KAMPALA EXCELLENCE EXAMINATION BOARD (KEEB)

A' LEVEL CBC BIOLOGY ITEM BANK WITH MODEL RESPONSES

OTHERS INCLUDE;

- ***New Advanced Level Curriculum Scenario Items***
- ***Ordinary Level New curriculum Holiday Assessment***
- ***End of termly Assessment Nursery to S.6***
- ***Practical Books***
- ***Leaner's books***

STUDENT NAME: ____

CLASS: __________________ STREAM: _________ YEAR: ___________

SCHOOL: ____

SIGNATURE: ____

FOREWORD

This A’ Level CBC Biology Item Bank is designed to make advanced Biology both accessible and intellectually stimulating. Each task is carefully structured to align with competency-based assessment, promoting analytical reasoning, interpretation of data, and application of biological principles to real-world contexts. The progression of items guides learners from foundational understanding to higher order thinking, ensuring coherent development of skills. The book consists of scenario-based items with responses, as well as self-test items, providing learners with opportunities to practice and reinforce their understanding independently.

The accompanying responses are precise and technically grounded, modeling the reasoning processes expected at advanced level. Beyond serving as an assessment tool, this item bank functions as a guide for structured inquiry, fostering problem-solving, critical analysis, and evidence-based thinking. It is crafted to make learning Biology not only rigorous and technically sound but also engaging, insightful, and deeply rewarding.

It is my hope that this item bank will inspire both learners and teachers to approach Biology with curiosity, confidence, and a sense of purpose. By engaging with these tasks, learners are encouraged to see beyond memorization, to think critically, and to appreciate the elegance and relevance of Biology in everyday life. May this collection serve not only as a reference but as a companion in the journey toward scientific competence and lifelong intellectual growth.

SECTION ONE

(Items with responses)

The following compilation presents scenario-based items with detailed responses, demonstrating the reasoning and application of biological concepts expected at A’ Level. Learners are encouraged to engage actively, analyze critically, and use the explanations to guide their own problem-solving.

1. In a Southeast Asian coastal village, illegal cyanide fishing is practiced; fishermen capture live fish for aquariums. This has led to a significant die-off of non-target coral reef species. A marine biologist, Dr.

Hakeem, collects tissue samples from affected damselfish. Cyanide is a potent inhibitor of cytochrome c oxidase.

Table: Metabolic Analysis of Damselfish Gill Tissue

Sample	**Cytochrome c oxidase activity** (% of normal)	**Gill cell membrane integrity** (% of cells damaged)	**Gill ATP concentration** (mM)	**Oxygen uptake rate** ($mgO_2/g/h$)
Unaffected fish	100	5	4.8	9.5

Cyanide exposed fish	3	60	0.8	1.2

Task:

(a) Explain, in simple steps, how cyanide inhibition of cytochrome c oxidase leads to the changes shown in the table above.

- ***Inhibition of cytochrome c oxidase*: Cyanide binds to the iron-hem group of cytochrome c oxidase, the terminal enzyme of the mitochondrial electron transport chain, preventing electrons from being transferred to oxygen, the final electron acceptor. This causes a rapid decrease in cytochrome c oxidase activity from 100% in unaffected fish to 3% in cyanide exposed fish, blocking the electron transport chain.**
- ***Disruption of oxidative phosphorylation*: With the electron transport chain blocked, the proton gradient across the inner mitochondrial membrane cannot be maintained. This stops ATP production through oxidative phosphorylation, causing a rapid decrease in gill ATP concentration from 4.8 mM in normal fish to 0.8 mM in cyanide-exposed fish.**
- ***Reduced oxygen utilization*: Since oxygen can no longer accept electrons at the end of the chain, mitochondria cannot use oxygen efficiently. This explains the decrease in oxygen uptake rate from 9.5 mg O_2/g/h in unaffected fish to 1.2 mg O_2/g/h in cyanide-exposed fish.**
- ***Loss of cell membrane integrity*: ATP is required for active transport systems, such as sodium potassium pumps, that maintain ion balance and cell membrane stability. Low ATP levels disrupt these systems, leading to swelling and damage of gill cells, increasing cell damage from 5% to 60%.**
- ***Overall metabolic collapse*: The combination of blocked respiration, low ATP, and damaged membranes causes gill tissue to fail. This metabolic collapse reduces oxygen exchange and contributes to the death of non-target coral reef species in areas affected by cyanide fishing.**

(b) Using the information provided, propose strategies to solve the challenges.

- ***Enforcement and regulation*: Increase coastal patrols and inspections, impose fines or penalties on cyanide fishers, and ensure laws banning cyanide fishing are actively applied.**
- ***Community awareness*: Hold workshops and training for fishermen showing how cyanide fishing destroys reefs and reduces long-term fish catches, encouraging sustainable practices.**
- ***Alternative livelihoods*: Provide resources and training for aquaculture, fish farming, or ecofriendly net fishing so fishermen can earn income without harming reefs.**
- ***Coral reef restoration*: Establish coral nurseries, transplant resilient corals to damaged areas, and protect reef zones to help fish populations recover.**

***Research and monitoring*: Regularly test water for cyanide, track fish health, and assess reef recovery to guide management decisions and prevent future damage.**

2. Mr. Owen, a biologist, observed several water-related phenomena. He noticed that small aquatic striders and fish milt can remain on the surface of water without sinking. He also observed that water moves steadily through narrow plant vessels from the roots to the leaves, and that during cold seasons, ice forms on the surface of water while aquatic organisms continue to survive below. Additionally, he noted that aquatic plants are able to grow successfully due to a certain property of water.

Task

(a) Which property of water enables insects and fish milt to remain on the water surface, and how does this benefit aquatic systems?

- ***The property is high surface tension of water, produced by strong cohesive hydrogen bonds between water molecules at the surface. This creates a resistant film that supports small organisms and materials. Ecologically, this allows surface-dwelling insects to forage and escape predators, and it keeps fish milt at the surface where fertilization can occur efficiently, supporting reproductive success in aquatic ecosystems.***

(b) Explain the property of water that allows it to rise through narrow plant vessels, and state its importance for plant survival.

- ***Cohesion-adhesion and capillary rise in vessels; Water moves through narrow plant vessels because of the combined effects of cohesion, which holds water molecules together, and adhesion, which enables them to adhere to the walls of xylem vessels. These forces generate capillary action, drawing water upward from roots to leaves. This movement is essential for plant survival because it supplies water for photosynthesis, maintains cell turgor, and supports transpiration cooling and mineral transport.***

(c) Which property of water explains the formation of ice on the surface of water, and why is this important for aquatic life?

- ***Density anomaly and freezing properties of water; The formation of ice on the surface of water is explained by water's density anomaly, where water expands and becomes less dense when it freezes due to the formation of a rigid hydrogen-bonded lattice. As a result, ice floats and forms an insulating layer at the surface. This insulation reduces heat loss from the underlying water, maintaining liquid conditions and stable temperatures that allow aquatic organisms to remain alive during cold seasons.***

(d) Explain how aquatic plants such as algae are able to make their own food, referring to the relevant property of water.

- ***Aquatic plants such as algae can manufacture their own food through photosynthesis, a process that relies on the high transparency of water, which allows solar radiation to penetrate water to photosynthetic tissues. This penetration of light enables chloroplasts within algal cells to absorb***

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sufficient light energy for carbon fixation, ensuring continuous primary productivity in aquatic habitats.

3. Early research on the structure of the cell membrane showed that lipid-soluble compounds passed rapidly into cells. The membrane was found to be selectively permeable to mineral ions, sugars and amino acids. Further work demonstrated that all membranes have the same basic structure but can differ greatly in the types of lipid and protein they contain. Many of the specialized proteins present provide a means of communication between cells and molecules in their environment. (a) Apart from lipid solubility, suggest two factors which could affect the rate of penetration of a molecule through the membrane.

- ***<u>Molecular size</u>: Smaller molecules diffuse more rapidly through the phospholipid bilayer than larger ones.***
- ***<u>Electrical charge</u>: Uncharged molecules cross more easily than ions, which require specific transport proteins.***

(b) Describe how the structure of the cell membrane is related to

(i) its selective permeability

- ***Selective permeability is achieved through the organization of the phospholipid bilayer and the specific membrane proteins embedded within it.***
- ***The phospholipid bilayer forms a hydrophobic core that allows only lipid-soluble molecules to diffuse through, while effectively excluding polar and charged substances. To manage the movement of these excluded molecules, the membrane incorporates specific transport proteins; such as channels, carriers, and pumps; that recognize and move only particular ions, sugars, or amino acids. Together, this enables the cell to regulate substance movement and maintain a stable internal environment.***

(ii) its communication with molecules in the cell's environment.

- ***Communication occurs through receptor proteins, glycoproteins, and glycolipids in the cell membrane. Receptor proteins bind specific extracellular signals, such as hormones or antigens, and initiate intracellular responses. The carbohydrate chains of glycoproteins and glycolipids allow cells to recognize, adhere to, and interact with other cells, enabling coordinated physiological activities.***

(c) Describe how prokaryotes and eukaryotes differ in terms of the membrane-bound structures they contain.

- ***Prokaryotes lack membrane-bound organelles, so processes such as respiration and photosynthesis occur on enfolding's of the plasma membrane. Eukaryotes possess numerous membrane-bound structures, including the nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, and in plants, chloroplasts. These compartments allow specialization and efficient division of cellular functions.***

(d) If the membrane proteins present in the cell membrane were damaged, suggest what would happen to the cell membrane.

- ***Damaged carrier and channel proteins prevent ions and nutrients from moving in and out, disrupting essential cellular processes such as respiration and protein synthesis.***
  Receptor proteins that are damaged cannot detect extracellular signals, so the cell cannot respond to its environment.
- ***Membrane-bound enzymes lose their activity if proteins are damaged, slowing vital biochemical reactions.***
- ***Damaged glycoproteins and glycolipids impair cell recognition and adhesion, preventing proper interactions with other cells.***

4. Farmers in Mbale (Mt. Elgon slopes) and Gulu (Northern Uganda) reported contrasting yields of beans and sorghum. Beans thrive in Mbale but fail in Gulu, while sorghum thrives in Gulu but shows yellowing and stunted growth in Mbale. A student investigation compared environmental factors, leaf anatomy, and photosynthetic activity of these crops in the two districts.

District	**Altitude (m)**	**Average temperature (°C)**	**Rainfall (mm/year)**	**Dominant vegetation**	**Type of leaf anatomy**	**Rate of CO2 uptake (μmol m^{-2} s^{-1})**	**Main excretory product**
Mbale	1600	20	1500	Bananas, Beans	No Kranz	18	Latex
Gulu	900	33	700	Acacia, Sorghum	Cranz present	32	Oils

Farmers from Gulu recently attempted growing beans using irrigation but yields remained low despite frequent watering.

Adapted: "Comparative analysis of C_3 and C_4 crop adaptations in East Africa". African plant science review 2022. Tasks

(a) Assess why beans and Sorghum show contrasting performance in Mbale and Gulu.

- ***Beans are C3 plants with no Kranz anatomy, so RuBisCO can bind O_2 at high temperatures, causing photorespiration, which wastes RuBP and CO_2, reducing photosynthetic efficiency.***

Beans grow well in Mbale because the moderate temperature (20 °C) and high rainfall (1500 mm) favor CO_2 fixation, supporting good growth. In Gulu, high temperature (33 °C) and low rainfall (700 mm) increase photorespiration and limit CO_2 uptake, causing poor yields.

- ***Sorghum is a C4 plant with Kranz anatomy. PEP carboxylase, which does not bind O_2, fixes CO_2 into oxaloacetate, converted to malate and shunted to bundle sheath cells, where CO_2 is released for the Calvin cycle. This concentrates CO_2 around RuBisCO, minimizing photorespiration and allowing efficient photosynthesis under high temperature, intense light, and low water. Sorghum thrives in Gulu, while cooler, wetter conditions in Mbale reduce its efficiency, explaining poor growth there.***

(b) Suggest the strategies that could help improve the yield of beans in Gulu based on the physiological and anatomical characteristics of the plants.

- ***Grow heat-tolerant C_3 bean varieties that maintain photosynthesis at high temperatures.***
  Use shading or agroforestry to reduce leaf temperature and light stress, lowering photorespiration.
- ***Conserve soil moisture through mulching or drip irrigation to support stomatal opening and CO_2 uptake.***
- ***Ensure adequate soil fertility, especially nitrogen, to sustain photosynthesis. Plant during cooler periods to reduce heat stress and improve growth.***

5. A commercial greenhouse in Kisoro grows spinach, a C_3 plant for local markets. To increase yield, the manager installed high-intensity LED lights and maintained regular watering, and kept the greenhouse at 25°C. After several weeks, the following observations were made:

Condition	Light (lux)	CO_2 (ppm)	Sugar (mg g^{-1} FW)	Leaf chlorophyll (SPAD)
Early season	**20,000**	**420**	**18**	**42**
Mid season	**40,000**	**280**	**15**	**43**
Late season	**40,000**	**120**	**6**	**42**

Despite maximum lighting, late-season plants showed small leaves, thin stems, and poor carbohydrate accumulation, leading to low harvests.

The manager is unsure why sugar production dropped and wonders whether installing even brighter lights will solve the problem.

TASKS

(a) Explain the changes in sugar production by the plants during the season.

- ***During the season, sugar production decreased due to the progressive decrease in CO_2 concentration. CO_2 is the substrate for RuBP carboxylase in the Calvin cycle, so a lower CO_2 concentration reduces the rate at which RuBP is carboxylated to 3-phosphoglycerate. This***

molecule is then converted into triose phosphates and subsequently into sugars and starch. As CO_2 decreased from 420 ppm to 280ppm, then to 120 ppm, RuBP carboxylation also decreased progressively, reducing sugar accumulation in the leaves despite sufficient ATP and NADPH from the light reactions.

(b) Assess whether increasing light further will improve sugar production, using the data.

- ***Increasing light will not significantly increase sugar production because insufficient carbon dioxide limits the Calvin cycle. At only 120 ppm CO_2, RuBP carboxylase (RuBisCO) cannot fix enough carbon to form 3-phosphoglycerate. Even though the light reactions supply sufficient ATP and NADPH, the low CO_2 restricts the production of triose phosphates and hence sugars. Therefore, additional light cannot increase sugar synthesis.***

(c) Suggest and justify one practical greenhouse intervention to restore sugar production.

- ***Intervention: Enrich greenhouse air with Carbon dioxide.***

Justification: Higher CO_2 concentration increases the substrate for RuBisCO, enhancing carboxylation in the Calvin cycle. This boosts 3-PGA and triose phosphate formation, increasing sucrose and starch synthesis, and improving leaf growth and overall yield.

(d) Predict how sugar production would change if daytime temperatures rise above 35 °C while CO_2 remains at 120 ppm, and explain your reasoning.

- ***Sugar production would decrease further because high temperatures increase the oxygenase activity of RuBP carboxylase (RuBisCO), leading to photorespiration. During photorespiration, RuBP binds with O_2 instead of CO_2, producing phosphoglycerate instead of 3-phosphoglycerate. This wastes RuBP, reduces the formation of triose phosphates, and prevents the synthesis of sugars and starch. ATP and NADPH from the light reactions are consumed without generating carbohydrate, and the already low CO_2 concentration (120 ppm) further limits carbon fixation, compounding the decrease in sugar production.***

6. A plant breeder is developing a new variety of beans that can tolerate drought conditions in Eastern Uganda. She observes that, even within the same variety, some plants survive prolonged dry spells better than others. She collects seeds from the best-performing plants and grows the next generation under similar conditions. Over several generations, the breeder notices an increasing proportion of drought tolerant plants.

Tasks

(a) Explain why some plants survive better than others in the same variety.

- ***Some plants survive better than others because of variation in functional and physical characteristics within the population.***
- ***These differences may arise from gene mutations, chromosomal mutations, or recombination during sexual reproduction, leading to variation in traits such as root depth, stomatal regulation, and drought tolerance.***

- ***Plants with favorable variations maintain water balance and photosynthetic activity under dry conditions, while those with unfavorable variations are less likely to survive.***

(b) Discuss how meiosis contributes to the differences observed among the plants.

- ***Meiosis contributes to variation in the offspring by generating new combinations of alleles.***
- ***During prophase I, crossing over occurs between chromatids of homologous chromosomes, shuffling linked genes and creating genetic recombination.***
- ***During metaphase I, homologous chromosomes align randomly at the equator, and in anaphase I, they segregate independently into gametes.***
- ***These processes ensure that each gamete carries a unique combination of alleles, producing offspring with different traits such as drought tolerance.***

(c) Explain how the differences among plants could lead to improved drought tolerance in future generations.

- ***In the presence of variation, plants respond differently to environmental stress.***
- ***Those with favorable traits for drought tolerance are more likely to survive and reproduce, passing their advantageous alleles to the next generation.***
- ***Plants with unfavorable variations are less likely to survive, reducing their representation in subsequent generations.***
  Over time, this natural selection increases the proportion of drought-tolerant individuals, producing a population better adapted to dry conditions.
- ***Additionally, some variations may affect reproductive compatibility, so plants with certain traits are more likely to breed among themselves. Over time, this can lead to the formation of a distinct strain or population specialized for drought tolerance.***

7. A Ugandan professional farmer is breeding an oilseed plant species to improve yield and plant vigor. In this species:

The allele for tallness is dominant over dwarfness.

The allele for chlorophyll production shows incomplete dominance with the allele for non-chlorophyll, so heterozygotes are variegated.

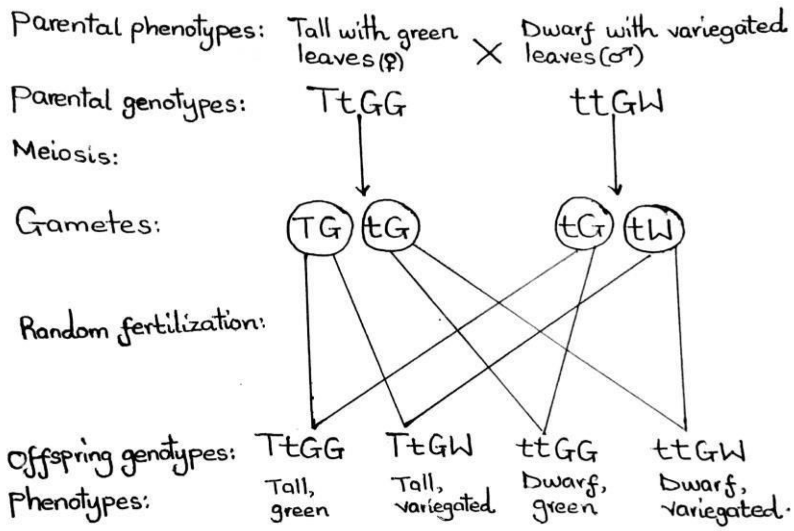
The farmer crosses a tall plant with green leaves with a dwarf plant with variegated leaves. Some offspring grow well, while others fail to survive.

Tasks:

(a) Predict the possible combinations of height and leaf color among the offspring and indicate which combinations are most likely to survive.

Let T represent the allele for tallness ***t represent the allele for dwarfness***

G represent the allele for chlorophyll production ***W represent the allele for non-chlorophyll.***



Survival chances

- ***TtGG: Plants with this genotype have high chances of survival because they are tall to reach and compete for light and have green leaves with chlorophyll to absorb sufficient light for photosynthesis.***
  TtGW: Plants with this genotype have moderate chances of survival, they are tall to reach light but variegation reduces the amount of chlorophyll in leaves hence absorb less light for photosynthesis.
- ***ttGG: Plants with this genotype have moderate chances of survival, they are dwarf thus may be shaded but have full green leaves with chlorophyll to absorb sufficient light for photosynthesis.***
- ***ttGW: Plants with this genotype have low chances of survival because they are dwarf and variegated. They can be shaded and lack enough chlorophyll to absorb light for photosynthesis.***

(b) Explain why certain offspring may struggle to survive.

- ***Some offspring struggle because of reduced height and low chlorophyll content.***
- ***Dwarf plants may be shaded by taller plants, reducing light capture.***
- ***Variegated leaves contain less chlorophyll, limiting light absorption for the Calvin cycle.***
- ***Reduced photosynthesis leads to lower sugar and energy production, impairing growth, development, and reproductive success.***
- ***Therefore, dwarf variegated offspring have the lowest survival probability.***

(c) Suggest a breeding approach the farmer could use to increase the number of offspring with optimal traits.

- ***The farmer can use selective breeding with pure-breeding lines:***
- ***Use pure-breeding tall green plants (TTGG) as parents, ensuring that all alleles for height and chlorophyll production are homozygous and consistently passed to the next generation.***
- ***Exclude dwarf and variegated plants from breeding because they introduce alleles that reduce height or chlorophyll content.***

- ***By repeatedly crossing TTGG × TTGG, the farmer increases the proportion of offspring expressing the optimal combination of maximum height and full chlorophyll, leading to vigorous growth and high photosynthetic efficiency.***

8. A group of A 'Level students carried out an experiment to investigate the light-independent reactions of photosynthesis using single-celled algae, Chlorella, grown in a thin, transparent "lollipop." Carbon dioxide labeled with carbon-14 (^{14}C) was supplied to the algae. At intervals of 10 seconds, samples of photosynthesizing Chlorella were dropped into hot methanol to stop the reactions instantaneously. The radioactive compounds formed were extracted and identified as summarized below:

Support material

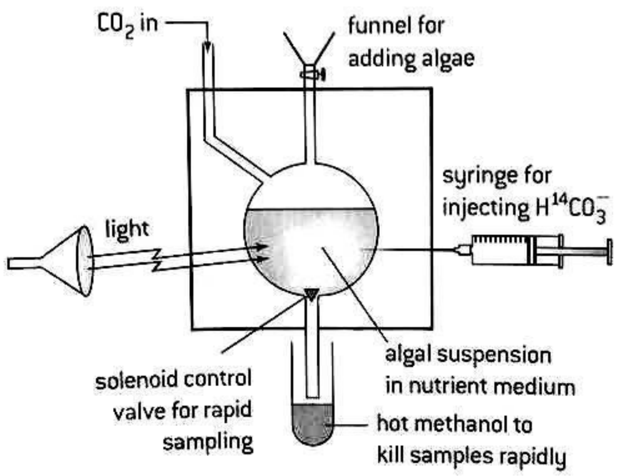


Table of results

Time (seconds)	*Compound identified as radioactive*
0	Carbon dioxide
10	Glycerate-3-phosphate
20	Glycerate-3-phosphate + phosphoglyceraldehyde
30	Glycerate-3-phosphate + phosphoglyceraldehyde + glucose
40	Glycerate-3-phosphate + phosphoglyceraldehyde + glucose + ribulose bisphosphate
50	Glycerate-3-phosphate + phosphoglyceraldehyde + glucose + ribulose bisphosphate + amino acids

Tasks

(a) Explain the following observations from the experiment:

i) Why dropping the algae into hot methanol instantly stops the reactions.

- ***Hot methanol rapidly denatures enzymes by disrupting their tertiary and quaternary structures, including all enzymes involved in the Calvin cycle.***
- ***This sudden denaturation stops all catalytic activity, preventing further fixation of ^{14}C and transformation of intermediates such as 3-phosphoglycerate and phosphoglyceraldehyde.***
- ***As a result, the metabolic state of the cells is arrested at that precise moment, allowing accurate tracking of carbon incorporation over time.***

ii) Why radioactive carbon appears in ribulose bisphosphate and amino acids.

- ***Ribulose bisphosphate (RuBP) is regenerated from phosphoglyceraldehyde (PGAL) during the Calvin cycle. As radioactive carbon from CO_2 is fixed into 3-phosphoglycerate and converted to PGAL, some of it becomes incorporated into newly formed RuBP. Additionally, PGAL serves as a carbon skeleton for amino acid synthesis, explaining why radioactive carbon is also detected in amino acids.***

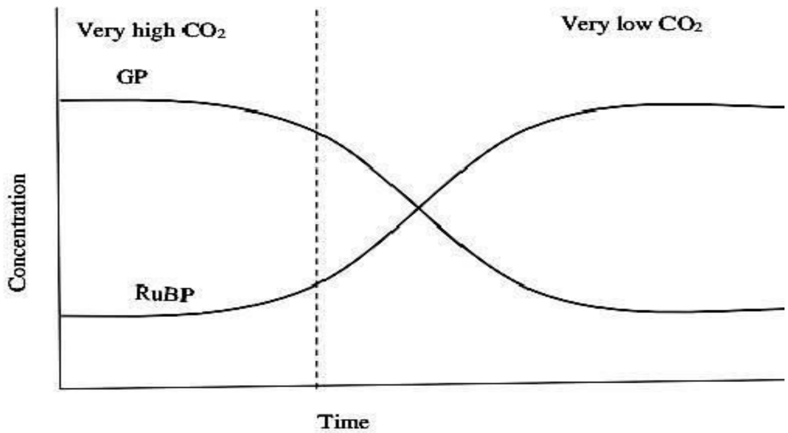
(b) (b) Suggest why the experiment was carried out in the presence of light, even though it studies the light-independent reactions.

- ***Even though the experiment investigates light-independent reactions, these reactions rely on ATP and NADPH produced during the light-dependent reactions to drive carbon fixation.***
- ***ATP provides the energy required for the phosphorylation and regeneration of Calvin cycle intermediates, while NADPH supplies the reducing power to convert 3-phosphoglycerate into phosphoglyceraldehyde.***
- ***Conducting the experiment in light ensures a continuous supply of ATP and NADPH, allowing the Calvin cycle to proceed efficiently. Without light, the cycle would slow or stop due to a lack of these essential energy carriers.***

(c) Account for the economic importance of the organisms used in the experiment above.

- ***Chlorella is a protein-rich organism and is used as a food supplement for humans and as a high-protein feed for livestock and aquaculture.***
- ***Its high lipid content makes it a potential source for biofuel production, contributing to renewable energy solutions.***
- ***Chlorella can absorb excess nutrients from wastewater, helping in water treatment and environmental management.***
- ***It serves as a model organism in research, especially to study photosynthesis and carbon fixation, with applications in agriculture and biotechnology.***

(d) In a further experiment, they collected the algae at intervals of 1-minute over a period of 5-minutes and measured the quantities of glycerate-3-phosphate (GP) and Ribulose bisphosphate (RuBP) formed. Due to limited supply of hydrogen carbonate, they decreased the supply of carbon dioxide until the 5minutes elapsed. The results obtained sparked confusion among the A' level scientists. They presented their results graphically as shown below.



As a plant specialist, one of the A' level scientists has approached you for help and presented the graph above in which he asked you to;

(i) Account for the quantities of GP and RuBP before and after the scientists became insufficient of hydrogen carbonate.

- ***At high CO_2 levels**: The concentration of GP was high while RuBP was relatively low. This is because RuBP carboxylase (RuBisCO) catalyzed the carboxylation of RuBP with CO_2 and water, producing large amounts of GP during the Calvin cycle. Continuous regeneration of RuBP kept the cycle active, but its instantaneous concentration appeared lower as it was being rapidly used.*
- ***At low CO_2 levels**: The concentration of RuBP became high while GP decreased. This occurred because limited CO_2 restricted the carboxylation of RuBP, so less GP was produced. As a result, RuBP accumulated in the cycle while GP levels decreased.*

(ii) Based on the relationship between carbon dioxide availability and the concentrations of GP and RuBP, suggest and explain one practical application of this knowledge.

- ***The knowledge can be applied in agriculture to optimize photosynthesis and increase crop productivity; Farmers can grow crops in greenhouses where CO_2 levels are enriched above ambient concentrations. Higher CO_2 ensures more RuBP is carboxylated, increasing GP formation and enhancing the Calvin cycle's efficiency, which boosts the production of sugars and starch. This leads to faster plant growth, higher biomass accumulation, and improved yields, especially for C3 crops that are more sensitive to CO_2 limitation.***

9. During the National Mountain Marathon held in Kapchorwa (altitude 2,200 m), three athletes Peter, Sarah, and James showed different endurance abilities. All trained for three months under distinct environmental conditions before the event:

• Peter trained at sea level (Entebbe).

• Sarah trained in Kapchorwa. • James trained in Mbarara (1,400 m) but recently recovered from mild carbon monoxide exposure after sleeping near a charcoal stove.

Before and after the race, physiological data were recorded:

Parameter	Peter	Sarah	James
Resting heart rate (beats/min)	68	60	72
Heart rate after race	160	120	185
Blood O_2 saturation (%)	98	93	82
Blood CO_2 concentration (%)	3.5	4.2	5.8
Hemoglobin level (g/dL)	14.5	17.2	13.0
Recovery time to normal breathing (min)	10	3	18

Sarah completed the race first, followed by Peter, while James collapsed and required oxygen therapy.

Task:

(a) Explain the physiological reasons for the different performances among the three athletes.

Sarah had the best performance due to full acclimatization, as explained below;

- ***Training at 2,200 m stimulated increased erythropoietin release, which raised her hemoglobin level to 17.2 g/dL, increasing the oxygen-carrying capacity of blood and improving oxygen delivery to working and recovering muscles.***

  Exposure to low oxygen partial pressures at high altitude increased her capillary density and mitochondrial efficiency, enabling more effective oxygen uptake and utilization during the race.
- ***Altitude training strengthened her heart, increasing stroke volume so it could pump more blood per beat, explaining her low resting heart rate (60 bpm).***
- ***During the race, she needed only a modest increase in heart rate (to 120 bpm) because her entire cardiovascular and respiratory systems were already conditioned to deliver oxygen efficiently at altitude.***
- ***Her rapid CO_2 clearance and return to normal breathing (3 min) resulted from acclimatization increasing hemoglobin and capillary density, which improved oxygen delivery to muscles and the oxidation of lactic acid, allowing faster removal of CO_2.***
- ***Adequate oxygen supply during recovery allowed faster oxidation of accumulated lactic acid, reducing fatigue and speeding recovery.***

Peter had moderate performance due to lack of altitude adaptation;

- ***Training at sea level left him with normal hemoglobin (14.5 g/dL), so he carried less oxygen per unit blood than Sarah under altitude conditions.***
- ***At 2,200 m the reduced atmospheric oxygen forced his heart to beat much faster (160 bpm) to maintain oxygen supply to muscles during the race.***
- ***He produced more lactic acid due to reduced oxygen availability, leading to earlier fatigue than Sarah.***
- ***His recovery was slower (10 min) because his respiratory system is not adapted for rapid CO_2 removal at low oxygen pressure.***

- ***Reduced oxygen delivery after the race slowed the oxidation of lactic acid, prolonging his fatigue and breathing difficulty.***

<u>James had poor performance due to Carbon monoxide exposure and inadequate acclimatization;</u>

- ***Recent carbon monoxide exposure caused formation of carboxyhaemoglobin, reducing available hemoglobin for oxygen binding and directly lowering oxygen saturation to 82%.***
- ***Carbon monoxide also increases hemoglobin's affinity for oxygen, making it difficult for tissues to receive the oxygen that is bound.***
- ***The severe oxygen deficit forced his heart to beat extremely fast (185 bpm) in an attempt to compensate.***
- ***His high CO_2 level (5.8%) indicates inefficient gas exchange and respiratory stress.***
- ***Poor oxygen delivery caused rapid lactic acid build-up in muscles, accelerating fatigue.***
- ***During recovery, the very low oxygen availability limited lactic acid oxidation, explaining his long recovery time (18 min) and collapse requiring oxygen therapy.***

(b) Suggest strategies that could help James improve his performance and recovery.

- ***<u>Altitude acclimatization</u>: Gradually training at higher altitudes will stimulate increased hemoglobin production and capillary density, improving oxygen delivery to muscles during exercise.***
- ***<u>Recovery from carbon monoxide exposure</u>: Avoiding carbon monoxide sources and allowing full recovery ensures hemoglobin is available for oxygen transport, restoring effective oxygen delivery to tissues.***
- ***<u>Cardiovascular conditioning</u>: Regular endurance training strengthens the heart, increases stroke volume, and reduces the heart rate response during high-intensity activity.***
  <u>Respiratory training</u>: Breathing exercises or controlled hypoxic exposure can enhance ventilator sensitivity, improving CO_2 clearance and oxygen uptake during exertion.
- ***<u>Nutrition and oxygen support</u>: Adequate iron intake and antioxidants support red blood cell production and reduce oxidative stress, aiding oxygen transport and lactic acid oxidation during recovery.***

10. Mulondo began experiencing recurrent abdominal discomfort and intestinal irritation, particularly after eating meals rich in lipids. Medical tests later revealed that he had both peptic and pyloric ulcers, linked to excessive secretion of gastric acid. The acidity was further worsened whenever he consumed fatty foods whose breakdown released additional organic acids, lowering the intestinal pH beyond what bile salts could effectively neutralize.

During nutritional counselling, Mulondo was advised to always take protein-rich foods such as bean soup, egg albumen, and probiotic yoghurt before meals containing significant amounts of lipids. After following this dietary adjustment for several weeks, his symptoms reduced dramatically.

<u>Task</u>

(a) i) Identify the major biological molecules present in bean soup, egg albumen, and yoghurt that help stabilize intestinal conditions in Mulondo's digestive system.

- ***Bean soup, egg albumen, and yoghurt contain proteins that are digested into amino acids, which act as buffers to neutralize excess gastric acid and fatty acids. Probiotic yoghurt also contains live beneficial bacteria that support gut pH stability and mucosal health.***

ii) Explain the biochemical mechanisms by which the molecules identified in (a)(i) reduce Mulondo's discomfort when taken before lipid-rich meals.

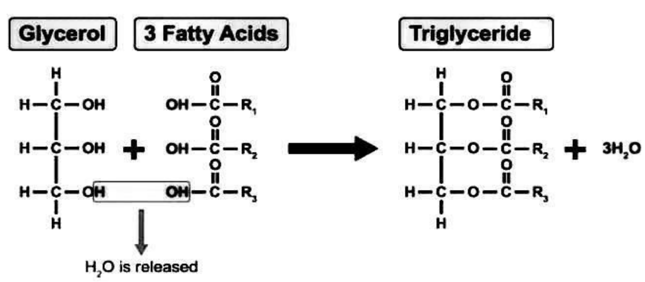
- ***Each amino acid has a basic amino group ($–NH_2$) that can accept excess H^+ ions when the intestine becomes too acidic from gastric acid or fatty acid breakdown, and an acidic carboxyl group (–COOH) that can release H^+ ions if pH rises too high.***
- ***This dual action allows amino acids to function as biological buffers, stabilizing gut ph. In Mulondo's case, these buffering effects protected his peptic and pyloric ulcers from further irritation, reduced discomfort, and supported normal digestive processes.***

(b) i) Explain how bile normally counteract the drop in pH when acidic food enters the duodenum, and why this mechanism may fail in Mulondo's condition.

- ***Bile contains salts such as sodium glycocholate and sodium taurocholate, as well as sodium bicarbonate ($NaHCO_3$).***
- ***The alkaline bicarbonate neutralizes acidic chyme entering the duodenum, maintaining an optimal pH for intestinal enzymes like pancreatic lipase and protecting the intestinal mucosa from acid damage.***
- ***In Mulondo's case, excessive gastric acid and additional acids released from lipid breakdown lower intestinal pH beyond the neutralizing capacity of bicarbonate, causing irritation of the duodenal lining and worsening peptic and pyloric ulcers.***

ii) Describe how fatty acids from dietary lipids react chemically to form complex lipids in both plants and animals.

Three fatty acids react with the three hydroxyl (–OH) groups of one glycerol molecule in a condensation reaction to form a triglyceride. During this process, three ester bonds are formed and three molecules of water are released.



- ***In animals, these triglycerides are stored in adipose tissue as energy reserves, while in plants, they are stored as oils in seeds to provide energy during germination and early growth.***

(c) i) Explain how the complex biological molecules in bean soup, egg albumen, and yoghurt are digested into end-products that can help resist rapid pH fluctuations as they move along the alimentary canal.

- ***<u>In Mulondo's mouth</u>, proteins are mechanically broken down by chewing, rolling the food into a bolus that is swallowed and propelled along the esophagus by peristalsis into the stomach.***
- ***<u>In the stomach</u>, proteins are exposed to gastric juice secreted by the gastric glands. This juice contains pepsinogen, an inactive precursor, which is converted to the active enzyme pepsin by hydrochloric acid. Pepsin hydrolyzes peptide bonds, breaking proteins into smaller polypeptides.***
- ***<u>In the duodenum</u>, the polypeptides mix with pancreatic juice from the pancreas, which contains trypsinogen. Enterokinase from the intestinal lining activates trypsinogen to trypsin, which further hydrolyzes polypeptides into shorter peptides.***
- ***<u>In the ileum</u>, peptides are finally broken down into free amino acids by peptidases present in the succus entericus. These amino acids are absorbed into the bloodstream, providing building blocks for protein synthesis and tissue repair. Importantly, in Mulondo's case, these amino acids help stabilize intestinal pH by neutralizing excess H^+ ions from gastric acid and fatty acid breakdown, reducing irritation of the peptic and pyloric ulcers.***

ii) Describe the general roles of these nutrients in the bodies of animals.

<u>Amino acids from protein digestion play the following roles in animal bodies;</u>

- ***<u>Protein synthesis</u>: Amino acids are the building blocks for all proteins, including structural proteins, enzymes, and transport proteins, supporting growth, tissue repair, and overall physiological function.***
- ***<u>Buffering of body fluids</u>: The amino and carboxyl groups of amino acids can accept or donate H^+ ions, helping to stabilize the pH of blood and other body fluids.***
- ***<u>Precursor for nitrogenous compounds</u>: Amino acids supply nitrogen for the synthesis of hormones, neurotransmitters, and nucleotides, which are essential for regulation and signaling in the body.***
- ***<u>Energy production</u>: Amino acids can be deaminated to produce carbon skeletons that enter the Krebs cycle, providing energy (ATP) during periods of high demand or fasting.***
- ***<u>Support for enzymes and hormones</u>: Amino acids contribute to the formation of enzymes and hormones, ensuring that metabolic reactions and physiological signaling occur efficiently.***
- ***<u>Immune function</u>: Certain amino acids, like glutamine and arginine, are critical for the production and proliferation of immune cells, supporting the body's defense mechanisms.***

11. A food poisoning outbreak is traced to a bacterial toxin that destroys the tight junctions between intestinal epithelial cells. This allows the toxin to enter the bloodstream. The toxin's mechanism is to act as a non-competitive inhibitor of succinate dehydrogenase, a crucial enzyme in both the Krebs cycle and the electron transport chain.

<u>Table: Systemic Effects of the Bacterial Toxin</u>

Tissue/Analyte	Observed effect	Underlying cause
Intestinal Epithelium	Loss of barrier function; inflammation	Destruction of tight junctions
Blood Serum	High levels of succinate	Inhibition of succinate dehydrogenase

Muscle Cells	Low ATP, cramping	Disrupted Krebs cycle and electron transport.
Kidney Tubules	Reduced filtration rate	Epithelial cells lining tubules are energy-deficient

TASK:

(a) Explain the dual consequence of this toxin: first, how it breaches the body's primary epithelial barrier, and second, how its enzymatic inhibition disrupts aerobic respiration systemically.

- ***The bacterial toxin breaches the body's primary epithelial barrier by destroying the tight junctions between intestinal epithelial cells. Tight junctions normally seal the spaces between adjacent cells, preventing pathogens and toxins from passing through the intestinal wall. Once these junctions are disrupted, the intestinal barrier becomes "leaky," allowing the toxin to enter the bloodstream and expose tissues systemically.***
- ***After entering the bloodstream, the toxin acts as a non-competitive inhibitor of succinate dehydrogenase, a crucial enzyme in both the Krebs cycle and the electron transport chain. Inhibition of this enzyme prevents the conversion of succinate to fumarate and disrupts electron transfer, reducing ATP synthesis in cells. Energy-deficient tissues, such as muscle and kidney cells, experience low ATP levels, leading to muscle cramping and impaired kidney filtration. Additionally, accumulation of succinate in the blood reflects the metabolic block and contributes to systemic metabolic stress.***

(b) Propose strategies to manage this poisoning, addressing both the epithelial damage and the metabolic crisis.

- ***<u>Restoring the epithelial barrier</u>: Oral or intravenous rehydration solutions help maintain fluid balance and limit further absorption of the toxin. Nutrients such as glutamine and probiotic supplements may support regeneration of epithelial cells and restoration of tight junctions.***
- ***<u>Counteracting metabolic inhibition</u>: Support cellular energy production by providing glucose and electrolytes. In severe cases, administering ATP precursors or cofactors e.g., FAD, NAD^+, may help partially bypass the inhibited enzymatic step. Oxygen therapy and close monitoring of high-energy-demand organs i.e. muscles and kidneys are essential.***
- ***<u>Preventing further exposure</u>: Treat the underlying bacterial infection with appropriate antibiotics if necessary, and remove contaminated food sources to stop additional ingestion of the toxin.***
- ***<u>Symptomatic management</u>: Address muscle cramps through electrolyte correction and pain relief. Monitor kidney function closely, providing dialysis if filtration is severely compromised.***

12. A small town is struggling with worsening air pollution from nearby factories and vehicle emissions. Residents are experiencing respiratory issues, and as part of a health initiative, you decide to explore the root causes and solutions with the community. During your visit, you notice several hints about the connection between air quality and health:

✓ A doctor at the local clinic mentions that damage to the epithelial tissues lining the lungs can reduce their ability to filter harmful particles. They point out that this has left many residents more vulnerable to respiratory conditions.

✓ Conversations with townsfolk reveal how pollutants like dust and smoke have visibly increased in the air, leading to frequent coughing and wheezing. You start to wonder how these pollutants might be affecting the microscopic layers protecting their lungs.

✓ At a town hall meeting, people talk about their frustrations with chronic health issues. They seem eager for practical ideas to protect their lungs and improve the air quality in their community.

Nearby schools are excited to join the cause. The head teacher asks you to help inspire students to take part in awareness campaigns or green projects to protect the lungs of future generations.

TASK

Write a simple write up that you will use to teach and inspire these students to join the campaign and save the environment.

Protecting Our Lungs and the Environment

- ***Air pollution from vehicles and factories introduces harmful particles and gases such as dust, smoke, carbon monoxide and nitrogen oxides into the air we breathe. When inhaled, these pollutants travel down the bronchi and bronchioles and eventually reach the alveoli-tiny air sacs lined by a single layer of epithelial cells and surrounded by capillaries where gaseous exchange occurs. Normally, oxygen diffuses from the alveoli into the blood, while carbon dioxide diffuses out across the alveolar–capillary membrane.***
- ***Pollutants irritate and damage the epithelial lining of the airways. This triggers inflammation, causing swelling of bronchioles, increased mucus secretion, and narrowing of the air passages. Wheezing arises when air is forced through these narrowed bronchioles, producing a whistling sound. Coughing occurs as a reflex to clear excess mucus and trapped particles from the trachea and bronchi. Damage to alveolar cells, together with thickening of alveolar walls, reduces surface area and increases the diffusion distance for gases, lowering the rate of oxygen uptake. This results in shortness of breath, especially during exercise, when the body demands more oxygen.***
- ***Carbon monoxide further worsens the problem by binding tightly to hemoglobin to form carboxyhemoglobin, decreasing the blood's ability to carry oxygen. This reduces the oxygen available for aerobic respiration in body tissues, leading to fatigue and respiratory distress.***
- ***To protect the lungs, communities can reduce pollution by planting trees, limiting smoke emissions, and promoting cleaner fuel use. Trees trap particulate matter and release oxygen, improving air quality and supporting efficient gaseous exchange. As students, you can participate in environmental awareness campaigns, tree-planting activities, and projects that monitor air quality around your school and community.***
- ***Understanding how pollutants interfere with the biology of breathing; from airway inflammation to impaired gas exchange, highlights why protecting the environment is essential for maintaining healthy lungs and overall body function.***

13. You are part of a biotechnology research team attempting to culture human kidney cells to test a new life-saving drug. During one trial, the solute concentration of the culture medium was accidentally altered.

You measured the following values for the cytoplasm of a normal kidney cell:

Solute potential (Ψs): –650 kPa

Pressure potential (Ψp) under normal conditions: +350 kPa

For the altered medium, the water potential (Ψ) was measured as –900 kPa.

Later, when preparing another batch of cells, the external temperature was increased. Surprisingly, the membranes remained functional, allowing normal transport of water and solutes despite the temperature shift.

You also observed that some drug molecules entered the cells rapidly, while others only entered after being aided by special molecules within the cell membrane.

TASKS

(a) Calculate the water potential (Ψ) of a normal kidney cell before the medium was altered. Show your working.

Water potential Ψ = solute potential (Ψs) + pressure potential (Ψp).

Given Ψs = −650 kPa and Ψp = +350 kPa,

Ψ(cell) = −650 kPa + 350 kPa

= −300 kPa.

(b) Predict the net movement of water when the cells were placed in the altered medium (Ψ = –900 kPa) and explain whether the cells would swell or shrink.

- ***Water always moves down a water potential gradient, from a region of higher water potential (less negative) to one of lower water potential (more negative).***
- ***The normal kidney cell has a water potential of –300 kPa, while the altered medium has a water potential of –900 kPa. Because the cell water potential of –300 kPa is higher than –900 kPa of the medium, water will leave the cell by osmosis into the surrounding medium. As water exits, the volume of the cytoplasm decreases, causing the kidney cell to shrink.***
- ***In animal cells this shrinkage is known as crenation, where the cell loses water and its membrane pulls inward due to the loss of internal hydrostatic pressure.***

(c) Explain why some drug molecules entered the cells easily while others required assistance, based on the events described.

- ***Some drug molecules entered the kidney cells rapidly because they moved by simple diffusion. These molecules were likely small, non-polar, or lipid-soluble, allowing them to dissolve in the hydrophobic phospholipid bilayer and diffuse directly across the membrane down their concentration gradient. This movement is passive and does not require membrane proteins or metabolic energy, so entry is fast.***
- ***Other drug molecules could not diffuse through the phospholipid bilayer because they were large, polar, or charged, and therefore unable to pass through the hydrophobic fatty-acid***

interior of the membrane. These molecules entered the cell only when aided by specific transport proteins embedded in the membrane:

- ***Some were transported by facilitated diffusion, where channel or carrier proteins allow solutes to cross the membrane down their concentration gradient. This process is protein-mediated but still passive, requiring no ATP.***

Others required active transport, where carrier proteins (pumps) move molecules against their concentration gradient. This form of transport requires cellular energy (ATP) and is essential for substances that must accumulate inside the cell even when external concentrations are low.

(d) Account for why the cell membranes remained functional despite the change in temperature.

- ***The kidney cell membranes continued to function because the fluid mosaic structure allows controlled flexibility over moderate temperature changes. As temperature rises, phospholipid molecules move more freely, but cholesterol within the bilayer stabilizes the membrane by preventing it from becoming excessively fluid. This keeps the membrane semi-permeable and preserves the shape and activity of embedded proteins such as carriers, channels, and pumps. Since the temperature increase stayed within the cell's physiological tolerance, the phospholipids did not melt and the proteins did not denature, allowing normal transport of water and solutes to continue.***

(e) Explain the practical applications of the knowledge of cell–water relations.

- ***<u>Medical treatment e.g. IV fluids and hydration therapy:</u> Health professionals must use intravenous solutions that are isotonic with blood plasma. This prevents red blood cells from swelling in hypotonic solutions or shrinking in hypertonic ones, ensuring safe fluid replacement during illness, surgery, or dehydration.***
- ***<u>Kidney dialysis and filtration technologies:</u> Dialysis machines depend on controlled diffusion and osmosis across a selectively permeable membrane. Waste substances like urea, diffuse out of the blood while water movement is regulated by adjusting solute concentrations in the dialysate, preventing osmotic imbalance in patients with kidney failure.***
- ***<u>Organ and tissue preservation:</u> Transplanted organs must be stored in isotonic preservation solutions. This prevents osmotic gain or loss of water that could damage cell membranes, ensuring tissues remain viable before transplantation.***
- ***<u>Pharmaceutical and drug delivery design:</u> Drug developers must know whether a molecule can cross membranes by diffusion or requires transport proteins. Understanding membrane permeability and solute gradients helps design drugs that enter target cells effectively without causing osmotic disturbance.***

14. Odongo, a researcher, is developing a new drug that must enter human cells to destroy infectious bacteria effectively. During testing, he observed that some drug molecules entered cells easily, while others only passed after being aided by certain molecules within the cell membrane. He also noticed that the membrane remained flexible despite variations in external temperature.

When he consulted a cytologist, the expert described the membrane as a "fluid mosaic" and added that it behaves as a "selectively permeable barrier."

<u>Tasks</u>

(a) Why did the cytologist describe the structure and behavior of the membrane as so?

The cytologist described the membrane as:

- ***Fluid mosaic*** ***because the phospholipid bilayer allows lateral movement of lipids and proteins, hence fluid; and the irregular, scattered arrangement of proteins, glycoproteins, and glycolipids gives a mosaic appearance.***
  Selectively permeable barrier ***because it controls substance passage, permitting small, nonpolar molecules to pass freely while restricting large, polar, or charged molecules unless specific transport proteins assist their movement.***

(b) Provide a description of the structure of the cell membrane as described by the cytologist.

- ***The cell membrane is composed of a phospholipid bilayer, where the hydrophilic phosphate heads face outward toward the watery environments inside and outside the cell, and the hydrophobic lipid tails face inward, away from water.***
- ***The lipid tails interact through hydrophobic interactions and van der Waals forces, allowing lateral movement of phospholipids that gives the membrane its fluid character.***
- ***Proteins are associated with or embedded in the bilayer. Extrinsic (peripheral) proteins are attached to the inner or outer surfaces, while intrinsic (integral) proteins either partially penetrate one phospholipid layer or span the entire bilayer. These are called transmembrane proteins, some of which have pores.***
- ***Some proteins are linked to short carbohydrate chains as glycoproteins, and some phospholipids are linked to carbohydrates as glycolipids. The irregular arrangement of these scattered proteins and carbohydrate conjugates gives the membrane its mosaic appearance.***
- ***In animal cells, cholesterol molecules are interspersed among the phospholipid tails, stabilizing the membrane while maintaining fluidity.***

(c) Point out the key differences in the ultra-structure between the two cells Odongo is dealing with in his investigations to develop the new drug.

Differences between a human cell and a bacterial cell

Human cell	***Bacterial cell***
True membrane-bound nucleus present	***No membrane around the nuclear region (Lacks a true nucleus)***
Has a linear DNA in the nucleus	***Has a circular DNA in the nucleoid***
Membrane-bound organelles such as mitochondria present.	***Membrane-bound organelles such as mitochondria absent.***
Has larger ribosomes (80S) in the cytoplasm and on RER	***Has smaller ribosomes (70S) in the cytoplasm***
Flagella if present have the 9+2 arrangement of microtubules.	***Flagella lack the 9+2 arrangement of microtubules.***
Larger size (10–100 µm)	***Smaller size (0.2–2 µm)***

Divide by mitosis and meiosis	***Reproduce by binary fission***

(d) How do the various components of that cell structure relate to its roles?

- ***The phospholipid bilayer forms a flexible, semi-rigid barrier that encloses the cytoplasm, separating the cell's internal environment from the external surroundings while maintaining the overall shape and integrity of the cell.***
  Transmembrane (integral) proteins provide selective channels and carriers that regulate the movement of ions, nutrients, and waste across the membrane.
- ***Peripheral proteins anchor the membrane to the cytoskeleton, supporting cell shape and aiding in mechanical stability.***
- ***Glycoproteins and glycolipids participate in cell recognition, signaling, and immune system interactions by providing unique molecular markers on the cell surface.***
- ***Cholesterol molecules modulate membrane fluidity and stability, preventing membranes from becoming too rigid at low temperatures or too fluid at high temperatures.***
- ***Some transmembrane proteins act as receptors, detecting extracellular signals such as hormones or neurotransmitters and triggering intracellular responses.***
- ***Membrane-bound enzymes catalyze specific reactions at the membrane surface, facilitating processes such as signal transduction, energy transduction, and localized metabolic activity.***
- ***The mosaic arrangement of lipids and proteins allows functional specialization, with distinct regions supporting processes like endocytosis, exocytosis, and intercellular communication.***
- ***Transmembrane proteins with pores or channels contribute to selective permeability, enabling essential molecules to pass while restricting harmful or unnecessary substances.***
- ***Carbohydrate chains attached to proteins or lipids (glycoproteins and glycolipids) stabilize the membrane surface and mediate interactions with the extracellular matrix or other cells.***

S.5 BIOLOGY

PROPOSED GUIDE

(a) Meaning of blood groups B^- and B^+, and explanation for anaemia & jaundice

Meaning of blood group B^- and B^+

Blood group B means that the person's red blood cells have B antigens on their surface.

The "+" or "–" refers to the Rhesus (Rh) factor.

B^+ means the person has Rh factor (D antigen) on red blood cells.

B^- means the person lacks the Rh factor.

Why Patricia's second baby became anaemic and jaundiced

Patricia is B^- (Rh-negative) while her first child was B^+ (Rh-positive).

During her first pregnancy or delivery:

The baby's Rh^+ red blood cells entered Patricia's blood.

Her immune system recognized these Rh^+ cells as foreign and produced anti-Rh antibodies.

These antibodies remained in her bloodstream (sensitization).

During the second pregnancy:

The second baby was also B^+ (Rh-positive).

Patricia's anti-Rh antibodies crossed the placenta.

They attacked and destroyed the baby's red blood cells, causing haemolysis.

How this led to the baby's condition

1. Anaemia

Rapid destruction of red blood cells reduced the baby's RBC count from the normal $4.5–5.5 \times 10^6/\mu L$ to $2.0–3.0 \times 10^6/\mu L$, causing severe anaemia.

2. Jaundice

Breakdown of many RBCs released large amounts of haemoglobin, which was converted to bilirubin, raising levels from the normal <1 mg/dL to 8–15 mg/dL.

Excess bilirubin deposited in tissues produced the yellowish skin colour.

3. Conclusion

The baby's state is a classical case of Rhesus incompatibility (also called Haemolytic Disease of the Newborn – HDN), not HIV/AIDS, and it is treatable

(b) Advice to Patricia on living positively with her baby & how such cases can be prevented

<u>How Patricia can live positively with her second born</u>

1. Follow medical treatment

Ensure the baby receives the recommended treatments such as phototherapy or exchange transfusion if necessary.

Attend regular check-ups to monitor haemoglobin and bilirubin levels.

2. Exclusive breastfeeding

Breastfeed exclusively for 6 months to improve the child's immunity and growth.

3. Emotional support

Avoid unnecessary fear; the child's condition does not mean HIV/AIDS.

Seek counselling and support from family or health workers.

4. Nutrition

Provide a balanced diet (when baby grows older) rich in iron to rebuild blood levels

5. Immunization and health monitoring

Ensure the baby receives all immunizations and routine growth monitoring

How such cases can be prevented among couples before marriage

1. **Blood group and Rhesus factor testing**

Couples should determine their ABO and Rh blood groups before marriage or pregnancy.

2. **Use of Anti-D immunoglobulin (RhoGam)**

If a woman is Rh-negative and her partner is Rh-positive, she should receive Anti-D injection:

at 28 weeks of pregnancy

within 72 hours after delivery

after miscarriage, abortion, or ectopic pregnancy

This prevents formation of antibodies against Rh^+ blood.

3. **Health education and genetic counselling**

Couples should undergo counselling to understand risks and preventive measures.

4. **Regular antenatal care**

Early and frequent antenatal visits allow early detection and management of blood incompatibility

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(a) Using your knowledge of biochemistry of energy production in cells, justify the doctor's dietary recommendation. (12 marks)

1. **Carbohydrates (posho) provide rapid ATP via aerobic respiration** (4 marks)
   - Ingested starch → digested to glucose → absorbed into blood; glucose enters cells and is metabolised by **glycolysis → pyruvate → acetyl-CoA → Krebs cycle → oxidative phosphorylation** in mitochondria. *(2 marks — 1 for pathway named, 1 for mitochondria/oxidative phosphorylation).*
   - Aerobic breakdown of one glucose yields about **~36 ATP** (table), so carbohydrates are an efficient source of **rapid ATP** for muscle contraction and high intensity work. *(1 mark)*
   - Carbohydrate stores as **muscle and liver glycogen** can be mobilised quickly during exercise to maintain blood glucose and ATP supply. *(1 mark)*
2. **Proteins (soya beans) support muscle repair, provide amino acids and enable sustained energy** (3 marks)
   - Soya is a high-quality plant protein supplying **essential amino acids** necessary for **repair and synthesis** of muscle proteins damaged during training ; this helps performance and recovery. *(1 mark)*
   - Amino acids can be deaminated and their carbon skeletons fed into Krebs cycle or used for **gluconeogenesis** when glycogen is low, providing **secondary energy**. *(1 mark)*
   - Soya also contains micronutrients (e.g., B-vitamins) that are cofactors for respiration enzymes supporting ATP production. *(1 mark)*
3. **Lipids yield more ATP per molecule but are slower to mobilise why a mixed diet helps** (2 marks)
   - Fatty acids (e.g., palmitic acid) yield **~129 ATP** on oxidation and higher energy per gram (≈38 kJ/g), but **β-oxidation and transport into mitochondria are slower** and less useful for immediate high-intensity bursts. *(1 mark)*
   - Therefore, recommending **carbohydrate (fast ATP) + protein (repair and sustained supply)** is appropriate for an athlete needing both immediate energy and recovery. *(1 mark)*
4. **Practical nutrient-timing & composition justification** (3 marks)
   - **Pre-exercise** carbohydrate (posho) helps top up glycogen and maintain blood glucose so muscles can rapidly produce ATP during events. *(1 mark)*

- **Post-exercise** protein (soya) supplies amino acids to repair muscle and stimulate protein synthesis (leucine effect), and also helps replenish glycogen when combined with carbohydrate. *(1 mark)*
- Combining both reduces muscle protein breakdown, improves performance and speeds recovery — exactly what an athlete needing more "energy productivity in form of ATP" requires. *(1 mark)*

Mark allocation summary (12 marks)

- Carbohydrate → pathway & ATP yield (4)
- Protein roles (repair / gluconeogenesis / cofactors) (3)
- Lipid vs carbohydrate tradeoffs (2)
- Nutrient timing and practical application (3)

What to lose marks for: vague statements without linking to ATP production, failing to mention glycogen or mitochondria, or claiming fats are best for immediate energy.

(b) Apart from dietary adjustment, suggest appropriate measures Nyakoojo should take to improve performance in upcoming finals. (8 marks)

1. **Structured training plan — periodisation** (2 marks)
    - Use periodised training (base → build → peak → taper) to progressively overload and then taper before finals to arrive rested and at peak performance. *(1 mark for naming, 1 mark for reason)*
2. **Incorporate interval and sport-specific conditioning** (1 mark)
    - High-intensity interval training (HIIT) and sport-specific drills improve aerobic and anaerobic energy systems and raise mitochondrial density and glycolytic capacity. *(1 mark)*
3. **Strength and resistance training** (1 mark)
    - Builds muscle power and improves efficiency of force production; reduces injury risk. *(1 mark)*
4. **Adequate rest & sleep** (1 mark)
    - Sleep (7–9 hrs) is essential for recovery, hormone regulation (e.g., growth hormone) and muscle repair poor sleep reduces performance. *(1 mark)*
5. **Hydration and electrolyte management** (1 mark)
    - Maintain hydration before/during/after events; dehydration reduces blood volume and cardiac output and impairs ATP delivery to muscles. *(1 mark)*
6. **Monitor and correct medical issues (e.g., anaemia, infections)** (1 mark)

- Check for iron deficiency or other medical causes of fatigue; treat appropriately (iron supplements, investigate endocrine issues). *(1 mark)*

7. **Psychological preparation and competition strategy** (bonus if included; folded into other points)
    - Mental rehearsal, goal setting and stress management improve focus and performance (can be counted if candidate gives clear brief point). *(up to 1 mark — included in the 8 if used*

SUMMERY

(a) The doctor's advice is justified because posho (starchy carbohydrate) supplies glucose which is rapidly metabolised by glycolysis, the Krebs cycle and oxidative phosphorylation in mitochondria to generate ≈36 ATP per glucose molecule; glycogen stores in muscle/liver provide immediately available fuel during competition. Soya beans provide high-quality protein (essential amino acids) needed for muscle repair and for gluconeogenesis when glycogen is low; they also provide B vitamins and cofactors important for enzymatic steps in respiration. Although fats yield more ATP per molecule (~129 ATP for palmitic acid) and have higher energy density (~38 kJ/g), they are slower to mobilise, so combining carbohydrate (fast ATP) and protein (repair and sustained supply) is optimal for boosting ATP availability and recovery. Proper timing carbohydrate before events to top up glycogen and protein after exercise to aid repair further supports performance. *(Expand with a short sentence about glycogen, mitochondria and insulin if space/time allows.)*

(b) Non-dietary measures: adopt a periodised training plan with specific interval and strength sessions to improve aerobic and anaerobic capacity; include resistance training to increase muscle power; ensure adequate sleep and recovery to allow muscle repair and hormonal recovery; maintain hydration and electrolyte balance; screen and treat medical causes of fatigue (e.g., iron-deficiency anaemia); use mental skills and competition tapering to peak at finals

Item 3

Human breast milk contains several **protective proteins** especially **IgA antibodies**, **lactoferrin**, and **lysozyme** which together form the infant's first line of immune defence.

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1. IgA antibodies protect mucosal surfaces (4 marks)

- Human milk contains **high levels of IgA (0.6 mg/100 mL)** compared to cow's milk (0.02 mg) and plant milk (0 mg).
- These **secretory IgA antibodies** line the baby's **gut, throat, and respiratory tract**, forming a protective coating.

- They **bind to pathogens** (bacteria, viruses, and toxins) and **prevent them from attaching to the baby's epithelial cells**.
- IgA therefore **neutralizes pathogens without causing inflammation**, which is important because a baby's immune system is still immature.

Marks: 4
• Identification of IgA – 1 mark
• Role in mucosal immunity – 1 mark
• Prevents pathogen attachment – 1 mark
• No-inflammation protection – 1 mark

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2. Lactoferrin prevents growth of microbes by starving them of iron (3 marks)

- Human breast milk contains **0.3 mg lactoferrin**, much higher than cow's milk.
- Lactoferrin **binds iron tightly**, making it unavailable to bacteria that require iron for growth.
- It therefore **inhibits multiplication of harmful bacteria** like *E. coli* and some fungi.
- Lactoferrin also **damages microbial membranes** and enhances growth of beneficial gut bacteria.

Marks: 3
• Iron-binding explanation – 1 mark
• Prevention of bacterial growth – 1 mark
• Additional antimicrobial function – 1 mark

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3. Lysozyme destroys bacterial cell walls (3 marks)

- Breast milk contains **high lysozyme levels (0.1 mg)** compared to cow's milk (0.001 mg).
- Lysozyme **breaks down peptidoglycan**, the main component of bacterial cell walls.
- This causes **lysis and death of bacteria**, especially Gram-positive organisms.
- Thus, lysozyme provides additional protection in the infant gut and respiratory tract

Humans have made significant use of the special protective proteins found in breast milk **IgA antibodies, lactoferrin, and lysozyme** to advance **medicine, food technology, and public health**.

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1. Use of antibodies (especially IgA) in vaccine development (3 marks)

- IgA's ability to **neutralize pathogens at mucosal surfaces** has inspired the design of **oral and nasal vaccines**.
- Vaccines now stimulate **mucosal immunity** similar to IgA in breast milk, providing protection against diseases like polio, measles, and influenza.
- Monoclonal antibodies, designed based on natural IgA, are used to treat infections and immune disorders.

Marks:
• Application to vaccines – 1
• Mucosal immunity concept – 1
• Therapeutic antibodies – 1

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2. Use of lactoferrin as a natural antimicrobial additive (3 marks)

- Lactoferrin is now commercially extracted (mainly from cow's milk) and added to **infant formula** to mimic immunity provided by breast milk.
- It is also used in **food preservation** because its iron-binding ability inhibits microbial growth, increasing shelf-life of meat and dairy products.
- In medicine, lactoferrin is used in **wound dressings** and supplements to reduce infections.

Marks:
• Use in infant formula – 1
• Use in food preservation – 1
• Use in medical/health products – 1

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3. Use of lysozyme in food and pharmaceutical industries (3 marks)

- Lysozyme's ability to **break bacterial cell walls** makes it an important antimicrobial agent.
- It is added to **cheese, canned foods, and beverages** to prevent spoilage.
- Pharmaceutical companies use lysozyme in **eye drops, throat lozenges, and nasal sprays** to fight bacterial infections.

Marks:
• Use in food preservation – 1
• Use in medicine – 1
• Mechanism/basis for use – 1

4. Use in biotechnology and genetic engineering (1 mark)

- Human milk proteins like lactoferrin and lysozyme are produced through **recombinant DNA technology** in bacteria and plants, making large-scale production possible for medical and nutritional use

  item 4

(a) Key feature of glandular epithelium + how modes of secretion explain the symptoms

Identification of glandular epithelium (2 marks)

A cell is identified as **glandular epithelium** when it shows:

- **Abundant secretory vesicles** in the cytoplasm (1 mark)
- **Well-developed Golgi bodies and rough ER** for synthesis and packaging of secretions (1 mark)

These features distinguish it from typical covering epithelium, whose main function is protection, not secretion.

How different modes of secretion explain the three patients' symptoms (6 marks)

1. Holocrine secretion; Excess oil production (2 marks)

- Holocrine glands (e.g., **sebaceous glands in skin**) release secretion when **the whole cell bursts** and disintegrates.
- This explains the patient with **excess oil**, because holocrine secretion continuously releases lipid-rich sebum when cells rupture.

→ Excess holocrine activity = oily skin

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2. Merocrine secretion , Digestion problems (2 marks)

- Merocrine glands (e.g., **pancreatic acinar cells**) release enzymes by **exocytosis** without losing any cell material.
- If these cells malfunction, they may either over-release or under-release digestive enzymes, leading to **poor digestion or enzyme imbalance**.

→ **Impaired merocrine enzyme secretion = digestion problems**

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3. Apocrine secretion; Fluctuating blood sugar (2 marks)

- Apocrine secretion involves **loss of part of the cell's apex**, which pinches off with the secretion.
- Some stomach and endocrine-related mucous cells use modified apocrine modes.
- If cells that secrete hormones (e.g., incretins from the stomach lining) release hormones irregularly, this can lead to **unstable blood sugar**.

→ **Irregular apocrine-associated hormone release = fluctuating glucose levels**

(Note: Pancreatic islet cells are merocrine, but the scenario involves stomach-derived hormones modulating glucose.)

(b) Identifying which slide belonged to an endocrine gland (4 marks)

To identify an endocrine gland under the microscope, look for:

1. Absence of ducts (1 mark)

Endocrine glands are **ductless**; they release hormones directly into the blood.

2. Dense network of capillaries (1 mark)

You would see numerous blood vessels to allow hormone uptake.

3. Cells arranged in clusters or cords (1 mark)

Endocrine tissues like the pancreatic islets appear as **clusters of lightly stained cells** distinct from surrounding exocrine cells.

4. Lack of large secretory vesicles with digestive or oil content (1 mark)

Endocrine cells have small hormone granules rather than enzyme- or lipid-filled vesicles typical of exocrine cells.

(c) Artificial gland implants: Ethical concern, benefit, and scientific reflection

(i) Ethical concern (2 marks)

- Artificial glands may require **genetic modification** of cells, raising concerns about unknown long-term effects, possible tumor formation, or modification of human genetic integrity.
  OR
- Access and cost may be unequal, creating **ethical inequality** in who can receive such therapy.

(Any one ethical concern earns 2 marks.)

(ii) One potential benefit (2 marks)

- Artificial gland implants can **restore normal secretion** (hormones, enzymes, mucus) for patients with damaged glands.
- This may reduce dependency on lifelong medication, improving quality of life.

(iii) How a biologist should respond when evidence contradicts their assumptions (2 marks)

A biologist should:

- **Re-evaluate their hypothesis** and accept that scientific conclusions must follow evidence.
- **Adjust interpretations** and redesign experiments rather than holding onto incorrect assumptions.
- Maintain **scientific objectivity**, openness, and integrity.

Item 5

(a) Justify the village health team's observation as regards the health status of the citizens

The village health team (VHT) attributes the citizens' respiratory and circulatory health problems to the use of charcoal for cooking in poorly ventilated kitchens. This observation is justified by the following:

1. High carbon monoxide (CO) levels in households

Table 4 shows that enclosed kitchens with no ventilation have CO levels of 350 ppm, which is extremely high.

CO binds strongly to haemoglobin to form carboxyhaemoglobin, reducing oxygen transport.

2. Reduced oxygen-carrying capacity of blood

Table 3 shows Katanga residents have:

Low blood oxygen saturation (75–85%) compared to 98% in normal individuals.

Low oxyhaemoglobin levels (65–70%) compared to 99% in normal individuals.

High carboxyhaemoglobin levels (20–30%), whereas normal is $<1\%$.

This clearly indicates CO poisoning from charcoal smoke.

3. Compensatory increase in breathing and heart rate

Due to reduced oxygen available to tissues:

Respiratory rate increases to 28/min (normal is 16/min).

Pulse rate increases to 100–120 bpm (normal is 70 bpm)

These are physiological responses to hypoxia, confirming impaired respiratory and circulatory function caused by exposure to charcoal smoke.

4. Higher health complaints correlate with poor ventilation

Households with no ventilation report 70% health complaints, compared with only 10% in outdoor cooking.

This shows a direct relationship between poor ventilation, high CO levels, and increased illness.

Conclusion:

The medical data, increased CO levels, reduced oxygen saturation, and high reported illness all support the VHT's observation that charcoal use in poorly ventilated kitchens is causing respiratory and circulatory health complications.

(b) Practical measures to mitigate the reported health complications

1. Improve kitchen ventilation

Build windows, vents, or open eaves to allow smoke to escape.

Encourage construction of chimneys as shown by reduced CO (80 ppm) in such homes.

2. Promote outdoor cooking

Cooking outside reduces CO concentration drastically (to 25 ppm) and minimizes inhalation of smoke.

3. Transition to cleaner energy sources

Encourage the community to use:

Gas stoves (LPG)

Electric cookers

Improved biomass stoves that produce less smoke

4. Public health education

Sensitize residents about dangers of carbon monoxide poisoning.

Educate on early symptoms (headache, dizziness, shortness of breath).

5. Regular monitoring of indoor air quality

Routine checks for carbon monoxide levels.

Early detection can prevent severe poisoning.

6. Planting trees and improving general air quality

Trees increase oxygen availability and reduce air pollutants.

7. Medical interventions

Provide medical check-ups for vulnerable groups such as children and pregnant women.

Treat suspected CO poisoning early with oxygen therapy

Item 6

(a) Curve type, what it shows, which athlete's curve is shifted and why that helps (8 marks)

Answer (8 marks)

1. **Type of curve (2 marks)**
   - The relevant plot is the **oxygen–haemoglobin dissociation curve**, which is **sigmoid (S-shaped)**. (1)
   - The sigmoid shape reflects **cooperative binding**: binding of one O_2 to haemoglobin increases the affinity for the next O_2 molecules. (1)
2. **What the curve shows about oxygen binding (2 marks)**
   - At high partial pressures of O_2 (e.g., in the lungs) haemoglobin is highly saturated with O_2 (steep upper part → high loading). (1)
   - At lower PO_2 (e.g., in active muscle) the right-hand, steep portion means small drops in PO_2 cause large O_2 release (unloading). (1)
3. **Which athlete's curve is shifted and why that helps (4 marks)**
   - **Kato's curve is shifted to the right** compared with Angel's (1). This means Kato's haemoglobin has **lower affinity** for O_2 at any given PO_2 and therefore **releases O_2 to tissues more easily** (1).
   - A right shift can be produced by physiological factors common in highlanders: **higher 2,3-BPG (2,3-diphosphoglycerate) in RBCs, slight increases in temperature, and chronic exposure to elevated CO_2 or mild acidity** — all reduce Hb affinity and promote unloading. (1)
   - **Why this helps at high altitude:** ambient PO_2 is lower, so easier unloading at the muscle (despite a lower arterial PO_2) improves O_2 delivery to working muscle and helps sustain performance. (1)

(Marks: 2 for curve type/coop, 2 for explanation of binding/loading/unloading, 4 for identifying right shift + mechanism + functional benefit.)

(b) Prediction if Angel's blood became more acidic during intense exercise + ethics of artificial induction (7 marks)

Answer (7 marks)

1. **Physiological prediction (4 marks)**
   - **Acidosis (lower pH)** produces the **Bohr effect**, shifting the O_2–Hb curve **to the right**. (1)

- This **increases O_2 unloading** at active muscles which can **improve local O_2 delivery** and momentarily help performance. (1)
- **However** excessive acidosis (high $[H^+]$) also reduces Hb affinity for O_2 in the lungs, potentially **reducing arterial O_2 saturation**, especially at altitude where lung PO_2 is already low this may **limit VO_2max and endurance**. (1)
- Additionally, systemic acidosis impairs muscle contractility and enzymatic metabolism (inhibits glycolytic enzymes, causes fatigue), so overall performance may **fall if acidosis is severe**. (1)

2. **Ethical/fairness discussion about artificial methods (e.g., blood doping) (3 marks)**
   - **Fairness:** Artificially inducing a right shift (by blood manipulation or doping) is **unfair** because it gives an athlete an unnatural competitive advantage over others who follow rules. (1)
   - **Health risks:** Methods such as blood transfusions or drugs that alter blood chemistry carry **serious medical risks** (clotting, infections, cardiac strain). (1)
   - **Regulation and ethics:** Sports authorities ban blood doping; it violates the spirit of fair play and informed consent if athletes are pressured into it. Thus it is **unethical** and should not be used. (1)

(Marks: 4 for balanced physiological prediction (benefit vs harm), 3 for ethical/fairness/health/regulatory point.)

(c) Why scientists must remain objective and evidence-driven when comparing physiological adaptations (5 marks)

Answer (5 marks)

1. **Avoid bias and premature conclusions (2 marks)**
   - Scientists must not assume that one observed trait (e.g., performance) is caused solely by a single adaptation many confounding factors exist (training history, hydration, nutrition, genetics, illness, measurement error). (1)
   - Remaining objective prevents misattribution and faulty generalisation from a small sample. (1)
2. **Use rigorous methods and reproducible evidence (2 marks)**
   - Use controls, adequate sample sizes, statistical analysis, repeat experiments, and peer review to confirm findings before claiming adaptation differences. (1)
   - Consider alternative explanations and test them — e.g., measure 2,3-BPG, haemoglobin concentration, VO_2max, capillary density rather than infer from performance alone. (1)
3. **Scientific integrity and ethical reporting (1 mark)**
   - Report results honestly, acknowledge uncertainty, and update hypotheses when new data contradict initial assumptions. (1)

(Marks: 2 for bias/avoidance, 2 for methods/reproducibility, 1 for integrity.)

summary

- (a) **O_2–haemoglobin dissociation curve (sigmoid); Kato's curve is shifted right allowing easier O_2 unloading at low PO_2, helping at altitude.**
- (b) **Acidosis shifts curve right (Bohr effect) may help unloading but excessive acidosis lowers arterial O_2 saturation and impairs muscle function; blood doping to induce such shifts is unethical, unsafe, and banned.**
- (c) **Scientists must be objective, control confounders, use reproducible measurements, and let data drive conclusions**

ITEMS

SECTION A

ITEM 1:

Tom is a prominent farmer dealing in citrus fruits in Kawogo village. He has recently had a decrease in yield as a result of yellowing, and drying of citrus plants, yet he always invest alot of money in his Ochard plantation. The agriculture officer diagonized plants and found roots rotting with black patches. The agriculture officer told Mr. Tom that a fungal disease mainly affecting roots was affecting his citrus plants.

Tasks

a) Identify the tissues affected in the infected organ of the citrus plants.

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b) Explain how any two of the above tissues adapted for their role.

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ITEM 2:

During a scientific investigation, each student was given 50 micro meter long specimen. After observing using a light microscope, one of the students made a drawing of the specimen which was 20mm long. The student got stack because he was unable to find magnification.

Tasks:

a) Help the student understand the meaning of magnification and coming up with the magnification of the drawing.

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b) Mention the advantages of using the microscope that was used by students.

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ITEM 3

Jane was sweeping amidst the moving wind. She later coughed mucus containing dust and she was surprised that dust did not enter one of her vital organs.

(a) Help her understand what happened.

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(b) Identify the organ that was most likely to be affected by the dust.

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(c) Explain how any one tissue in the above-named organ able to perform its role.

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SECTION B

ITEM 4.

In one of the investigations to determine effect of inhibitors on enzyme-controlled reaction, John used a combination of amylase enzyme and egg solution while Simon used amylase enzyme and starch solution. The teacher said that John's combination would not give any accurate result because amylase enzyme does not break down eggs.

Tasks

a) Help John understand why his combination could only give false results.
b) Explain how the different types of the factor under investigation affect enzyme activity and how they can be overcome if possible.

ITEM 5:

The bodies of organisms have many chemicals of life. These enable organisms survive successfully on planet earth. It has been observed that fats are a common food store in many organisms living in cold environments and desserts.

Tasks: Explain the observations in the scenario and how are fats formed in the bodies of living organisms.

ITEM 6

A detergent company tests a bacterial enzyme (*Lipase-X*) that breaks down oil stains. During trials, adding a surfactant reduces stain removal. The enzyme works best at 40°C and pH 7. Lab results show how temperature, pH, and the surfactant affect enzyme activity.

Data:

Condition	Enzyme Activity (%)	Stain Removal Score (/10)
40°C, pH 7, no surfactant	100	9
40°C, pH 7, with surfactant	45	4
60°C, pH 7, no surfactant	20	2
40°C, pH 9, no surfactant	30	3

Microscopy confirms the bacteria producing the enzyme are prokaryotic with many ribosomes.

Adapted: *Industrial Biotechnology for Schools* (2023). "Enzymes in Detergents."

Task:

(a) Explain why the surfactant lowers enzyme activity and why temperature or pH changes reduce performance.

(b) Suggest how to reformulate the detergent to improve stain removal without harming enzyme function.

ITEM 2

A biotech firm produces insulin using genetically modified *E. coli*. Some batches yield little insulin due to errors in DNA replication. Data compares plasmid copy numbers, insulin yield, and DNA polymerase mutation rates across batches.

Data:

Batch	Plasmid Copies per Cell	Insulin Yield (mg/L)	DNA Polymerase Error Rate (%)
A	50	120	0.1
B	15	30	5.2
C	45	110	0.3

Electron microscopy shows abnormal nucleoid regions and fewer ribosomes in low-yield batches.

Adapted: *Basic Biotechnology Review* (2023). "Insulin Production Using GM Bacteria."

Task:

(a) Explain how DNA replication errors reduce insulin production.

(b) Propose quality checks to ensure consistent insulin yields.

ITEM 7

Coral reefs are bleaching due to industrial pollution containing cyanide, which inhibits mitochondrial respiration. Researchers expose coral fragments to cyanide and measure ATP production, oxygen use, and bleaching.

Data:

Cyanide (ppm)	ATP Production (%)	O_2 Use (mg/L/h)	Bleaching Observed?
0	100	8.5	No

0.5	60	4.8	No
2.0	20	1.9	Yes
5.0	5	0.5	Yes

Microscopy shows swollen mitochondria with damaged cristae in bleached coral.
Adapted: *Marine Science for Schools* (2023). "Cyanide Pollution in Coral Reefs."

Task:
(a) Explain how cyanide reduces ATP production and leads to coral bleaching.
(b) Suggest a monitoring and prevention plan to protect reefs from cyanide pollution.

ITEM 8
Scientists develop a flu vaccine by inserting a viral protein gene into tobacco plants. Some GM plants produce little vaccine protein despite high mRNA levels. Data show mRNA levels, protein yield, and chloroplast health in different plant lines.
Data:

Plant Line	Vaccine mRNA Level	Vaccine Protein (mg/g leaf)	Chloroplast Health (%)
Normal	10	0	98
GM Line 1	85	12	95
GM Line 2	15	1	70
GM Line 3	90	0.5	40

Microscopy reveals damaged chloroplasts in low-protein GM lines.
Adapted: *Plant Biotechnology Journal* (2023). "Molecular Farming in Plants."

Task:
(a) Explain why high mRNA does not always lead to high protein yield in GM plants.
(b) Recommend changes to improve vaccine production without damaging plant health.

ITEM 9
A wastewater plant's bacteria are struggling to break down organic waste due to a new pollutant that inhibits a key respiratory enzyme. The table shows how pollutant concentration affects enzyme activity, ATP production, and bacterial growth.
Data:

Pollutant (mg/L)	Enzyme Activity (%)	ATP Production (%)	Cell Division Rate (/h)
0	100	100	0.8
10	70	75	0.6
50	30	35	0.2
100	10	12	0.05

Microscopy shows irregular cell shapes and incomplete division in affected bacteria.
Adapted: *Water Treatment Basics* (2023). "Enzyme Inhibition in Wastewater Bacteria."

ITEM 10

Cystic Fibrosis is a genetic disease caused by a faulty ion channel protein, leading to thick mucus that blocks ducts and tubes lined with epithelium. In the pancreas, this blocks the release of digestive enzymes. A researcher is studying how the resulting nutrient malabsorption affects cellular respiration in intestinal epithelial cells.

Table: Analysis of Intestinal Epithelial Cells in a CF Model

Cell Parameter	Cystic Fibrosis Model	Healthy Model
Thickness of mucus layer	150 µm	50 µm
Glucose absorption efficiency	30%	95%
Pyruvate Dehydrogenase Activity	Low	Normal
Mitochondrial ATP Output	Low	Normal

Task:

(a) Analyse the sequence of events, from the faulty protein to the thick mucus, and finally to the reduced ATP output in the intestinal epithelial cells, explaining the role of glucose and pyruvate dehydrogenase.

(b) Justify a nutritional supplement strategy that could bypass the blocked digestive enzymes and provide substrates to support the aerobic respiration of the gut epithelium.

ITEM 11

In Karamoja, farmers are testing sorghum and amaranthus for drought resistance.
During prolonged dry spells, sorghum stays green and continues growing, while amaranthus wilts rapidly and shows reduced leaf area.
Scientists recorded data on leaf anatomy, chloroplast density, stomatal behaviour, and water content of both plants under the same conditions.
Data

Plant	Leaf Type	Average Leaf Water Content (%)	Chloroplasts per Mesophyll Cell	Average Stomatal Opening (μm)	Photosynthetic Pathway
Sorghum	Narrow with thick cuticle	80	60	2.0	C_4
Amaranthus	Broad with thin cuticle	55	38	4.5	C_3

Reference: ***"Drought Adaptations and Photosynthetic Pathway Efficiency in Tropical Crops, Journal of Plant Ecology (2022)."***
Task:
Using the information provided,
(a) Explain the physiological reasons why sorghum survives better than amaranthus under drought.

(b) Propose strategies to enhance drought resistance of amaranthus in Karamoja.