. Energy storage

The autotrophs like green plants, by the process of photosynthesis synthesize certain substances like the glucose, cellulose, starch… which are variables sources of energy.

c. Production of O_2 for the living organisms' respiration

The oxygen produced by the photosynthesis is necessary for the living organisms' respiration. Thus without photosynthesis, no oxygen can be produced; without oxygen no respiration; without respiration no life on Earth.

d. Cleaning the atmosphere

Photoautotrophs absorb carbon dioxide from surrounding air, and release Oxygen (produced by photosynthesis) in atmosphere.

e. Formation of Ozone layer

Ozone layer is a thick layer in the atmosphere which is formed Ozone molecule (O_3). Oxygen atoms which make ozone molecule are produced by photosynthesis. Ozone layer protects the Earth from high solar radiations, and this allows the existence of the life on the Earth.

Synthesis of the organic substances: food for the heterotrophs (animal and mushrooms). The organic substances produced by photosynthesis are the food for the heterotrophs which are unable to synthesize these substances by their own means.

Application activity 1.4

(a) A well watered potted bean plant was destarched by putting it in the dark for 36 hours. Three of its leaves were smeared with Vaseline as follows: leaf I on both sides; leaf II on the lower surface only; leaf III on the upper surface only. All the other leaves were left untreated. The plant was then placed in sunlight for eight hours after which an iodine test for starch was carried out. The observation was as follows:

Leaf I-brown colour; Leaf II-slight blue-black stain; Leaf III-intense blue-black stain; Leaf IV (untreated leaf)-very intense blue-black stain. Explain these observations.

(b) A student carried out an investigation to show how light intensity affected the rate of photosynthesis for a water plant, Elodea. The student used a test containing water plant immersed in water at different light intensity. After 5 minutes of each experiment, the student counted the number of bubbles. The results are shown in the following table.

Light intensity/Cd (candela)	Number of bubbles after 5minutes
0.05	17
0.10	44
0.15	63
0.20	98
0.25	104
0.75	50

Plot a suitable graph for the result of experiment.

Explain the results recorded between 0.25 Cd and 0.75 Cd of light intensity.

Skills Lab 1

Automobiles and machines must be supplied with gasoline or electricity as a source of energy before they can move. Your muscles require energy in the form of ATP to contract. Muscles can produce ATP by using oxygen (aerobic respiration) or not using it (anaerobic respiration). Anaerobic respiration in muscle cells produces lactic acid. When muscles do a lot of work quickly, the buildup of lactic acid reduces their ability to contract until exhaustion eventually sets in and contraction stops altogether. This is called muscle fatigue.

Materials: clothespin, timer

Procedure:

- Hold a clothespin in the thumb and index finger of your dominant hand.
- Count the number of times you can open and close the clothespin in a 20-s period while holding the other fingers of the hand straight out. Make sure to squeeze quickly and completely to get the maximum number of squeezes for each trial.
- Repeat this process for nine more 20-s periods, recording theresult for each trial in a suitable table. Do not rest your fingers between trials.
- Repeat the procedure for the nondominant hand.

a) What happened to your strength as you progressed through each trial?

b) Describe how your hand and fingers felt during the endof your trials.

c) What factors might cause you to get more squeezes (to have less fatigue)?

d) Were your results different for the dominant and thenondominant hand? Explain why theywould be different.

e) Your muscles would probably recover after 10 min of rest to operate at the original squeeze rate. Explain why.

f) Prepare a suitable graph of anaerobic respiration your muscle.

End Unit Assessment 1

1. What are the products of the light dependent reactions of photosynthesis?

   a) ATP, RuBP and reduced NAD

   b) ATP, oxygen and reduced NADP

   c) GP, oxygen and reduced NAD

   d) GP, reduced NADP and RuBP

2. Before the Krebs cycle can proceed, pyruvic acid must be converted into

   a) Citric acid

   b) Glucose

   c) Acetyl-CoA

d) Glucose
e) NADH

3. The net number of ATP made directly by glycolysis is
   a) 2
   b) 4
   c) 32
   d) 38

4. Cellular respiration is similar to photosynthesis in that they both
   a) Produce ATP
   b) Involve chemiosmosis
   c) Make phosphoglyceraldehyde (PGAL)
   d) All of the above

5. By accepting electrons and protons, the oxygen used in aerobic respiration turns into
   a) CO_2
   b) H_2O
   c) $C_6H_{12}O_6$
   d) ATP

6. The Krebs cycle occurs in the
   a) Cytosol
   b) Outer mitochondrial membrane
   c) Mitochondrial matrix
   d) Space between the inner and outer mitochondrial membrane

7. During each turn of the Krebs cycle,
   a) Two CO_2 molecules are produced
   b) Two ATP molecules are consumed
   c) Pyruvic acid combines with oxaloacetic acid
   d) Glucose combines with a four-carbon molecule.

8. Most of the ATP synthesized in aerobic respiration is made
   a) During glycolysis
   b) Through fermentation
   c) In the cytosol
   d) Through chemiosmosis

9. Where does each stage of aerobic respiration occur in a eukaryotic cell?

	Link reaction	**Krebs cycle**	**Oxidative phosphorylation**
A	cytoplasm	mitochondrial matrix	mitochondrial cristae
B	mitochondrial cristae	cytoplasm	mitochondrial matrix
C	cytoplasm	mitochondrial cristae	mitochondrial matrix
D	mitochondrial matrix	mitochondrial matrix	mitochondrial cristae

10. The diagram summarises how glucose can be used to produce ATP, without the use of oxygen.

glucose ⟶ X ⟶ Y in mammals

↓

Z in yeast

Which compounds are represented by the letters X, Y and Z ?

	X	**Y**	**Z**
A	ethanol	pyruvate	lactate
B	lactate	ethanol	pyruvate
C	pyruvate	ethanol	lactate
D	pyruvate	lactate	ethanol

11. a. Copy and complete the table to show the differences between mesophyll and bundle sheath cells in C4 plants. Insert a tick (x) when an item is present in the cell and a cross (√) when it is not.

Item	**Mesophyll cell**	**Bundle sheath cell**
PEP carboxylase		
rubisco		
RuBP		
enzymes of Calvin cycle		
high concentration of oxygen		
light dependent reactions		
contact with air spaes		

b. Explain what is meant by photorespiration.

12. a. Explain what is meant by a limiting factor.

b. List four factors that may be rate-limiting in photosynthesis.

c. At low light intensities, increasing the temperature has little effect on the rate of photosynthesis. At high light intensities, increasing the temperature increases the rate of photosynthesis. Explain these observations.

UNIT 2

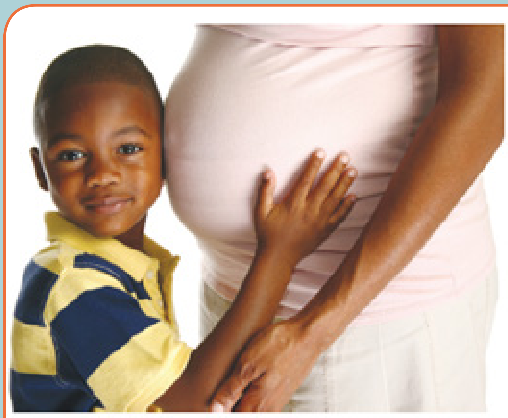
HUMAN REPRODUCTION AND FAMILY PLANNING

Key Unit Competence:

Explain the role of human reproductive hormones, stages of pregnancy and family planning methods.

Introductory activity 2

Observe the photo below and answer the questions that follow:



A

B

a) The woman in A is pregnant. What do you think about the origin of the fetus in the womb of the pregnant woman?

b) Use the photo B to imagine the embryonic development in mother's uterus.

c) Use the photo in B and identify the observable parts of the female reproductive system. Are you satisfy with that description? Justify your response.

d) The child on the photo is a boy. Can you identify the parts of the male reproductive system? What represent the gesture of that boy? Are challenging!!!!

e) What do you think about foetus position observed in mother's uterus on the photo B?

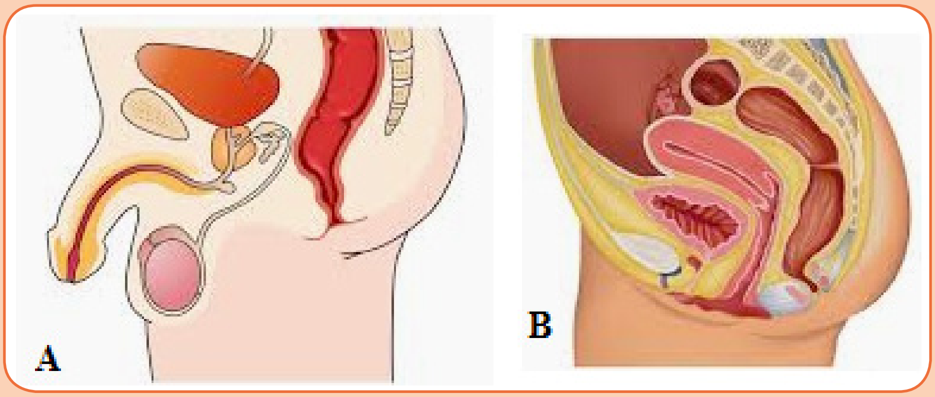
f) The child boy on picture A is the first borne of her mother and the fetus in the womb will be the second and last borne of this mother. Can you advocate for such a family planning? Give reasons

Animals reproduce sexually, but some, on occasion, can reproduce asexually. Sexually reproducing animals have gonads for the production of gametes, and many have accessory organs for the storage and passage of gametes into or out of the body. Animals have various means of ensuring fertilization of gametes and protecting immature stages. Human reproduction is any form of sexual reproduction resulting in human fertilization. It typically involves sexual intercourse between a man and a woman.

2.1. Human reproductive systems

Activity 2.1

The diagrams below represent male and female reproductive system. Observe and use them to answer questions that follow.



a) Identify the structures representing a male and female human reproductive system.

b) Use the choice in (a) to locate and suggest the function of the following male human reproductive organs on the diagram: testis, epididymis, vas deferens, seminal vesicles and prostate gland.

c) Use the choice indicating the female human reproductive system to locate and suggest the function of the following female human reproductive organs on the diagram: urethra, vagina, uterus, ovaries and oviducts.

Human beings reproduce by sexual means where the male and female involve in sexual intercourse, resulting in fertilization. During sexual intercourse, the interaction between the male and female reproductive systems results in fertilization of the woman's ovum by the man's sperm. The ovum and sperm are specialized reproductive cells called **gametes**, generated by a process called **gametogenesis** (i.e., spermatogenesis in males and oogenesis in females).

2.1.1. Structure of male reproductive system

The main visible differences between boys and girls at birth are their reproductive organs. The sex of a child is determined at the time of fertilization of the ovum by the spermatozoon. The differences between a male and a female are genetically determined by the chromosomes that each possesses in the nuclei of the cells.

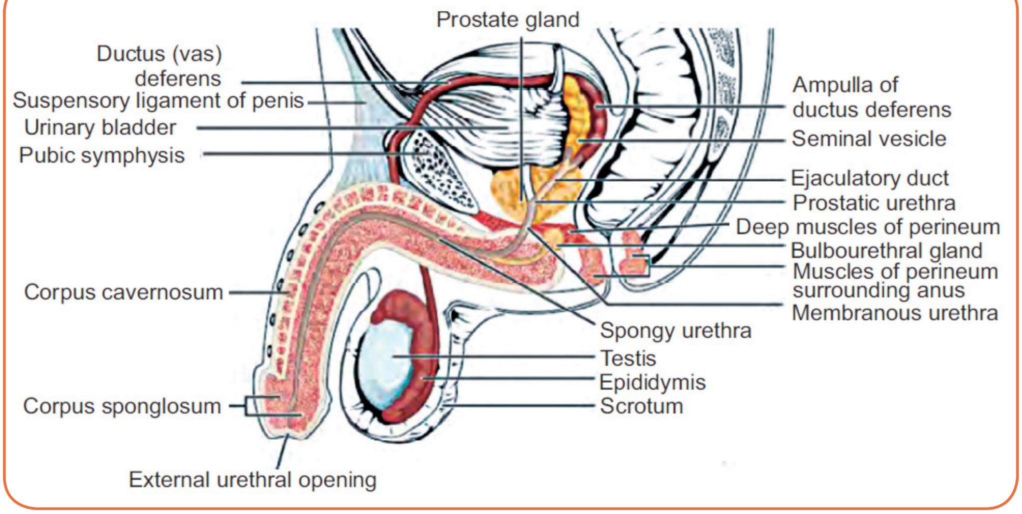


Figure 2.1 Overview of components of male reproductive system

The male gonads are paired testes, which are suspended within the sacs of the scrotum. The testes begin their development inside the abdominal cavity, but they descend into the scrotal sacs as development proceeds. If the testes do not descend and the male does not receive hormone therapy or undergo surgery to place the testes in the scrotum results in sterility (the inability to produce offspring). Sterility occurs because undescended testes developing in the body cavity are subject to higher body temperatures than those in the scrotum. A cooler temperature is critical for the normal development of sperm.

Sperm produced in the seminiferous tubules of the testes mature within the epididymides (sing., epididymis), which are tightly coiled tubules lying just outside the testes. Maturation seems to be required for the sperm to swim to the egg.

Once the sperm have matured, they are propelled into the vasa deferentia (sing., vas deferens) by muscularcontractions. Sperm are stored in both the epididymides and the vasa deferentia. When a male becomes sexually aroused, sperm enter the ejaculatory ducts and then the urethra, part of which is located within the penis.

The penis is the male organ of sexual intercourse. The penis has a long shaft and an enlarged tip called the glans penis. The glans penis is normally covered by a layer of skin called **the foreskin**. Circumcision, the surgical removal of the foreskin, is often done soon after birth.

In addition to these organs, the male reproductive system consists of a series of ducts and glands. Ducts include the vas deferens and ejaculatory ducts. They transport sperm from the epididymis to the urethra in the penis.

Glands include the seminal vesicles, prostate gland, and bulbourethral glands (also called Cowper's glands). They secrete substances that become part of semen.

- Two seminal vesicles contribute about 60% of the volume of semen. The fluid from the seminal vesicles is thick, yellowish, and alkaline. It contains mucus, the sugar fructose (which provides most of the sperm's energy), a coagulating enzyme, ascorbic acid, and local regulators called **prostaglandins**.
- The prostate gland secretes its products directly into the urethra through several small ducts. This fluid is thin and milky; it contains anticoagulant enzymes and citrate (a sperm nutrient).
- The *bulbourethral glands* are a pair of small glands along the urethra below the prostate. Before ejaculation, they secrete clear mucus that neutralizes any acidic urine remaining in the urethra. Bulbourethral fluid also carries some sperm released before ejaculation, which is one reason for the high failure rate of the withdrawal method of birth control (coitus interruptus).

Semen is the fluid that is ejaculated from the urethra. Semen contains secretions from the glands as well as sperm. The secretions control pH and provide the sperm with nutrients for energy.

Table 2.1: Parts of the male reproductive system and their functions

Structure	Function
Testes	Produce sperm cells and sex hormone **"testosterone".**
Epididymis	Sites of maturation and storage of sperm.
Vas deferens	Carries sperm from the epididymis to its junction with the urethra.

Seminal vesicle	Secretes fructose into the semen, which provides energy for the sperm.
Prostate gland	Secretes an alkaline buffer into the semen to protect the sperm from the acidic environment of the vagina.
Cowper's gland	Secretes mucus-rich fluids into the semen that may protect the sperm from acids in the urethra.
Urethra	Carries semen during ejaculation and urine from the bladder to the exterior of the body.
Penis	Deposits sperm into the vagina during ejaculation

Note: Male infertility refers to a male's inability to cause pregnancy in a fertile female. In humans it accounts for 40-50% of infertility. It affects approximately 7% of all man. Male infertility may be due to:

- Absence of sperms in the semen (Azoospermia).
- Low sperm count e.g. when ones ejaculate less than 1 cm^3 of semen.
- Abnormal sperm e.g. sperms with 2 tails, or without tail, or without acrosomes,
- Auto-immunity e.g. antibodies attack one's sperms
- Premature ejaculation: the man has orgasm before copulation
- Impotence i.e. inability to achieve or maintain an erection of the penis.

2.1.2. Structure of female reproductive system

The female reproductive system is a collection of organs and other structures located primarily in the pelvic region. Most of the structures are inside the body. It includes the ovaries, the oviducts, the uterus, and the vagina.The female reproductive system has several functions:

- Producing eggs, which are female gametes
- Secreting female sex hormones
- Receiving sperm during sexual intercourse
- Supporting the development of a fetus
- Delivering a baby during birth

During puberty, a girl develops into a sexually mature woman, capable of producing eggs and reproducing.

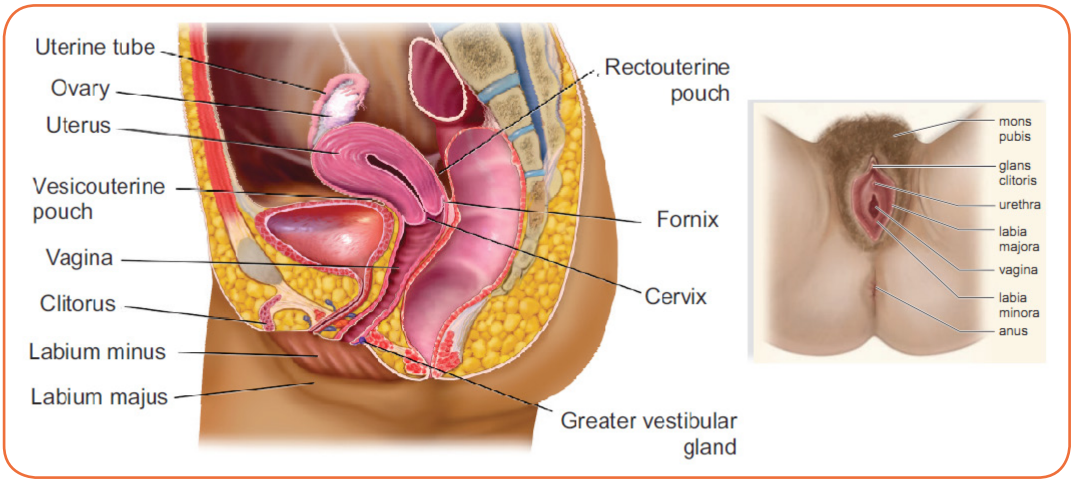


Figure 2.2: Overview of human female reproductive system (ventral and left view)

The external genital organs of a female are known collectively as the vulva. The pubic hairs and two folds of skin called **labia minora** and **labia majora** are on either side of the urethral and vaginal openings. Beneath the labia majora, pea-sized greater vestibular glands (Bartholin glands) open on either side of the vagina. They keep the vulva moist and lubricated during intercourse.

At the juncture of the labia minora is the clitoris, which is homologous to the penis in males. The clitoris has a shaft of erectile tissue and is capped by a pea-shaped glans. The many sensory receptors of the clitoris allow it to function as a sexually sensitive organ. The clitoris has twice as many nerve endings as the penis. Orgasm in the female is a release of neuromuscular tension in the muscles of the genital area, vagina, and uterus.

Table 2.2: Parts of the female reproductive system and their functions

Structure	Function
Ovaries	Produce eggs and sex hormone “estrogen and progesterone”.
Oviducts (fallopian tubes)	Carry the ovum from the ovary to the uterus and is a site of fertilization.
Fimbria	Sweep the ovum into the oviduct following ovulation.
Uterus (womb)	– Pear-shaped organ in which the embryo and fetus develop. – Involved in menstruation.
Cervix	– Separates the vagina from the uterus. – Holds the fetus in place during pregnancy. – Dilates during birth to allow the fetus to leave the uterus.

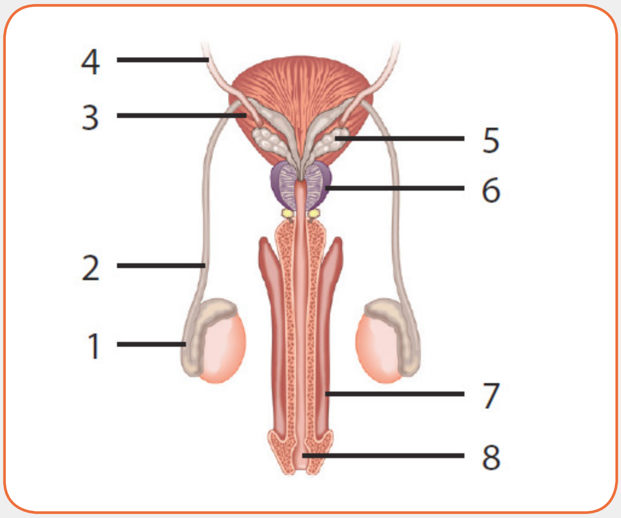
Vagina	– Receives penis during copulation and serves as birth canal. – Provides a passageway for the sperm and menstruation flow.

Note: Female infertility is defined as the inability to conceive or carry a pregnancy to term after 12 months of unprotected intercourse, or 6 months of unprotected intercourse if the female is over 35 years old. In females, infertility may be due to:

- Failure to ovulate due to the lack of some hormones.
- Damage of the Fallopian tubes / oviducts, for example the tubes may be completely blocked by nature or after an infection.
- Damage on the uterus; for example, the endometrium can be destroyed.
- Damage on the cervix, for example the cervix may be narrow or too wide or may stop producing cervical mucus needed for the sperm to reach uterus.
- Antibodies against sperms, for example, the cervix, the uterus or the oviduct of a woman can produce antibodies against her husband's sperms.

Application activity 2.1

The figure below represents the male reproductive system.



a) Justify why it is representing a male reproductive system.

b) Refer to the figure and identify the parts represented by the numbers 1 to 8.

c) How can you justify the function of organ 2, 5 and 7 according to the structure of male reproductive system?

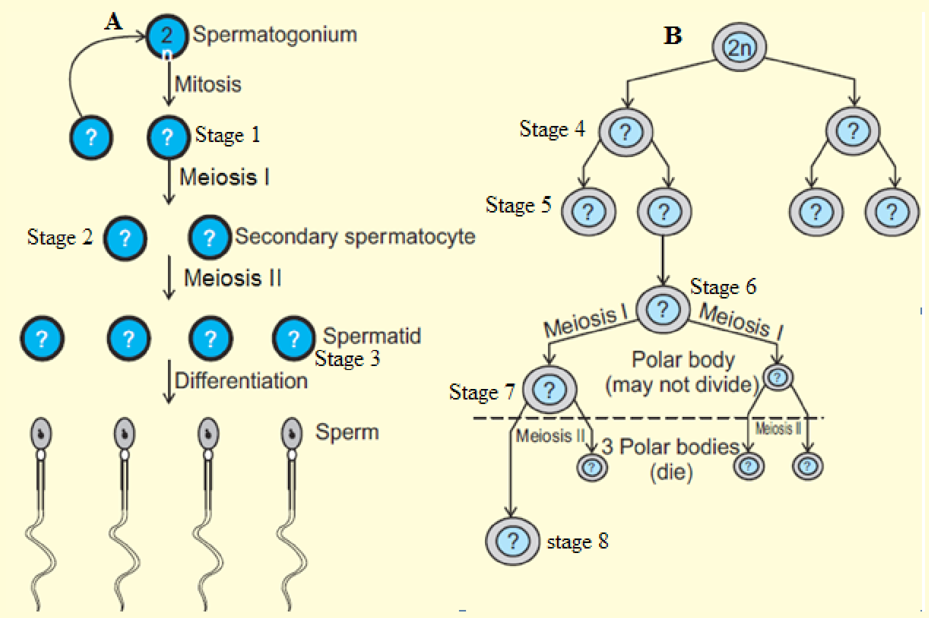
2.1.3. Gametogenesis

Activity 2.2

Gametes are haploid cells that are formed from diploid germ cells through the process of gametogenesis. The significance of developing haploid gametes lies in the fact that after fertilization, the developing zygote attains the diploid status back. In this way, the developing embryo gets the single copy of all the chromosomes from each parent.

Based on the chart diagrams of spermatogenesis and oogenesis shown below.

i) Compute the number of chromosomes at each stage, assuming 2n = 46.



ii) Which diagram does it represent spermatogenesis and oogenesis? Explain why?

A) Spermatogenesis

The process of formation of haploid male gametes or spermatozoa from diploid reproductive cells in males is called **spermatogenesis.** The complete process is broadly divided into two parts, formation of **spermatids** and **spermatogenesis or spermatoleosis**.

– Formation of Spermatids

The process of formation of spermatids is further divided into three stages as:

a) **Multiplication phase:** The primordial germ cells or sperm mother cells differentiate from germinal epithelium of testis and increase in size with prominent nuclei. These cells divide repeatedly by mitosis (i.e., equational division) and produce a number of diploid daughter cells, known as spermatogonia. Thus, in this stage, multiplication of germ cells takes place mitotically.

b) **Growth phase:** In this phase, spermatogonia increase in size by accumulating food reserves and are now called primary spermatocytes.

c) **Maturation phase:** The primary spermatocytes (which are diploid) undergo first maturation division which is **meiotic division** (or **reductional division**) to produce two haploid secondary spermatocytes. These haploid secondary spermatocytes divide further by mitosis to give rise to four haploid spermatids. This mitotic division is called second maturation division.

The spermatids so produced are non-motile rounded structures that metamorphose into functional and motile spermatozoa through a process known as **spermiogenesis** or **spermatoleosis**. The spermatozoa from testis are incapable of fertilizing an ovum. They undergo several morphological, physiological and biochemical changes as they move through the epididymis to attain this structural and physiological maturity. The epididymis i) provides a favorable environment to spermatozoa in acquiring fertilizing ability and ii) stores them until they are ejaculated or move down to the vas deferens.

The morphological changes include structural remodeling of acrosome and formation of disulfide linkages. The physiological and biochemical changes include increase in net negative charge on spermatozoa, change in pattern of motility, change in content of sialic acid, increase in specific activity and reflection power, resistance to pH and temperature and changes in metabolic patterns.

– Spermiogenesis

A series of changes in spermiogenesis that transform a non-motile spermatid into motile, functional spermatozoa are listed below:

- The nucleus shrinks and flattens by losing water. Only DNA is left in the nucleus, making cells very light that aids to its motility.
- The two **centrioles** of a centrosome form proximal and distal centrioles that lie at the posterior end of nucleus and give rise to axial filament of the flagellum and acts as a basal granule respectively.

- The **mitochondria** gather around axial filament and gradually unite to form spiral sheath or nebenkern. It acts as power house of the sperm and provides energy.
- The **golgi bodies** form the covering over nucleus called acrosome. During acrosome formation, one or more vacuoles start enlarging with a small, dense body called **pro-acrosomal granule** which further enlarges to form acrosomal granule. The vacuole loses its liquid content and forms the cap of spermatozoan. The remaining part of golgi apparatus is reduced and discarded from sperm.

During all these steps, head of the developing sperm remains embedded in sertoli cells for nourishment. At the end, fully formed spermatozoan shows distinct head, middle piece and tail region.

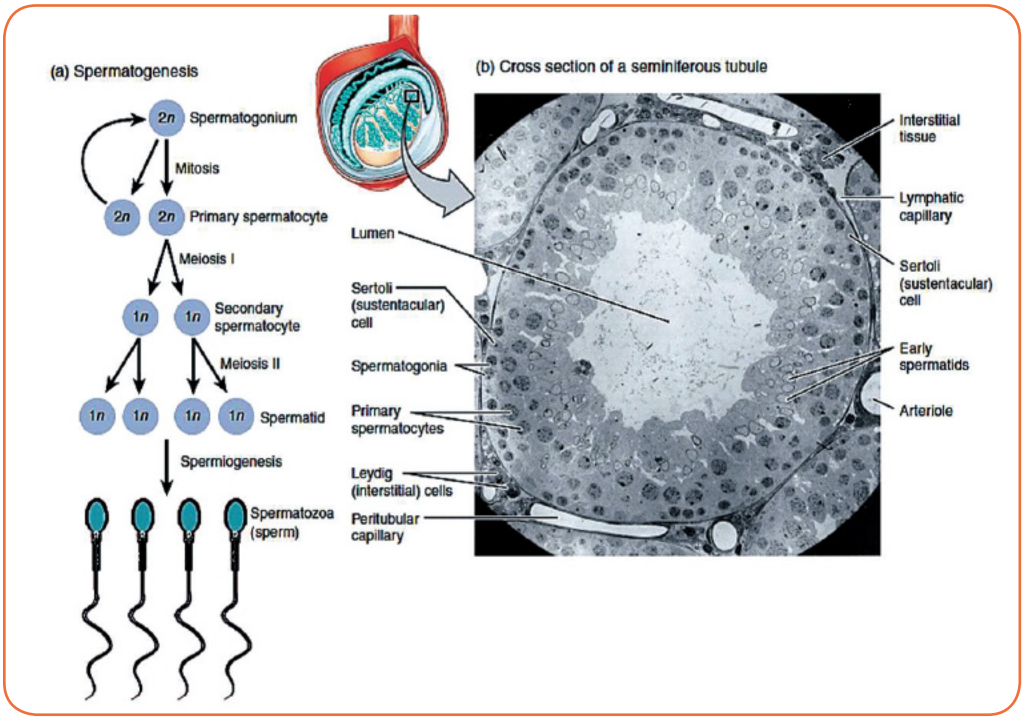


Figure 2. 3 Process of spermatogenesis

– **Structure of Spermatozoa**

The sperms are microscopic and motile cell. Each sperm is composed of four parts a head, a neck, a middle piece and a tail. A plasma membrane covers the whole body of sperm.

i) **Head** is the enlarged end of the sperm, containing an elongated haploid nucleus. The anterior of the nucleus is covered by a cap-like structure called **acrosome.** The acrosome contains enzymes sperm or **hyaluronidases**, which are used to contact and **penetrate the ovum at the time of fertilization.**

ii) **Neck** is very short and is present between the head and middle piece. It contains the proximal centriole towards the nucleus which plays a role in the first cleavage of the zygote and the distal centriole which gives rise to the axial filament of the sperm.

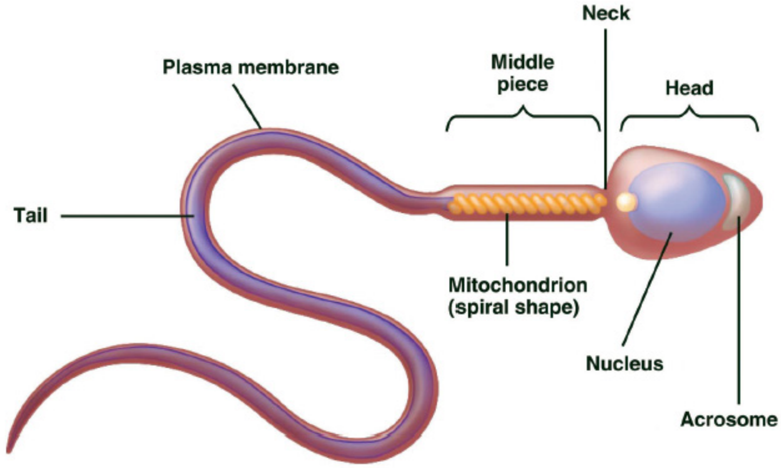


Figure 2.4 Structure of a sperm

iii) **Middle piece** possesses **numerous mitochondria** which **produce energy for the movement of the sperm.** At the end of the middle piece, there is a ring centriole (annulus) with unknown function.

iv) **Tail** is several times longer than the head. It consists of an axial filament surrounded by a thin layer of cytoplasm. The **tail provides motility to the sperm**, which is essential for fertilization.

B) Oogenesis

The process of oogenesis occurs in the ovaries. The three phases of proliferation, growth and maturation occur in discontinuous steps.

a) **Proliferative or multiplication phase**: During early foetal development, certain cells within the germinal epithelium of the ovary become enlarged. These cells proliferate by mitosis, producing undifferentiated germ cells called **egg mother cells**or oogonia (2n). The oogonia divide mitotically to produce groups of oogonia, termed follicles.

b) **Growth and differentiation phase**: During this long phase, which may last upto years, one cell in a follicle prepares for the formation of ovum. It starts meiotic division but gets arrested at prophase-I stage and is called **primary oocyte**. The remaining cells of the follicle lose the potential to become primary oocyte and are known as the follicular cells or granulosa cells. These follicular cells serve to protect and nourish the primary oocyte. The complete follicle with a primary oocyte surrounded by a layer of follicular cells is called **the primary** or **the ovarian follicle**.

c) **Maturation phase:** At puberty, only one of the primary oocytes resumes division per menstrual cycle, alternately in each ovary. The tertiary follicle matures into a Graafian follicle, within which the primary oocyte makes two successive to form secondary oocyte. However, the secondary oocyte again gets arrested at metaphase stage of meiosis-II and is released from the ovary during ovulation. It waits in the oviduct for the sperm to arrive. If fertilization occurs, sperm entry into the secondary oocyte marks the resumption of meiosis. The 2^{nd} maturation division (meiosis-II) again divides the secondary oocyte into two unequal daughter cells: a large ootid and a very small 2^{nd} polar body. The ootid undergoes maturation into a functional haploid ovum. A thin vitelline membrane develops outside the plasma membrane of the ovum that protects and nourishes the latter.

– **Structure of Ovum**

An ovum is a spherical, non-motile cell, in the secondary oocyte stage of oogenesis. Human ovum is microlecithal with large amount of cytoplasm. Cytoplasm is differentiated into outer, smaller and transparent exoplasm or egg cortex and inner, larger and opaque endoplasm or ooplasm. Egg cortex is with some cytoskeletal structures like microtubules and microfilaments, pigment granules and cortical granules of mucopolysaccharides. Endoplasm is with cell-organelles, informosomes, tRNAs, histones, enzymes etc.

The ovum is covered over by a thin, transparent vitelline membrane which is further covered over by zona pellucida. There is a narrow space between these two membranes known as perivitelline space. During discharge of ovum from the Graafian follicle, several layers of follicular cells adhere to the outer surface of zona pellucida and are arranged radially forming corona radiata.

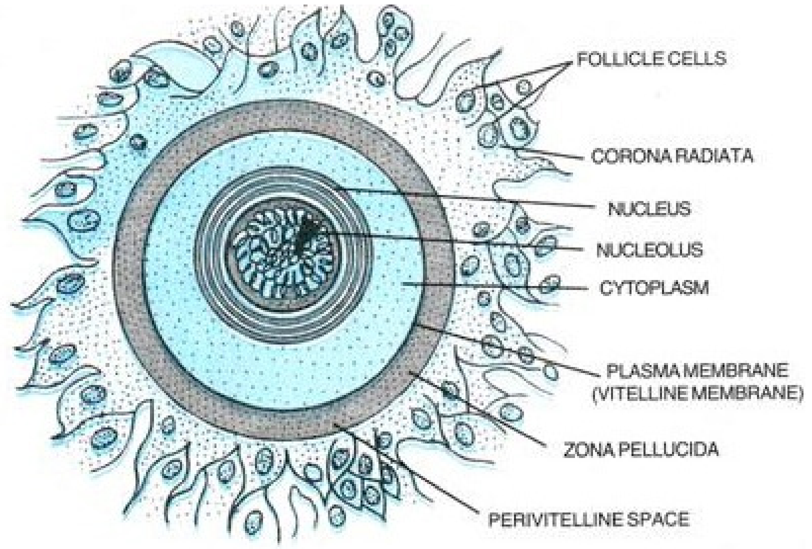


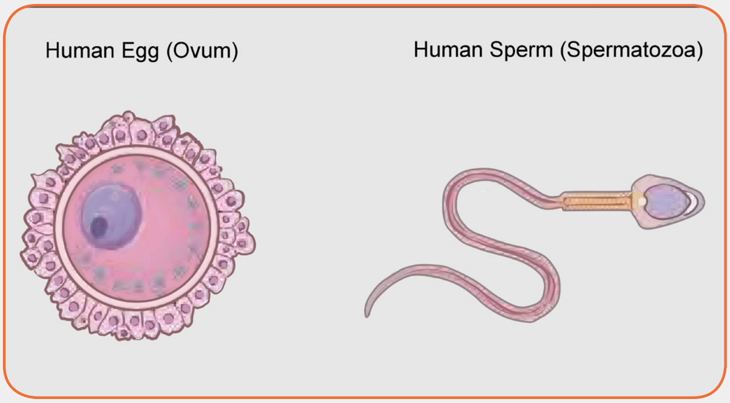
Figure 2.4: Structure of a mature human ovum with corona radiata surrounding it.

Table 2.3: Differences between spermatogenesis and oogenesis

Spermatogenesis	Oogenesis
It occurs in the testis.	It occurs in the ovaries.
The whole process is completed in the testes so that mature spermatozoa are released from the testes.	The process gets completed in the oviduct i.e., oocytes at metaphase-II stage are released from the ovaries.
Equal meiotic divisions occur.	Unequal meiotic divisions occur.
No polar body is formed.	Polar body is formed.
One spermatogonium produces four functional spermatozoa.	One oogonium produces only one functional ovum.

Application activity 2.2

1. Suppose that four hundred sperm mother cells have undergone a process of spermatogenesis in a testis of human. How many chromosomes are produced at the end of spermatogenesis? How many chromosomes does each sperm have?
2. On the basis of your observations, use the drawn structure of a human spermatozoan and an ovum and label their respective parts along with the functions of each:



Egg	Sperm
Zona pellucida	Nucleus
Vitelline membrane	Middle piece
Corona radiata	Acrosome

2.1.4. Cycle in humans

Activity 2.3

Human beings grow and develop from childhood to adulthood, during such period of growth and development; there are changes in some parts of body which may occur physiologically, physically and even psychologically. These changes prepare individual adulthood to reproduce. Different researchers indicated these changes to be coordinated by different types of hormones.

1. Suggest the hormones involved during such period of changes in body parts?
2. Discuss the significance of these hormones you have mentioned above during such period of changes.
3. Describe the role of hormones involved during pregnancy and birth.
4. Which day of the cycle will ovulation take place?

The menstrual cycle refers to the periodical changes in the reproductive behaviour of a female which tend to occur in a sequence of events one after the other in the periodical circle. At the onset of puberty, the cycle begins and repeats after 28 days unless interrupted by pregnancy. The changes are stimulated by the gonadotrophic hormone such as; follicle stimulating hormone (FSH) and luteinizing hormone (LH). These hormones stimulate ovaries to secrete; oestrogen (steroid) and progesterone hormones. These four hormones are involved in menstrual cycle. Two of them including; FSH and LH are produced by pituitary gland and the other two are released by ovaries respectively. The most obvious sign of the cycle is the monthly discharge of blood a process called **menstruation**. The first day of menstruation is regarded as the first day of the cycle.

The three phases of the menstrual cycle are the follicular phase, ovulation and the luteal phase.

a. Follicular phase

Menstrual cycle usually begins when blood is first discharged from the uterus during the first to fifth day (1-5 days). Following the reduction of progesterone, the hypothalamus releases gonadotropin releasing hormone (GnRH) which stimulates anterior pituitary gland to secrete follicle stimulating hormone (FSH). FSH brings about the following effects:

- Stimulates the development of a primary follicle
- Contributes to the shedding of uterine wall

- Causes production of oestrogen by uterine cells. The oestrogen produced promotes healing, repair and growth of uterine lining, inhibits further secretion of FSH. Oestrogen levels keep on raising until day 13 where they stimulate secretion of luteinizing hormone (LH) by anterior pituitary gland.

b. Ovulatory phase

Around the 14th day, the high levels of oestrogen causes release of luteinizing hormone (LH).The release of LH brings about ovulation (release of mature egg from the ovary). Immediately after and slightly before ovulation, a woman is fertile and can conceive a baby if she has sexual intercourse or if sperm is present in her oviduct.

c. Luteal phase

After ovulation, the remains of ovarian follicle form corpus luteum also known as **Yellow body**, which secrete large amounts of progesterone hormone and smaller oestrogen. These two hormones; stimulate further development of mammary glands, inhibit release of FSH and thickening wall of uterus in anticipation of pregnancy. If oocyte (ovum) is not fertilized with in about 36 hours of being shed into oviduct, it dies and corpus luteum gets smaller. Thus levels of progesterone and oestrogen keep on reducing until day 28 days i.e. 14 days after ovulation. Low levels of progesterone remove the inhibitory effect on FSH, causing its release thus menstruation and the cycle starts again.

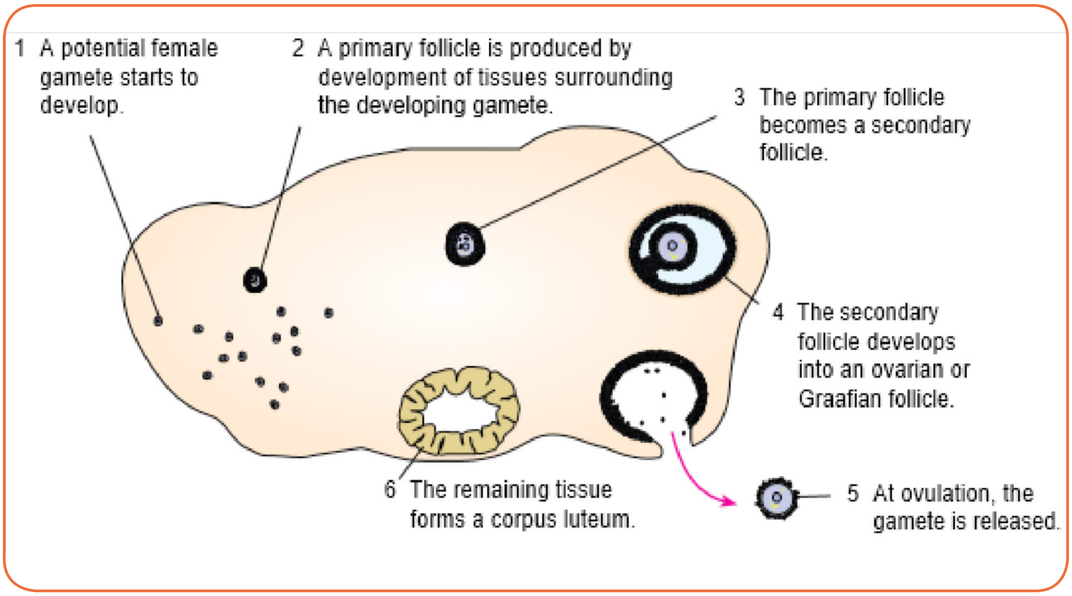


Figure 2.5: Growth of ovarian follicle

The menstrual cycle is the regular natural changes that occurs in the female reproductive system (specifically the uterus and ovaries) that makes pregnancy possible. The cycle is required for the production of oocytes, and for the preparation of the uterus for pregnancy. The uterine events during menstrual cycle can also be divided into three phases:

Menstrual phase: when endometrium tissue is discharged and vaginal bleeding occurs at the end of ovulatory cycle if pregnancy has not occurred. It is called **menstruation**. It describes the shedding of endometrium when implantation does not occur. When pregnancy does not occur, the level of progesterone falls and this leads to the shedding of endometrium. Menstrual bleeding lasts between 3 and 5 days. The first day of the period is the first day of the cycle.

Proliferative phase: It stimulates the thickening of endometrium of the uterus. This thickness of endometrium is stimulated by estrogen from follicles before ovulation which occurs when the ovarian follicles rupture and release the secondary oocyte ovarian cells. This results to the development of ovary. It acts like follicular phase.

Secretory phase: it occurs after ovulation for describes further thickening of endometrium (endometrium tissue become more complex) in preparation for implantation. This is stimulated by progesterone which is secreted by corpus luteum and this occurs when corpus luteum is functioning. It acts like lacteal phase.

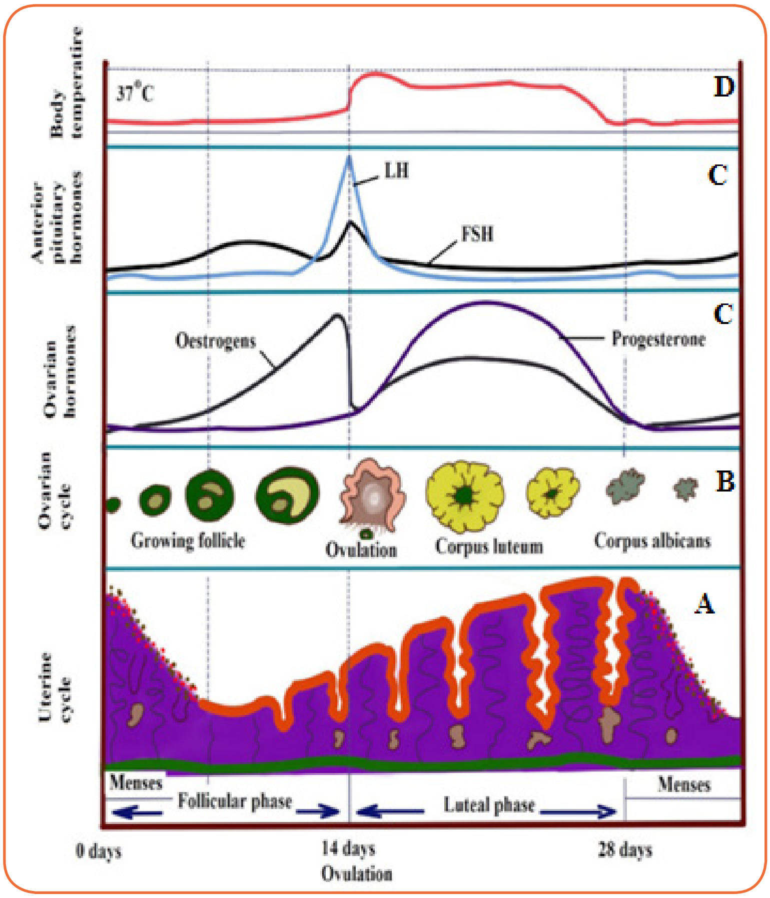
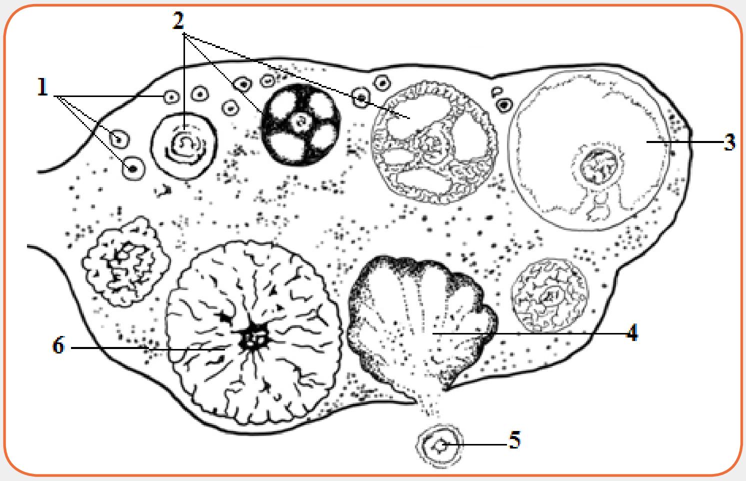


Figure 2.6: Menstrual cycle of human female

Application activity 2.3

1. The diagram below represents a section through a human ovary in ovulation.

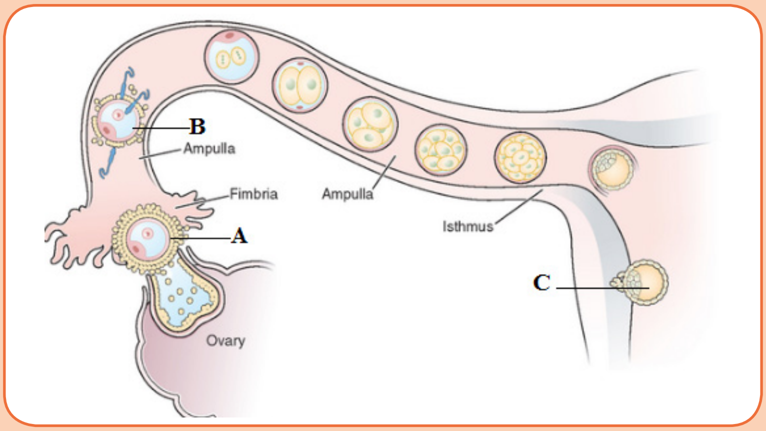


1. Use the diagram to locate the step at which ovulation take place. Explain your answer.
2. State what will happen to this structure next if pregnancy has not occurred.
3. State which hormone is needed to cause the changes seen in the diagram and indicated by the sequence (1), (2) and (3).

2.1.5. Fertilization and fatal development

Activity 2.4

The following diagram represents different stages that happen before fetal development. Use it to answer related questions.



i) Suggest the name of the cell labeled A.

ii) Name the process which is happening on the cell labeled B. What are the conditions required for the process to happen? Justify your answer.

iii) Describe the process which is happening in C and what happens after?

a. Copulation

It is act of mating where sperms from male are transferred into the female tract. Male mammals have an intromittent organ called **penis** which becomes erect at a moment of mating for insertion into female's vagina. The erection of penis is brought by hydraulic action (penis becomes gorged with blood). This occurs as a result of sexual arousal which brings about by ejaculation (release of sperm). The semen's are secreted from accessory glands into vas deferens and bladder sphincter closes preventing urine from entering urethra. Sperms are expelled from epididymis into vas deferens and out of the body by a series of muscle contraction of penis. In a female, sexual arousal results in the swelling of clitoris and stimulates the secretion of mucus which lubricates vagina during sexual intercourse.

b. Fertilization

Fertilization is the fusion of male and female nuclei to form zygote. Copulation results in the ejection of spermatozoa into vagina. The spermatozoa swim in the watery mucus of vagina and uterus up into the oviduct where the fertilization takes place in the upper part of the oviduct. From the vagina or uterus spermatozoa propel using energy from mitochondria. If ovulation has already taken place, the egg and sperm meet in the upper part of oviduct and once they come into contact, acrosome raptures and release lytic enzyme which dissolve corona radiata of the egg and soften zona pellucida and vitelline membrane. The following processes take place:

– **Capacitation**

This is a stage where by sperm undergoes essential changes while passing through female genital track and this takes about 7 hours. These changes include the removal of a layer of glycoprotein from outer surface of sperm, by enzyme in uterus. Cholesterol also is removed to weaken the membrane.

– **Acrosome reaction**

This involves the releasing of enzyme found in acrosome such as hyaluronidases and protease. These enzymes digest corona radiata (narrow path in the follicle cells) and the zona pellucida (a protective glycoprotein surrounding the plasma membrane of the egg).

– **Fusion**

In this stage the head of sperm will fuse with the microvilli surrounding the secondary oocyte and penetrate its cytoplasm.

– **Cortical reaction**

This stage involves the releasing of enzymes by lysosomes in cortical granules (outer region of the secondary oocytes); the enzymes cause the zona pellucida to thicken and harden forming a fertilization membrane. This cortical reaction prevents the entry of other sperm inside ovum (polyspermy).

– **Zygote formation**

The secondary oocyte is stimulated to complete meiosis II, during this time of stimulation the nucleus of sperm and secondary oocyte are called pro-nuclei and then the two nuclei fuse to form the zygote (2n).

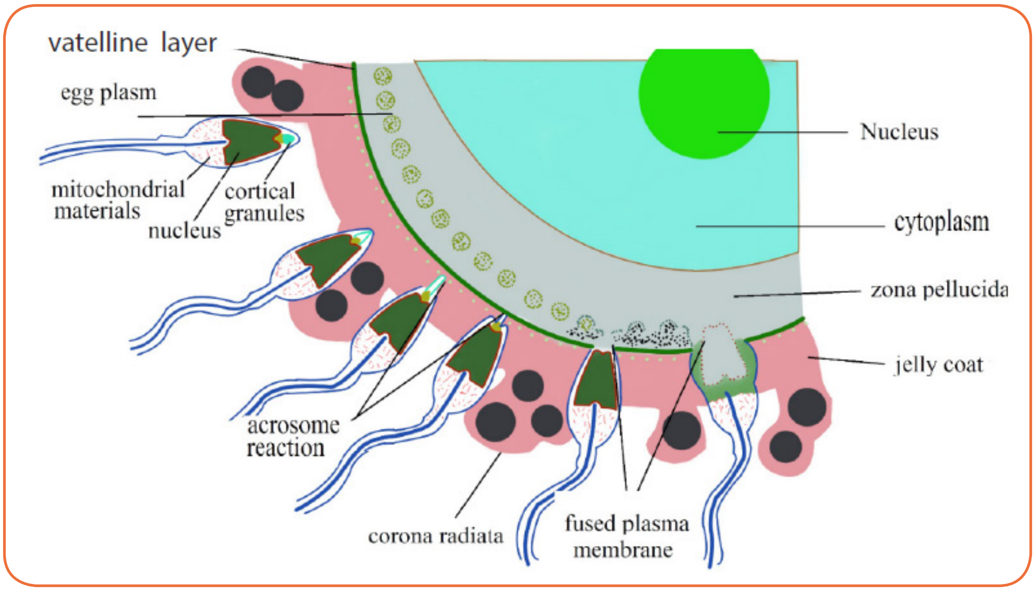


Fig 2.7: Process of fertilization

2.1.6. Embryonic development

The zygote spends the next few days travelling down the oviduct (Fallopian tube) by peristaltic contraction and by beatings of the cilia in wall of the oviduct toward the uterus. As it travels, it divides by mitosis several times to form a ball of cells called **a morula**. The cell divisions, which are called cleavage, increase the number of cells but not their overall size. More cell divisions occur, and soon a fluid-filled cavity forms inside the ball of cells. At this stage, the ball of cells is called **a blastocyst**.

The blastocyst reaches the uterus and becomes embedded in the endometrium at roughly the 5^{th} – 10^{th} day. Once in the uterus, the blastocyst burrows into the uterine wall a process called **implantation**. After implantation, the blastocyst becomes embryo. It grows through multiplication and differentiation of its cells forming tissues and organs. The heart and blood vessels are the first organs formed and embryo now called **foetus**.

During embryonic development, cells of the embryo migrate to form three distinct cell layers: the ectoderm, mesoderm, and endoderm. Each layer will eventually develop into certain types of tissues and cells in the body of vertebrates.

- **Ectoderm:** forms tissues that cover the outer body; develops into cells such as nerves skin, hair, and nails.
- **Mesoderm:** forms tissues that provide movement and support; develops into cells such as muscles, bones, teeth, and blood.
- **Endoderm:** forms tissues involved in digestion and breathing; develop into organs such as lungs, liver, pancreas, and gall bladder.

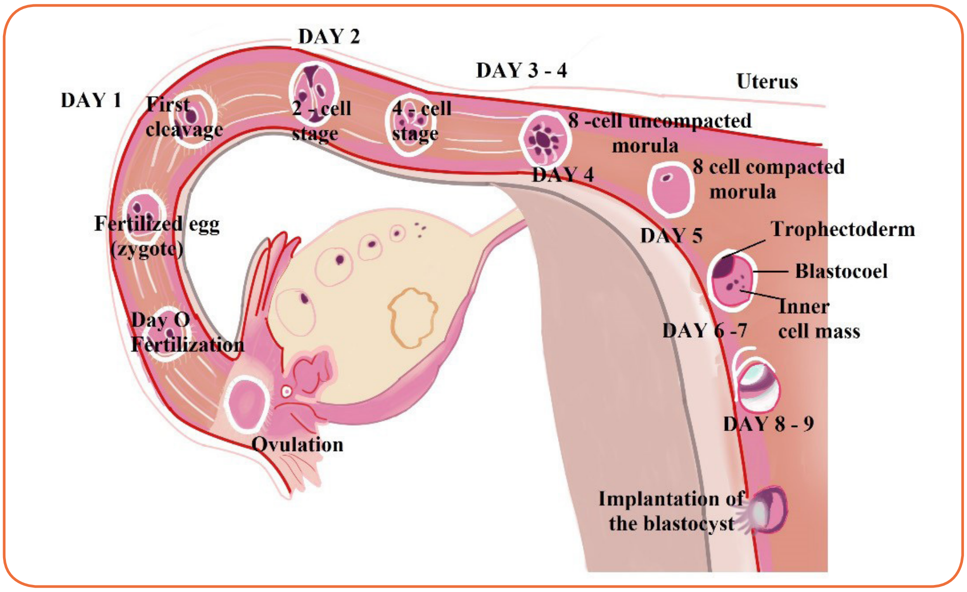
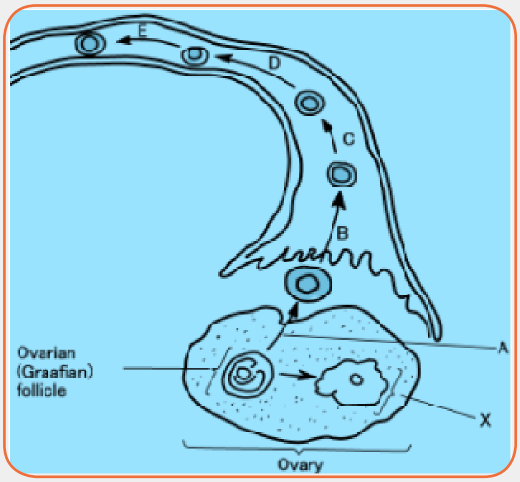


Figure 2.8: Embryo development during the first nine days

Application activity 2.4

The diagram below shows some of the events which take place in the ovary and oviduct (Fallopian tube) around the time of fertilization.



a) Name the following:

i) The process labeled A.

ii) The type of nuclear division taking place at D and E.

iii) The structure labeled X.

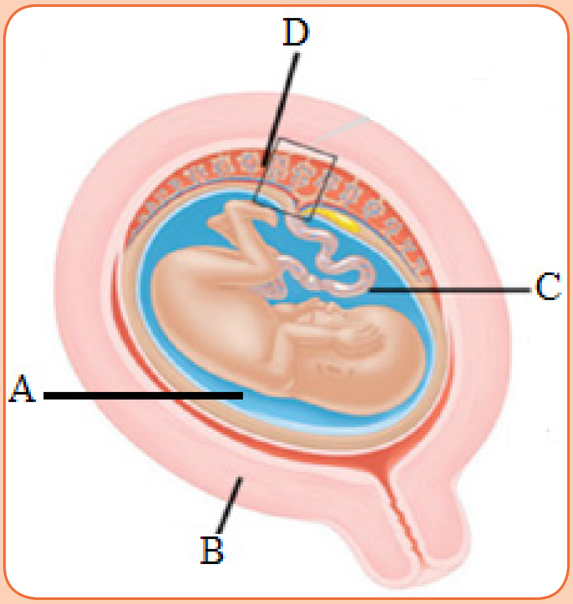
iv) One hormone produced by structure X.

b) On the diagram, use the letter F to label the region where fertilization took place

2.1.7. Role of placenta in the development of an embryo

Activity 2.5

The drawing below shows a developing human fetus inside the uterus. Observe the diagram and attempt the related questions.



a) Suggest the name of the parts marked A to D.

b) Which part is involved in transport of substance from mother to fetus on the diagram and why?

c) Suggest four substances which pass from the mother to the embryo.

d) Name one substance which passes from the embryo to the mother.

e) What is the importance of the placenta?

The placenta is a temporary organ in which nutrients and wastes are exchanged between the mother and the embryo or foetus.

The foetal part of the placenta consists of the allantoids and chorion. The chorion forms many large projections called **chorionic villi** which contain a dense network of foetal capillaries which in turn are connected to two umbilical arteries and umbilical vein in the umbilical cord. The umbilical arteries carry blood from the foetus to the placenta, while the umbilical vein carries blood in the opposite direction. Although maternal blood in the endometrium is in close proximity with the foetal blood in the umbilical capillaries, they do not mix because they separated by membranes of the villi and capillary.

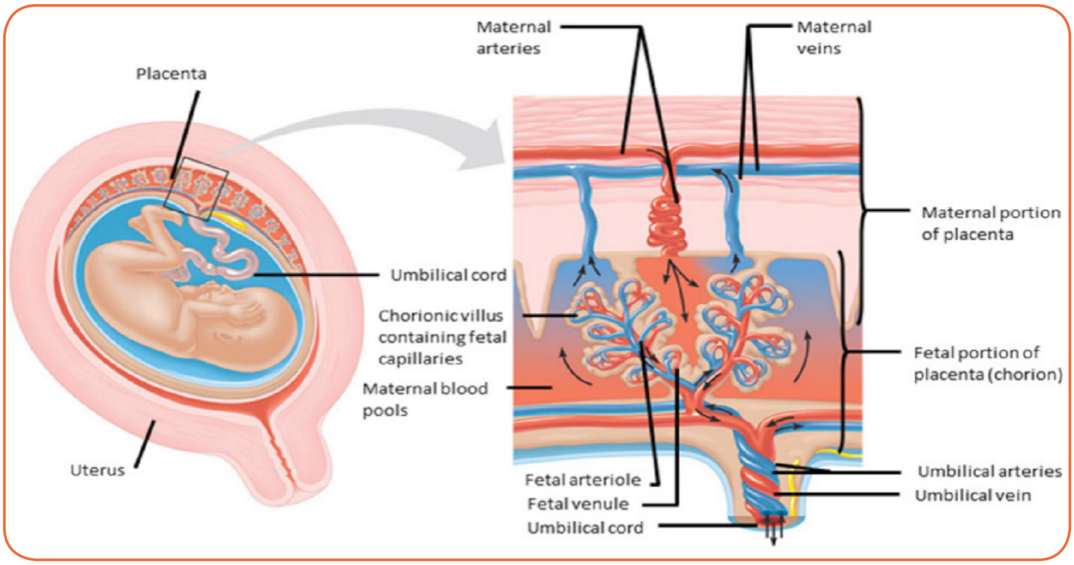


Figure 2.9: Structure of the placenta

The placenta is an organ that develops in your uterus during pregnancy with specifically the following functions:

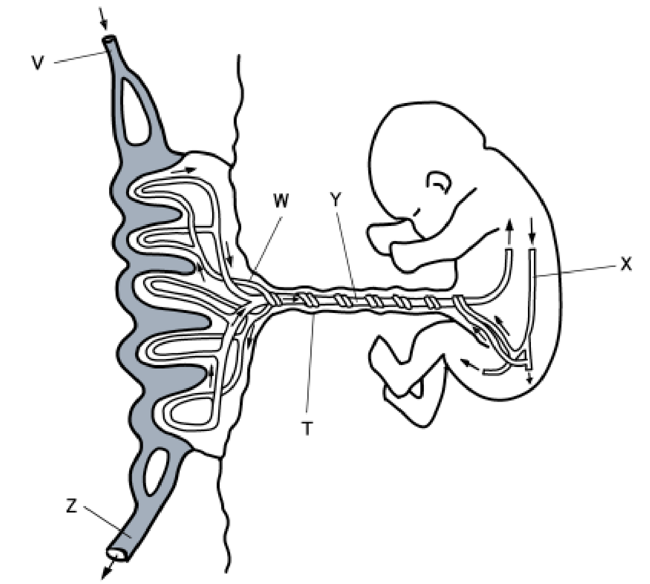
- It allows diffusion of nutrients such as water, glucose, amino acids, simple proteins and mineral salts from maternal blood.
- It is a site of gaseous exchange: haemoglobin of the foetus has high affinity to oxygen compared to adult haemoglobin.
- It offers passive natural immunity on the foetus. Certain maternal antibodies can cross the placental barrier.
- It protects foetal circulation from the high pressure in the maternal circulation
- Prevents mixing of maternal and foetal blood which would cause agglutination (clotting) if the two blood types are incompatible.
- It produces and secretes hormones such as the HCG (human chorionic gonadotrophin), progesterone, oestrogen, and relaxin.

Note: The action of HCG is similar to that of LH. HCG stimulates the corpus luteum to secrete progesterone and oestrogen throughout the first trimester. HCG is produced in such large quantities that some of it is excreted in the urine of a pregnant woman (positive test of pregnancy). Secretion of HCG declines around tenth week and the corpus luteum reduces.

The placenta does not give complete protection to the foetus. Certain pathogens, toxins, and drugs can enter the foetal circulation and cause damage. Examples are; HIV, rubella toxins, alcohol, nicotine and heroin.

Application activity 2.5

The diagram shows the structure of the placenta and parts of the fetal and maternal circulatory systems.



a) Complete the table by listing the blood vessels that carry oxygenated blood. Use the letters in the diagram to identify the blood vessels.

Circulatory system	Blood vessels that carry oxygenated blood
Maternal	
Fetal	

b) What happens on thestructure **T** after birth?

c) The placenta is adapted for the exchange of substances between the maternal blood and the fetal blood. Describe the exchanges that occur across the placenta to keep the fetus alive and well.

2.1.8. Physiological changes in females during pregnancy and Parental care

Activity 2.6

Observe the following images that show pregnant women.

Use your personal observation or conduct research from medical personnel, internet or library to answer the following questions:

a) Suggest the physical changes that can be observed to the pregnant women.
b) What physiological and behavioral changes that can happen when women get pregnant.
c) It is necessary to practice a special parental care to pregnant women. Provide reasons that justify this statement.

Pregnancy refers to the development that take place between fertilization of the ovum to birth of the foetus. When fertilized egg becomes implanted in uterine wall, pregnancy starts. And a number of important events take place during this period. The period from fertilization to birth is called **gestation period**. In human it is about nine months.

A. Changes during pregnancy

A pregnant woman's body undergoes various; physiological, physical and behavioural changes.

a) Physiological changes during pregnancy

- Respiration rate rises for increased maternal oxygen consumption which is needed for demand of placenta, uterus and foetus.
- More blood vessels grow and pressure of expanding uterus on large veins causes blood to slow in its return to the heart.
- Rise up and out of pelvic cavity this action displaces the stomach and intestine.
- Blood volume increase greatly.
- Placenta produces large amount of progesterone and oestrogen by 10 to 12 week of pregnancy to control uterine activity.

- Increased requirement of calcium due to increase of parathyroid gland.
- Experiences warm (hot flashes) caused by basal metabolic rate and increased hormonal level.
- Stretching of abdomen wall and ligaments that support uterus.
- Kidney work extra hard to excrete waste products of both mother and foetus.

b) Physical changes during pregnancy

- Breast may become large and more tender because of increased level of oestrogen hormone progesterone thus breast gets even bigger to prepare for breast feeding.
- Nipples may stick out more.
- By the end of third trimester, a yellow, watery, pre-milk may leak from nipples.
- Changes in hair and nail growth and texture due to hormone changes.
- Leg cramp caused by fatigue from carrying pregnant weight.
- Feet and ankles may swell because of extra fluid in the body during pregnancy.

c) Behavioural changes during pregnancy

- Physical discomfort such as urinary frequency can be frustrating.
- Fear and anxiety lessen especially when foetal movements are felt.
- Self-introspection
- Nesting behaviour begins. Some woman exhibits mood swings and emotional liability.

B. Delivery process

By the end of pregnancy, near the time of birth, the amniotic sac raptures (breaks) and amniotic fluid drains through birth canal and labour usually begins which involves the contractions of muscular walls of the uterus.

Initiation of birth: Uterine contractions start when the foetal pituitary gland secretes adrenocorticotrophic hormone (ACTH) which stimulates foetal adrenal gland to secrete corticosteroids. These hormones pass into blood sinuses in placenta to cause maternal cells to secrete prostaglandins (local hormone) and cause uterine wall to contract. This contraction pushes the foetal head against the cervix to stimulating stretcher receptor to send information to mother's brain and causes release of oxytocin hormone. The prostaglandin and oxytocin hormone together result intense contraction of uterine walls called **labour** which stimulates more release of oxytocin hormone and as positive feedback mechanism.

The delivery process can be summarized into three main stages:

- **Dilation stage:** During this stage, water sac filled with amniotic fluid forms and precedes the head, widening soft tissue of birth canal, cervix, and vagina for canal of constant diameter. The amnion raptures and amniotic fluid drains through vagina.
- **The expulsion stage:** During this stage, cervix is fully dilated while abdominal muscle bear down in supporting rhythmic contraction of uterus shorten the uterine wall and baby is pushed into and through the birth canal. The head and shoulder align themselves first.
- **Placenta stage:** This stage begins with complete expulsion of baby and ends with expulsion of foetal membrane. The cord is clamped and cut when delivery of baby is complete. This leads carbon dioxide enrichment into baby's blood which activates respiratory centre and baby begins to breath with the first cry at the same time foetal circulation changes to baby's own systemic and pulmonary circulation.

C) Parental care

Antenatal care is the care you get from health professionals during your pregnancy. It is sometimes called **pregnancy care** or **maternity care.** Prenatal care, also known as antenatal care, is a type of preventive healthcare. Its goal is to provide regular check-ups that allow doctors or midwives to treat and prevent potential health problems throughout the course of the pregnancy and to promote healthy lifestyles that benefit both mother and child.

a) Health needs of the pregnant mother

The pregnant mother needs to maintain good health status so that she has a healthy baby. To remain healthy she needs:

- To avoid contractions diseases such as malaria, STIs and HIV and AIDS as these may harm the foetus.
- To avoid smoking and drinking alcohol as these interfere with growth and development of the foetus, especially brain development.

- To eat an adequate balanced diet so that she maintains her good health and is able to give birth to a healthy baby. Malnourished mothers usually give birth to babies who are underweight. Such babies often have growth and development problems because they do not eat well and tend to get sick often.
- To attend the ante-natal clinic once a moth so that her health and nutritional needs and those of the foetus are monitored. In the ante-natal clinic the mother has her weight monitored, blood pressure checked and urine checked to establish the level of sugar.

During the antenatal period, the promotion of the women healthy is the care and health of their babies before and after birth. Educating mothers about the benefits of good nutrition, adequate rest, good hygiene, family planning and exclusive breastfeeding, immunization and other disease prevention measures aims to develop women's knowledge of these issues so they can make better decisions affecting their pregnancy outcome and never forget the difficulties some women will face in being able to improve their lifestyles.

b) Nutritional needs of the pregnant mother

The pregnant mother needs additional nutritional requirements to meet the needs of the growing foetus and those of her body. The pregnant mother therefore needs to eat additional balanced diet to cater for these additional nutritional requirements in her own body and for that of the growing foetus. The mother needs the increased nutrients because of:

- The increase in the rate at which her body burns energy. More carbohydrates and fats are required. Adequate amounts of carbohydrates and fats are required for the additional weight the mother puts on. The mother puts on additional weight of about 10 to 12.5kg during pregnancy. More energy giving foods are required to make up this additional weight.
- The increase in her blood volume of her additional weight. More iron is required to form additional blood required by the body.
- The development of the placenta which requires nutrients to form and making the amniotic fluid within which the foetusgrows require more nutrients.
- Increased muscles for both the mother and the growing foetus. The mother's body requires additional muscles, especially the breast and uterine tissues. More proteins are required to develop these muscles.
- The need to store more fat. This fat is stored during the first four months of pregnancy. From 5-9 months the stored nutrients are used by the fast growing foetus. The mother starts to appear thinner.
- Preparation of breast-feeding. Nutrients are required to prepare milk to be used to breast-feed the baby.

The breast milk contains antibodies that help your baby fight of viruses and bacteria. Breastfeeding lowers your baby's risk of having asthma or allergies. Plus, babies who are breastfed exclusively for the first 6 months, without any formula, have fewer ear infections, respiratory illnesses, and bouts of diarrhea. In humans breastfeeding is associated with many other benefits:

- It makes earlier a closer contact between the mother and her infant
- The infant has a better control over its own milk intake, this prevents over eating in late life
- Fats and irons from breast milk are better absorbed than those in cow's milk and milk is easily digested.
- Breast feeding provides important antibodies that help to prevent respiratory infections and meningitis,
- Breastfeeding helps the mother's reproduction organ return to a normal state more rapidly
- Breast feeding promotes the secretion of LH (and prolactin) and this makes a delay in follicle development and ovulation,
- The act of sucking on the breasts, promotes the development of the jaw, facial muscles and teeth (sucking from a bottle requires less effort).

Application activity 2.6

1. Copy and complete the table to show, for each hormone, the precise site of its secretion, and its effects on the ovary or on the endometrium of the uterus.

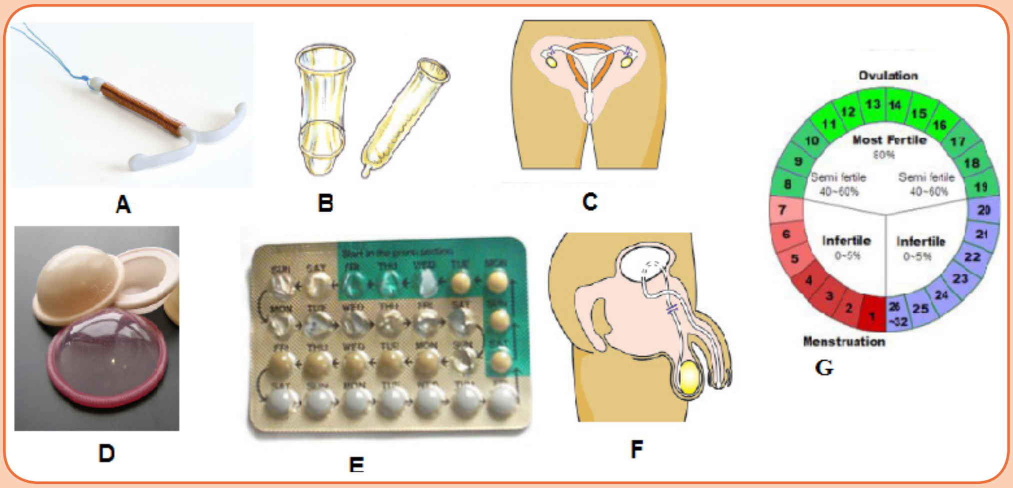
Hormone	Site of secretion	Effect(s) of hormone	
		Ovary	Endometrium
FSH			None
LH			None
Estrogens		None	
Progesterone		None	

Alcohol consumption for pregnant women is generally more dangerous on an embryo than a fetus. Suggest the reasons.

2.2. Family planning and contraceptive methods

Activity 2.7

The photos below show various contraceptive methods.



a) Use the photos to identify the letters that represent natural and artificial contraceptive methods. Justify your choice.

b) The most effective contraceptive method for young people is the use of condom. Provide the reasons for this statement.

Contraception is the prevention of conception that is preventing the fusion of the male gamete with the female gamete. Both natural and artificial methods exist.

2.2.1 Natural contraceptive methods

Natural birth control methods include specific actions that people can do naturally to help prevent an unintended pregnancy. Instead, these methods to prevent pregnancy require that a man and woman not have sexual intercourse during the time when an egg is available to be fertilized by a sperm.

The fertility awareness methods are based upon knowing when a woman ovulates each month. In order to use a fertility awareness method, it is necessary to watch for the signs and symptoms that indicate if ovulation has occurred or is about to occur.

i) Calendar rhythm method

The calendar rhythm method to avoid pregnancy relies upon calculating a woman's fertile period on the calendar. Based upon her 12 previous menstrual cycles, a woman subtracts l8 days from her shortest menstrual cycle to determine her first fertile day, and 11 days from her longest menstrual cycle to determine her last fertile day. She can then calculate the total number of days during which she may ovulate. If a woman's menstrual cycles are quite irregular from month to month, there will be a greater number of days during which she might become pregnant.

The calendar method is only about 80% effective in preventing pregnancy and when used alone, it is considered outdated and ineffective.

ii) Basal body temperature method

The basal body temperature (BBT) method is based upon the fact that a woman's temperature drops 12 to 24 hours before an egg is released from her ovary and then increases again once the egg has been released. Unfortunately, this temperature difference is not very large. It is less than 1-degree F (about a half degree C) when the body is at rest.

The basal body temperature method requires that a woman take her temperature every morning before she gets out of bed. A special thermometer that is more accurate and sensitive than a typical oral thermometer must be used, and the daily temperature variations carefully noted. This must be done every month. Online calculators are available to help a woman chart her basal body temperature.

To use the basal body temperature as a birth control method, a woman should refrain from having sexual intercourse from the time her temperature drops until at least 48 to72 hours after her temperature increases again.

iii) Mucus inspection method

The mucus inspection method depends on the presence or absence of a particular type of cervical mucus that a woman produces in response to estrogen. A woman will generate larger amounts of more watery mucus than usual (like raw egg white) just before release of an egg from her ovary. This so-called egg-white cervical mucus stretches for up to an inch when pulled apart. A woman can learn to recognize differences in the quantity and quality of her cervical mucus by examining its appearance on her underwear, pads, and toilet tissue; or she may gently remove a sample of mucus from the vaginal opening using two fingers. She may choose to have intercourse between the time of her last menstrual period and the time of change in the cervical mucus. During this period, it is recommended that she have sexual intercourse only every other day because the presence of seminal fluid makes it more difficult to determine the nature of her cervical mucus. If the woman does not wish to become pregnant, she should not have sexual intercourse at all for 3 to 4 days after she notices the change in her cervical mucus.

iv) Withdrawal method

Withdrawal is a behavioral action where a man pulls his penis out of the vagina before he ejaculates. The withdrawal method also relies on complete self-control. You must have an exact sense of timing to withdraw your penis in time.

Because this can be difficult for the man to complete successfully, the withdrawal method is only about 75%-80% effective in preventing pregnancy.

v) Abstinence

Abstinence from sexual activity means not having any sexual intercourse at all. No sexual intercourse with a member of the opposite sex means that there is no chance that a man's sperm can fertilize a woman's egg.

vi) Lactation amenorrhea method

Lactation Amenorrhea method can postpone ovulation for up to 6 months after giving birth. This natural birth control method works because the hormone required to stimulate milk production prevents the release of the hormone that triggers ovulation. This method is highly effective for the first six months after childbirth. The mother has to breastfeed the baby at least every four hours during the day and every six hours through the night. She also has to be aware of her menstrual period. After six months fertility may return at any time.

Advantages of natural birth control

- A woman does not need to take medication or use hormonal manipulation.
- No procedures or fittings by a physician are required.

Disadvantages of natural birth control include

- It can be difficult to estimate or know precisely when a woman is fertile, allowing increased chances for unplanned conception.
- Natural methods are not as effective as some forms of contraception.
- Ovulation test kits are used by some couples using natural methods of contraception, and the cost of these kits is another potential disadvantage.
- Being unable to have intercourse at certain times of the month is a disadvantage for some women.

2.2.2. Artificial contraceptive methods

Artificial contraception also known as birth control are medication used to prevent pregnancy.

Oral Contraceptive pills: a chemical method of contraception. One version uses a combination of progesterone and oestrogen that inhibits ovulation. Others are single hormones that require very careful management when taken.

Intrauterine device (IUD) the coil is placed inside the uterus an exact understanding how this works is unclear. A possible explanation is that it 'irritates' the endometrium such that rejects implantation of embryos. The device is made from plastic or copper and inserted by a doctor. Nevertheless, this device is very effective.

Condom is another mechanical method of contraception that prevents the sperm from reaching the egg. Composed of a thin barrier of latex this is placed over the erect penis and captures semen on ejaculation. This is also a good barrier to prevent the transmission of sexual diseases.

Cap (diaphragm) is another barrier method again made from latex. The cap is placed over the cervix to prevent the entry of sperm in semen. This technique requires that the cap is put in position in advance of sexual intercourse and that it is used in combination with a spermicidal cream. When used correctly this is an effective contraceptive however this is not a barrier against the transmission of sexual diseases.

Sterilization is a surgical and near permanent solution for contraception such as: Vasectomy. In men this involves cutting the vas deferens and prevents sperm entering the semen. In this state, man still ejaculates normally and releases semen however this does not contain sperm. Tubal ligation involves the cutting of fallopian tube so that eggs cannot reach the uterus. In women the surgery cuts or ties the oviducts thus preventing sperm from reaching the egg in fertilisation.

Advantages and disadvantages of birth control

Advantages of birth control/contraceptives

- Gives great protection against unplanned pregnancy if one follows instructions.
- Condoms to some extent protect against pregnancy and STDS.
- Combinations of pills reduce/prevent cysts in breasts and ovaries.
- Improved family wellbeing.
- Improved maternal and infant health.

Disadvantages of birth control/contraceptives

- Necessity of taking medication continually.
- High cost of medication.
- Hormonal contraceptive does not protect against STDS.
- Eggs may fail to mature in the ovary for a woman who uses hormonal contraceptives.
- Woman must remember to take them regularly.

- Woman must begin using hormonal contraceptive in advance before they become effective.
- Some women experience several; headaches, breast tenderness, chest pain, discharge from vagina, leg cramps and swelling or pain.

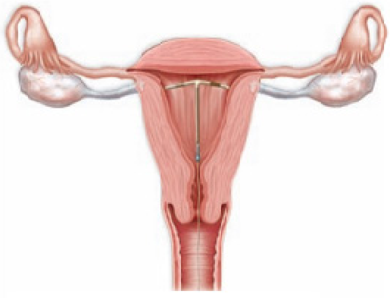
Application activity 2.7

1. Determining the fertile period

Count the number of days of your menstrual cycles and count the number of days for 10 consecutive cycles. Choose the cycle with the highest number of days and the cycle with the lowest number of days. Subtract 18 from the lowest cycle and 11 from the highest cycle.

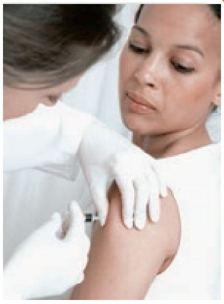
Example: Mary has 27 days as her shortest cycle and 36 as her longest cycle. She has had her menstruation on 09/08/2019. What will be her fertile period?

2. The diagrams below represent different contraceptive methods.

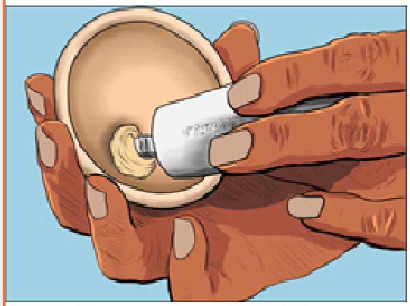


a. Intra-uterine device placement

b. Hormone skin patch



c. Progesterone injection



d. Diaphragm and spermicidal jelly

e. Male condom placement

f. Oral contraception pills

i) Use the diagrams to state contraceptive method that can prevent both STDs and pregnancy. Justify your answer.

ii) Suppose you are married, which contraceptive method do you prefer to use and why?

Skills Lab 2

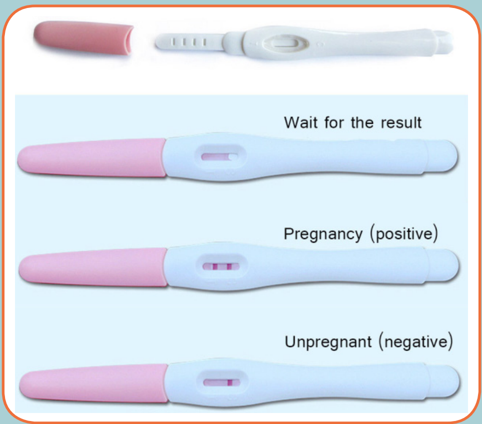
Pregnancy test

The HCG Card Pregnancy Test is a rapid chromatographic immune assay for the qualitative detection of human chorionic gonadotropin in urine to aid in the early detection of pregnancy. The test utilizes a combination of antibodies including a monoclonal HCG antibody to selectively detect elevated levels of HCG.

The pregnancy test works by checking the urine for a hormone called human chorionic gonadotropin (HCG). The woman body only makes this hormone if she pregnant. HCG is released when a fertilized egg attaches to the lining of the uterus when pregnancy begins. If pregnancy test is positive, it means that woman is pregnant. If the pregnancy test is negative, it means that woman is not pregnant.

Procedure:

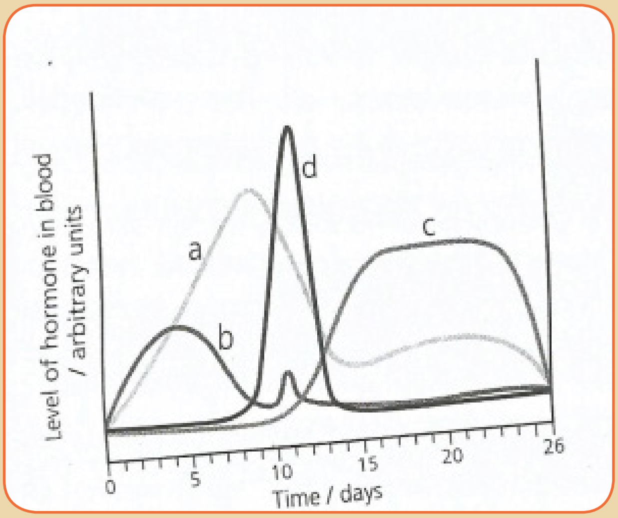
- Carefully read the instruction included in your test kit before collecting your urine sample.
- Remove the plastic cap to expose the absorbent window.
- Use collected first morning urine one to two weeks after the first missed period.
- Collect urine in a cup and then dip the indicator stick into the cup to measure the HCG hormone level.
- Hold an indicator stick directly in the urine stream until it is soaked, which should take about five seconds.
- Remove the HCG card pregnancy and make observation.
- Take conclusion of the observation following the indicated interpretation.



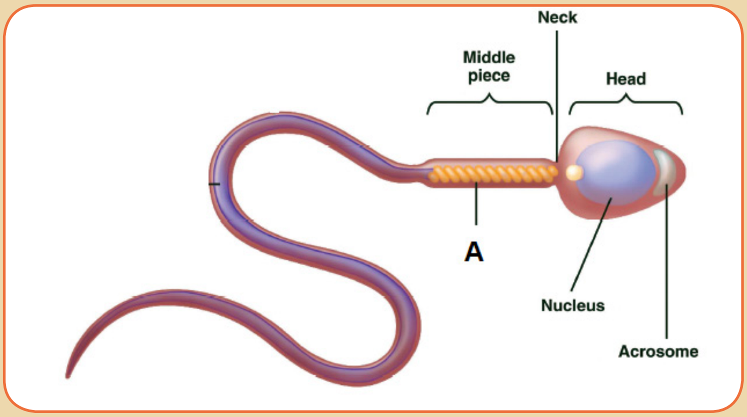
(Source:https://zionmedicalsolutions.com/product/one-step-pregnancy-test-cassette-25-tests/)

End Unit Assessment 2

1. Which of the following do sperm NOT travel through?
    a) Ureter
    b) Urethra
    c) Vas deferens
    d) Epididymis
2. The placenta in humans is derived from the:
    a) Embryo only
    b) Uterus only
    c) Endometrium and embryo
    d) None of the above
3. The graph below shows the level of reproductive hormones in the blood of an un-named mammal during its reproductive cycle.



   a) Name the hormones labelled (a) to (d)
   b) Give the likely day of the cycle on which ovulation takes place and give reasons for your answer.
4. Answer the following questions:
   a) Define the term fertilization
   b) The diagram below shows the structure of a human sperm.

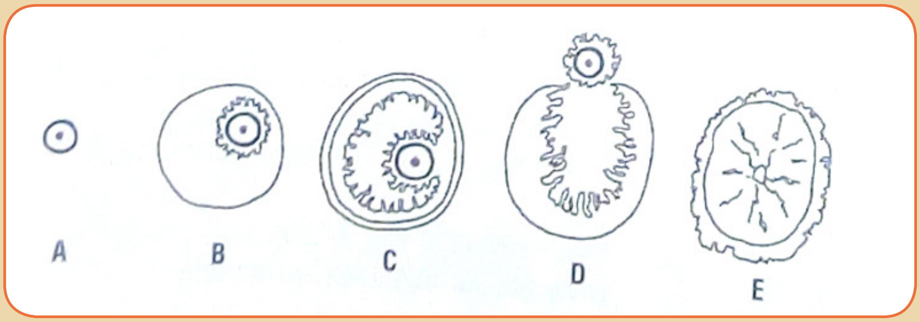


i) Explain the part played by the organelle labelled A in the process leading to fertilization.

ii) The acrosome contains an enzyme that breaks down proteins. Describe the function of this enzyme in the process leading to fertilization.

5. Which contraceptive methods can protect against sexually transmitted diseases / infections?

6. The diagram shows the sequence of events in the development of a mature ovarian (Graafian) follicle and corpus luteum



a) What is the main hormone produced by the ovary when stage B is present?

b) Which two of stages A to E would you expect to find in the ovary of a woman during the early stages of pregnancy?

c) Give the reason for your answer on b.

d) Some oral contraceptives contain only estrogens. Which of the stages A to E would you expect to find in the ovary of a woman who had been taking such an oral contraceptive for a prolonged period of time?

e) Give reasons for your answer on d.

UNIT 3

FERTILIZERS

Key Unit Competence:

Analyze the components of quality fertilizers and their benefits, effects of misuse and dangers associated with substandard fertilizers.

Introductory activity 3

Observe the pictures below showing some common fertilizers used in agriculture and attempt the following questions:

i) It is a must for a farmer to use fertilizers. Why?

ii) The fertilizers shown above are different. How are they different?

iii) Why a farmer does use different fertilizers (NPK, UREA, …) on only one same plant?

iv) Can the fertilizers above become hazardous? When? What is chemical hazard?

v) How the types of fertilizers mentioned above can have effect to the environment or living things?

vi) Suggest the measures to avoid hazard while using fertilizers.

3.1. Classification of fertilizers

Activity 3.1

Observe the following fertilizers:

i) Read the labels of given fertilizers and propose the components of each.

ii) Categorize the above fertilizers according to their ways of manufacturing?

iii) Suggest any other examples of fertilizers you have ever heard or used at home.

iv) Use engine research or library textbook to describe the nutrients that plants need in order to grow from fertilizers

A fertilizer is any material, organic or inorganic, that is used to supply nutrients to the soil.Fertilizer is a substance added to soil to improve plants' growth and yield.Fertilizers replace the chemical components that are taken from the soil by growing plants. However, they are also designed to improve the growing potential of soil, and fertilizers can create a better growing environment than natural soil. They can also be tailored to suit the type of crop that is being grown.

Fertilizers are categorized into natural fertilizers (or organic fertilizers) and artificial fertilizers (or chemical fertilizers)

3.1.1. Natural Fertilizers

The name organic fertilizer refers to materials used as fertilizer that occur regularly in nature, usually as a by-product or end product of a naturally occurring process. They are made from remains of dead plants, wastes from animals or they can be minerals. Examples include manures and minerals. Manure is an organic material that is used to fertilize land.

Farmyard manure: animal manure that consists of feces.

Green manure: is a term used to describe specific plant or crop varieties that are grown and turned into the soil to improve its overall quality.

Compost manure: is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. **Minerals:** Mineral mined powdered limestone, rock phosphate and sodium nitrate, are inorganic compounds which are energetically intensive to harvest and are approved for usage in organic agriculture in minimal amount.

3.1.2. Artificial Fertilizers

Artificial fertilizers are man-made chemical compounds that mimic the soil's natural minerals and elements to maximize plant growth. They usually contain different ratios of nitrogen, phosphorus, potassium, calcium, magnesium and other elements.

Examples: Urea, N.P.K, ammonium dihydrogen phosphate, $NH_4 (H_2PO_4)$, etc.

Table 3.1: Differences between natural and artificial fertilizers

Natural fertilizers	Artificial fertilizers
It is a natural substance. It is obtained by decomposition of animal wastes such as manure of cattle, buffaloes and plant residues.	It is a human made substance. It is an inorganic salt or an organic compound.
It contains small amounts of essential plant nutrients such as nitrogen, phosphorus and potassium.	They are very rich in plant nutrients such as nitrogen, phosphorus and potassium.
It adds a great amount of organic matter in the form of humus in the soil.	It does not add any humus to the soil.
Nutrients present in the natural fertilizer are absorbed slowly by the crop plants since manure is not soluble in water. Nutrients exist locked inside the organic compounds of humus.	Being soluble in water, an artificial fertilizer is readily absorbed by the crop plants.
It is not nutrient specific and it tends to remove the general deficiency of the soil.	It is nutrient specific. It can provide specifically nitrogen, phosphorus and potassium to the soil according to the need.
It is voluminous and bulky so it is inconvenient to store, transport, handle and apply to the crop.	It is compact and concentrated so it is easy to store, transport and apply to the crop.

It is cheap and is prepared in rural homes or fields.	It is costly and is prepared in factories.
It is environment friendly	Risk of environmental pollution

3.1.3. Components of a fertilizer

Typically, fertilizers are composed of nitrogen, phosphorus, and potassium compounds. They also contain trace elements that improve the growth of plants. The primary components in fertilizers are nutrients which are vital for plant growth.

First it is important to understand that all industrial Fertilizers, by convention, regardless of type and specific use, have something called a NPK ratio. The NPK ratio will be prominently labeled on the package and indicates the percentage of major (or primary) nutrients the fertilizer contains. Example: Urea is a fertilizer with an NPK ratio of 46-00-00.

The nutrients of plants are classified into three types namely: major nutrients, secondary nutrients and micronutrients.

a. The major nutrients

The major nutrients for soil are nitrogen (N), phosphorus (P), and potassium (K). These major nutrients usually are lacking or insufficient in the soil because plants consume them in large amounts for their growth and survival.

The letter N represents the actual nitrogen content in the fertilizer by percentage mass while P and K represent the amount of oxide in the form of phosphorus (V) oxide (P_2O_5) and potassium oxide (K_2O) respectively.

Example:

- If a fertilizer is labeled 17-17-17, it means that the fertilizer contains17% by mass N, 17% by mass P_2O_5 and 17% by mass K_2O.
- If fertilizer is labeled 10-20-20, it means that the fertilizer contains 10% by mass N, 20% by mass P_2O_5 and 20% by mass K_2O.

Table 3.2: Role of nutrients

Nutrients	Role
Nitrogen **(N)**	– Stimulates the overall plant growth. – In synthesis of proteins. – In synthesis of chlorophyll. – Early feeding of corn.

Phosphorus **(P)**	– Promotes early growth, as well as early maturity of plants. – Promotes growth of healthy roots and flowering and helps in the formation of high-yielding seeds. – Increases the resistance of the plants to frost and disease.
Potassium **(K)**	– Regulates the structure in leaves that allows CO2 to enter the leaf, andoxygen and water to exit. – It helps the production of sugars. – Formation of fruits and flowers.

If a fourth number is included on the label of a fertilizer, it indicates the sulphur content. That fertilizer is **NPKS**.

b. Secondary nutrients

The category of secondary nutrients, are calcium (Ca), magnesium (Mg), and Sulphur (S). As, these nutrients are generally enough in the soil, so fertilization is not always needed. Also, large amounts of Calcium are added when lime is applied to acidic soils. In fact, Sulphur is usually found in sufficient amounts from the slow decomposition of soil.

c. Micronutrients

Micronutrients are those elements essential for plant growth which are needed but in only very small (micro) quantities. These elements are even called **minor elements** or trace elements. The common micro nutrients are boron (B), copper (Cu), iron (Fe), chlorine (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn). In fact, recycling organic matter such as grass clippings and tree leaves is an excellent way of providing micro nutrients to growing plants.

Table 3.3: Characteristics of some common artificial Fertilizers

Name	Chemical formula	Composition of essential elements	Comments
Ammonium sulphate	$(NH_4)_2SO_4$	21%N	Crystalline salt soluble in H_2O easily tends to acidify the soil, leached from the soil, applied as top dressing (an application of manure or fertilizer to the surface layer of soil or a lawn).

Calcium ammonium nitrate	(NH_4 NO_3 +$CaCO_3$)	25-26%N	Half N in nitrate and the other half in the ammonium form, highly hygroscopic, generally applied as top-dressing.
Urea	$CO(NH_2)_2$	45-46%N	White crystalline material, soluble in water, produces both $NH_4$and NO_3in the soil, pellets coated hence releases N slowly

Depending on the nature of the essential elements that a fertilizer can supply to the soil, the fertilizers have been classified into the following groups:

– **Nitrogenous Fertilizers: N-type Fertilizers**

These Fertilizers supply only nitrogen as a major nutrient to the soil. Examples: ammonium sulphate, urea, sodium nitrate (also called Chile saltpeter or Chile nitre).

– **Phosphorus Fertilizers: P-type Fertilizers**

These fertilizers supply phosphorus as major nutrient to the soil. Examples: Calcium dihydrogen phosphate, $Ca\ (H_2PO_4)_2H_2O$, phosphate slag, $Ca_3(PO_4)_2CaSiO_3$

– **Potassium Fertilizers: (K-type Fertilizers)**

These Fertilizers supply only potassium as a major nutrient to the soil. Examples: potassium chloride, potassium sulphate.

– **Mixed Fertilizers**

Mixed fertilizers are those which can supply more than one essential element to the soil.

Depending on the nature of the essential element supplied by the fertilizer, mixed Fertilizers can be classified into the following groups:

- **NP Fertilizers:** These Fertilizers supply two essential elements, nitrogen and phosphorus, to the plant. Examples: Ammonium dihydrogen phosphate, $(NH_4)(H_2PO_4)$,(also called dihydrogen ammoniated phosphate or ammophos). Calcium dihydrogen phosphate nitrate, $Ca(H_2PO_4)_2 2Ca(NO_3)_2$,(also called calcium superphosphate nitrate or nitrophosphate).
- **PK Fertilizers:** It is a mixture of two compounds; containing phosphorus and the other containing potassium. For example, a mixture of $H_2PO_4)2H_2O$, and K_2SO_4.
- **KN fertilizer**. Example: KNO_3

- **NPK Fertilizers**: These are Fertilizers that contain %N, %P as P_2O_5 and %K as K_2O.Example: A mixture of $(NH_4)_2SO_4$, (N-type fertilizer), $(H_2PO_4)2H_2O$ (P-type fertilizer), and K_2SO_4(K-type fertilizer).

3.1.4. Characteristics of a good fertilizer

A good fertilizer should have the following characteristics:

- It should contain the required nutrients, in such a form that they can be assimilated by the plants.
- It should be cheap.
- It should be soluble in water.
- It should be stable, so that it may be available for a long time for the growing plant.
- It should not be injurious to the plants.
- It should be able to correct the acidity of the soil.

Application activity 3.1

Andrew is a farmer in rural village. He always used to spray insecticides in the farm in order to kill insects and use different fertilizers while growing crops. In his casual work, Andrew uses to combine fertilizers. After getting advice from the Sector Agronomist, Andrew is suspecting that he has not used well the fertilizers, contributed to the pollution of atmosphere and has contributed to water pollution.

i) Which fertilizers does Andrew combine while growing his crops and why?

ii) Referring to the mistakes done above by Andrew, suggest to Andrew the advice to follow while selecting fertilizer to be used.

iii) A NPK fertilizer is labeled 13-13-13. Interpret this labeling.

3.2. Use of organic and inorganic fertilizers

Activity 3.2

A plot of land has been divided into two parts and in both Irish potatoes has been cultivated by two cultivators.

One of them harvested 2000 kg of Irish potatoes of big size and the other harvested 50kg of Irish potatoes of small size.

Given that on both plots of land, the following work has been done at the same time

- Cultivation,
- planting of the same seeds
- weeding (or hoeing)
- spraying with the same chemicals
- Harvesting

i) Suggest reason(s) which caused the difference in the harvest.

ii) Provide advice to the cultivator who harvested 50 Kg.

Organic fertilizers contain only plant- or animal-based materials that are either a byproduct or end product of naturally occurring processes, such as manures, leaves, and compost. Inorganic fertilizer, also referred to as synthetic fertilizer, is manufactured artificially and contains minerals or synthetic chemicals.

3.2.1. Organic Fertilizers

The use of organic fertilizer may have many advantages but also it may have some disadvantages

a. Advantages

- The manures add organic matter (**called humus**) to the soil which restores the soil texture for better retention of water and for aeration of soil. For example, organic matter present in the manures increases the water holding capacity in sandy soils and drainage in clay soil.
- The organic matter of manures provides food for the soil organisms (decomposers such as bacteria, fungi, etc.) which help in making nutrients available to plants.
- Nutrient release: slow and consistent at a natural rate that plants are able to use. No anger of over concentration of any element, since microbes must break down the material.
- Trace minerals: typically present in a broad range, providing more balanced nutrition to the plant.
- They will not burn: safe for all plants with no danger of burning due to salt concentration.
- Long lasting: does not leach out since the organic matter binds to the soil particles where the roots have access to it.
- Fewer applications required: once a healthy soil condition is reached, it is easier to maintain that level with less work

- Controlled growth: does not over-stimulate to exceptional growth which can cause problems and more work.

b. Disadvantages

- Many organic products produce inconsistent results.
- The level of nutrients present in organic fertilizer is often low.
- The time of their preparation is too long.

3.2.2. Inorganic Fertilizers

The use of inorganic fertilizers may have many advantages but also it may have some disadvantages.

a. Advantages

- Chemical fertilizers are made with synthetic ingredients designed to stimulate plant growth.
- Commercial chemical fertilizers have the advantage of predictability and reliability
- Formulations are blended with accuracy and you can buy different blends for different types of plants; commercial formulated fertilizers allow you to know exactly which nutrients you're giving your plants, rather than guessing at the composition of organic formulas.

b. Disadvantages

- They can burn plants
- They require a specific timetable of application and watering because of fast release of nutrients
- On groundwater, artificial fertilizers have the following disadvantages:

– Increased nitrate levels increase the risks of blue baby syndrome, a rare form of anaemia which affects babies below 6 months of age. The cause is the oxidation by nitrite ions of Fe^{2+} in haemoglobin to Fe^{3+}. The oxidized hemoglobin cannot bind oxygen, and the baby turns blue from lack of oxygen. Conditions in the digestive tracks of young children are more favorable to the bacteria which reduce nitrates to nitrites than those in adults.

– Another hazard of chemical fertilizers is that carcinogenic nitrosoamines (yellow oil substance) may be formed in the human digestive track by the conversion of nitrate into nitrite. The nitrite produced in the stomach it combines with HCl to produce nitrous acid. Nitrous acid can react with any secondary amine in foods to form nitrosoamines and the reaction of nitrite with amino acids.

- Repeated use or excess use of the same fertilizer producing acidic ions (NH_4^+). Example of such a fertilizer is $(NH_4)_2SO_4$.
- Repeated use or excess use of the same fertilizer producing basic ions. Example of such a fertilizer is $CaCO_3$.
- Warm temperatures and high rain fall: Cations such as Ca^{++}, Mg^{++}, K^+ which are essential to living organisms, are leached (dissolved) from the soil profile, leaving behind more stable materials rich in Fe and Al oxides. This natural weathering process makes soils acid.

Other causes of acid soils include:

- Man-made processes also contribute significantly to soil acidity. For example, Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) released primarily by industrial activities react with water to form acid rain, which acidifies soils, particularly forest soils with.
- Organic acids from plants during decomposition;
- CO_2 from root respiration and microbial respiration.

Application activity 3.2

Jane is a farmer in rural village. He always used to spray insecticides in the farm in order to kill insects and use different fertilizers while growing crops. In his casual work, Jane uses to combine fertilizers and varies artificial fertilizers according to plant crop she wants to grow. After getting advice from the Sector Agronomist, Jane is now using the fertilizers appropriately.

i) Provide the advantages of using combined fertilizers while growing crops.

ii) Why do the farmers use specific fertilizer on specific plant crop?

3.3. Dangers of the use of the substandard fertilizers

Activity 3.3

Agriculture practice contributes to pollution of atmosphere and water pollution. Observe the photos below and answer related questions.

i) What is the situation of living things' life on the picture above?

ii) In which way agriculture practice can lead to the consequences observed on the photos?

iii) Suggest the advice to prevent the consequences observe on the photos.

One of the problems with chemical fertilizers is they seep through the soil into the groundwater and other water sources, leading to contamination. Now, NPK in small quantities is non-toxic, but a lot can kill the balance of nature in various ways. Nitrogen is especially tricky.

Sub-standard fertilizer means any fertilizer which does not conform to the required NPK ratio.

Example: A fertilizer may be labeled 16-00-00, while the real NPK ratio is for example 25-00-00, 10-00-05, etc

Using these Fertilizers can lead to:

- Soil pollution (basic soil or acidic soil) due to accumulation of ions which are acidic or basic
- Poor growth of plants
- Poor harvest
- Eutrophication
- Fertilizer burn: leaf scorch resulting from over-fertilization, usually referring to excess nitrogen salts. Fertilizer burn is the result of desiccation of plant tissues due to osmotic stress, creating a state of hypertonicity.

Effects of acid soil

Major effects of extremes in pH levels include gaps in nutrient availability and the presence of high concentrations of minerals that are harmful to plants.

In very alkaline soil, certain micronutrients such as zinc and copper become chemically unavailable to plants. In very acidic soil, macronutrients such as calcium, magnesium and phosphorous are not absorbed while others reach toxic levels,

Acid soil, particularly in the subsurface, will also restrict root access to water and nutrients.

In addition to affecting how nutrients are dispensed to growing plants, pH levels also influence microorganism activity that contributes to the decomposition of organic materials. A neutral pH is ideal for microbial action that produces chemical changes in soil, making nitrogen, sulfur and phosphorus more available. A pH that is either too high or too low may also interfere with the effectiveness of pesticides by changing their basic composition or weakening their ability to kill unwanted insects.

Plant growth and most soil processes, including nutrient availability and microbial activity, are favored by a soil pH range of 5.5 – 8.

Example: The optimal pH range for most plants is between 5.5 and 7.0 as it is shown in the table below.

Crop	pH
Avocado	6.0-6.5
Macadamia	5.0-6.5
Pineapple	4.7-5.7
Sugarcane	6.0-7.0

For soils the pH should be maintained at above 5.5 in the topsoil and 4.8 in the subsurface.

Eutrophication: the undesirable overgrowth of vegetation caused by high concentration of plants nutrients (Nitrogen and Phosphorous) in bodies of water (lakes, rivers, etc).

As consequence, water plants (e.g: water hyacinth: amarebe) grow more vigorously and this prevents the sun light from reaching the water and stops photosynthesis of aquatic plants which provide oxygen in the water to animals needed then animals die, deposits of organic matter on the bottom of the lake build up.

When lake water is enriched with nutrients (e.g.: nitrates and phosphates), algal flourish, and produce an algae bloom, a green scum with an unpleasant smell. When algal die they are decomposed by aerobic bacteria. When the oxygen content falls too low to support aerobic bacteria, anaerobic bacteria take over.

They convert the dead matter into unpleasant-smelling decay products and debris which falls to the bottom. Gradually, a layer of dead plant material builds up on the bottom of the lake. The lowering of the oxygen concentration leads to the death of aquatic animals (fish, crabs, etc).

Figure 3.1: Eutrophication of a water body and its effect.

In order to reduce the effects of substandard fertilizers different measure can be taken:

- Standardization of the fertilizer before use.
- Production of fertilizers in Rwanda, as this will help us to choose good minerals (where necessary) in producing fertilizers.
- Use of chemical fertilizers with coated pellets so that nutrients are released slowly.
- Regular watering.

Application activity 3.3

Fertilizers application normally results in increased yield with diminishing returns until maximum yield is reached. A cultivator James is advised to use NPK 17-17-17 in growing Irish potatoes. When James reached the Agrotech, he missed NPK 17-17-17 and bought NPK 16-00-00 and he used in excess to fit with the fertilizer he wanted.

i) Were fertilizers used by James the same? How are they different?

ii) Show how using NPK 16-00-00 will be dangerous than using NPK 17-17-17.

iii) What can be done to avoid or minimize those dangers?

Skills Lab 3

Making rich organic fertilizer

The best manure for gardens is properly composted manure. It's often called black gold, especially when it contains cow manure. Well rotted farmyard manure is rich and full of slow releasing natural plant nutrients.

Procedure:

- Select an area in a farm that is protected from strong wind and sun, for instance, under the shade of a tree.
- Mark the area you intend to locate the compost (the minimum area is 1.25m x 1.25m).
- Dig a shallow trench, same size as the compost heap 20cm deep. Cover the sides of the trench with water or a mixture of water and cow dung to prevent moisture and nutrients from leaking from the compost heap. The shallow trench will become the foundation of the compost heap. The trench also helps to hold moisture especially during the dry season.

Foundation layer

- Put the dry plants material such as small tree branches, maize stalks or sorghum stalks. Cut the plant material into small pieces. Spread the dry material evenly over the bottom of the trench to make a layer of 15-25cm. Sprinkle with water using a watering can or basin to ensure all material is moist but not wet.
- Layer 1: put dry plant material such as grass, dry leaves mixed with top soil, manure and ashes. The layer should be about 20-25cm thick. Mix the material with soil, manure and ashes and sprinkle water to make it moist.
- Layer 2: Make another layer of moist (green) material which is fresh or wilted such as weeds or grass cuttings, stems and vegetable leaves, tree branch leaves, damaged fruits, or vegetables or even kitchen waste. Do not sprinkle water in this layer. But you can spread it to remain even or flat.
- Layer 3: is composed of animal manure collected from fresh or dried cow dung, chicken waste, donkey manure and sheep or goat droppings. The animal manure can be mixed with soil, old compost and some ashes to make a layer that is 5 -10 cm thick. Make a watery mixture and spread it over as a thin layer about 1-2cm thick.

- Covering layer: protect the heap from the sun or animals or anything that might interrupt with the mixture. The cover should be sealed with only the ventilation stick.
- Turning the compost: open up the compost heap mixing all the layers while sprinkling water to make it moist but not wet after three weeks.
- Decomposition progress checking: using the ventilation or temperature stick, you can keep on checking the decomposition process of your compost every week by pulling out the stick. If it has a white substance on it and has a bad smell, it means the decomposition is not going on well. You can turn the compost further and sprinkle some more water to make it moist.
- Ready compost: A mature compost heap is about the half the size of the original heap. Check to ensure the compost has a dark brown colour or black soil, which has a nice smell. All the original material should not be seen if the decomposition process went on well.

End Unit Assessment 3

I. Multiple choice (Choose the best answer)

1. If nitrogen is the main element of fertilizers then fertilizers are classified as
   a) Structural fertilizers
   b) Non-structural fertilizers
   c) Nitrogen fertilizers
   d) Respiratory fertilizers
2. Increased ratio of chemical nutrients in ecosystem is classified as
   a) Triplication
   b) Eutrophication
   c) Crystallization
   d) Distillation
3. Greenhouse gas which can be emitted from storage of nitrogen-based Fertilizers is
   a) Nitrous oxide
   b) Nitric oxide
   c) Oxygen
   d) Hydroxide

4. Organic Fertilizers can be derived from
   a) Animal materials
   b) Carbon materials
   c) Plant materials
   d) Both (a) and (c)

II. Open-ended questions

1. Ammonia itself can be used as a fertilizer but has some disadvantages. Explain the disadvantages of using ammonia as a fertilizer.
2. Give any two advantages of the use of
   a) Natural Fertilizers
   b) Artificial Fertilizers
3. Give any two causes of acid soils
4. Discuss the advantages and disadvantages of the use of organic and inorganic Fertilizers.
5. Identify the effects of misusing Fertilizers and the dangers of substandard fertilizers.

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