A'LEVEL CBC BIOLOGY ITEM BANK

WITH MODEL RESPO

NSES

A Route To Excellence THE COMPETENCY BASED CURRICULUM

FOREWORD

This A' Level CBC Biology Item Bank is designed to make advanced Biology both accessible and intell ectually stimulating. Each task is carefully structured to align with competency-based assessment, p romoting 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 reinf orce their understanding independently.

The accompanying responses are precise and technically grounded, modeling the reasoning process es 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, insi ghtful, and deeply rewarding.

It is my hope that this item bank will inspire both learners and teachers to approach Biology with cur iosity, 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 t oward scientific competence and lifelong intellectual growth.

SECTION ONE

(Items with responses)

The following compilation presents scenario-based items with detailed responses, demonstrating th e 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 biologis t, Dr.

Hakeem, collects tissue samples from affected damselfish. Cyanide is a potent inhibitor of cytochro me 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 eco friendly net fishing so fishermen can earn income without harming reefs.*
- ***Coral reef restoration**: Establish coral nurseries, transplant resilient corals to damaged area*

s, and protect reef zones to help fish populations recover.

<u>Research and monitoring</u>: Regularly test water for cyanide, track fish health, and assess ree f recovery to guide management decisions and prevent future damage.

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

<u>Task</u>

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

- ***The property is <u>high surface tension of water</u>, produced by strong cohesive hydrogen bonds between water molecules at the surface. This creates a resistant film that supports small o rganisms and materials. Ecologically, this allows surface-dwelling insects to forage and esc ape 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 it s importance for plant survival.

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

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

- ***<u>Density anomaly and freezing properties of water;</u> The formation of ice on the surface of w ater 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 floa ts and forms an insulating layer at the surface. This insulation reduces heat loss from the u nderlying water, maintaining liquid conditions and stable temperatures that allow aquatic or ganisms to remain alive during cold seasons.***

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

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

cells to absorb sufficient light energy for carbon fixation, ensuring continuous primary producti vity in aquatic habitats.

3. Early research on the structure of the cell membrane showed that lipid-soluble compounds pa ssed rapidly into cells. The membrane was found to be selectively permeable to mineral ions, sug ars and amino acids. Further work demonstrated that all membranes have the same basic struct ure but can differ greatly in the types of lipid and protein they contain. Many of the specialized pr oteins present provide a means of communication between cells and molecules in their environm ent. (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 tha n 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 th e movement of these excluded molecules, the membrane incorporates specific transport pr oteins; such as channels, carriers, and pumps; that recognize and move only particular ion s, sugars, or amino acids. Together, this enables the cell to regulate substance movement a nd 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 anti gens, and initiate intracellular responses. The carbohydrate chains of glycoproteins and gly colipids allow cells to recognize, adhere to, and interact with other cells, enabling coordinat ed 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 photo synthesis occur on enfolding's of the plasma membrane. Eukaryotes possess numerous me mbrane-bound structures, including the nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, and in plants, chloroplasts. These compartments allow specializa tion 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, di srupting essential cellular processes such as respiration and protein synthesis.***
  Receptor proteins that are damaged cannot detect extracellular signals, so the cell cannot r espond to its environment.
- ***Membrane-bound enzymes lose their activity if proteins are damaged, slowing vital bioche mical reactions.***
- ***Damaged glycoproteins and glycolipids impair cell recognition and adhesion, preventing pr oper interactions with other cells.***

4. Farmers in Mbale (Mt. Elgon slopes) and Gulu (Northern Uganda) reported contrasting yields of b eans and sorghum. Beans thrive in Mbale but fail in Gulu, while sorghum thrives in Gulu but shows y ellowing 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 tem perature (°C)**	**Rainfall (mm/year)**	**Dominant vegeta tion**	**Type of le af anatomy**	**Rate of CO_2 uptak e** (μmol m^{-2} s^{-1})	**Main excr etory produ ct**
Mbale	1600	20	1500	Bananas, Beans	No Kranz	18	Latex
Gulu	900	33	700	Acacia, So rghum	Cranz pre sent	32	Oils

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

Adapted: "Comparative analysis of C_3 and C_4 crop adaptations in East Africa". African plant sc ience 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 (150 0 mm) favor CO_2 fixation, supporting good growth. In Gulu, high temperature (33 °C) and lo w 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 i s released for the Calvin cycle. This concentrates CO_2 around RuBisCO, minimizing photore spiration and allowing efficient photosynthesis under high temperature, intense light, and l ow water. Sorghum thrives in Gulu, while cooler, wetter conditions in Mbale reduce its effici ency, 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 photoresp iration.***
- ***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 d uring 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 gree nhouse 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 carbohydrat e accumulation, leading to low harvests.

The manager is unsure why sugar production dropped and wonders whether installing even brighter l ights 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 conc entration. CO_2 is the substrate for RuBP carboxylase in the Calvin cycle, so a lower CO_2 conc entration reduces the rate at which RuBP is carboxylated to 3-phosphoglycerate. This molec ule 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 decrease d progressively, reducing sugar accumulation in the leaves despite sufficient ATP and NAD PH 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 fi x enough carbon to form 3-phosphoglycerate. Even though the light reactions supply suffici ent ATP and NADPH, the low CO_2 restricts the production of triose phosphates and hence su gars. 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.

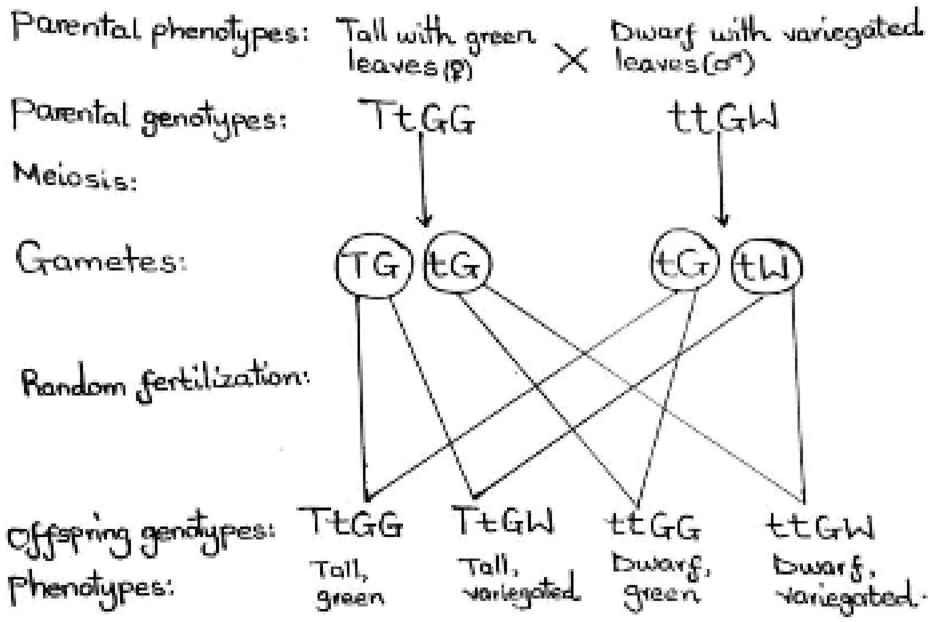
The farmer crosses a tall plant with green leaves with a dwarf plant with variegated leaves. Some offspring grow well, while others fail to survive.

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.



<u>*Survival chances*</u>

- ***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:

<u>Support material</u>

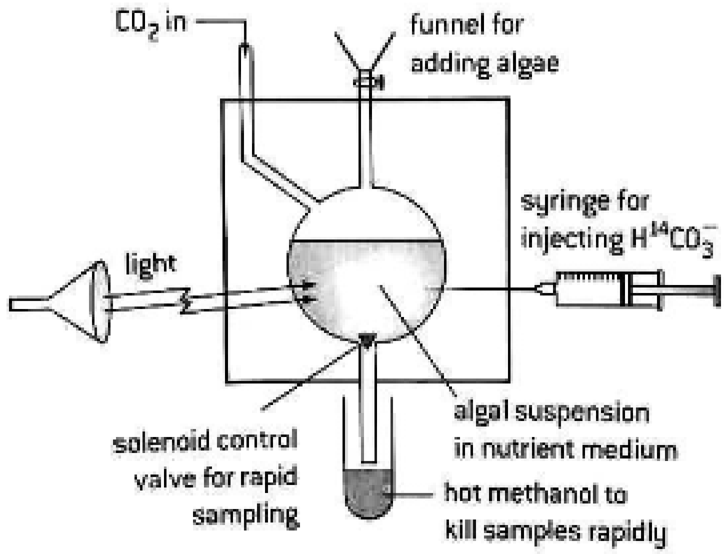


Table of results

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 ¹⁴C 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 det ected in amino acids.

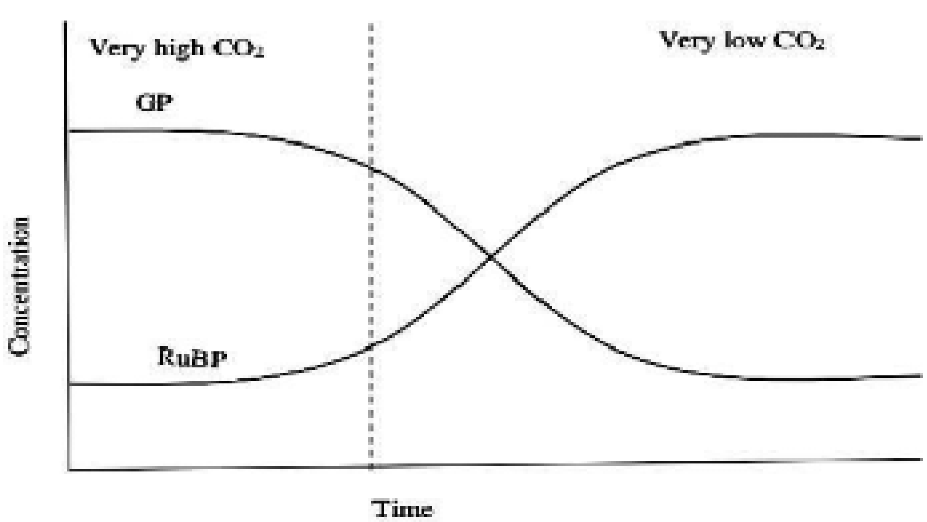
(b) (b) Suggest why the experiment was carried out in the presence of light, even though it studie s the light-independent reactions.

- ***Even though the experiment investigates light-independent reactions, these reactions rely o n 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 i ntermediates, while NADPH supplies the reducing power to convert 3-phosphoglycerate int o phosphoglyceraldehyde.***
- ***Conducting the experiment in light ensures a continuous supply of ATP and NADPH, allowin g 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 h igh-protein feed for livestock and aquaculture.***
- ***Its high lipid content makes it a potential source for biofuel production, contributing to rene wable energy solutions.***
- ***Chlorella can absorb excess nutrients from wastewater, helping in water treatment and envir onmental management.***
- ***It serves as a model organism in research, especially to study photosynthesis and carbon fi xation, 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-min utes 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 ca rbon 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 gra ph above in which he asked you to;

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

- ***<u>At high CO_2 levels</u>: 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 wa ter, producing large amounts of GP during the Calvin cycle. Continuous regeneration of RuB P kept the cycle active, but its instantaneous concentration appeared lower as it was being r apidly used.***
- ***<u>At low CO_2 levels</u>: The concentration of RuBP became high while GP decreased. This occurr ed 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 a nd RuBP, suggest and explain one practical application of this knowledge.

- ***The knowledge can be applied in agriculture to optimize photosynthesis and increase crop p roductivity; Farmers can grow crops in greenhouses where CO_2 levels are enriched above a mbient concentrations. Higher CO_2 ensures more RuBP is carboxylated, increasing GP form ation and enhancing the Calvin cycle's efficiency, which boosts the production of sugars an d starch. This leads to faster plant growth, higher biomass accumulation, and improved yiel ds, 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 fro m 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 therap y.

<u>Task</u>:

(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 hemoglob in level to 17.2 g/dL, increasing the oxygen-carrying capacity of blood and improving oxyge n 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 t he race.

- *Altitude training strengthened her heart, increasing stroke volume so it could pump more bl ood 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 ef ficiently at altitude.*
- *Her rapid CO_2 clearance and return to normal breathing (3 min) resulted from acclimatizatio n increasing hemoglobin and capillary density, which improved oxygen delivery to muscles a nd the oxidation of lactic acid, allowing faster removal of CO_2.*
- *Adequate oxygen supply during recovery allowed faster oxidation of accumulated lactic aci d, reducing fatigue and speeding recovery.*

<u>Peter had moderate performance due to lack of altitude adaptation;</u>

- *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 th an Sarah.*
- *His recovery was slower (10 min) because his respiratory system is not adapted for rapid C O_2 removal at low oxygen pressure.*
- *Reduced oxygen delivery after the race slowed the oxidation of lactic acid, prolonging his fa tigue 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 avail able hemoglobin for oxygen binding and directly lowering oxygen saturation to 82%.*
- *Carbon monoxide also increases hemoglobin's affinity for oxygen, making it difficult for tis sues 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 l ong 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 hemo globin production and capillary density, improving oxygen delivery to muscles during exerci se.*

- ***Recovery from carbon monoxide exposure: Avoiding carbon monoxide sources and allowing full recovery ensures hemoglobin is available for oxygen transport, restoring effective oxygen delivery to tissues.***
- ***Cardiovascular conditioning: Regular endurance training strengthens the heart, increases stroke volume, and reduces the heart rate response during high-intensity activity.***
  Respiratory training: Breathing exercises or controlled hypoxic exposure can enhance ventilator sensitivity, improving CO_2 clearance and oxygen uptake during exertion.
- ***Nutrition and oxygen support: 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.

Task

(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.

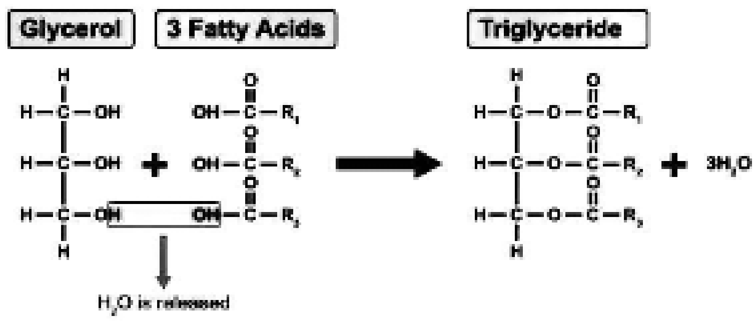
- ***Bile contains salts such as sodium glycocholate and sodium taurocholate, as well as sodium bicarbonate ($NaHCO_3$).***
- ***The alkaline bicarbonate neutralizes acidic chyme entering the duodenum, maintaining an o***

ptimal 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.

Amino acids from protein digestion play the following roles in animal bodies;

- ***Protein synthesis**: Amino acids are the building blocks for all proteins, including structural proteins, enzymes, and transport proteins, supporting growth, tissue repair, and overall physiological function.*
- ***Buffering of body fluids**: 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.*
- ***Precursor for nitrogenous compounds**: Amino acids supply nitrogen for the synthesis of hormones, neurotransmitters, and nucleotides, which are essential for regulation and signaling in the body.*
- ***Energy production**: Amino acids can be deaminated to produce carbon skeletons that enter the Krebs cycle, providing energy (ATP) during periods of high demand or fasting.*
- ***Support for enzymes and hormones**: Amino acids contribute to the formation of enzymes and hormones, ensuring that metabolic reactions and physiological signaling occur efficiently.*
- ***Immune function**: 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.

Table: Systemic Effects of the Bacterial Toxin

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.