

A - LEVEL BIOLOGY

(Q and A)

CONTENT MASTERY
&
KNOWLEDGE APPLICATION

**Scenario-Based
Questions**



Majanja Ronald

0701 828913 / 0777 317670

Volume 1

Edition 1

Content Mastery and Knowledge Application Tool (CM-KAT)

A-LEVEL BIOLOGY

(Q and A)

**CONTENT MASTERY
&
KNOWLEDGE APPLICATION**

'Scenario-Based Questions'

Volume 1

Edition 1

TABLE OF CONTENTS

1. CELL STRUCTURE & MICROSCOPY.....	3
2. HISTOLOGY.....	16
3. CHEMICALS OF LIFE.....	32
4. NUTRITION IN PLANTS.....	43
5. TRANSPORT IN HUMANS.....	57
6. RESPIRATION.....	84
7. HOMEOSTASIS.....	99

CELL STRUCTURE AND MICROSCOPY

ITEM 1

A team of biology students was given onion epidermal tissue and a thin section of a mitochondrion to examine under different types of microscopes. They used a light microscope for the onion tissue and an electron microscope for the mitochondrion.

Under the light microscope, the students observed the onion cells and note that the nucleus and cell wall were clearly visible, but the ribosomes could not be seen.

Under the electron microscope, the mitochondrion image appeared highly detailed. The image measured 10mm in length while the actual mitochondrion is $2\mu\text{m}$ long.

Task:

As a learner of biology with knowledge about microscopy;

(a) Explain why the students were unable to see ribosomes using the light microscope but could observe fine details of the mitochondrion using the electron microscope.

Ribosomes are too small to be seen under the light microscope since it has a lower resolution, but the electron microscope has a much higher resolution, allowing it to reveal the fine internal structure of organelles like the mitochondrion. ✓

(b) State the advantages of using a light microscope over an electron microscope.

- Light microscope produces coloured images but electron microscope produces black and white images. ✓
- Both living and non-living specimen can be viewed under a light microscope but only dead specimen can be viewed under electron microscope. ✓
- Light microscope requires less expertise to operate as compared to electron microscope. ✓

- Light microscope is small and portable and can be used almost everywhere but electron microscope is very large requiring a special room for operation. ✓
- With a light microscope, material is rarely distorted during preparation but with an electron microscope, material may be distorted during preparation. ✓
- Light microscope is cheaper to purchase than an electron microscope. ✓
- Specimen preparation is simple and quick with a light microscope but complex and time-consuming with an electron microscope ✓

(c) State the differences in the functioning of the light microscope and electron microscope.

<i>Light microscope</i>	<i>Electron microscope</i>
• uses light as the radiation	Uses electron beam as the radiation. ✓
• Uses a glass lens to focus light through the specimen	Uses electromagnetic lens to focus an electron beam through the specimen. ✓
• Radiation enters at the bottom and specimen is viewed at the top.	Radiation enters at the top and specimen is viewed at the bottom. ✓
• Stains used are coloured dyes.	Stains used contain heavy metals. ✓
• Image is not projected to screen.	Image is projected onto the fluorescent screen. ✓

(d) Calculate the magnification of the mitochondrion image seen under the electron microscope.

$$\text{Image size} = 10\text{mm} = (10 \times 1000)\mu\text{m} = 10000\mu\text{m} \checkmark$$

$$\text{Actual size of mitochondrion} = 2\mu\text{m}$$

$$\text{Magnification} = \frac{\text{Image size}}{\text{Object (Actual) size}} \checkmark = \frac{10000}{2} \checkmark$$

$$\text{Magnification} = \times 5000 \checkmark$$

ITEM 2

Leo, a biology student is investigating the ultrastructure of a plant cell. He wants to observe the general cell shape, the nucleus and the arrangement of chloroplasts. He also aims to study the detailed internal structure of the chloroplast. The student has access to both the light and electron microscope.

Task:

As a learner of biology with knowledge about microscopy;

(a) Advise Leo on the type of microscope to use to;

(i) observe the overall shape of the plant cell and its chloroplasts?

Leo should use the light microscope ✓ because it allows visualization of the whole cell and large organelles like chloroplasts in relatively natural colour at lower resolution and magnification. ✓

(ii) study the detailed internal structure of the chloroplasts?

Leo should use the electron microscope ✓ because it has a much higher resolution and magnification needed to see fine structural details inside organelles like chloroplasts. ✓

(b) State the advantages and disadvantages of using the light microscope compared to the electron microscope in regards to the student's investigation.

ADVANTAGES:

- Light microscope produces coloured images but electron microscope produces black and white images. ✓
- Both living and non-living specimen can be viewed under a light microscope but only dead specimen can be viewed under electron microscope. ✓
- Light microscope requires less expertise to operate as compared to electron microscope. ✓

- Light microscope is small and portable and can be used almost everywhere but electron microscope is very large requiring a special room for operation. ✓
- With a light microscope, material is rarely distorted during preparation but with an electron microscope, material may be distorted during preparation. ✓
- Light microscope is cheaper to purchase than an electron microscope. ✓
- Specimen preparation is simple and quick with a light microscope but complex and time-consuming with an electron microscope ✓

DISADVANTAGES:

- Light microscope has a lower magnification than the electron microscope. ✓
- Light microscope has a lower resolution than the electron microscope. ✓
- Light microscope investigates a smaller field depth than the electron microscope. ✓

ITEM 3

A team of researchers investigated three unknown cell samples labelled A, B and C. They observed the samples under an electron microscope and the recorded the following features.

Sample A: Contains a cell wall, a large permanent vacuole and membrane-bound organelles including chloroplasts.

Sample B: Lacks a true nucleus, has plasmids, cell wall made of murein and 70S ribosomes freely floating in the cytoplasm.

Sample C: Has membrane-organelles including mitochondria, contains centrioles and does not have a cell wall and chloroplasts.

Task:

As a student of biology with knowledge about cell structure;

(a) Identify which of the samples A, B and C represents a plant cell, an animal cell and a bacterial cell. Give reasons for your answer.

- Sample A is a plant cell ✓ because it contains a cell wall, large permanent vacuole and chloroplasts all of which are characteristic of plant cells. ✓
- Sample B is a bacterial cell ✓ because it lacks a true nucleus, has plasmids, a cell wall made of murein and 70S ribosomes which are typical features of prokaryotic cells. ✓
- Sample C is an animal cell ✓ because it contains mitochondria and centrioles but lacks cell wall and chloroplasts which are typical features of animal cells. ✓

(b) Classify each of the cells as either prokaryotic or eukaryotic, and justify your classification.

- Sample A (plant cell) is eukaryotic ✓ because it has a nucleus and membrane bound organelles like chloroplasts. ✓
- Sample B (bacterial cell) is prokaryotic ✓ because it lacks a nucleus and membrane bound organelles. ✓
- Sample C (Animal cell) is eukaryotic because it has a nucleus and membrane-bound organelles like mitochondria. ✓

(c) State three structural differences between prokaryotic and eukaryotic cells not based on the features provided.

PROKARYOTIC CELLS	EUKARYOTIC CELLS
• Have circular DNA	Have linear DNA ✓
• Divide by binary fission	Divide by mitosis or meiosis ✓
• Are generally smaller in size	Are generally larger in size ✓
• Respiration occurs in mesosomes	Respiration occurs in mitochondria ✓
• Their flagella, if present, lack the internal 9+2 microtubule arrangement	Their flagella, if present, have the 9+2 microtubule arrangement ✓

• Cell wall is made of murein/peptidoglycan	Cell wall in plants is made of cellulose ✓
• Their DNA is naked (not associated with proteins)	Their DNA is associated with proteins called histones ✓

(d) Explain the significance of membrane-bound organelles in cell samples A and C.

- Potentially harmful products, reactants and enzymes are isolated and hence preventing damage to the cell. ✓
- Chemical reactions are isolated, hence preventing interference. ✓
- Allows different metabolic reactions to occur efficiently at the same time. ✓
- Provides a large surface area over for the occurrence of reactions. ✓
- Allows reactants and enzymes to be in close proximity and hence increasing the rate of reactions. ✓

(e) Despite being much smaller, bacteria can still carry out all necessary life processes. Briefly explain how this is possible without membrane-bound organelles.

- The cytoplasm of the bacteria contains the necessary enzymes and molecules that perform metabolic reactions like protein synthesis.
- Their small size allows quick diffusion of materials for efficient metabolism. ✓
- The plasma membrane of the bacteria also performs important functions like respiration. ✓
- The bacterial DNA located freely in the cytoplasm controls all cellular activities. ✓

ITEM 4

A team of microbiologists collected samples from two environments; a hot spring and a freshwater pond. They isolated two different types of prokaryotic microorganisms.

Microorganism A was isolated from the hot spring. It could survive in high temperatures and produced methane as a metabolic by-product. It lacked peptidoglycan in its cell wall and had unique ether-linked membrane lipids.

Microorganism B was isolated from the pond. It had a cell wall made of peptidoglycan, 70S ribosomes, and its DNA was found in circular form floating freely in the cytoplasm.

Task:

As a student of biology who has knowledge about prokaryotes;

(a) Categorise microorganisms A and B into Archaeobacterium and Eubacterium, giving reasons for your answers based on their structural and metabolic features given.

- Microorganism A is an Archaeobacterium ✓ because:
 - ✓ It produces methane which is characteristic of methanogenic Archaeobacteria ✓
 - ✓ Its cell wall lacks peptidoglycan and has ether-linked membrane lipids which are unique to Archaeobacteria. ✓
 - ✓ Survives in extreme conditions, hot spring, which is a typical habitat for thermophilic Archaeobacteria. ✓
- Microorganism B is an Eubacterium ✓ because:
 - ✓ It has a cell wall made of peptidoglycan, 70S ribosomes and circular DNA freely floating in the cytoplasm which are typical features of Eubacteria. ✓
 - ✓ It was found in a freshwater pond, a common habitat for many Eubacteria. ✓

(b) State the other structural differences between Archaeobacteria and Eubacteria not mentioned in the scenario.

ARCHAEBACTERIA	EUBACTERIA
• Have introns in some of their genes	Introns in their genes are rare. ✓
• Their DNA is associated with histones in some species	Their DNA is not associated with histones. ✓

(c) State other non-structural differences between Archaeobacteria and Eubacteria not mentioned in the scenario.

ARCHAEBACTERIA	EUBACTERIA
• Their growth is not inhibited by common antibiotics	Their growth is usually inhibited by antibiotics. ✓
• Initiator amino acid for protein synthesis is methionine	Initiator amino acid for protein synthesis is formylmethionine. ✓
• Use several kinds of RNA polymerase in transcription	Use one kind of RNA polymerase in transcription. ✓
• Not known to cause disease in humans	Many species are pathogenic. ✓

(d) Explain one ecological importance of Eubacteria.

- Eubacteria decompose dead organic matter ✓ which helps in recycling of nutrients like nitrogen and carbon. ✓

ITEM 5

A group of A-level biology students conducted an experiment to investigate how different substances affect the permeability of beetroot cell membranes. They cut equal-sized beetroot cubes and placed them in water baths at different temperatures of 20°C, 40°C, 60°C and 80°C. After 30 minutes, they measured the absorbance of the solution in each test tube using a colorimeter

which indicated the amount of red pigment, betalain, that had leaked from the beetroot cells. The students observed that as temperature increases, more pigment leaks out of the beetroot cells.

Task:

As a student of biology having knowledge of the plasma membrane structure and function;

(a) Explain why increasing temperature affected the permeability of the beetroot cell membranes.

Increase in temperature causes the kinetic energy of molecules within the membrane to increase ✓ which causes the phospholipids in the plasma membrane to become more fluid, ✓ disrupting their tight/close packing ✓ and hence allowing more red pigment to leak out of the beetroot cells. ✓

(b) Describe the structure of the plasma membrane based on the fluid-mosaic model.

According to the fluid-mosaic model, the plasma membrane consists of a bilayer of phospholipids ✓ in which proteins are embedded. ✓ The phospholipids are fluid ✓ and proteins float about in an irregular pattern forming a mosaic. ✓

The hydrophilic phosphate heads of phospholipids face outwards into internal and external aqueous environments ✓ while hydrophobic hydrocarbon tails face inwards forming a hydrophobic interior. ✓

Some proteins are located on the surface ✓ and are called extrinsic/peripheral proteins, ✓ some penetrate only part of the way into the membrane ✓ and are called intrinsic proteins/integral ✓ and others span the membrane from one side to the other ✓ and are called trans-membrane proteins ✓

Some proteins and phospholipids have short carbohydrate chains attached ✓ forming glycoproteins ✓ and glycolipids ✓ respectively.

Plasma membrane in animal cells also contains cholesterol ✓ embedded in each phospholipid layer.

(c) How does the structure of the plasma membrane contribute to its selective permeability.

- The plasma membrane consists of a phospholipid bilayer with a hydrophobic interior which restricts passage of ions or polar molecules and allows non-polar molecules to diffuse through. ✓
- Channel and carrier proteins are embedded in the plasma membrane which allow selective transport of **specific** ions and large polar molecules across the membrane ✓

(d) Predict what would happen to membrane permeability if the beetroot cells were placed in a solution containing a solvent such as ethanol instead of water and explain why.

- The permeability of the plasma membrane of beetroot cells would increase. ✓ Ethanol is non-polar ✓ and therefore disrupts the hydrophobic interactions between the phospholipid hydrocarbon tails ✓ which distabilizes the membrane structure ✓ and hence leads to increased leakage of the red pigment out of the beetroot cells into the surrounding solution. ✓

ITEM 6

A pharmaceutical company is designing a new drug that targets cancer cells. For the drug to be effective, it must enter cancer cells without harming normal cells. Scientists have studied the plasma membrane structure of both cell types and discovered that cancer cells have:

- A different composition of glycoproteins and glycolipids on their outer membrane surface.
- A higher number of glucose transporter proteins.
- A more fluid phospholipid bilayer than normal cells.

To test drug delivery, they use lipid-soluble and water-soluble versions of the drug in their experiments.

Task:

As a student of biology with knowledge of plasma membrane structure and function;

(a) Describe the role of glycoproteins and glycolipids enabling the targeted entry of the drug into cancer cells.

- Glycoproteins and glycolipids serve as cell-surface markers that enable cell recognition. Cancer cells have unique glycoproteins and glycolipids different from those of normal cells which can be identified by the designed drug and this enables entry of the drug into the targeted cancer cells instead of the normal cells. ✓

(b) Explain how transporter proteins and membrane fluidity might influence the rate at which the drug enters cancer cells.

- Transporter proteins allow uptake of specific substances including drugs that mimic natural molecules; A higher number of such proteins in cancer cells leads to faster drug entry into the cancer cells; ✓
- Membrane fluidity affects the permeability of the membrane; Increased membrane fluidity makes the membrane more permeable; allowing faster diffusion of the drug into the cancer cells; ✓

(c) Explain how the water-soluble or lipid-soluble nature of the drug affects its ability to cross the plasma membrane.

- Lipid-soluble drugs can diffuse easily through the phospholipid bilayer; while water-soluble drugs cannot cross the bilayer and instead require channel or carrier proteins; Therefore, lipid-soluble drugs enter into the cells faster than water-soluble ones; ✓

ITEM 7

A group of medical researchers studied liver cells to understand how they respond to hormones, take in nutrients and maintain homeostasis. They observed that the plasma membrane of these cells contains a phospholipid bilayer and embedded proteins among other components.

They also noted the plasma membrane is highly dynamic and selectively permeable. Enabling the cells to respond quickly to changes in blood.

Task:

As a student of biology with knowledge of cell biology;

(a) State the functions of the following mentioned components of the plasma membrane.

(i) **Phospholipid bilayer.**

- Serves as a semi-permeable barrier allowing non-polar substances to pass through and restricting passage of polar molecules and ions. ✓
- Makes the membrane flexible since the phospholipids are fluid ✓

(ii) **Proteins.**

- Provide structural support. ✓
- Channel and carrier proteins are used for selective transport of ions and polar molecules across the membrane. ✓
- Some proteins act as enzymes. ✓
- Some proteins act as receptor sites for hormones and neurotransmitters. ✓
- Surface(extrinsic) proteins provide attachment for cytoskeleton ✓

(b) Explain two ways in which the structure of the plasma membrane is adapted to allow selective permeability.

- Presence of phospholipid bilayer with a hydrophobic interior; allows passage of non-polar (lipid-soluble) molecules and restricts passage of ions and polar (water-soluble) molecules across the membrane; ✓

- Presence of transport proteins (channel and carrier proteins); ✓
which selectively transport specific ions and polar molecules
across the membrane by facilitate diffusion or active transport; ✓

(c) Explain how the composition of the plasma membrane of liver cells;

(i) enables them to respond to the hormones.

- Plasma membrane contains receptor proteins ✓ which are either glycoproteins or intrinsic proteins ✓ to which specific hormones bind ✓ triggering intracellular signalling pathways that lead to a response. ✓

(ii) maintains plasma membrane function under changing temperatures.

- Plasma membrane contains cholesterol ✓ which regulates membrane fluidity under changing temperatures. ✓ Cholesterol increases membrane fluidity at low temperatures by disturbing the close packing of the phospholipids ✓ and reduces membrane fluidity at high temperatures by interacting with phospholipid tails to reduce their mobility. ✓

HISTOLOGY

ITEM 8

A team of botanists investigated how different parts of a herbaceous dicotyledonous plant maintain their shape, perform photosynthesis and store nutrients. They dissected various plant organs such as stems, leaves and roots and observed a range of cell types under the microscope. They found some tissues made of thin-walled cells, others with irregularly thickened walls and a few with heavily lignified walls that appeared dead.

Task:

As a student of biology;

(a) Identify the simple plant tissues observed by the researchers and state where each tissue is most commonly found in a plant.

- Parenchyma; ✓ found in the central pith of stems, ✓ outer cortex of stems and roots, ✓ xylem, phloem and medullary rays of wood.
- Collenchyma; ✓ located in outer region of cortex of the stem, ✓ midrib of leaves, ✓ and petioles of leaves.
- Sclerenchyma; ✓ Sclerenchyma fibres are located in the pericycle of stems, ✓ xylem, and phloem, While sclerenchyma sclereids are located in the cortex, ✓ pith, phloem, fruits and seeds.

(b) Describe the structural features of each tissue named in (a) above.

PARENCHYMA:

Parenchyma consists of roughly spherical cells ✓ which may be elongated at times ✓

Each parenchyma cell has a large central vacuole, ✓ a thin cell wall ✓ and a thin layer of cytoplasm at the periphery. ✓

Many air spaces exist between the cells. ✓

COLLENCHYMA:

Collenchyma consists of polygonal, elongated cells, with end walls that are often pointed.

Cells have deposition of extra cellulose at their corners, and thinner side walls.

Between the cells are extremely small or non-existent air spaces.

SCLERENCHYMA:

Sclerenchyma consists of fibres and sclereids.

Fibres are polygonal and elongated, with tapering interlocking ends walls, while sclereids are roughly spherical.

Both fibres and sclereids have heavily lignified cell walls, with simple pits in their walls where there is no lignin deposition and an empty lumen.

(c) Explain how the structural features are related to the functions of these tissues in the plant.

PARENCHYMA:

- Has many intercellular air spaces; for easy gaseous exchange;
- Parenchyma cells have a large central vacuole; for storage of large amounts of water and nutrients;
- Parenchyma cells have thin cell walls; for easy diffusion of materials into and out of the cells;
- Parenchyma cells have permeable cell walls; permitting entry of water by osmosis into them to cause turgidity to provide support;
- Mesophyll cells (chlorenchyma) contain numerous chloroplasts; for carrying out photosynthesis;
- Transparent cell walls of the mesophyll cells; allow penetration of light for photosynthesis to take place;

- The aerenchyma in many aquatic plants contains many large intercellular air spaces; ✓ for easy diffusion of gases to provide buoyancy; ✓

COLLENCHYMA:

- Cells are polygonal, elongated parallel to the longitudinal axis of the organ and closely packed; ✓ to increase their combined strength to provide support; ✓
- Cells have deposition of extra cellulose at their corners; ✓ to increase their strength to provide mechanical support; ✓
- Cells have non-lignified cell walls and thus living; ✓ enabling the tissue to grow and stretch without imposing limitations on the growth of other cells around it; ✓

SCLERENCHYMA:

- Consists of elongated fibres and roughly spherical sclereids whose cells walls are heavily thickened with lignin, ✓ of great tensile and compressional strength, ✓ increasing their strength to provide support. ✓
- The end walls of fibres interlock with one another, ✓ increasing their combined strength to provide support. ✓
- Fibres are arranged into sheets of tissue extending for a considerable distance longitudinally, ✓ increasing their combined strength to provide support. ✓
- Fibres and sclereids are closely packed, ✓ increasing their combined strength to provide support. ✓

ITEM 9

Researchers at a botanical institute investigated how certain vascular plants transport water, mineral salts and organic substances across different parts of their bodies. They collected samples from various plant organs including roots, stems and leaves and examined them under a microscope. The students assisting in the study observed long tube-like structures, some

with thickened lignified walls and others containing cytoplasm but **no nuclei** at maturity.

Task:

As a biology student with knowledge of plant anatomy;

(a) Name the two main types of plant tissues observed in the vascular plants.

- Xylem. ✓
- Phloem. ✓

(b) Describe the structure and function of each tissue named in (a) above.

XYLEM:

Structure:

Xylem consists of tracheids, vessels, parenchyma and fibres. ✓

Tracheids and vessels have an empty lumen, lignified cell walls, bordered pits in their side walls. ✓

Tracheids have tapering end walls, with pits. ✓

Vessels are long, tube-like, open-ended and consist of cells (vessel elements) fused end to end. ✓

Vessel elements are shorter and wider than tracheids. ✓

Function:

- Xylem transports water and mineral salts from the roots to aerial parts of the plant and gives mechanical support to the plant. ✓

PHLOEM:

Structure:

Phloem consists of sieve tubes, companion cells, parenchyma, fibres and sclereids; ✓

Sieve elements lack a nucleus and have a thin layer of cytoplasm confined at the periphery. ✓

Sieve tubes are long, tube-like and consist of sieve elements fused end to end. At the end of each sieve element is a sieve

plate, having sieve pores, through which fine cytoplasmic filaments run from one cell to another.

Companion cells possess dense cytoplasm, containing numerous organelles.

Plasmodesmata connect each sieve element to its adjacent companion cells.

Function:

- Phloem translocates organic solutes from the leaves to other parts of the plant.

(c) **Explain how the structural features of each named tissue are related to its functions in the plant.**

XYLEM:

Structural features related to the transport function:

- Vessel elements are joined end to end to form a continuous vessel; for continuous flow of water up the xylem;
- Vessel elements are open-ended; allowing continuous flow of water from one element to another up the xylem;
- Tracheids and vessel elements have an empty lumen; allowing large volumes of water to be transported without obstruction by the living contents;
- End walls of tracheids are perforated with pits; permitting flow of water from one tracheid to another up the xylem;
- Bordered pits in the side walls of tracheids and vessel elements; allow horizontal flow of water from one cell to another;
- Bordered pits have a torus; which controls the lateral flow of water from one cell to another;
- Tracheids and vessel elements have lignified cell walls; making them more rigid such that they don't collapse under the high tension created by the transpiration pull;
- Tracheids and vessel elements have lignified cell walls; preventing leakage of water out of them;

- Tracheids and vessel elements have lignified cell walls; ✓
increasing the adhesion of water molecules onto the walls
thereby increasing the rise of water by capillarity; ✓
- Tracheids and vessel elements have a narrow lumen; ✓
increasing the rise of water by capillarity; ✓

Structural features related to the support function:

- Cell walls of tracheids, vessel elements and fibres are heavily
thickened with lignin of great tensile and compressional
strength; ✓ increasing their strength to provide mechanical
support; ✓
- Tracheids and fibres have tapering end walls which interlock
with one another; ✓ increasing their combined strength to
provide support; ✓
- Xylem parenchyma cells can take in water by osmosis and
become turgid; ✓ hence providing support; ✓

PHLOEM

- Sieve elements are joined end to end to form a continuous tube;
✓ for continuous flow of solute solution down the sieve tube; ✓
- Sieve plates have pores; ✓ permitting the flow of solute solution
from one sieve element to another; ✓
- Sieve elements lack a nucleus and have a thin layer of
cytoplasm confined at the periphery; ✓ reducing resistance to
the flow of solute solution; ✓
- Companion cells contain numerous mitochondria to produce
energy in form of ATP; ✓ for active loading of sugar into the sieve
tubes; ✓
- Plasmodesmata connect sieve elements to companion cells; ✓
allowing exchange of materials between the companion cells
and sieve elements; ✓
- Fine cytoplasmic filaments run from one sieve element to
another via sieve pores; ✓ for transport of the organic solutes
by cytoplasmic streaming; ✓

- Cell walls of the sieve elements are thin; ✓ for easy entry of water at the source by osmosis to build up pressure; ✓

ITEM 10

Researchers at a biomedical institute studied tissues lining various organs and they collected the samples from patients undergoing treatment for different medical conditions. They aimed to classify the tissues and understand their roles in maintaining organ function and body homeostasis.

Samples were taken from kidney tubules, trachea and blood vessels.

Task:

As a biology student, use your knowledge of epithelial tissues to:

(a) Identify each type of epithelial tissue lining the organs from which samples were obtained.

- Kidney tubules: lined by cuboidal epithelium. ✓
- Trachea: Lined by ciliated epithelium. ✓
- Blood vessels: Lined by squamous epithelium. ✓

(b) Explain how the structure of each type of epithelial tissue identified is related to its function in the organ from where it was obtained.

- Cuboidal epithelium has microvilli on its free surface, ✓ increasing surface area for re-absorption of substances from the kidney tubules. ✓
- Ciliated epithelium has cilia on its free surface, ✓ which beat rhythmically to move mucus and the trapped debris (microbes, dust and other small particles) to the throat for swallowing or coughing out. ✓ Goblet cells in the ciliated epithelium secrete mucus ✓ which traps microbes, dust and other small foreign particles. ✓ preventing them from reaching the lungs.

- Squamous epithelium is thin ✓ allowing rapid diffusion of materials across it in blood capillaries ✓ and it is smooth ✓ allowing friction-free passage of blood through the blood vessels. ✓
- (c) **Describe two general characteristics of epithelial tissues that distinguish them from other tissue types.**
- Epithelial tissues are avascular (lack blood vessels) but innervated ✓ and therefore depend on diffusion from underlying connective tissues for nutrients and oxygen. ✓
 - Epithelial tissues contain closely packed cells with minimal intercellular spaces ✓ forming a protective barrier. ✓

ITEM 11

A team of medical students conducted a comparative study of tissues lining different organs. Tissue Samples were collected from the air sacs of the lungs, the small intestine, urinary bladder and the skin and were observed under the microscope in the histology laboratory.

Task:

As a student of biology;

- (a) **Name each type of lining tissue that was obtained from the different organs by the researchers.**
- Air sacs of the lungs: lined by squamous epithelium. ✓
 - Small intestine: Lined by columnar epithelium. ✓
 - Urinary bladder: Lined by transitional epithelium ✓
 - Skin: Lined by Stratified epithelium. ✓
- (b) **Explain the structural adaptation of each lining tissue that allows it to perform its function effectively in the organ.**
- Squamous epithelium is thin, ✓ allowing rapid diffusion of gases (oxygen and carbon dioxide) during gas exchange. ✓

- Columnar epithelium has microvilli on its free surface, increasing surface area for absorption and secretion. Goblet cells in the columnar epithelium secrete mucus which protects the intestine from self-digestion and lubricates the lining for easy passage of food or solid matter.
- Transitional epithelium has the ability to stretch, allowing large quantities of urine to be accommodated in the urinary bladder and it is thick preventing escape of urine into surrounding tissues.
- Stratified epithelium is thick and keratinized, protecting the underlying tissues against abrasion/wear, mechanical damage and water loss.

(c) Suggest why epithelial tissues are more prone to wear and tear and explain how their structure helps to overcome this.

- Epithelial tissues often line surfaces exposed to the external environment or to friction e.g skin, vagina, oesophagus, etc and therefore are subject to abrasion.
- To overcome this, some epithelial tissues have multiple layers of cells e.g stratified epithelium that can be shed and replaced continuously.

ITEM 12

A medical case study reported two patients with different types of epithelial tissue damage. Patient A had severe burns affecting the skin while patient B has a stomach ulcer caused by the erosion the epithelium lining the stomach.

Another medical case study reported exposure of factory workers to chemical fumes over a prolonged period of time which resulted into damage of the epithelial tissue lining their respiratory pathways.

Task:

As a student of biology having knowledge of animal tissues;

(a) Name the types of epithelial tissue damaged in patient A, patient B and factory workers.

- Damaged tissue in patient A is stratified epithelium. ✓
- Damaged tissue in patient B is columnar epithelium. ✓
- Damaged tissue in factory workers is ciliated epithelium. ✓

(b) Explain how the structure of each epithelial tissue named in (a) normally enables it to perform its function.

- Stratified epithelium is thick and keratinised, ✓ protecting the underlying tissues against abrasion/wear, mechanical damage and water loss. ✓
- Columnar epithelium has microvilli on its free surface, ✓ increasing surface area for absorption and secretion. ✓ Goblet cells in the columnar epithelium secrete mucus ✓ which protects the stomach from the acidic contents of the stomach and from self-digestion by stomach enzymes. ✓
- Ciliated epithelium has cilia on its free surface, ✓ which beat rhythmically to move mucus and the trapped debris (microbes, dust and other small particles) to the throat for swallowing or coughing out. ✓ Goblet cells in the ciliated epithelium secrete mucus ✓ which traps microbes, dust and other small foreign particles, ✓ preventing them from reaching the lungs.

(c) Describe the general functions of epithelial tissues in protecting the body from infectious agents.

- Epithelial tissues form protective barriers, preventing entry of pathogens and toxins. ✓
- In the respiratory tract, the secreted mucus and the cilia trap and remove microbes and foreign particles. ✓

(d) Explain the possible health consequences of damage to the epithelial tissues in patient A, patient B and factory workers.

• In the factory workers, the damage causes inflammation and irritation of the respiratory tract ✓ leading to coughing, difficulty in breathing. ✓

Damage also causes loss of cilia ✓ reducing the ability to clear mucus and trapped pathogens ✓ and thus increasing risk of infection. ✓

• In patient A, the damage causes loss of protective barrier ✓ which increases the risk of dehydration, infection and damage to underlying tissues. ✓

The burns can impair sensory functions ✓ and hence impairing temperature regulation. ✓

• In Patient B, the damage exposes the underlying tissues to stomach acid ✓ causing pain, bleeding, inflammation and in severe cases, perforation of the stomach wall. ✓

(e) How are micrographs of healthy tissues obtained from healthy organs of a human different from micrographs of diseased tissues?

MICROGRAPH OF HEALTHY TISSUE	MICROGRAPH OF DISEASED TISSUE
• Cell shape and size is uniform	Cell shape and size is often irregular. ✓
• Tissue is highly organized	Tissue organization is highly disrupted. ✓
• Inflammatory cells are rare or absent	Inflammatory cells are common ✓
• Dead cells are absent	Dead cells are present in severe damage ✓
• Fibrosis(scarring) is minimal	Fibrosis is common in chronic conditions. ✓
• Blood vessels are normal	Blood vessels may be blocked, leaky or enlarged. ✓

ITEM 13

Messi, a 38-year old footballer suffered from a severe knee injury during a football match as he danced through the defensive unit of the opponent team. The Doctor diagnosed damage to the cartilage and bone in the knee joint as well as some strain to the connective tissues surrounding the joint. Messi was seen putting on a worrying face, showing an unpleasant situation.

Task:

As a student of biology;

(a) Explain the roles of cartilage, bone and connective tissues in the knee joint.

- Bone provides a rigid framework and support in the knee joint. ✓
Bone also provides attachment to muscles and connective tissues, enabling movement. ✓
- Cartilage covers the ends of the bones (femur and tibia) where they meet to form the knee joint, ✓ reducing friction during movement ✓ and serving as a shock absorber to protect bones from impact. ✓
- Connective tissues like ligaments connect bones to bones, ✓ providing stability during movement. ✓
- Connective tissues like tendons connect muscles to bones, ✓ enabling movement when muscles contract. ✓

(b) Explain how damage to cartilage and connective tissues might have affected the function of Messi's knee making him to put on a worrying face.

- When the cartilage is damaged, its smooth surface is disrupted ✓ which increases friction between bones during movement, ✓ causing pain. ✓ The shock absorbing nature of the cartilage also decreases ✓ which can lead to further wear and tear of bones in the joint. ✓
- Damage to ligaments reduces joint stability, ✓ making the knee more prone to unnatural movements or dislocation, ✓ leading to pain and a higher risk of further injury. ✓

(c) Explain why Messi's damaged cartilage may take longer to heal than his damaged bone.

- Cartilage is avascular (lacks blood vessels) and therefore oxygen and nutrients required for repair are delivered slowly to the damaged area through diffusion. ✓ While bone is vascularised (has blood supply), and therefore nutrients and oxygen required for repair are delivered to the damaged area quickly. ✓

(d) Suggest possible ways that you could use to help Messi to begin the recovery from the injury.

- Resting and immobilization to prevent further damage. ✓
- Taking anti-inflammatory medication to reduce pain and swelling. ✓
- Use of supportive devices like clutches to offload the injured joint. ✓

(e) Explain how the structure of cartilage is related to its functions in joints.

- Cartilage at joints has smooth surface, allowing frictionless movement of bones at joints. ✓
- Cartilage at joints has an elastic and compressible matrix, to absorb mechanical shock produced at joints. ✓

(f) Explain how the structure of bone tissue supports its functions.

- Matrix of bone is impregnated with mineral salts, giving it extreme hardness to withstand compressional strains and tension; ✓
- Bone tissue contains rich-blood supply, allowing passage of nutrients, respiratory gases and metabolic wastes towards and away from the bone cells; ✓
- Bone is innervated, allowing coordination of bone resorption and reconstruction; ✓
- Matrix contains numerous collagen fibres, which give the bone additional mechanical strength; ✓

- Trabeculae of spongy bone have spaces between them, reducing the weight of the bone for easy locomotion; ✓
- Trabeculae are oriented in the direction in which the bone is stressed, to withstand tension and compression forces; ✓

ITEM 14

A team of pathologists is investigating the cause of death of a middle-aged male patient. They collected tissue samples from for major internal organs: liver, heart, lungs and intestines. Micrographs of each organ's tissue were taken and examined under a microscope.

The liver micrograph showed enlarged hepatocytes with large fat droplets.

The heart micrograph showed damaged muscle fibres and presence of fibrous scar tissue.

The lung micrograph revealed ruptured alveolar walls and accumulation of inflammatory cells.

The intestine micrograph showed shortening and blunting of villi and infiltration of white blood cells in the mucosa.

The team also referred to archived micrographs of healthy tissue from the same organs for comparison.

Task:

As a student of biology with knowledge of histopathology;

(a) Explain how tissue analysis using micrographs is important in diagnosing and monitoring of diseases.

- Tissue analysis using micrographs reveals changes/abnormalities in tissue structure cellular organization such as inflammation, necrosis, fibrosis or abnormal cell growth. Micrographs can also reveal presence of pathogens such as bacteria or parasites within tissues. This allows clinicians to make accurate disease

diagnosis ✓ and hence helping them to choose the appropriate treatment. ✓

Repeated tissue analysis can be used to monitor the disease progression or the disease's response to treatment ✓ by observing whether tissue structure is improving, worsening or remaining unchanged. ✓

(b) State two observable differences between the;

(i) Healthy liver tissue and the diseased liver tissue based on the micrographs.

HEALTHY LIVER TISSUE	DISEASED LIVER TISSUE
• Shows uniform hepatocytes with minimal fat deposits.	Shows swollen hepatocytes with large fat deposits. ✓
• Has clearly defined sinusoids.	Has compressed or distorted sinusoids. ✓

(ii) Healthy and disease heart tissues based on the micrographs.

HEALTHY HEART TISSUE	DISEASED HEART TISSUE
• Has striated muscle fibres arranged in an orderly fashion with visible intercalated discs.	Has disorganized/disrupted muscle fibres with loss of striations and damaged or absent intercalated discs. ✓
• Contains normal cardiac muscle cells with no areas of dead cells, infiltration by immune cells and fibrotic (scar) tissue formation.	Usually shows areas of necrosis (dead cells), infiltration by immune cells and fibrotic (scar) tissue formation. ✓

(iii) Healthy lung tissue and the diseased one based on the micrographs.

HEALTHY LUNG TISSUE	DISEASED LUNG TISSUE
• Has small, thin-walled alveoli.	Has enlarged, thick-walled alveoli. ✓
• Shows minimal or no infiltration of inflammatory cells.	Shows accumulation of inflammatory cells. ✓

(c) Describe two structural changes in the intestine that may impair its function as observed in the micrograph of its diseased state.

- Shortened and blunted villi reduce surface area for absorption. ✓
- Infiltration of white blood cells in the mucosa indicates inflammation which may disrupt epithelial function and absorption. ✓

(d) Explain how the structural changes in the tissues of the liver and the heart could help identify the specific disease affecting each organ.

- In the liver, the presence of swollen hepatocytes with large fat droplets suggests fatty liver disease, ✓ which indicates impaired lipid metabolism. ✓
- In the heart, fibrosis and damaged muscle fibres suggest myocardial infarction (heart attack) ✓ which indicates lack of oxygen supply to heart muscle. ✓

CHEMICALS OF LIFE

ITEM 1

During a biology field trip, students studied how different organisms survive in extreme environments. In cold marine environments, they found that many marine mammals have large fat stores in the form of triglycerides, revealed through biochemical analysis. They also studied a desert-dwelling rodent, the Kangaroo rat, and learned from research articles that it relies on its stored lipids to survive in the desert.

Task:

As a learner of biology with knowledge of lipids as chemicals of life;

(a) Describe how a triglyceride is formed.

A triglyceride is formed from a glycerol molecule and three fatty acid molecules. Each hydroxyl group of the glycerol molecule undergoes a **condensation reaction** with the carboxyl group of the fatty acid molecule to form a triglyceride with formation of ester bonds.

(b) Explain how;

(i) the Kangaroo rat is able to survive in the desert, relying on lipids.

- The Kangaroo rat oxidizes its stored lipids during aerobic respiration to produce metabolic water and this internal water enables it to spend long periods without drinking and hence making it able to survive in the desert where water is scarce.
- Lipids are energy rich compounds since they contain a large proportion of hydrogen and a small portion of oxygen and therefore oxidation of a small amount of lipids yields large amounts of energy enabling the Kangaroo rat to survive in deserts where food is scarce.

(ii) the properties of lipids are related to their functions in the mammals living in cold marine environments.

- Lipids are poor conductors of heat, reducing heat loss to the cold surrounding and hence helping to maintain body temperature.
- Lipids are less dense than water, allowing marine mammals to stay buoyant in water and hence aiding swimming.
- Lipids have a high calorific value due to their high hydrogen content allowing marine mammals to rely on lipid stores for energy over long periods without feeding and hence maintaining vital body processes in times of food scarcity, migration, etc

ITEM 2

You are part of group of scientists that wants to design a self-sustaining biodome that mimics the earth's natural ecosystem. Water recycling is crucial for the success of this habitat. As the lead scientist, you are tasked with ensuring that all organisms within the biodome can survive and function optimally.

Task:

Using your understanding of water's physical properties, explain how they contribute to maintaining biological functions within the biodome.

- Water is a liquid at room temperature, providing a medium for chemical reactions in the cells and a habitat for aquatic organisms.
- Water has a high surface tension, enabling some small organisms like pond skaters to land and move on the water surface without sinking and also enabling water to form droplets on surfaces and run off for example on feathers of birds.

- Water has a low viscosity, and hence can serve as a lubricant e.g. synovial fluid in joints.
- Water is a universal solvent, making it a transport medium like in blood, lymphatic, excretory systems, alimentary canal, xylem and phloem.
- Ice is less dense than water, insulating the water below it thereby increasing the chances of survival of aquatic organisms in cold climates.
- Water is colourless and transparent enabling light to penetrate through for aquatic plants to photosynthesize. and for aquatic animals to see through
- Water is incompressible providing support in non-woody plants through turgidity and maintaining the hydrostatic skeleton in some animals e.g. earthworms.
- Water has a high tensile strength allowing transport of a continuous water column up the xylem of tall trees without splitting

ITEM 3

Researchers at a human physiology institute are investigating various proteins extracted from different tissues. They aim to understand how these proteins contribute to vital processes in the body. The researchers have identified several proteins but have yet to determine their structural categories and specific roles each plays in the human body.

Task:

As a student of biology with knowledge about proteins as chemicals of life;

- (a) Describe the different properties and functions of the main structural categories of proteins, giving an example of a protein in each case.

- Proteins are categorized into **fibrous proteins** and **globular proteins**.
- Fibrous proteins are insoluble in water, consist of long parallel polypeptide chains, have repetitive regular amino acid sequences, have a relatively stable structure, and perform **structural functions**. Examples include; collagen, keratin, fibroin.
- Globular proteins are soluble in water, their polypeptide chains are folded into a roughly spherical shape, have irregular amino acid sequences, have a relatively unstable structure and perform **metabolic functions**. Examples include; enzymes, antibodies, some hormones.

(b) Describe the different functions of proteins in the human body.

- Act as buffers, for example plasma proteins
- Transport materials into and out of the cell, for example carrier and channel proteins in the cell membrane.
- Transport of oxygen, for example haemoglobin.
- Storage of oxygen, for example myoglobin.
- Aid in blood clotting, for example fibrinogen.
- Signaling and communication, for example receptor proteins in cell membrane.
- Defend the body against infections, for example antibodies.
- Coordination of body activities, for example hormones like insulin.
- Protection against U.V rays, for example melanin.
- Act as a source of energy during starvation, for example storage proteins.
- Support and locomotion, for example myosin and actin in muscles, collagen in bone, tendons and connective tissue.

- Act as enzymes, speeding up biochemical reactions; for example digestive enzymes like lipase. ✓
- For sensitivity, for example rhodopsin is a photosensitive pigment in the retina ✓
- Storage of food nutrients, for example casein in milk. ✓

(c) Explain how the structure of proteins allows them to carry out a wide range of functions.

- Proteins have a variety of structures ✓ due to various amino acid sequences in their polypeptide chains ✓ and due to different ways of folding of these polypeptide chains, ✓ enabling them to perform various functions. ✓

Globular proteins have unique three-dimensional structures ✓ formed through specific folding of their polypeptide chains ✓ enabling them to perform various metabolic functions. ✓

Fibrous proteins have mechanical strength achieved by the arrangement long parallel polypeptide chains held together by strong hydrogen bonds, ✓ enabling them to perform structural functions. ✓

ITEM 4

A team of scientists studied how a digestive enzyme, amylase, breaks down starch to maltose. They observed that the rate of reaction increased with temperature up to a point and then suddenly dropped. They also tested two enzyme inhibitors: Inhibitor A binds to amylase at a site other than the active site while inhibitor B has a structure similar to that of starch and binds to the active site of amylase. Both compounds slow down the reaction.

Task:

As a learner of biology;

(a) **Explain why the reaction rate increases with temperature initially and then rapidly decreases at higher temperatures.**

- The reaction rate increased initially due to increase in the kinetic energy of both substrate and enzyme molecules; ✓ which increased their chances of collision; ✓ leading to formation of more enzyme-substrate complexes; ✓ and hence forming more products; ✓
- The reaction rate decreased at higher temperatures due to denaturation of the enzyme; ✓ which prevents the substrate from binding to the active site of the enzyme; ✓ As a result, the enzyme-substrate complex is not formed; ✓ and hence no products are formed; ✓

(b) (i) **Identify the type of inhibitors, A and B.**

- A is a non-competitive inhibitor; ✓
- B is a competitive inhibitor; ✓

(ii) **Explain how each of the inhibitors, A and B affects enzyme activity.**

- Inhibitor A binds to the enzyme at a site away from the active site; ✓ and therefore does not compete with the substrate for the active site of the enzyme; ✓ But when this inhibitor binds to the enzyme, the shape of the active site of the enzyme is distorted/altered/changed; ✓ preventing the substrate from entering or fitting precisely into the active site; ✓ As a result, the normal enzyme-substrate complex is not formed; ✓ therefore the reaction does not proceed to form products; ✓ and hence enzyme activity reduces;
- Inhibitor B has a shape/structure which is **similar** to that of the substrate; ✓ and therefore both the inhibitor and substrate compete for the active site of the enzyme; ✓ A competitive inhibitor binds to the active site of the enzyme; ✓ preventing the substrate from doing so; ✓ which prevents formation of an enzyme-substrate complex; ✓ and hence reducing enzyme activity; ✓

(c) Explain how increasing the concentration of starch would affect the activity of amylase in the presence of each of the inhibitors, A and B.

- In presence of inhibitor A, increasing the concentration of starch would not affect the activity of amylase ✓ because inhibitor A does not compete with starch for the active site of amylase; ✓
- In presence of inhibitor B, increasing the concentration of starch would increase the activity of amylase ✓ because starch would outcompete inhibitor B for the active site of amylase. ✓

ITEM 5

Researchers at a biotechnology company developed a new drug to reduce the effects of a metabolic disorder caused by the excessive activity of a particular enzyme. To better understand how the drug works, the researchers conducted experiments involving enzyme activity and inhibition.

In experiment 1, they used a substrate known to bind precisely to the enzyme's active site, causing the reaction to proceed rapidly. However, when they introduced a new molecule similar in shape to the substrate, the reaction rate decreased significantly. The researchers noted that this molecule temporarily binds to the enzyme's active site without reacting. In experiment 2, the researchers explored the use of enzyme inhibitors in crop preservation. They aimed at preventing browning in harvested fruits by inhibiting the activity of polyphenol oxidase, an enzyme responsible for the browning reaction.

Task:

As a student of biology with knowledge about enzymes;

(a) Describe how the substrate is worked upon by the enzyme using the information in the scenario.

The substrate is worked upon by the enzyme according to the lock and key hypothesis; ✓

According to the lock and key hypothesis, the shape of the substrate is complementary to that of the active site of the enzyme; ✓ and therefore the substrate fits exactly/perfectly/accurately/precisely into the active site; ✓

like the way a key fits into a lock; ✓ forming an enzyme-substrate complex; ✓ which is maintained by bonds formed between the enzyme and the substrate; ✓ At this point, the enzyme lowers activation energy; ✓ causing the reaction to occur forming products; ✓ and hence forming an enzyme-products complex; ✓

Once products are formed, they escape into the surrounding medium; ✓ leaving the active site free to bind with subsequent substrate molecules; ✓

(b) Identify the type of enzyme inhibition demonstrated in experiment 1 and explain how it occurs.

- Competitive inhibition; ✓
- A competitive inhibitor has a shape/structure which is similar to that of the substrate; ✓ and therefore both the inhibitor and substrate compete for the active site of the enzyme; ✓ A competitive inhibitor binds to the active site of the enzyme; ✓ preventing the substrate from doing so; ✓ which prevents formation of an enzyme-substrate complex; ✓ and hence reducing enzyme activity; ✓

(c) Apart from preventing browning in harvested fruits, describe other commercial applications of enzyme inhibition.

- Some drugs act by inhibiting enzymes; ✓ e.g penicillin inhibits enzyme involved in bacterial cell wall synthesis.
- Some herbicides and insecticides act by inhibiting enzymes; ✓ e.g organophosphate insecticides inhibit enzyme acetyl cholinesterase.
- Some food preservatives prevent food spoilage by inhibiting enzymes; ✓ e.g sodium benzoate inhibits enzymes involved in energy production in bacteria.

ITEM 6

A team of agricultural scientists developed a biofertilizer using enzymes to break down organic matter in the soil. During their experiments, they observed that the rate of enzyme activity increases with an increase in substrate concentration but eventually levels off. They also tested a compound that attaches to a site on the enzyme away from the active site and found out that enzyme activity decreases regardless of how much substrate is added.

To understand the mechanism of enzyme-substrate interaction, they used computer simulations which revealed a change in the enzyme's shape as the substrate binds to it.

Task:

As an A level biology student:

(a) Explain why the rate of enzyme activity increases with increase in substrate concentration and then levels off.

- Enzyme activity increases with increase in substrate concentration due to increase in the number of collisions between enzyme and substrate molecules; ✓ leading to formation of more enzyme-substrate complexes; ✓ and hence forming more products; ✓ Enzyme activity then levels off because all active sites of the enzyme molecules are now occupied; ✓

(b) Identify the type of inhibition mentioned in the scenario and explain how it affects enzyme activity.

- Non-competitive inhibition; ✓
- Inhibitor A binds to the enzyme at a site away from the active site; ✓ and therefore does not compete with the substrate for the active site of the enzyme; ✓ But when this inhibitor binds to the enzyme, the shape of the active site of the enzyme is distorted/altered/changed; ✓ preventing the substrate from entering or fitting precisely into the active site; ✓ As a result, the normal enzyme-substrate complex is not formed; ✓ therefore the reaction does not proceed to form products; ✓ and hence enzyme activity reduces; ✓

(c) Explain how enzymes work using the information from computer simulations above.

Enzymes work based on the induced-fit hypothesis; ✓
According to this hypothesis, the shape of the substrate is not complementary to that of the active site of the enzyme; ✓ but as the substrate interacts with the enzyme, the active site changes into a precise shape into which the substrate fits perfectly; ✓ forming an enzyme-substrate complex; ✓ which is maintained by bonds formed between the enzyme and the substrate; ✓ At this point, the enzyme lowers activation energy; ✓ causing the reaction to occur forming products; ✓ and hence forming an enzyme-products complex; ✓
Once products are formed, they escape into the surrounding medium; ✓ leaving the active site free to bind with subsequent substrate molecules; ✓

(d) Explain how pH would affect enzyme activity in the biofertilizer.

An enzyme works efficiently over a particular narrow pH range; ✓
When the pH is altered above or below the optimum pH, the rate of enzyme activity decreases; ✓ because changes in pH alter the ionic charge of the acidic and basic groups of the enzyme; ✓ thereby disrupting the ionic bonding within the enzyme molecule; ✓ which in turn leads to distortion of the 3D-shape of the enzyme; ✓ The shape of the active site is altered; ✓ such that the substrate no longer fits into it; ✓ preventing formation of the enzyme-substrate complex; ✓ and thus enzyme activity reduces.

NUTRITION IN PLANTS

ITEM 1

A group of biology students investigated photosynthesis in leaf cells of Spinach, a typical C_3 plant. Under an electron microscope, they observed the structure of chloroplasts in the palisade mesophyll cells in which photosynthesis occurs. They exposed the plant to bright light for 6 hours and then after stained the leaves with iodine. The leaves turned back indicating that they contained starch, one of the products of photosynthesis.

Task:

As a learner of biology with knowledge about photosynthesis;

(a) Explain how the structure of the chloroplast is related to photosynthesis.

- Chloroplast is surrounded by a double membrane which isolates photosynthetic reactions from other activities of the cell;
- Stroma contains various enzymes for catalyzing light-independent reactions of photosynthesis;
- Stroma contains numerous thylakoids increasing surface area for trapping large amounts of light;
- Thylakoids are stacked up to form grana providing a large surface area for maximum light absorption within a small space;
- Chloroplast contains different light harvesting pigments increasing the range of wave length of light absorbed;
- Stroma is colourless allowing light to reach the photosynthetic pigments in the thylakoid membranes without interference;
- Contains carotenoids (xanthophylls and carotenes) which protect chlorophyll against bleaching from excess light and from oxidation by oxygen produced during photosynthesis;

- Stroma contains circular DNA and small ribosomes for manufacturing enzymes needed to catalyse the light-independent reactions of photosynthesis;
- Stroma is gel-like providing a ground substance in which other structures like thylakoids can be embedded;

(b) Describe the role of light in the process of photosynthesis.

- Light is used in the light-dependent stage of photosynthesis to form ATP and reduced NADP.
- Light strikes chlorophyll molecules in photosystem I (PS I) and photosystem II (PS II). The light energy excites electrons in the chlorophyll molecules, boosting them to a higher energy level.
The electrons are then released and taken up by primary electron acceptors. Electrons released from PS II and some from PSI flow from the primary electron acceptors along a chain of electron carriers, located at progressively lower energy levels. As electrons flow from one electron carrier to the next, energy is released which is used to form ATP.
- Light splits water into hydrogen ions, electrons and oxygen. The electrons from water replace those lost from photosystem II. The hydrogen ions from water together with some electrons released from PSI are taken up by NADP to form reduced NADP. Oxygen is given off as a by-product.

(c) Describe a sequence of events which occur in the chloroplasts of the mesophyll cells leading to the formation of starch.

In the stroma of the chloroplast, carbon dioxide combines with ribulose biphosphate (RuBP) in presence of enzyme RuBP carboxylase forming a 6-carbon unstable intermediate which immediately splits it into two molecules of glycerate phosphate (GP). Each molecule of GP is reduced to triose phosphate (TP)/phosphoglyceraldehyde (PGAL) using energy from ATP and hydrogen from reduced NADP.

Some of the triose phosphate is converted to glucose which is polymerized to form starch.

s

ITEM 2

A team of plant physiologists was studying a drought resistant maize variety. They observed its leaf cells under an electron microscope and noticed two distinct photosynthetic cell types. One cell type contained chloroplasts with many well-developed grana, while the other cell type contained chloroplasts with few or no grana and large volume of stroma. The researchers also analysed the plant's photosynthetic process and confirmed that it fixes carbon dioxide initially into a 4-carbon compound.

Task:

As a student of biology;

(a) State whether maize is a C_3 or C_4 plant and justify your answer using the information provided.

Maize is a C_4 plant because it has two types of photosynthetic cells in its leaves and its first product of carbon dioxide fixation is a 4-carbon compound, both of which are characteristic features of C_4 plants.

(b) Describe the general structure of the chloroplast.

The chloroplast is an oval-shaped organelle surrounded by a double membrane which encloses a gel-like matrix called the stroma. The stroma contains many flattened fluid-filled sacs called thylakoids which form stacks called grana at intervals. Some thylakoids have tubular extensions connecting the grana called intergranal lamellae.

The stroma also contains circular DNA, small (70S) ribosomes, lipid droplets and starch grains.

(c) Explain the significance of the presence of many well-developed grana in some chloroplasts and the absence of grana in other chloroplasts in the leaves of the maize plant.

The chloroplasts which have many well-developed grana are found in the mesophyll cells and are specialized for carrying out light-dependent reactions. The presence of many well-developed grana optimizes absorption of light which is used in the light-dependent reactions to produce ATP and NADPH (reduced NADP) which are then used in the light dependent stage (calvin cycle)

The chloroplasts that lack grana are found in bundle sheath cells and are specialised for carrying out the light-independent reactions (Calvin cycle). The absence of grana prevents occurrence of the light-dependent reactions, implying that oxygen is not produced. This keeps the concentration of carbon dioxide in the bundle sheath chloroplasts higher than that of oxygen, preventing enzyme RuBP carboxylase from accepting oxygen and thus preventing photorespiration which would reduce the photosynthetic efficiency of the plant.

(d) Describe how carbon dioxide in the atmosphere is converted into sucrose in a maize plant.

Carbon dioxide diffuses from the atmosphere through the stomata into the intercellular airspaces of the leaf. Carbon dioxide dissolves in the moisture on the cell walls of mesophyll cells and diffuses into the cytoplasm of the mesophyll cells.

In the cytoplasm of mesophyll cells, carbon dioxide combines with phosphoenolpyruvate (PEP) to form a 4-carbon compound, oxaloacetate in presence of enzyme PEP carboxylase. Oxaloacetate is reduced to malate by accepting hydrogen from reduced NADP. Malate is shunted through the plasmodesmata in the cell walls to the chloroplasts of the bundle sheath cells where it is converted to pyruvate by having carbon dioxide and hydrogen removed. The hydrogen removed reduces NADP. Pyruvate is

moved back into the mesophyll cells where it is phosphorylated by ATP to regenerate PEP.

In the stroma of the bundle sheath chloroplasts, the carbon dioxide released from malate combines with ribulose biphosphate(RuBP) in presence of enzyme RuBP carboxylase to form a 6-carbon unstable compound which splits immediately into two molecules glycerate phosphate(GP)/phosphoglyceric acid(PGA). Each GP molecule is reduced to triose phosphate(TP) / phosphoglyceraldehyde (PGAL) using hydrogen from reduced NADP and energy from ATP.

Some of the TP is converted to hexose sugars, glucose and fructose which are then combined in a condensation reaction to form sucrose. Most of the TP is used to regenerate RuBP through phosphorylation by ATP.

(e) Explain how the photosynthetic mechanism in maize gives the plant an advantage in hot, dry environments.

The photosynthetic mechanism in maize gives it an advantage in hot, dry environments because it prevents photorespiration in conjunction with water conservation.

In hot, dry conditions, plants partially close their stomata to reduce water loss through transpiration but this lowers the carbon dioxide concentration inside the leaves which would lead to photorespiration. However, the initial carbon dioxide fixing enzyme in maize is PEP carboxylase which has a very high affinity for carbon dioxide and no affinity for oxygen, making it to still fix carbon dioxide instead of oxygen even at low carbon dioxide levels. Also, the malate formed during the initial carbon dioxide fixation is shunted into bundle sheath chloroplasts where it is decarboxylated releasing carbon dioxide and as a result, a high concentration of carbon dioxide builds around enzyme RuBP carboxylase, making the enzyme to bind with carbon dioxide instead of oxygen.

In addition, the bundle sheath chloroplasts in maize lack grana preventing occurrence of light-dependent reactions resulting in no

production of oxygen. ✓ This keeps a low concentration of oxygen around enzyme RuBP carboxylase ✓ making the enzyme to bind with carbon dioxide instead of oxygen. ✓

ITEM 3

Samello, a biology student visited two agricultural fields located at different altitudes.

The lowland field had sugarcane, while the highland field had barley. She collected leaf samples and observed them under a microscope. In the sugarcane leaves, she noticed two distinct types of photosynthetic cells arranged in a ring-structure around the vascular bundles, while in the barley leaves, only one type of photosynthetic cell was observed.

Later, she illuminated isolated chloroplasts from barley, and biochemical analysis showed production of ATP and reduced NADP in them.

Task:

As a student of biology with knowledge about photosynthesis in plants;

(a) Which of the plants, sugarcane and barley, is a C₃ plant and which one is a C₄ plant? Justify your answer based on the information given.

- Sugarcane is a C₄ plant ✓ because its leaves contain two types of photosynthetic cells which is a characteristic feature of C₄ plants. ✓
- Barley is a C₃ plant ✓ because its leaves contain one type of photosynthetic cell which is a characteristic feature of C₃ plants. ✓

(b) Identify the photosynthetic cell type(s) seen by Daniella in:

(i) Sugarcane leaves.

- Mesophyll cells ✓ and bundle sheath cells. ✓

(ii) Barley leaves.

- Mesophyll cells. ✓

(c) (i) State the site of production of ATP and reduced NADP in the chloroplast.

- Thylakoid membranes. ✓

(ii) Describe how ATP and reduced NADP are produced in the chloroplasts.

- ATP and reduced NADP are produced during the light-dependent reactions of photosynthesis. ✓
- Light strikes chlorophyll molecules in photosystem I (PS I) and photosystem II (PS II). ✓ The light energy excites electrons in the chlorophyll molecules, boosting them to a higher energy level. ✓ The electrons are then released and taken up by primary electron acceptors. ✓ Electrons released from PS II and some from PSI flow from the primary electron acceptors along a chain of electron carriers, ✓ located at progressively lower energy levels. ✓ As electrons flow from one electron carrier to the next, energy is released ✓ which is used to form ATP. ✓
- Light splits water into hydrogen ions, electrons and oxygen. ✓ The electrons from water replace those lost from photosystem II. ✓ The hydrogen ions from water together with some electrons released from PSI are taken up by NADP ✓ to form reduced NADP. ✓

(iii) Describe the role of ATP and reduced NADP produced in the chloroplasts.

- ATP and reduced NADP are used in the Calvin cycle ✓ during which ATP provides energy ✓ while reduced NADP provides hydrogen ✓ for reducing glycerate phosphate (GP) to triose

phosphate (TP). ✓ ATP provides phosphate group for regenerating the carbon dioxide acceptor, ribulose biphosphate (RuBP). ✓

(iv) Explain how the internal structural features of the chloroplast suit it for the production of ATP and reduced NADP.

- Stroma contains numerous thylakoids, ✓ increasing surface area for trapping large amounts of light; ✓
- Thylakoids form stacks called grana, ✓ providing a large surface area for maximum light absorption within a small space; ✓
- Chloroplast contains different light harvesting pigments, ✓ increasing the range of wave length of light absorbed; ✓
- Stroma is colourless and transparent, ✓ allowing light to pass through to reach the photosynthetic pigments in the thylakoid membranes; ✓

(d) State the ways in which photosynthesis in sugarcane differs from that in barley.

In sugarcane	In barley
• Carbon dioxide is fixed twice	Carbon dioxide is fixed once ✓
• First stable product of carbon dioxide fixation is oxaloacetate	First stable product of carbon dioxide fixation is glycerate phosphate ✓
• Carbon dioxide acceptors are PEP and RuBP	Carbon dioxide acceptor is RuBP only ✓
• Carbon dioxide fixing enzymes are PEP carboxylase and RuBP carboxylase	Carbon dioxide fixing enzyme is RuBP carboxylase only ✓
• Photorespiration does not occur	Photorespiration can occur ✓
• Photosynthesis is more efficient	Photosynthesis is less efficient ✓
• Photosynthesis occurs in mesophyll and bundle sheath cells	Photosynthesis occurs in mesophyll cells ✓

• Maximum photosynthetic rate is reached at higher temperature	Maximum photosynthetic rate is reached at lower temperature ✓
• Photosynthesis is associated with higher light saturation point	Photosynthesis is associated with lower light saturation point ✓

ITEM 4

Agricultural scientists were studying lettuce, a C_3 plant, in a controlled greenhouse to improve its yield. They varied light intensity and carbon dioxide concentration while keeping the temperature at 25°C .

After 10 days, they subjected half of the lettuce plants to water stress by reducing irrigation. They measured the rate of photosynthesis using gas exchange analysis. The scientists noticed a sharp decline in the rate of photosynthesis under water stress.

Biochemical analysis of the leaves showed that some of the triose phosphate produced during the Calvin cycle was used to synthesize proteins and lipids rather than starch.

Task:

As a student of biology;

- (a) (i) Explain how changes in light intensity and carbon dioxide concentration affect the photosynthetic rate of lettuce.

EFFECT OF LIGHT INTENSITY:

Increase in light intensity causes the rate of photosynthesis to increase ✓ because increase in light intensity causes the production of ATP and reduced NADP to increase ✓ and hence more carbon dioxide is reduced to carbohydrate. ✓ The increase in light intensity also causes more stomata to open ✓ allowing entry of more carbon dioxide into the leaves ✓ and hence more carbohydrate is formed. ✓

The increase in the rate of photosynthesis with increases in light intensity reaches a point and levels off because other factors like carbon dioxide concentration become limiting.

EFFECT OF CARBON DIOXIDE CONCENTRATION:

Increase in carbon dioxide concentration causes the rate of photosynthesis to increase because increase in carbon dioxide concentration provides **more** substrate for fixation by enzyme RuBP carboxylase in the Calvin cycle and hence leading to formation of **more** carbohydrate.

The increase in the rate of photosynthesis with increase in carbon dioxide concentration reaches a point and levels off because other factors like light intensity become limiting.

(ii) Suggest ways through which the scientists could manipulate environmental factors to optimize lettuce yield in the greenhouse.

- Maintaining optimum light intensity using supplemental lighting from artificial light sources.
- Maintaining optimum temperature through use of heating systems during cold periods and use of ventilation or shading in hot periods.
- Increasing carbon dioxide levels through release of carbon dioxide into the greenhouse from gas cylinders or through burning fuels like natural gas inside the greenhouse.
- Providing adequate water supply through irrigation.

(b) Explain how water stress reduces the rate of photosynthesis in lettuce.

During water stress, the plant wilts and the leaves of the wilted plant secrete abscisic acid which causes the stomata to close, thereby preventing entry of carbon dioxide into the leaves. Eventually the concentration of carbon dioxide inside the leaves decreases and hence reducing the rate of photosynthesis.

(c) Describe how triose phosphate from the Calvin cycle can be converted into;

(i) Proteins.

Triose phosphate enters the glycolysis pathway where it is converted to pyruvate through a series of reactions. Pyruvate is converted to acetyl-CoA which enters the Krebs cycle. The Krebs cycle intermediates are converted to a variety of amino acids through transamination. The amino acids are then polymerized to form proteins.

Lipids.

Triose phosphate is converted to glycerol.

Triose phosphate also enters the glycolysis pathway where it is converted to pyruvate through a series of reactions. Pyruvate is converted to acetylCoA which is used to synthesize a variety of fatty acids. Glycerol combines with fatty acids to form lipids.

(d) Explain why it is beneficial for lettuce to convert some triose phosphate into proteins and lipids rather converting it all to carbohydrates.

Because proteins and lipids perform different functions necessary for growth and development of the plant that carbohydrates cannot perform.

Proteins serve as enzymes, signaling molecules, transport molecules ✓ and are structural components of cells and tissues. ✓
Lipids serve as long-term energy storage molecules, signaling molecules ✓ and are structural components of cell membranes. ✓

ITEM 5

On a mountain slope, ecologists observed that millet dominates at low altitudes, while wheat dominates at high altitudes.

They also measured the rate of photosynthesis in these plants at different temperatures and found that:

- **In wheat, the rate of photosynthesis increased up to 25°C and then decreases rapidly.**
- **In millet, the rate of photosynthesis remained high even at 35°C.**

Task:

As a student of biology;

(a) Explain why millet dominates at low altitude while wheat dominates at high altitude.

Altitude affects distribution of millet and wheat through its influence on environmental temperature ✓ which reduces with increase in altitude. ✓

Wheat dominates at high altitude because it is a C₃ plant. ✓ At high altitude, temperature is lower ✓ which favours carbon dioxide fixation by RuBP carboxylase in C₃ plants ✓ and minimizes photorespiration ✓ making photosynthesis in C₃ plants more efficient at lower temperatures. ✓

Millet dominates at low altitude because it is a C₄ plant. ✓ At low altitude, temperature is higher ✓ but enzyme PEP carboxylase in C₄ maintains a high affinity for carbon dioxide and no affinity for oxygen, ✓ preventing photorespiration ✓ and

hence maintaining a high photosynthetic efficiency in C₄ plants even at higher temperatures. ✓

(b) Explain why the rate of photosynthesis in wheat decreases rapidly above 25°C, while millet maintains a high rate of photosynthesis even at 35°C.

- Above 25°C, RuBP carboxylase in wheat increasingly accepts oxygen instead of carbon dioxide ✓ leading to photorespiration ✓ and at higher temperatures, the photosynthetic enzymes like RuBP carboxylase become denatured. ✓
- The initial carbon dioxide fixing enzyme in millet, PEP carboxylase has a very high affinity for carbon dioxide and no affinity for oxygen ✓ and a high concentration of carbon dioxide is built around RuBP carboxylase in the Calvin cycle. ✓ As a result, photorespiration in millet is prevented, ✓ thereby maintaining a high rate of photosynthesis even at 35°C. ✓

ITEM 6

A group of biology students conducted an experiment on two potted bean plants, A and B.

Plant A was well watered daily.

Plant B was subjected to water stress by withholding water for five days.

They measured stomatal aperture size and rate of photosynthesis using a gas exchange sensor.

In plant A, stomata were widely open during the day and closed at night.

In plant B, the stomata gradually closed even during daylight hours as time of subjection to water stress increased.

The rate of photosynthesis in plant B decreased significantly after day 3.

The students were asked to explain their observations.

Task:

(a) Using the photosynthetic theory, explain why the stomata of plant A were open during the day and closed at night.

- During the day, the guard cells photosynthesize, leading to an increase in the concentration of sugars (sucrose) inside them which lowers their water potential. This causes water to move from the neighbouring epidermal cells into the guard cells by osmosis. The guard cells become turgid and the stomata open.
- At night, guard cells stop to photosynthesize, leading to a decrease in the concentration of sugars (sucrose) inside them which increases their water potential and as a result, water moves out of the guard cells into the neighbouring epidermal cells by osmosis. The guard cells become flaccid and the stomata close.

(b) Explain how water stress caused the stomata of plant B to gradually close during the day.

During water stress, plant B wilted and the leaves of the wilted plant secreted abscisic acid which caused movement of potassium ions out the guard cells, thereby increasing their water potential. As a result, water moved out of the guard cells into the neighbouring cells by osmosis. Guard cells became flaccid and the stomata closed.

(c) Explain why the rate of photosynthesis in plant B decreased significantly after day 3.

Due to closure of stomata which reduced the entry of carbon dioxide into the leaves leading to a decrease in the concentration of carbon dioxide inside the leaves and consequently, the rate of photosynthesis decreased since carbon dioxide is a raw material of photosynthesis.

TRANSPORT IN HUMANS

ITEM 1

A 55-year old patient visited a cardiologist complaining of fatigue and shortness of breath. An echocardiogram revealed that the patient's left ventricular wall was thinner than normal and the heart is unable to pump blood at the required pressure. Additionally, the patient's ECG showed irregular electrical activity, suggesting a problem with the heart's conduction system.

In contrast, a 22-year old marathon runner had significantly thickened left ventricular wall, allowing a high cardiac output during prolonged exercise. Despite this, the athlete's heart continues to beat rhythmically even when temporarily isolated during experimental conditions.

Task:

- (a) (i) **Explain why the left ventricular wall is normally thicker than the right ventricular wall.**

The left ventricle has to pump blood to all the body parts including those far from the heart; and therefore the thicker wall enables the left ventricle to contract **more** strongly/forcefully to pump blood at a **higher** pressure so that the blood can effectively reach the entire body.

While the right ventricle has to pump blood to the lungs which are close to the heart and therefore the thinner wall enables the right ventricle to contract **less** strongly/forcefully to pump blood at a **lower** pressure so that the delicate lung capillaries are not damaged.

- (ii) **Explain why the patient with a thinner left ventricular wall experienced fatigue and shortness of breath.**

A thinner left ventricular wall causes the left ventricle not to contract strongly enough and as a result, it pumps blood at a lower pressure than required. This implies that less oxygenated blood reaches the

tissues, leading to insufficient energy production and hence fatigue.

Also, the lower pressure generated causes inefficient forward movement of blood, leading to accumulation of blood in the pulmonary/lung capillaries. This increases pressure in the lung capillaries, forcing fluid out of them into the alveoli of the lungs, causing pulmonary edema which interferes with gas exchange and hence causing shortness of breath.

(iii) Explain why the athlete's significantly thickened left ventricular wall is advantageous during intense exercise.

The significantly thickened left ventricular wall allows stronger contraction of the left ventricle, leading to a higher stroke volume and hence leading to a higher cardiac output. As a result, more oxygen and nutrients are supplied to the muscles during the intense exercise.

(b) (i) Explain why the athlete's heart continues to beat rhythmically even when temporarily isolated.

Because the human heart is myogenic (has an intrinsic mechanism of generating impulses) which is due to presence of the sinoatrial node (SAN) made up of specialised cardiac muscles cells that generate impulses (waves of excitation) regularly without stimulation from the nervous system and these impulses cause the heart muscles to contract to bring about the heartbeat even when the heart is isolated.

(ii) Describe how the human heart normally generates and conducts impulses to maintain rhythmic contractions.

The waves of excitation (impulses) are generated by the sinoatrial node (SAN) which is also the pace maker. The waves of excitation then spread to the walls of both atria causing them to contract at the same time. The waves of excitation are then picked by the atrioventricular node (AVN) which sends them down via the bundle

of His to the Purkyne (Purkinje) tissue ✓ which spreads the waves of excitation to the walls of both ventricles causing them to contract at the same time from the apex/bottom upwards. ✓

(iii) Explain the structural adaptations of the cardiac muscle that make it suitable for its function.

- Cardiac muscle cells contain many large mitochondria ✓ for producing large amounts of ATP needed for continuous contraction for the muscle without fatigue. ✓
- The myofibrils in the cardiac muscle fibres contain actin and myosin filaments ✓ which slide past each other to cause contraction of the muscle. ✓
- The cardiac muscle fibres branch and cross-connect forming a net-like structure, ✓ allowing rapid spread of electrical impulses through the muscle. ✓
- The intercalated discs separating individual muscle cells are modified to allow rapid diffusion of ions; ✓ which allows rapid spread of electrical impulses through the muscle; ✓
- The SAN contains specialised cardiac muscle cells that generate electrical impulses without nervous stimulation, ✓ ensuring that the heart beats automatically and rhythmically. ✓

ITEM 2

During a school biology experiment, a group of students manually monitored the heart rate of a healthy, 18-year old male subject before, during and after jogging for 10 minutes. They observed the following:

- Before exercise, his resting heart rate was 68 beats per minute.
- During exercise, it increased to 130 beats per minute.
- Five minutes after stopping, it gradually decreased to 80 minutes per minute.

Task:

(a) Explain how exercise causes an increase in the heart rate.

Exercise causes the rate of respiration to increase, leading to an increase in the production of carbon dioxide which causes an increase in the carbon dioxide concentration of blood. The rise in the blood carbon dioxide concentration is detected by chemoreceptors in the carotid and aortic bodies which respond by sending impulses to the cardiac accelerator centre in the medulla of the brain. The cardiac accelerator centre responds by sending impulses via the sympathetic nerve to the sinoatrial node (SAN), stimulating it to generate impulses at a higher rate and hence causing the heart to beat faster.

(b) Explain why the heart rate needs to increase during exercise.

During exercise, demand for oxygen and nutrients increases; and waste products like carbon dioxide accumulate faster; and therefore the heart rate needs to increase to deliver **more** oxygen and nutrients to the **highly** respiring tissues especially muscles and to remove waste products like carbon dioxide faster, thereby maintaining body homeostasis.

(c) Explain why the heart rate remains elevated for some time after exercise stops.

After exercise, the heart continues to beat faster so as to continue supplying **more** oxygen to the tissues to pay the oxygen debt.

(d) Describe how the heart rate returns to the normal resting rate after exercise.

After exercise, the cardiac **inhibitory** centre in the medulla of the brain is activated/stimulated which sends impulses via the parasympathetic (vagus) nerve to the SAN, stimulating it to generate impulses at a lower rate and hence causing the heart rate to decrease back to the normal resting rate.

(e) **Suggest two ways the students could improve the accuracy of their investigation.**

- Using electronic heart rate monitor or electrocardiogram (ECG) sensor instead of manual pulse counting to reduce human error. ✓
- Repeating the experiment with multiple subjects and get the average of the results to reduce the effect of individual variation. ✓

ITEM 3

A researcher studied the effect of physical activity on the heart rate by monitoring a trained athlete and untrained person as they performed the same 15-minute cycling session.

Both individuals had similar resting heart rates.

During exercise, the untrained individual's heart rate rose faster and to a higher maximum than the athlete's.

After exercise, the athlete's heart rate returned to normal more quickly.

Task:

(a) **Describe how the nervous system controls the heart rate in humans.**

The heart rate is controlled by the **autonomic** nervous system. ✓

When the cardiac accelerator centre in the medulla of the brain is stimulated, it send impulses via the sympathetic nerve to the sinoatrial node (SAN), stimulating it to generate electrical impulses at a higher rate and hence causing the heart rate to increase. ✓

When the cardiac inhibitory centre in the medulla of the brain is stimulated, it sends impulses via the parasympathetic (vagus) nerve to the SAN, stimulating it to generate impulses at a lower rate and hence slowing down the heart rate. ✓

(b) Explain why the untrained person's heart rate increased more than the trained athlete's heart during exercise.

The untrained person's heart is weaker and has smaller chambers resulting into a lower stroke volume which results into a lower cardiac output and due to this, the untrained person's heart needs to beat faster to meet the high metabolic demands of exercise.

But the trained athlete's heart is stronger and has larger chambers resulting into a higher stroke volume which leads to a higher cardiac output and due to this, the trained athlete's heart needs to beat at a slower rate to meet the same high metabolic demands of exercise.

(c) Explain why the trained athlete's heart rate returned to normal more quickly after exercise.

- The trained athlete's heart has a **higher** stroke volume than that of an untrained person and therefore delivers **more** oxygen to the tissues per beat. This enables the athlete to pay the oxygen debt **more** efficiently after exercise, allowing the heart rate to return to normal **more quickly** than in untrained persons.

(d) Suggest why it is important for athletes to warm up before intense exercise.

- Warming up **gradually** increases the heart rate, reducing the risk of **sudden strain** on the heart and **gradually** increases blood flow to the muscles, making them warmer and **more flexible**, reducing chances of muscle strains or tears.

ITEM 4

During a national inter-school athletics competition held at a high-altitude location, students from both lowland and highland regions participated in a 1500-meter race. Among the participants were an elite long-distance runner who had trained at high altitude for years, a trained sprinter from lowlands and a non-athletic student from lowlands.

All participants underwent medical tests before and after the race. Before the race, resting heart rates and ECG patterns were recorded. After the race, heart rate recovery over 5 minutes and the duration of each stage in the cardiac cycle were measured. The ECG still showed a normal wave pattern during and after exercise.

Task:

(a) (i) Describe the sequence of events which occur in the cardiac cycle.

- **Atrial diastole:**

The atria relax ✓ allowing blood returning to the heart to flow into them. ✓ At first the atrioventricular valves are closed, ✓ but as the atria fill with blood, the pressure inside them rises and eventually becomes greater than that inside the ventricles, ✓ pushing the atrioventricular valves open ✓ and blood then begins to flow passively from the atria into the relaxed ventricles. ✓

- **Atrial systole:**

The atria contract, ✓ forcing all the blood remaining in the atria into the relaxed ventricles. ✓

- **Ventricular systole:**

The ventricles contract, ✓ pressure inside them rises beyond that in the atria, ✓ causing the atrioventricular valves to close ✓ and

this prevents back flow of blood into the atria. ✓ The closure of the atrioventricular valves produces the first heart sound, **lub.** ✓ The ventricular pressure also rises beyond that in the aorta and pulmonary artery, ✓ forcing the semilunar valves open ✓ and this allows blood to flow from the ventricles into these blood vessels. ✓

• **Ventricular diastole:**

The ventricles relax, ✓ pressure inside them falls below that in the aorta and pulmonary artery, ✓ causing the semilunar valves to close ✓ and this prevents back flow of blood into the ventricles. ✓ The closure of the semilunar valves produces the second heart sound, **dub.** ✓

The rising pressure inside the atria forces the atrioventricular valves open, ✓ allowing blood to flow from the atria into the relaxed ventricles. ✓

(iii) Name the different waves of an ECG trace and state what each wave represents.

P wave; ✓ represents atrial depolarization. ✓

QRS complex; ✓ represents ventricular depolarization. ✓

T wave; ✓ represents ventricular repolarization. ✓

(iii) Explain why the ECG still showed a normal wave pattern during and after exercise.

Because the sequence of electrical activity (conduction of electrical impulses) in the heart remains the same during and after exercise, ✓ leading to production of the P wave, QRS complex and T wave of the ECG in the same shape and order. ✓

(b) Compare the response of highland dwellers and lowland dwellers to exercise at a high-altitude location.

At high altitude, highland dwellers perform **better** during exercise than lowland dwellers. ✓ Because highland dwellers have structural and physiological adaptations which improve

oxygen delivery and utilization in muscles during exercise; ✓
making them to take longer in exercise without tiring; ✓
Such adaptations include:

- Higher red blood cell count; ✓ and higher haemoglobin concentration; ✓ increasing the oxygen carrying capacity of blood; ✓
- Higher capillary density in muscles; ✓ increasing oxygen delivery to the muscles; ✓
- Larger and more numerous mitochondria in the muscles; ✓ producing more ATP during aerobic respiration; ✓
- More myoglobin in muscles; ✓ increasing oxygen stores in muscles; ✓
- Hyperventilation (increased depth and rate of breathing); ✓ increasing the amount of oxygen taken in; ✓
- Larger lung size; ✓ to accommodate more air; ✓

But lowland dwellers lack such adaptations and therefore have reduced delivery and utilization of oxygen in muscles; ✓ making them to tire more quickly during exercise; ✓

ITEM 5

A 45-year old patient visits a cardiologist complaining of fatigue, shortness of breath during light exercise and occasional swelling in the ankles. An echocardiogram reveals that the bicuspid (mitral) valve does not close completely. The patient is also found to have a slightly narrow pulmonary valve opening. The doctor informs the patient that these valve defects affect the efficiency of blood circulation leading to the symptoms described.

Task:

(a) (i) Explain the role of the human heart in blood circulation.

The human heart is a muscular organ that pumps blood throughout the body; ✓ The right ventricle of the heart pumps deoxygenated

blood to the lungs; ✓ through the pulmonary artery; ✓ while the left ventricle pumps blood to the rest of the body; ✓ through the aorta; ✓

(ii) Explain how the structure of the human heart is related to its role in blood circulation.

- Human heart has valves (semilunar and atrioventricular valves); ✓ preventing back flow of blood; ✓
- Human heart is highly muscular to generate a contractile force for pumping blood; ✓
- Human heart is supplied by coronary arteries; ✓ to deliver oxygen and nutrients to the cardiac muscle; ✓
- Human heart chambers are elastic; ✓ allowing accommodation of large volumes of blood; ✓
- The heart chambers have a smooth inner lining; ✓ allowing frictionless flow of blood through the heart; ✓
- Human heart has a septum; ✓ for separating oxygenated blood from deoxygenated blood; ✓
- Human heart is innervated by the vagus (parasympathetic) and sympathetic nerve; to control the heart rate; ✓
- Human heart is surrounded by the pericardium; ✓ to limit expansion of the heart when being filled with blood; ✓
- Human heart possesses tendinous cords; ✓ which prevent atrioventricular valves from turning inside out; ✓

(b) Explain how the valve defects described in the scenario affect the efficiency of blood circulation.

- Failure of the bicuspid valve to close completely causes some blood to flow back into the left atrium during ventricular contraction; ✓ which reduces **stroke volume** (amount of blood pumped out of the left ventricle per beat); ✓ implying that less oxygenated blood reaches the body tissues; ✓
- Narrowing of the pulmonary valve opening reduces the amount of blood flowing from the right ventricle into the pulmonary

artery; ✓ and hence reducing the amount of blood reaching the
lungs; ✓

ITEM 6

The doctor examined a 15-year old boy who was complaining of fatigue and swelling in the abdomen. The doctor listened to the patient's heart using a stethoscope and detected an abnormal heart sound (murmur) during ventricular systole and another during ventricular diastole. Further tests revealed that the tricuspid valve does not close completely and the aortic valve opening is narrow. The doctor informed the patient that the heart normally produces two heart sounds during the cardiac cycle and that these abnormal heart sounds are due to these valve defects which disrupt normal blood flow.

Task:

(a) Name the two heart sounds produced normally by the heart during the cardiac cycle and state the cause of the production of each.

- First heart sound is called lub; ✓ produced due to the closure of the atrioventricular valves; ✓ during ventricular systole; ✓
- Second heart sound is dub; ✓ produced due to the closure of the semilunar/pocket valves; ✓ during ventricular diastole; ✓

(b) Describe the functions of the tricuspid and aortic valves during the cardiac cycle.

- Tricuspid valve opens during ventricular diastole; ✓ allowing blood to flow from the right atrium to the right ventricle; ✓ and closes during ventricular systole; ✓ preventing back flow of blood into the right atrium; ✓
- Aortic valve opens during ventricular systole; ✓ allowing flow of blood from the left ventricle to the aorta; ✓ and closes during ventricular diastole; ✓ preventing back flow of blood into the left ventricle; ✓

(c) (i) State two possible causes of heart valve defects.

- Damage from infection e.g rheumatic fever; ✓ and endocarditis caused by certain bacteria
- Abnormal development of valves during fetal development; ✓
- Chest physical trauma; ✓
- Aging; ✓

(ii) Explain how each valve defect described in the scenario affects blood flow.

- Failure of the tricuspid valve to completely close causes back flow of some blood into the right atrium during ventricular systole; ✓ implying that less blood is pumped from the right ventricle through the pulmonary artery to the lungs; ✓
- Narrowing of the aortic valve opening reduces the **stroke volume** (amount of blood pumped out of the left ventricle per beat); ✓ resulting in less oxygenated blood reaching the body tissues; ✓

ITEM 7

Diego, a 25-year old man went for a routine health check-up. Blood tests revealed that his haemoglobin levels were slightly lower than normal. The doctor explained to him that haemoglobin is crucial for transporting oxygen and carbon dioxide in the blood and that several factors can influence how much oxygen blood can carry. During the consultation, the Doctor advised him to start training at high altitude.

Task:

(a) (i) Describe the structure of haemoglobin.

Haemoglobin is a protein with a quaternary structure; ✓ consisting of four polypeptide chains; ✓ which include two alpha chains and two beta chains; ✓ Each α -polypeptide chain contains 141 amino acids; ✓ and each β -polypeptide chain contains 146 amino acids; ✓ Each

polypeptide chain has a haem group bound to it; ✓ with an iron atom at the centre of each haem group; ✓

(iv) Explain how haemoglobin is suited for transporting oxygen efficiently.

- Each haemoglobin molecule contains four haem groups each capable of binding with oxygen; ✓ giving haemoglobin a high oxygen-carrying capacity; ✓
- The iron atom in haem binds reversibly with oxygen; ✓ allowing oxygen to be loaded in the lungs and to be unloaded in the tissues; ✓
- When the first oxygen molecule binds to haem, the structure of haemoglobin is distorted; ✓ allowing the next oxygen molecules to bind more easily; ✓
- The affinity of haemoglobin for oxygen is reduced by the high carbon dioxide levels in tissues; ✓ allowing haemoglobin to release oxygen to the tissues; ✓
- Haemoglobin is water-soluble; ✓ allowing very many haemoglobin molecules to be packed within a single red blood cell without precipitating out; ✓

(b) Describe the role of haemoglobin in the transport of oxygen and carbon dioxide.

- Haemoglobin transports oxygen from the lungs to the tissues; ✓ Oxygen binds to the iron atom in each haem group of haemoglobin; ✓ forming oxyhaemoglobin; ✓
- Haemoglobin transports some carbon dioxide (about 10-20% of carbon dioxide) from the tissues to the lungs; ✓ Carbon dioxide binds to the amino group at the end of each polypeptide chain of haemoglobin; ✓ forming carbaminohaemoglobin; ✓

(c) Explain how high-altitude training might affect the amount of oxygen in Diego's blood (oxygen-carrying capacity of Diego's blood).

At high altitude, the oxygen levels in the air are lower/oxygen partial pressure is lower; ✓ and therefore Diego's body responds by producing **more** red blood cells; ✓ and **more** haemoglobin; ✓ which increases the oxygen-carrying capacity of Diego's blood; ✓

(d) Apart from haemoglobin concentration, explain two factors that influence the oxygen-carrying capacity of blood.

- Partial pressure of oxygen in the lungs; ✓
Increase in oxygen partial pressure in the lungs causes the oxygen-carrying capacity of blood to increase; ✓ because **more** oxygen diffuses into the blood and binds with haemoglobin in the red blood cells; ✓
- pH of blood; ✓
The lower the pH of blood, the lower the oxygen-carrying capacity of blood; ✓ due to a lower affinity of haemoglobin for oxygen making it less able to bind with oxygen; ✓

ITEM 8

During a marathon, the athlete's muscles work very hard, requiring more oxygen while producing a large amount of carbon dioxide. Therefore, the athlete's body must efficiently transport oxygen from the lungs to the muscles and carbon dioxide away from the muscles to the lungs. However, the blood pH must be kept within the normal range and the electrical neutrality of the red blood cells must be maintained as carbon dioxide is transported.

Task:

(a) How is oxygen transported to the muscles of the athlete?

Oxygen diffuses from the lungs into the blood plasma; and then diffuses into the red blood cells; where it binds to haemoglobin; forming oxyhaemoglobin; which is carried in blood to muscles; In the muscles, the oxygen tension (partial pressure) is lower while carbon dioxide tension (partial pressure) is higher; reducing the affinity of haemoglobin for oxygen; and hence causing release of oxygen from haemoglobin; which diffuses to the muscles;

N.B: Oxygen is transported in the same way to the rest of the tissues:

(b) How is carbon dioxide transported away from the muscles of the athlete?

Carbon dioxide diffuses from the muscles into the blood plasma; Some of the carbon dioxide (about 5%) dissolves in the blood plasma; and it is transported to the lungs in physical solution and as carbonic acid;

Most of the carbon dioxide diffuses from the blood plasma into the red blood cells; Inside the red blood cells, some of the carbon dioxide (about 10-20%) binds to haemoglobin; forming carbaminohaemoglobin; which is transported to the lungs; while most of the carbon dioxide combines with water; forming carbonic acid; in presence of enzyme carbonic anhydrase; Carbonic acid dissociates into hydrogen ions and hydrocarbonate ions; Hydrogen carbonate ions diffuse out of the red blood cells into the blood plasma; where they combine with sodium ions to form sodium hydrogen carbonate; which is then transported to the lungs;

When blood reaches the lungs, the reverse processes occur releasing carbon dioxide; which diffuses from blood into the lungs for expulsion;

NB: Carbon dioxide is transported in blood in three ways:

- In solution (about 5%)
- As carbaminohaemoglobin (10-20%)
- As hydrogen carbonate (about 85%)

(c) Explain how;

(i) the electrical neutrality of red blood cells is maintained during carbon dioxide transport.

When hydrogen carbonate ions diffuse out of the red blood cells into the plasma, the chloride ions diffuse from the plasma into the red blood cells; ✓ which maintains the electrical neutrality of the red blood cells; ✓ a phenomenon called chloride shift; ✓

(ii) pH of blood is kept within the normal range during carbon dioxide transport.

Haemoglobin combines with hydrogen ions from the dissociation of carbonic acid forming haemoglobinic acid; ✓ thereby preventing reduction in pH of blood; ✓

ITEM 9

A 35-year old man was found unconscious in his living room by a neighbour during a cold night. Investigations revealed that he had been running a charcoal heater indoors for warmth. On admission to the hospital, he presented with headache, dizziness, nausea and a cherry-red skin colour.

Task:

(a) Explain the likely cause of the patient's condition.

The patient's condition was caused by carbon monoxide poisoning; ✓ which was due to inhalation of carbon monoxide produced from incomplete combustion of charcoal; ✓

(b) Explain why the patient lost his consciousness.

The carbon monoxide inhaled bound to the haemoglobin in his red blood cells in preference to oxygen, forming carboxyhaemoglobin; ✓
since haemoglobin has a much higher affinity for carbon monoxide than for oxygen; ✓ This prevented oxygen from being transported to his tissues including the brain; ✓ resulting in reduced oxygen supply to the brain; ✓ and hence leading to unconsciousness; ✓

(c) Explain the immediate management strategy for a patient in such a condition.

The patient is first removed from the source of carbon monoxide; ✓
to prevent further inhalation of carbon monoxide; ✓
The patient is then administered with a mixture of almost pure oxygen that contains a small amount of carbon dioxide; ✓
The carbon dioxide stimulates the respiratory centre in the medulla of the brain; ✓ resulting in faster and deeper breathing; ✓ which accelerates removal of carbon monoxide from the lungs; ✓
The almost pure oxygen helps to displace carbon monoxide from haemoglobin; ✓ allowing oxygen to bind; ✓

(d) Suggest measures that could have prevented the patient's condition.

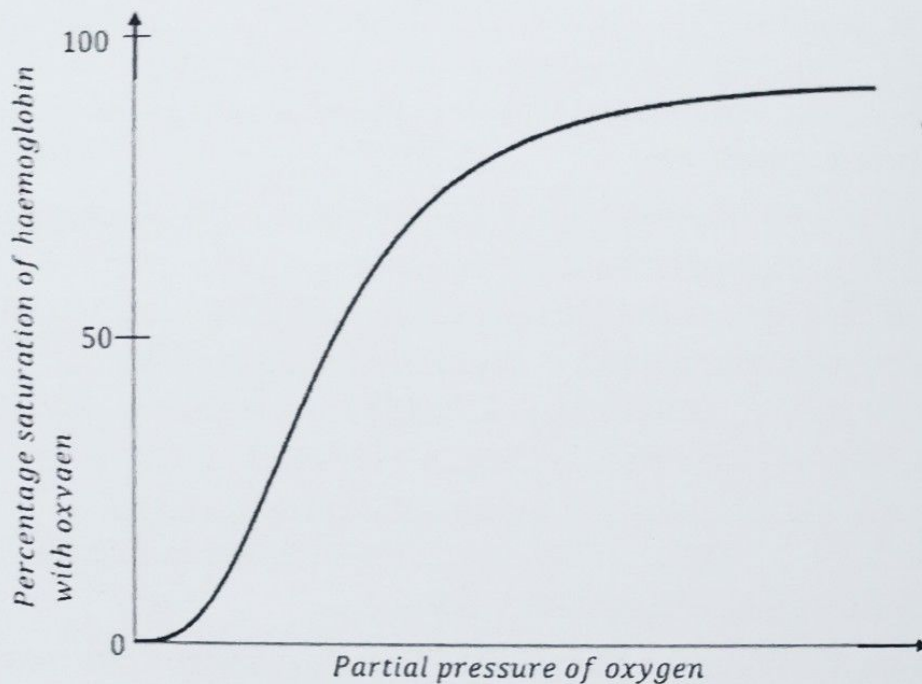
- Avoid using charcoal heaters indoors; ✓
- Ensure proper ventilation when using charcoal heaters; ✓
- Install carbon monoxide detectors in homes; ✓

ITEM 10

A biology student wanted to investigate how haemoglobin loads and unloads oxygen. He took a human blood sample and exposed it to varying oxygen partial pressures at normal body conditions. He also repeated the experiment but exposing blood to a higher partial pressure of carbon dioxide to simulate conditions in the tissues.

Task:

(a) Sketch a graph of the percentage saturation of haemoglobin with oxygen at different oxygen partial pressures at normal body conditions that the student obtained.



(a) Explain the shape of the graph in (a).

A sigmoid/S-shaped curve was obtained; ✓

Before binding to oxygen, the haemoglobin molecule is stable; ✓
being maintained by hydrogen bonds, ionic bonds and hydrophobic interactions; ✓ and thus making the first oxygen molecule to bind to haem with difficulty; ✓ which accounts for the initial **gradual** rise in percentage saturation; ✓ but after binding of the first oxygen molecule, the structure of haemoglobin is distorted; ✓ exposing the remaining haem groups; ✓ and hence the subsequent oxygen molecules bind more easily; ✓ accounting for the **rapid** rise in percentage saturation in the middle portion of the curve; ✓

The curve levels off at high oxygen partial pressures because almost all haem groups are already occupied by oxygen; ✓

(b) Explain the physiological significance of the shape of the graph in (a).

Over the steep part of the curve, a small increase in the oxygen partial pressure results in a relatively high percentage saturation of haemoglobin; ✓ and hence haemoglobin is easily loaded with oxygen in the lungs where oxygen partial pressure is high; ✓

Also over the steep part of the curve, a small decrease in the oxygen partial pressure results in a large fall in the percentage saturation of haemoglobin; ✓ and hence haemoglobin easily releases/unloads oxygen in the tissues where oxygen partial pressure drops/is low; ✓

(c) State how the percentage saturation of haemoglobin with oxygen was affected when he carried out the experiment at a higher carbon dioxide partial pressure and name this phenomenon.

The percentage saturation of haemoglobin was lowered; ✓ and this phenomenon is called the **Bohr effect**; ✓

(d) (i) Explain how the phenomenon named in (d) arises in tissues.

In **highly respiring** tissues, a lot of carbon dioxide is released; ✓ resulting in a high partial pressure of carbon dioxide in tissues; ✓ Carbon dioxide diffuses into the red blood cells where it reacts with water in presence of enzyme carbonic anhydrase; ✓ forming carbonic acid; ✓ which dissociates into hydrogen ions and hydrogen carbonate ions; ✓ Hydrogen ions bind to haemoglobin forming haemoglobinic acid; ✓ reducing its affinity for oxygen; ✓

(ii) State the physiological significance of the phenomenon named in (d).

Bohr effect causes haemoglobin to release oxygen **more readily** to the highly respiring tissues; ✓ enabling tissues to produce **more** energy (ATP) to meet their increased demands; ✓

ITEM 11

A severe outbreak of a viral disease occurred in a rural community. Scientists investigated the role of the immune system in protecting individuals from the virus.

A blood sample from a patient recovering from the infection was analysed and the scientists observed a high concentration of antibodies specific to the viral antigen. The scientists explained that antibodies help protect the body through different mechanisms.

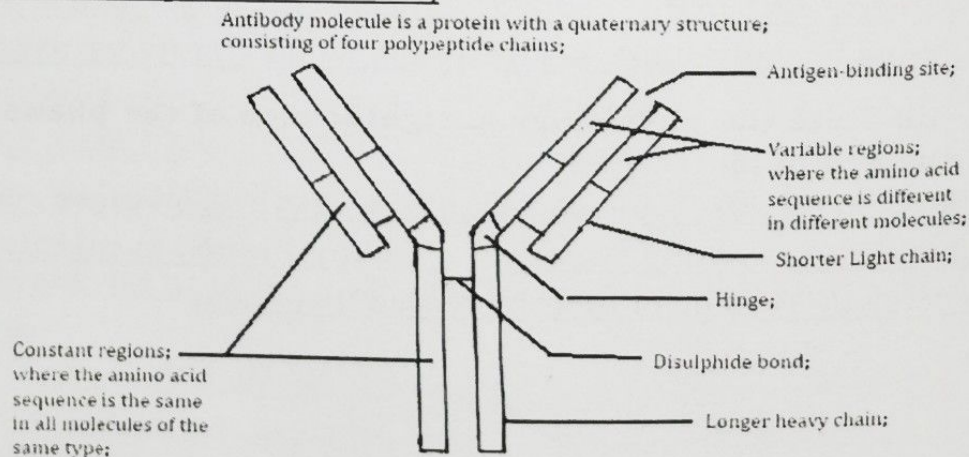
Following the outbreak, a vaccination program was introduced but some people refused to be vaccinated.

Task:

(a) Describe the structure of an antibody molecule.

An antibody molecule is a **Y-shaped** protein molecule; ✓ with a **quaternary structure**; ✓ It consists of two identical **heavy** polypeptide chains; ✓ and two identical **light** polypeptide chains; ✓ The chains are held together by disulphide bonds; ✓ Each heavy and light chain has a **variable region**; ✓ where the amino acid sequence is different in different molecules; ✓ and a **constant region**; ✓ where the amino acid sequence is the same for all molecules of the same type; ✓ Each heavy chain has a **hinge region** at the base of the Y arm; ✓ Each antibody molecule has two identical **antigen-binding sites**, one present at the tip of each Y arm; ✓

OR:



(b) Explain the different ways by which antibodies can act against pathogens.

- **Agglutination;** ✓ Some antibodies cause pathogens to clump together, making them more vulnerable to attack by phagocytes ✓
- **Opsonisation;** ✓ Some antibodies coat bacteria, making phagocytes to recognise and engulf the bacteria; ✓
- **Neutralisation;** ✓ Some antibodies combine with toxins produced by pathogens rendering them harmless; ✓
- **Precipitation;** ✓ Some antibodies bind soluble antigens together precipitating them out of solution and thus making phagocytes to easily engulf them; ✓
- **Lysis;** ✓ Some antibodies when attached to the pathogen act as binding sites for complement proteins, some of which cause breakdown of the pathogen; ✓

(c) Explain how vaccination gives long-term protection against disease in an individual.

The vaccine introduces a harmless form of the pathogen or its antigen into the body; ✓

Together with cytokines/lymphokines/interleukins released from T-helper (T₄) cells, the introduced pathogen or antigen activates specific B cells to divide rapidly by mitosis; ✓ forming a clone of identical B cells; ✓ Some of the B cells in the clone differentiate into **plasma cells;** ✓ which produce large quantities of antibodies specific to the antigen of the pathogen; ✓ while others differentiate into **memory cells;** ✓ which stay in the body for a long time retaining the ability to recognize the same antigen; ✓ So, when the same pathogen invades the body, the memory cells produce antibodies **rapidly** and in much **larger amounts;** ✓ which destroy the pathogen before causing disease; ✓

(d) Explain why refusal of some people to be vaccinated could reduce the effectiveness of the vaccination program.

Viral disease continues to spread among unvaccinated individuals; ✓ increasing risk of transmission to those who cannot be vaccinated

like infants and immunocompromised persons; ✓ reducing the effectiveness of the vaccination programme; ✓

ITEM 12

A new viral infection has emerged and scientists are developing different vaccines against it. The scientists explain that when vaccinated individuals are later exposed to the virus, the immune system will respond strongly preventing manifestation of the infection.

However, a few individuals who have been vaccinated have reported some allergic reactions to one of the developed vaccines, such as breathing difficulty, swelling and skin rashes.

Task:

(a) Describe the different types of vaccines, giving an example in each case.

- **Toxoid vaccines;** ✓ Contain detoxified/inactivated toxins produced by a pathogen which stimulate antibody production without causing disease; ✓ e.g tetanus/diphtheria vaccine; ✓
- **Killed vaccines;** ✓ Contain a **dead** pathogen capable of stimulating antibody production; ✓ e.g flu vaccine; ✓
- **Live vaccines;** ✓ Contain a weakened (attenuated) form of a pathogen capable of stimulating antibody production without causing disease; ✓ e.g TB/measles/mumps/polio vaccine; ✓
- **Recombinant vaccines;** ✓ Contain an antigen of a pathogen produced in another organism through genetic engineering which is capable of stimulating antibody production but cannot cause disease; ✓ e.g hepatitis B vaccine; ✓

(b) Explain how the immune system protects vaccinated individuals from the viral infection when they are later exposed to the virus.

The vaccine introduces a harmless form of the virus or its antigen into the body; ✓

Together with cytokines/lymphokines/interleukins released from T-helper (T₄) cells, the introduced virus or antigen activates specific B cells to divide rapidly by mitosis; ✓ forming a clone of identical B cells; ✓ Some of the B cells in the clone differentiate into **plasma cells;** ✓ which produce large quantities of antibodies specific to the antigen of the virus; ✓ while others differentiate into **memory cells;** ✓ which stay in the body for a long time retaining the ability to recognize the same antigen; ✓ So, when the same virus invades the body, the memory cells produce antibodies **rapidly** and in much **larger amounts;** ✓ which destroy the pathogen before causing disease; ✓

(c) (i) Define an 'allergic reaction'.

An **allergic reaction** is an antigen-antibody reaction that occurs in certain individuals upon exposure to substances that are harmless to other individuals under similar conditions; ✓

(ii) Describe how allergic reactions occur.

On first exposure to the **allergen**, the immune system produces **IgE** antibodies; ✓ which bind to **mast cells;** ✓

On subsequent exposure to the same allergen, the allergen binds to IgE antibodies on mast cells; ✓ which triggers mast cells to produce **histamine;** ✓ which causes inflammation, skin rash, itching and constriction of bronchioles; ✓

(iii) Give three examples of allergens (substances that induce allergy)

- Dust; ✓ Pollen; ✓ fungal spores; ✓ certain drugs; ✓ insect venom; ✓ certain food components; ✓ certain substances in fur or feathers;

ITEM 13

A pregnant woman attended a clinic for a routine medical check-up. Her blood type was tested and it was found that she was Rhesus negative (Rh-). The attending nurse explained that if her baby is Rhesus positive (Rh+), there would be a risk of haemolytic disease of the newborn.

To monitor infections and blood compatibility, the clinic also uses rapid diagnostic test kits.

Task:

- (a) Explain how haemolytic disease of the newborn arises when a rhesus negative mother bears a rhesus positive child in her womb.

During later stages of pregnancy, fragments of rhesus positive red blood cells of the foetus cross the placenta and enter the mother's blood; ✓ The mother's immune system recognizes the rhesus (D) antigens on the foetal red blood cells as foreign; ✓ and makes anti-rhesus (anti-D) antibodies them; ✓ The anti-rhesus antibodies cross the placenta into the foetal blood; ✓ and destroy the foetal red blood cells; ✓ rendering the child haemolytic; ✓

- (b) Explain how protection against haemolytic disease of the newborn can be achieved when a Rhesus negative mother bears a Rhesus positive child in her womb.

By giving an intravenous injection of anti-rhesus antibodies to the rhesus negative mother within 72 hours of her giving birth; ✓ The anti-rhesus antibodies attach to the rhesus antigens on the foetal red blood cells that enter the mother's blood; ✓ preventing the mother's immune system from recognizing them; ✓ and hence the mother's immune system is not stimulated to make anti-rhesus antibodies; ✓

(c) Explain why haemolytic disease of the newborn does not arise if a Rhesus negative mother of blood group O bears a child of any other blood group other than O.

A mother of blood group O contains antibodies **a** and **b** in her blood; ✓ and a child of any other blood group other O contains antigen A, B or both on the red blood cells; ✓ Therefore, when the rhesus positive foetal red blood cells enter the mother's blood, they are destroyed by the mother's **a** and **b** antibodies before they can stimulate production of anti-rhesus antibodies; ✓

(d) Explain why a Rh-woman who has not passed child-bearing age should not be given Rh+ blood in a transfusion.

The Rh antigens in the donor's blood would stimulate the mother's immune system to produce anti-rhesus antibodies; ✓ implying that haemolytic disease of the newborn would result if the woman carries a Rh+ child in her womb; ✓

(e) Explain the mechanism used in rapid diagnostic test kits to detect infection.

Rapid diagnostic test (RDT) kits detect infection using **antigen-antibody interactions**; ✓

When the sample is applied to the pad of the test strip, it flows along the strip by capillary action; ✓ and if the target antigen is present in the sample, it binds to **labelled antibodies** on the strip; ✓ forming an antigen-antibody complex; ✓ which continues to move along the strip until it reaches a region where **immobilised antibodies** specific to the antigen are fixed; ✓ These immobilised antibodies capture the complex forming a **visible coloured line**; ✓

The **excess labelled antibodies** bind with immobilised antibodies further along the strip forming a visible **control line**; ✓

Appearance of two visible lines indicates a positive result; ✓

Appearance of only the control line shows negative result; ✓

If the control line does not appear, the test is invalid; ✓

ITEM 14

A boy was playing football and fell, causing a deep cut on his knee. Blood started to flow from the wound but within a short time, blood started to clot at the site of the wound and then a scab was formed. The tissue around the wound became swollen and painful. Microscopic examination of the wound fluid revealed large numbers of phagocytes.

Task:

(a) (i) Describe how blood clotting occurs at the site of the wound.

Damaged tissue or ruptured platelets release thromboplastin (thrombokinase); ✓ which catalyses the conversion of a soluble plasma protein called prothrombin into thrombin; ✓ in presence of vitamin K and calcium ions; ✓

Thrombin catalyses the conversion of a soluble plasma protein called fibrinogen into and insoluble protein called fibrin; ✓ which forms a mesh-work of fibres in which blood cells are trapped; ✓ forming a blood clot; ✓

(ii) Of what importance is blood clotting when a blood vessel is cut?

- Prevents excessive bleeding/loss of blood; ✓
- Prevents entry of pathogens/diseases causing microorganisms into the body; ✓
- Initiates the process of wound healing; ✓

(b) (i) Name two phagocytic white blood cells.

- Neutrophils; ✓
- Monocytes; ✓
- Macrophages; ✓

(ii) Explain the role of phagocytes in protecting the body against infection.

Phagocytes engulf and digest pathogens and cell debris; ✓ and stimulate the adaptive immune system to produce a response; ✓ thereby aiding in prevention of infection; ✓

(v) How does phagocytosis of a pathogen occur?

- The phagocyte moves towards the pathogen; being attracted by chemicals released by the pathogen;
- Pathogen sticks to the phagocyte;
- Cell membrane of the phagocyte invaginates (cell membrane is extended around the pathogen); and the pathogen is engulfed; forming a phagosome/phagocytic vacuole;
- Lysosome fuses with the phagosome; and releases its hydrolytic enzymes into it; which digest the pathogen; and the soluble products of the digestion are absorbed into the cytoplasm of the phagocyte;

(c) Blood clotting and phagocytosis are some of the non-specific body defense mechanisms in humans.

(i) What is a non-specific defense mechanism?

A non-specific defense mechanism is one that does not target a particular pathogen but instead protects the body against a wide range of pathogens;

(ii) State other non-specific body defense mechanisms in humans.

- Skin barrier prevents entry of pathogens into the body;
- Mucous membranes prevent entry of pathogens deep into the tissues;
- Acid secreted in the stomach kills many bacteria;
- Lysozyme in tears, nasal secretions and saliva destroys certain bacteria;
- Cilia lining the respiratory tract (trachea and bronchi) help in preventing entry of pathogens into the lungs;
- Natural killer cells kill virus-infected cells;
- Commensal microorganisms on the skin and in the gut compete with pathogens for nutrients preventing them from flourishing;
- Inflammatory response increases blood flow and immune cell activity at the site of infection or injury;

RESPIRATION

ITEM 1

A researcher was investigating the difference in energy demands between liver cells and skin cells. He found out that liver cells contain a much higher number of mitochondria compared to skin cells. The researcher prepared thin sections of liver cells for observation under an electron microscope.

Task:

(a) Suggest why liver cells contain more mitochondria than skin cells.

Liver cells are metabolically more active than skin cells; and therefore need more ATP to sustain their metabolic process; Presence of more mitochondria in liver cells allows production of more ATP through aerobic respiration;

(b) Describe the structure of the mitochondrion as seen under the electron microscope.

The mitochondrion is a sausage/rod-shaped organelle; surrounded by a double membrane; consisting of an outer membrane which is smooth; and an inner membrane which is folded inwards to form cristae; The outer membrane and inner membrane are separated by a narrow space called the inter-membranal space; The cristae have stalked particles along their surface;

The double membrane encloses a gel-like matrix; which contains phosphate granules; circular DNA; small (70S) ribosomes;

Or: Accept well labelled diagram of the structure of the mitochondrion

(c) Explain how the structural features of the mitochondrion enable it to perform its function.

- Mitochondrion is surrounded by a double membrane; ✓ which isolates respiratory reactions from other activities of the cell; ✓
- Inner membrane of the mitochondrion is highly folded to form cristae; ✓ increasing surface area for reactions of the electron transport system; ✓
- Matrix of the mitochondrion contains various enzymes; ✓ for catalyzing reactions of the Krebs cycle; ✓
- Matrix of the mitochondrion contains small ribosomes and circular DNA; ✓ for synthesizing enzymes necessary for catalyzing respiratory reactions; ✓
- The cristae possess stalked particles along their surface which contain ATPase; ✓ that combines ADP and inorganic phosphate to form ATP; ✓
- Inner membrane has energy driven proton pumps; ✓ for actively pumping protons (hydrogen ions) from the matrix into intermembranal space; ✓
- Intermembranal space exists between the outer membrane and inner membrane; ✓ where protons accumulate to create the proton concentration gradient needed for ATP synthesis; ✓
- Inner membrane is impermeable to the movement of protons from the intermembranal space to the matrix; ✓ allowing creation of the proton concentration gradient needed for ATP synthesis; ✓
- Matrix of the mitochondrion contains a large amount of hydrogen carriers in FAD and NAD; ✓ for carrying hydrogen atoms from the Krebs cycle to the electron transport system for ATP synthesis; ✓

ITEM 2

A long distance runner was studied before, during and after the marathon. Analysis showed a high rate of oxygen consumption and increased carbon dioxide production in the leg muscles during the race. Muscle biopsy results indicated a very high rate of ATP turnover in the runner's leg muscles.

Task:

(a) Name the organelle in which ATP is produced in muscle cells.

- Mitochondrion; ✓

(b) Describe the structure of an ATP molecule.

An ATP molecule consists of a pentose/5-carbon sugar called ribose; ✓ a nitrogenous base called adenine; ✓ attached to carbon atom 1 of ribose; ✓ and three phosphate groups linked together; ✓ with the first phosphate group attached to carbon atom 5 of ribose; ✓

Or: Accept labelled diagram of the structure of ATP

(c) Explain why there was a high rate of ATP turnover in the runner's leg muscles.

During the marathon/race, the leg muscles repeatedly contract; ✓ creating a high demand for energy; ✓ Therefore, ATP is rapidly hydrolysed to release energy; ✓ and rapidly resynthesized in the mitochondria to keep up with the pace of repeated muscle contraction; ✓

(d) Explain the suitability of ATP for its function in the muscle cells.

- ATP is a small and mobile molecule making it able to carry energy to any part of the cell where it is needed; ✓
- ATP is soluble making it able to participate in metabolic reactions; ✓

- ATP is readily/easily hydrolysed to release energy to quickly satisfy the energy demands of the cell; ✓
- ATP can easily be regenerated from ADP and inorganic phosphate in the mitochondria which ensures constant supply of energy to the cell; ✓
- ATP releases a relatively large amount of energy when hydrolysed which satisfies the energy needs of the cell; ✓

(e) Explain why there was a high rate of oxygen consumption and increased carbon dioxide production in the muscles during the race

During the race, the rate of aerobic respiration increases; ✓ due to increased demand for ATP; ✓ and as a result, more oxygen is consumed since it is used in aerobic respiration; ✓ and more carbon dioxide is produced since it is a bi-product of aerobic respiration; ✓

ITEM 3

During a 400-meter sprint, a runner's muscle cells require rapid ATP production. Glucose molecules are quickly broken down to meet the ATP demand. Glucose is first broken down in the muscle cells into pyruvate through a series of enzyme-controlled reactions before further metabolic pathways occur.

Task:

- (a) Name the process by which glucose is broken down into pyruvate in the cells.
- Glycolysis; ✓
- (b) State the site of occurrence of the process named in (a) within the cells.
- Cytoplasm; ✓

(c) Of what significance is the process named in (a) in muscle cells.

- Glycolysis quickly produces ATP; ✓ which provides energy for immediate use in cellular activities; ✓ e.g muscle contraction.
- Glycolysis produces NADH (reduced NAD); ✓ which provides electrons for production of more ATP in the electron transport system; ✓
- Glycolysis breaks down glucose into pyruvate; ✓ which is then used in further respiratory pathways to yield ATP; ✓

(d) Describe the steps involved in the breakdown of glucose into pyruvate.

Glucose is phosphorylated by ATP; ✓ forming glucose phosphate; ✓

Glucose phosphate isomerises; ✓ forming fructose phosphate; ✓

Fructose phosphate is phosphorylated by ATP; ✓ forming fructose biphosphate; ✓

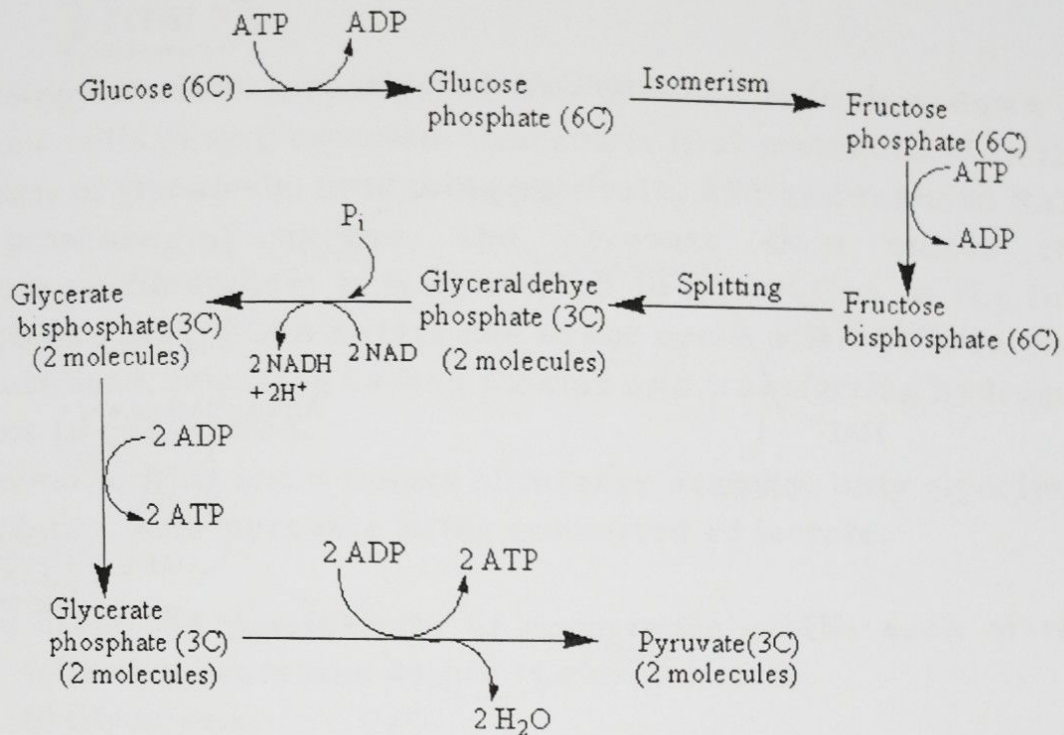
Fructose biphosphate splits into two molecules of glyceraldehyde phosphate; ✓

Each molecule of glyceraldehyde phosphate is dehydrogenated by NAD; ✓ and an inorganic phosphate is added; ✓ forming glycerate biphosphate; ✓

Each molecule of glycerate biphosphate is dephosphorylated by ADP; ✓ forming glycerate phosphate; ✓

Each molecule of glycerate phosphate is dephosphorylated by ADP; ✓ forming pyruvate; ✓ with loss of a water molecule; ✓

Or:



(e) Explain what would happen to pyruvate if the muscle cells run short of oxygen during the sprint.

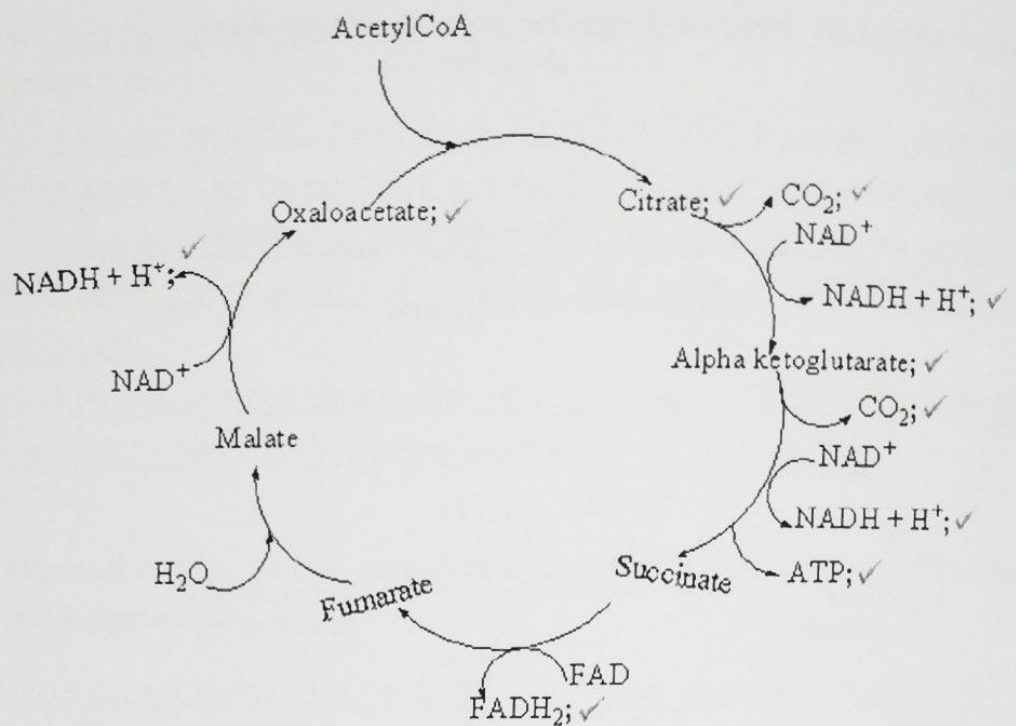
Pyruvate accepts hydrogen atoms from reduced NAD; ✓ in presence of enzyme lactate dehydrogenase; ✓ forming lactate; ✓

ITEM 4

A team of researchers was studying a rare genetic disorder that affects the function of mitochondria. They discovered that in affected cells, the enzyme succinate dehydrogenase was defective. This enzyme normally catalyses the conversion of succinate to fumarate during the Krebs cycle.

Task:

(a) Use a diagram to illustrate the Krebs cycle, indicating the key steps involved.



(b) Explain how a defective succinate dehydrogenase would affect the Krebs cycle and overall ATP production in the cell.

A defective succinate dehydrogenase blocks conversion of succinate to fumarate; reducing production of FADH₂ (reduced FAD) and NADH (reduced NAD); This eventually reduces the number of electrons available for the electron transport system; and hence lowering ATP production;

(c) Describe the functions of the Krebs cycle in the cell.

- Breaks down macro-molecules; e.g. pyruvate is broken down to carbon dioxide;
- Produces reduced NAD and reduced FAD molecules; which provide electrons for the electron transport system to produce ATP;
- Provides intermediates for synthesis of useful compounds; e.g citrate, oxaloacetate and α -ketoglutarate are used in the synthesis of amino acids;

ITEM 5

A biology student investigated how glucose is broken down in muscle cells during exercise. Glucose is first metabolized in the process of glycolysis, producing pyruvate, ATP and reduced NAD. In presence of oxygen, the pyruvate then enters the mitochondrion where it is converted to acetyl-CoA in the link reaction. Acetyl-CoA enters the Krebs cycle where it is further metabolized, releasing carbon dioxide and transferring hydrogen atoms to coenzymes.

However, during short bursts of intense activity, only glycolysis continues, with pyruvate being converted to lactate.

Task:

(a) State the precise site of occurrence of the each of the following processes within the muscle cells.

(i) Glycolysis.

Cytoplasm; ✓

(ii) Link reaction.

Matrix of the mitochondrion; ✓

(iii) Krebs cycle.

Matrix of the mitochondrion; ✓

(b) Explain why only glycolysis continues during short bursts of exercise?

During short bursts of exercise, oxygen supply becomes insufficient for aerobic respiration; ✓ and as a result, only glycolysis can continue to take place; ✓ since it is the only respiratory pathway that occurs in absence of oxygen; ✓

(c) Why it important to convert pyruvate to lactate during short bursts of exercise?

The conversion of pyruvate to lactate regenerates NAD⁺; ✓ allowing glycolysis to continue; ✓ which rapidly provides ATP for muscle contraction; ✓

(d) Apart from producing acetyl-CoA which enters the Krebs cycle, of what importance is the link reaction in cellular respiration?

Link reaction produces hydrogen atoms carried by NAD; ✓ which provide electrons and protons required for ATP production in the electron transport system; ✓

(e) (i) Identify the coenzymes to which hydrogen atoms are transferred in the Krebs cycle.

- NAD; ✓
- FAD; ✓

(ii) What is the importance of the hydrogen atoms carried by the coenzymes identified in (d) (i) in cellular respiration?

The hydrogen atoms split, producing electrons and hydrogen ions; ✓ which are required for synthesis of ATP in the electron transport system; ✓

(f) State differences between Glycolysis and the Krebs cycle.

Glycolysis	Krebs cycle
• Occurs in the cytoplasm	Occurs in the matrix of the mitochondrion; ✓
• Occurs in absence of oxygen	Occurs in presence of oxygen; ✓
• It is a non-cyclic pathway	It is a cyclic pathway; ✓
• ATP is used	ATP is not used; ✓
• Reduced FAD is not produced	Reduced FAD is produced; ✓
• Less reduced NAD is produced per glucose molecule oxidised	More reduced NAD is produced per glucose molecule oxidized; ✓
• Carbon dioxide is not produced/decarboxylation does not occur.	Carbon dioxide is produced/decarboxylation occurs ✓
• Begins with phosphorylation of glucose	Begins with combination of acetyl-CoA with oxaloacetate; ✓

ITEM 6

A researcher was investigating cellular respiration in isolated mitochondria. When glucose was provided as the respiratory substrate, ATP was produced at a high rate. Measurements showed that NADH and FADH₂ were generated in large amounts. Oxygen uptake was also detected and water was produced. When the researcher added a small amount of cyanide to the mitochondria, ATP production stopped almost immediately

Task:

- (a) Explain the role of NADH and FADH₂ in ATP production during cellular respiration.

NADH and FADH₂ carry hydrogen atoms to the electron transport system in the inner mitochondrial membrane; ✓ where the hydrogen atoms split into protons and electrons; ✓ The electrons flow along a chain of electron carriers; ✓ located at progressively lower energy levels; ✓ As electrons flow from one electron carrier to the next, energy is released; ✓ which is used to pump protons from the matrix into the intermembrane space; ✓ thereby creating a proton concentration gradient across the inner mitochondrial membrane; ✓ Protons diffuse back into the matrix along the proton concentration gradient through ATPase; ✓ As protons diffuse through ATPase, ADP is combined with inorganic phosphate to form ATP; ✓ The protons reunite with electrons to form hydrogen atoms which combine with oxygen to form water; ✓

- (b) Why is oxygen essential in cellular respiration?

Oxygen combines with hydrogen atoms to form water at the end of the electron transport chain; ✓ preventing accumulation of hydrogen atoms at the end of the chain; ✓ and hence allowing aerobic respiration to continue; ✓

(c) Explain why ATP production stopped after addition of cyanide.

Cyanide inhibits enzyme cytochrome oxidase at the end of the respiratory chain (electron transport system); ✓ preventing combination of oxygen with hydrogen atoms to form water; ✓ causing accumulation of hydrogen atoms at the end of the chain; ✓ which blocks the electron transport system; ✓ Eventually, aerobic respiration as a whole stops; ✓ and hence ATP production stops; ✓

ITEM 7

A long-distance runner trains regularly to improve endurance. During a marathon, her muscles increase their rate of aerobic respiration to increase ATP production. As glycogen reserves get depleted, his body increasingly relies on lipid metabolism and during recovery after the race, some proteins are metabolized.

Task:

(a) Explain how ATP is synthesized by chemiosmosis during aerobic respiration.

ATP is produced through a process of oxidative phosphorylation; ✓ Hydrogen atoms carried by NAD and FAD split into protons and electrons; ✓ The electrons flow along a chain of electron carriers; ✓ located at progressively lower energy levels; ✓ As electrons flow from one electron carrier to the next, energy is released; ✓ which is used to pump protons from the matrix into the intermembrane space; ✓ thereby creating a proton concentration gradient across the inner mitochondrial membrane; ✓ Protons diffuse back into the matrix along the proton concentration gradient through ATPase; ✓ As protons diffuse through ATPase, ADP is combined with inorganic

phosphate to form ATP; ✓ The protons re-unite with electrons to form hydrogen atoms which combine with oxygen to form water; ✓

(b) Describe how lipids and proteins are metabolized to enter the respiratory pathway.

Lipids are hydrolysed to fatty acids; ✓ and glycerol; ✓

Glycerol is dehydrogenated by NAD; ✓ and phosphorylated by ATP; ✓ forming glyceraldehyde phosphate; ✓ which enters glycolysis; ✓

Each fatty acid undergoes beta oxidation; ✓ producing many molecules of acetyl-CoA; ✓ which enters the Krebs cycle; ✓

Proteins are hydrolysed into amino acids; ✓

Each amino acid is deaminated; ✓ producing ammonia and a residual carbon compound (keto acid); ✓ The residual carbon compound can either be converted to:

- Pyruvate; ✓ which enters glycolysis; ✓
- Acetyl-CoA; ✓ which enters the Krebs cycle; ✓
- Krebs cycle intermediate; ✓ which enters the Krebs cycle; ✓

ITEM 8

An athletics competition was organized at Real Success Secondary School and a number of students participated in a 400m race. After the race, the students who participated were seen breathing heavily for several minutes and some of them complained of muscle fatigue and cramp.

The school doctor advised the participant students to always train to minimize cases of muscle fatigue and cramp.

Task:

(a) **Explain why some students experienced muscle fatigue and cramp.**

During the race, the muscles ran short of oxygen; ✓ and resorted to **anaerobic respiration;** ✓ resulting in production of **lactic acid;** ✓ which **accumulated** in the muscles; ✓ causing muscle fatigue and cramp; ✓

(b) **Explain why the students who participated breathed heavily for several minutes after the race.**

Breathed heavily to take in **extra** oxygen; ✓ to repay the oxygen debt; ✓

The extra oxygen is used to:

- restore ATP and creatine phosphate stores in muscles; ✓
- remove lactic acid from the muscles; ✓
- restore normal levels of oxygen in lungs, tissue fluids, haemoglobin and myoglobin; ✓

(c) **How does training minimize incidences of muscle fatigue and cramp in athletes?**

Training brings about adjustments in the respiratory and circulatory systems which include;

- Training increases cardiac output; ✓ allowing **more** blood to reach the tissues; ✓
- Training increases lung capacity; ✓ allowing lungs to take in **more** air and hence more oxygen; ✓
- Training stimulates production of **more** red blood cells; ✓ increasing the oxygen carrying capacity of blood; ✓
- Training increases number of capillaries in muscles; ✓ allowing more blood to reach the muscles; ✓

All the above adjustments cause delivery of **more** oxygen to the muscles during exercise; ✓ so muscles rely **more** on aerobic respiration than on anaerobic respiration; ✓ which reduces

production of lactic acid; ✓ and hence minimizing muscle fatigue and cramp; ✓

ITEM 9

A biology student carried out an investigation on respiration. He grew yeast in a glucose solution under anaerobic conditions. At the same time, he monitored the muscle activity of an athlete performing repeated sprints in short intervals.

In both yeast and muscle cells, glucose was first converted to pyruvate. Pyruvate was then converted to different products in yeast and muscle cells.

Task:

(a) Identify the process by which glucose is converted to pyruvate.

- Glycolysis; ✓

(b) Describe what happens to pyruvate in yeast and muscle cells under the conditions described in the scenario.

In yeast cells, pyruvate is decarboxylated; ✓ in presence of enzyme pyruvate decarboxylase; ✓ producing ethanal; ✓ Ethanal is converted to ethanol; ✓ by accepting hydrogen atoms from reduced NAD; ✓ in presence of enzyme alcohol dehydrogenase; ✓

In muscle cells, pyruvate is converted to lactate; ✓ by accepting hydrogen atoms from reduced NAD; ✓ in presence of enzyme lactate dehydrogenase; ✓

(c) Explain what would happen to the yeast cells if they continued to respire anaerobically for a long time.

Anaerobic respiration in yeast cells results in production of ethanol; ✓ and therefore if it occurred for a long time, ethanol

would accumulate in the yeast cells; ✓ becomes toxic to the cells; ✓ and hence kills them; ✓

(d) State the differences between anaerobic respiration and aerobic respiration.

Aerobic respiration	Anaerobic respiration
• Occurs in presence of oxygen	Occurs in absence of oxygen; ✓
• Results in greater ATP yield	Results in lower ATP yield; ✓
• Involves a cyclic pathway of reactions, the Krebs cycle at some stage	All the reactions in the pathway are non-cyclic; ✓
• It is a longer pathway of reactions	It is a shorter pathway of reactions; ✓
• Final products are carbon dioxide and water	Final products are ethanol and lactic acid; ✓
• Single metabolic pathway from pyruvate	Various metabolic pathways from pyruvate; ✓
• Products are non-toxic and oxidation is complete	Products are toxic and can be further oxidized; ✓

HOMEOSTASIS

ITEM 1

A team of biologists carried out an investigation on a mammal living in an environment with variable conditions. Despite fluctuations in the external conditions, the mammal maintains relatively stable internal conditions such as body temperature, water content and blood glucose concentration, a process known as homeostasis, which usually operates through negative feedback.

Task:

(a) What is negative feedback?

Negative feedback is a homeostatic control mechanism where deviation from the norm sets in motion a series of events which restores the norm; ✓

(b) Explain the importance of homeostasis in living organisms.

Homeostasis maintains stable/constant internal conditions; ✓
allowing metabolic processes to operate/function efficiently; ✓ which ensures survival of a living organism in a changing (fluctuating/variable) external environment; ✓

(c) Identify the three main components of a homeostatic control system and describe the role of each in homeostasis.

- **Detector;** ✓ Detects any deviation from the norm/set-point/reference point and sends out signals to the controller; ✓
- **Coordinator/regulator/Controller;** ✓ coordinates/processes information from the detector and sends out appropriate instructions to the effector; ✓
- **Effector;** ✓ produces changes which restore the norm/correct the deviation; ✓

(d) State the qualities of an efficient homeostatic control system.

- Easily detects any slight/small deviation from the norm; ✓
- Quickly responds to the deviation to restore the norm; ✓

ITEM 2

A group of researchers studied an endothermic mammal living in a temperate grassland. They recorded the following temperature values:

- Lower lethal temperature: -10°C
- Upper lethal temperature: 45°C
- Efficiency range: Between 5°C and 35°C

During a particularly harsh winter, temperatures dropped to -8°C at night while in summer, midday temperatures often reached 42°C .

Task:

(a) What does 'efficiency range' mean?

Efficiency range is the range of environmental temperature over which the body's physical mechanisms alone are capable of maintaining a constant body temperature; ✓

(b) State the low critical temperature and the high critical temperature of the endothermic mammal studied.

Low critical temperature is 5°C ; ✓

High critical temperature is 35°C ; ✓

(c) Explain the variation of metabolic rate of the mammal with environmental temperature outside the efficiency range.

Below the low critical temperature, metabolic rate increases with decrease in temperature; ✓ to generate heat to maintain a constant body temperature; ✓

Above the high critical temperature, metabolic rate increases with increase in environmental temperature; ✓ due to failure of the

body's cooling mechanisms; ✓ The increase in metabolic rate generates heat; ✓ which increases the metabolic rate further; ✓

(d) The efficiency range varies from animal to animal.

Giving a reason, state how the low critical temperature differs in an animal living in a cold environment and that living in a hot environment.

An animal living in a cold environment has a **lower** low critical temperature than that living in a hot environment; ✓ because it has better insulation mechanisms than the one living in a hot environment; ✓

(e) Explain what would happen to the mammal when temperature:

(i) rises beyond the upper lethal temperature.

The mammal would die; ✓ due to denaturation of enzymes; ✓ causing metabolic reactions to stop; ✓

(ii) falls below the lower lethal temperature.

The mammal would die; ✓ because enzymes are inactivated; ✓ causing metabolic reactions to stop; ✓

(f) Explain the behavioural and physiological adaptations of endotherms to survive in:

(i) cold environmental conditions.

Behavioural:

- Huddling together; ✓ to reduce surface area for heat loss; ✓
- Adding cloth in humans; ✓ to reduce heat loss; ✓
- Burrowing; ✓ to reduce heat loss; ✓

Physiological:

- Shivering; ✓ generates metabolic heat; ✓
- Vasoconstriction of skin arterioles; ✓ so that less blood flows near the skin surface; ✓ and hence reducing heat loss by convection, radiation and conduction; ✓
- Metabolic rate increases; ✓ generating more heat; ✓
- Sweating ceases; ✓ reducing heat loss through evaporation; ✓

- Hairs on the skin stand erect; trapping a thick layer of air; which insulates the body against heat loss;

(ii) hot environmental conditions.

Behavioural:

- Seeking shade; reducing heat gain from the sun;
- Removing clothing in humans; to encourage heat loss;
- Burrowing; to reduce heat loss through evaporation;
- Panting; to increase heat loss through evaporation;
- Stretching out; to increase surface area for heat loss;

Physiological:

- Sweating; to increase heat loss through evaporation;
- Vasodilation of skin arterioles; so that more blood flows near the skin surface; and hence increasing heat loss by convection, radiation and conduction;
- Metabolic rate reduces; to generate less heat;
- Hairs on the skin lie flat; so a thin air layer is trapped between the hairs; and hence reducing insulation against heat loss;

Note:

Low critical temperature is the lowest temperature at which physical mechanisms alone can regulate body temperature.

High critical temperature is the highest temperature beyond which the animal cannot regulate its body temperature.

Lower lethal temperature is the environmental temperature below which an animal cannot survive.

Upper lethal temperature is the environmental temperature above which an animal cannot survive.

ITEM 3

A biology trip involved a group of students who camped in a hot, dry savanna, where daytime temperatures were high but nights were much cooler.

Task:

(a) Explain how body temperature is regulated during the hot day and the cool night.

During the hot day, the rise in body temperature above the normal temperature is detected by the **heat loss centre** in the **hypothalamus**; ✓ which responds by:

- decreasing metabolic rate; ✓ thereby reducing the amount of heat generated; ✓
- causing vasodilation in skin arterioles; ✓ increasing heat loss from the skin by radiation, convection and conduction; ✓
- increasing sweating; ✓ thereby increasing heat loss through evaporation; ✓
- relaxing hair erector muscles which flattens hair trapping a thinner air layer; ✓ thereby reducing insulation against heat loss; ✓

As a result of the above responses, the body temperatures decreases back to the normal temperature; ✓

During the cool night, the fall in body temperature below the normal temperature is detected by the heat gain center in the hypothalamus; ✓ which responds by:

- increasing metabolic rate; ✓ thereby generating more heat; ✓
- causing vasoconstriction of skin arterioles; ✓ thereby reducing heat loss from the skin by radiation, convection and conduction; ✓
- inhibiting sweating; ✓ thereby reducing heat loss through evaporation; ✓

- causing contraction of hair erector muscles making the hair to stand to trap a thicker air layer; ✓ increasing insulation against heat loss; ✓
- causing shivering; ✓ thereby generating more heat; ✓

As a result of the above responses, the body temperature rises back to the normal temperature; ✓ (@ ½ mark)

(b) Explain how water balance is maintained in the body during the hot day and the cool night.

During the hot day, excessive sweating occurs; ✓ reducing the water potential of blood; ✓ The fall in water potential of blood is detected by **osmoreceptors** in the hypothalamus; ✓ which send nerve impulses to the posterior pituitary gland; ✓ stimulating it to release antidiuretic hormone (ADH) into the bloodstream; ✓ ADH travels in blood to the kidneys where it increases the permeability of the distal convoluted tubule and collecting duct to water; ✓ by increasing the number of water channels in the membranes lining these tubules; ✓ Therefore, more water is reabsorbed back into the blood stream; ✓ leading to production of a small volume of concentrated urine; ✓ thereby conserving more water; ✓

During the cool night, little or no sweating occurs; ✓ making the water potential of blood high; ✓ ADH release is inhibited; ✓ the permeability of the distal convoluted tubule and collecting duct to water reduces; ✓ less water is reabsorbed into the bloodstream; ✓ leading to production of a large volume of dilute urine; ✓ thereby conserving less water; ✓ (@ ½ mark)

ITEM 4

A desert ecologist studied two animals living in arid environments; the Kangaroo rat and the Camel, both of which experience water shortage but are excellent osmoregulators.

Task:

(a) What is the importance of osmoregulation in animals?

Osmoregulation prevents water imbalance; ✓

Osmoregulation prevents ionic/salt/solute imbalances; ✓

(b) Explain the adaptations of the Kangaroo rat and the Camel for survival in arid environments. *(18 marks)*

Kangaroo rat:

- Spends much of its time in burrows with a relatively humid atmosphere; thereby reducing water loss through evaporation;
- Metabolises fats; which yield more metabolic water than carbohydrates;
- The animal has a longer loop of Henle; which increases the surface area over which water is reabsorbed back into the bloodstream; thereby reducing amount of water lost through urine;
- The animal dries faeces before egestion due to its high water reabsorption in the rectum; thereby reducing amount of water lost through faeces;
- Has cool nasal passages in which water vapour is condensed during exhalation; thereby reducing water loss through evaporation;
- Has fewer and small glomeruli; which reduces the amount of glomerular filtrate formed; and hence reducing the amount of water lost in urine;
- Has a thick oily skin; reducing water loss through evaporation from the skin;
- Nocturnal life; to minimize water loss during the hot day;
- Has fur on the body; to reduce water loss by evaporation;

Camel

- Has longer loop of Henle; to increase surface area for reabsorption of water from the renal fluid into the bloodstream;
- Has fewer nephrons in its kidney; to reduce amount of glomerular filtrate formed;
- Body tissues are tolerant to desiccation; so as to take long without drinking water;
- Using metabolic water; from oxidation of fats stored in its hump;
- Retains a high urea concentration in the blood; which aids reabsorption of water from the kidney tubules;
- Has a high concentration of ADH in blood; which makes kidney tubules more permeable to water and hence more water is reabsorbed;
- Sweating is reduced; to reduce water loss by evaporation;
- Has high rectal reabsorption; reducing water loss through faeces;
- Has slit-like and closable nostrils guarded by dense hairs; to minimize water loss by evaporation during exhalation;
- Has dry mucus lining the nostrils; to absorb moisture from exhaled air;
- Drinks a lot of water when found; to compensate for the water lost;

ITEM 5

A researcher studied a xerophytic plant in a desert during a prolonged dry season. The soil had very little water, and daytime temperatures were extremely high. Despite these harsh conditions, the plant continued to survive and measurements showed that its cells maintained turgor pressure.

Task:

(a) Explain how xerophytic plants are able to survive water shortages.

- Some of them have succulent tissues that are tolerant to dehydration; ✓
- Many plants survive dry periods as seeds or spores which germinate into a new plant when water becomes available; ✓
- Some plants have extremely deep roots which absorb water from the deep layers of the soil; ✓
- Other plants have superficial roots which grow out horizontally close to the surface allowing them to absorb the maximum amount of water after a brief rain on a hot day; ✓
- Thick waxy cuticle of the leaves which is impermeable to water thereby reducing cuticular transpiration; ✓
- Rolled/folded leaves reducing the number of stomata exposed to the surface and hence reducing water loss through stomata; ✓
- Sunken stomata resulting in trapping of moist air above the stomata, reducing water loss through transpiration; ✓
- Leaves are small, reducing surface area over which transpiration occurs; ✓
- Reversal of stomatal rhythm like in CAM plants; allowing stomata to open at night when conditions do not favour transpiration; ✓
- Shedding of leaves in dry seasons, reducing surface area over which water loss through transpiration; ✓
- Hairy epidermis allowing moist air to be trapped in the hair layer and hence reducing transpiration rate; ✓

(b) What are the techniques employed by humans to manage xerophytes.

- Drip irrigation to deliver water directly to plant roots, reducing water wastage; ✓
- Mulching using organic or inorganic materials to retain soil moisture and reduce evaporation; ✓

- Terracing and contour ploughing which reduces water runoff and improves water infiltration; ✓
- Use of greenhouses to protect plants from extreme weather conditions; ✓
- Planting crops which are naturally resistant to dry or arid conditions e.g succulents; ✓
- Using genetically improved drought-resistant crop varieties like drought resistant maize; ✓

ITEM 6

Rice (*Oryza sativa*) is one of the most important staple foods worldwide and is cultivated as a semi-aquatic crop in paddy fields. Farmers deliberately flood the fields to create conditions that favour rice growth over weeds.

Researchers studying rice plants observed several features which help the plants thrive in aquatic conditions.

To maximize rice survival and increase yields, farmers apply a number of management techniques.

Task:

(a) Explain the adaptations of rice that enable it to grow successfully as a hydrophyte.

- Aerenchyna (large airspaces) in leaves, stems and roots; ✓
facilitates diffusion of oxygen and carbon dioxide; ✓ and provides buoyance to the plant when submerged; ✓
- Additional roots develop at the nodes of the stem; ✓ enabling absorption of nutrient ions from the floodwater; ✓
- Flowering is timed to occur when floodwaters have normally reached their peak; ✓
- Many rice varieties have tissues that are tolerant to ethanol; ✓
enabling them to survive on anaerobic respiration for several days when fully submerged; ✓

- Stomata mainly on the upper leaf surface; ✓ to allow efficient gas exchange in floating leaves exposed to air; ✓
- Rapid elongation when submerged by rising floodwater; ✓ keeping part of the stem and leaves in the air; ✓

(b) Explain the human management techniques used in rice cultivation that increase survival and crop yield.

- Controlled flooding of rice fields to suppress weeds and maintain suitable aquatic conditions for rice; ✓
- Selection of flood-tolerant varieties to ensure survival during flash flooding; ✓
- Proper drainage at key growth stages to improve oxygen supply to the roots; ✓
- Integration of pest and disease control to ensure healthier plants for better yields ; ✓
- Fertilizer application to provide nutrients that may be leached out in waterlogged soils; ✓

ITEM 7

A group of botanists was studying a temperate garden and they observed that most of the plants had broad green leaves, moderate-sized stems and were thriving under conditions of adequate water. The botanists also noted that some plants secreted products like latex, anthocyanins, oils, quinine and saponins, which play a role in everyday life.

Task:

- (a) Identify the category of plants described in the scenario.
- Mesophytes; ✓
- (b) Explain the adaptations of the category of plants identified in (a) that enable them to survive in their environment.

- Broad leaves; ✓ to provide large surface area for photosynthesis under adequate light and water supply; ✓
- Well-developed root system; ✓ for efficient absorption of water and mineral salts from the soil; ✓
- Well-developed vascular system (phloem and xylem); ✓ for efficient transport of water and nutrients throughout the plant; ✓
- Stomata are usually located on the lower epidermis; ✓ to reduce water loss through transpiration; ✓
- Waxy cuticle; ✓ to reduce water loss through transpiration; ✓

(c) State the uses of the plant excretory products mentioned in the scenario in daily life.

• **Latex:**

- ✓ Used in making rubber products like tyres, gloves, footwear; ✓
- ✓ Used in making adhesives; paints; and coatings; ✓

• **Anthocyanins:**

- ✓ Used as natural food colourants; ✓
- ✓ Used as antioxidants in cosmetics; ✓

• **Oils:**

- ✓ Used in making perfumes, cosmetics, soaps and detergents; ✓
- ✓ Used as natural insect repellants like citronella oil; ✓
- ✓ Used as lubricants; ✓

• **Quinine:**

- ✓ Medicinal as an anti-malarial drug; ✓

• **Saponins:**

- ✓ Used in making soaps and detergents; ✓
- ✓ Medicinal with antimicrobial properties; ✓

