Past-paper walk-through

Cellular Respiration ▪ 3.5

eXercise

Questions in this set

- 2026 Q3
- 2024 Q2
- 2023 Q2
- 2021 Q3
- 2019 Q3
- 2017 Q5
- 2017 Q7
- 2016 Q3
- 2015 Q2

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

2026 ▪ Q3

Cyanide is a chemical that affects the enzyme cytochrome *c* oxidase (CCO), a key enzyme in the mitochondrial electron transport chain. At high cyanide concentrations, CCO activity is much lower than when no cyanide is present. At low concentrations of cyanide, CCO activity is slightly higher than when no cyanide is present, as shown in Table 1.

Table 1. Effects of Cyanide on CCO Activity

No Cyanide	Low Cyanide	High Cyanide
Normal CCO activity	Slightly increases CCO activity	Greatly decreases CCO activity

Question 3

Some strains of bacteria produce cyanide, which they then release into their environment. Other strains of bacteria do not produce cyanide. Researchers grew both types of bacteria in high-concentration nutrient medium and then isolated the medium from the bacteria. One-half of each medium sample was left at a high concentration, while the concentration of the other half was lowered.

To study the effects of cyanide on mammalian cells, researchers then added the four samples of media to the cells growing in culture dishes, as shown in Table 2. They measured ATP and lactic acid production by the mammalian cells in each of the four treatment groups.

Table 2. Experimental Design to Test Effects of Cyanide on Mammalian Cells

Mammalian Cell Treatment Group	Cyanide in Nutrient Medium?	Concentration of Medium
1	Yes	High
2	Yes	Low
3	No	High
4	No	Low

Question 3

(a) Describe the advantage to cells of producing ATP from one molecule of glucose by aerobic cellular respiration rather than by glycolysis alone.
(b) Identify the two treatment groups that served as controls in the researchers' experiment.
(c) Based on the information provided in both tables, **predict** the treatment group that is likely to have the highest ATP production of all four treatment groups.
(d) The researchers claim that cells in which CCO activity is inhibited will show an increase in lactic acid production. **Support** the researchers' claim.

Question 3

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Question 3

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Question 2

2024 ▪ Q2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

(a) Describe the role of water in the hydrolysis of ATP.

Question 2

2024 ▪ Q2

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Question 2

(b)(i) Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled.

(b)(ii) Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25°C.

Question 2

2024 ▪ Q2

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(c)(i) Based on the data in Table 1, **describe** the effect of temperature on the rate of ATP synthesis in liver cells from toads.

Question 2

(c)(ii) Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25°C.

Question 2

2024 ▪ Q2

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Question 2

(d)(i) Oligomycin is a compound that can block the channel protein function of ATP synthase. **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane.
(d)(ii) Justify your prediction.

Solution 2

(a)

Mark scheme

- Water is added to (and used to break) the bond during hydrolysis — water is added in the process of cleaving/splitting a phosphate group from ATP (water breaks down/splits ATP into ADP + inorganic phosphate).

Solution 2

(b)(i) Mark scheme

- This is a construct-a-bar-graph task; the 3 points reward: (1) the data are represented as a bar graph, (2) the graph is appropriately labeled (axes titled with quantity and units — e.g., Rate (nmol/min/mg of mitochondrial protein) vs. Metabolic Marker/Temperature — with a legend distinguishing the three temperatures 20°C/25°C/30°C or the two markers Oxygen Consumption/ATP Synthesis), and (3) the data points/bars and their error bars are plotted at the correct values from Table 1: Rate of Oxygen Consumption = 12.8 ± 2.2 (20°C), 16.5 ± 2.0 (25°C), 22.1 ± 0.7 (30°C) nmol/min/mg; Rate of ATP Synthesis = 12.6 ± 1.6 (20°C), 16.8 ± 2.0 (25°C), 21.07 ± 0.8 (30°C) nmol/min/mg. Grade a student's bar graph against these three criteria.

Solution 2

(b)(ii)

Mark scheme

- 30°C. The rate of oxygen consumption at 30°C (22.1 ± 0.7) does not overlap with the rate at 25°C (16.5 ± 2.0), while the rate at 20°C (12.8 ± 2.2) overlaps within error with the rate at 25°C, so only 30°C is clearly different.

Solution 2

(c)(i)

Mark scheme

- As temperature increases, the rate of ATP synthesis also increases — there is a positive relationship (temperature and ATP synthesis rate are directly correlated), rising from 12.6 nmol/min/mg at 20°C to 16.8 at 25°C to 21.07 at 30°C.

Solution 2

(c)(ii)

Mark scheme

- 1,650 nmol. Calculation: 16.5 nmol/min/mg (rate of O2 consumption at 25°C) $\times$ 10 mg mitochondrial protein $\times$ 10 min = 1,650 nmol.

Solution 2

(d)(i)

Mark scheme

- The proton gradient will increase/become steeper (and may eventually plateau) — equivalently, the difference in proton concentration/pH across the inner mitochondrial membrane will increase, with an increase in proton concentration (decrease in pH) in the intermembrane space relative to the matrix.

Solution 2

(d)(ii)

Mark scheme

- Without protons being able to flow back into the matrix through ATP synthase (blocked by oligomycin), more protons will accumulate in the intermembrane space/between the two mitochondrial membranes, lowering the pH there, because the electron transport chain continues pumping protons into the intermembrane space even though they can no longer flow back through ATP synthase.

Question 2

2023 ▪ Q2

Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).
TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO_2
| Species | Mitochondria at Normal CO_2 (per 100 μm^2 of cell area) $\pm 2SE_{\bar{x}}$ | Mitochondria at Elevated CO_2 (per 100 μm^2 of cell area) $\pm 2SE_{\bar{x}}$ | |—|—|—| | 1 |

Question 2

1.0 ± 0.10 | 1.6 ± 0.10 | | 2 | 0.4 ± 0.05 | 0.9 ± 0.08 | | 3 | 0.5 ± 0.07 | 0.9 ± 0.10 | | 4 | 0.3 ± 0.03 | 0.6 ± 0.06 | | 5 | 0.7 ± 0.06 | 1.5 ± 0.22 | | 6 | 1.3 ± 0.15 | 2.4 ± 0.22 |

(a) Describe the role of the inner mitochondrial membrane in cellular respiration.

Question 2

2023 ▪ Q2

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6	1.3 ± 0.15	2.4 ± 0.22

Question 2

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2.

Question 2

2023 ▪ Q2

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Question 2

(c) Based on the data in Table 1, **describe** the relationship between the level of CO_2 and the average number of mitochondria per unit area of a cell.

Question 2

2023 ▪ Q2

Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).

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Question 2

(d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. Provide reasoning to **justify** your prediction. **Explain** why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO_2.

Solution 2

(a)

Mark scheme

- The inner mitochondrial membrane houses the electron transport chain components and ATP synthase, i.e., it is the site of oxidative phosphorylation. By separating the intermembrane space from the matrix, it allows a proton ($H+$) gradient to be established across it as electrons move through the ETC; this gradient then drives ATP synthesis via chemiosmosis through ATP synthase.

Solution 2

(b) Mark scheme

- Construct a bar graph (or modified/grouped bar graph) with the six plant species (1–6) on the x-axis and average number of mitochondria (per 100 μm^2 of cell area) on the y-axis, with appropriate axis labels/units and a legend distinguishing normal-CO2 bars from elevated-CO2 bars. Plot each species' two data points (normal and elevated CO2) at the values given in Table 1, each with error bars representing $\pm 2SE(\bar{x})$ as listed in the table (e.g., species 1: 1.0 ± 0.10 normal, 1.6 ± 0.10 elevated; species 6: 1.3 ± 0.15 normal, 2.4 ± 0.22 elevated). Points earned for: appropriate labeling; using a bar/modified bar graph format; correctly plotting the data points and error bars. Determine which species show a difference in mitochondria number between normal and elevated CO2: all six species (1

Solution 2

through 6) show a difference — every species has a higher (non-overlapping, given the error bars) mitochondria count under elevated CO2 than under normal CO2.

Solution 2

(c)

Mark scheme

- There is a positive relationship between CO2 level and the average number of mitochondria per unit cell area: the number of mitochondria is greater under elevated CO2 conditions than under normal CO2 conditions (across the species examined).

Solution 2

(d) Mark scheme

- Prediction: the offspring from this cross (pollen from the white-striped-leaf plant $\times$ ovules from the green-leaf plant) will all have green leaves (will not have white stripes). Justification: mitochondria (and mitochondrial DNA) are maternally inherited — they are transferred to offspring through the ovule/egg cytoplasm, not through the pollen — so all offspring inherit the mitochondrial genotype of the green (ovule-producing) parent, whose mitochondria are functional for chloroplast development. Separately, explain why plants with the same (nuclear) genotype can still differ in the structure and/or number of certain organelles in response to CO2: because changes in CO2 levels (the environment) affect the expression of certain genes — i.e., environmentally-induced differences in gene expression (not

Solution 2

differences in genotype) drive differences in organelle structure/number, such as the increase in mitochondria number seen at elevated CO2.

Question 3

2021 ▪ Q3

Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add the resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.

(a) Describe the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation.

(b) Identify an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment.

Question 3

(c) Predict the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars.

(d) The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** the claim.

Solution 3

(a)

Mark scheme

- The primary advantage of aerobic respiration over fermentation for a mammalian muscle cell is that more ATP (per glucose molecule) is produced by aerobic respiration.

Solution 3

(b)

Mark scheme

- An appropriate negative control (accept either): run the experiment without adding resveratrol (cells in culture medium alone); or treat the cells with DMSO alone (the solvent used to dissolve resveratrol, without the resveratrol itself). This isolates the effect of resveratrol itself from the effect of the solvent or of simply culturing the cells.

Solution 3

(c)

Mark scheme

- Predicted effect on short-term ATP production without glucose or other sugars (accept either): no ATP production; or reduced ATP production — because glycolysis/cellular respiration requires a sugar substrate to generate the ATP, NADH, and FADH2 that feed the electron transport chain.

Solution 3

(d)

Mark scheme

- Justification: because resveratrol stimulates production of electron transport chain components, more electrons can be transferred through the chain, so more oxygen is required as the final electron acceptor — hence oxygen consumption increases (provided glucose/substrate is not limiting).

Question 3

2019 ▪ Q3

The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

(a) Identify the cellular location where PDC is most active.

(b) Make a claim about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.

(c) PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

Solution 3

(a)

Mark scheme

- PDC (pyruvate dehydrogenase complex) is most active in the mitochondria, specifically the mitochondrial matrix, where pyruvate is converted to acetyl-CoA before entering the Krebs cycle.

Solution 3

(b) Mark scheme

- Glycolysis: Claim — no change in the amount of NADH produced by glycolysis. Reasoning — glycolysis occurs in the cytoplasm, before (upstream of) the PDC-catalyzed conversion of pyruvate to acetyl-CoA, so glycolysis continues normally and does not require PDC; its NADH output is unaffected. [1 point] Krebs (citric acid) cycle: Claim — decrease in the amount of NADH produced by the Krebs cycle. Reasoning — the Krebs cycle occurs after (downstream of) the PDC-catalyzed step in the pathway, using acetyl-CoA as its substrate; with PDC deficiency there is little/no acetyl-CoA available, so the Krebs cycle (and the NADH it generates) is greatly reduced/slowed down. [1 point]

Solution 3

(c)

Mark scheme

- The probability that the male offspring will have PDC deficiency is 0 (0%). The PDHA1 gene is X-linked. A male offspring receives his single X chromosome from his mother and his Y chromosome from his father. The mother is homozygous with no family history of the disorder, so both of her X alleles are normal (non-mutant); she can only pass a normal X to her son. The father's mutant X (which caused his own PDC deficiency) is never passed to a son (sons get his Y). Therefore the offspring cannot/will not have PDC deficiency — probability = 0.

Question 5

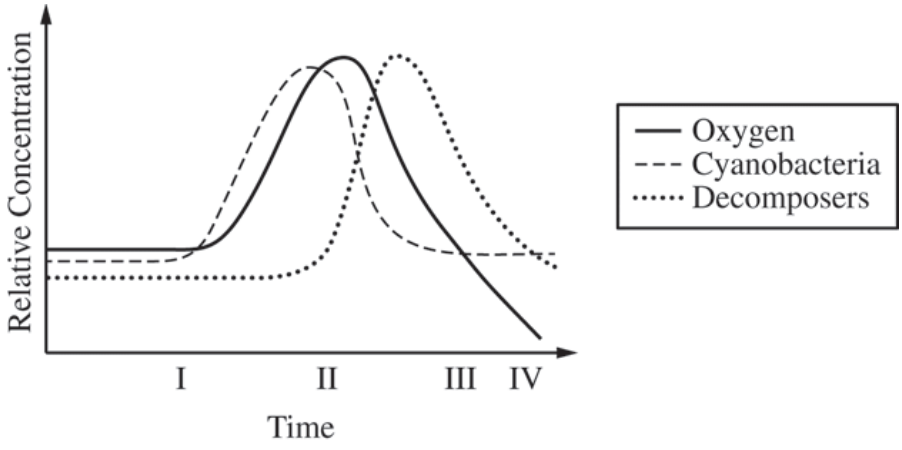
2017 ▪ Q5

[Figure 1: Line graph titled "Characteristics of a pond community over time." Y-axis: "Relative Concentration" (unscaled). X-axis: "Time", with four labeled time points I, II, III, IV. Legend shows three lines: solid = Oxygen, dashed = Cyanobacteria, dotted = Decomposers. The Cyanobacteria (dashed) curve starts at a low flat baseline, rises steeply to peak at time II, then declines back toward baseline by time III–IV. The Oxygen (solid) curve starts at a slightly higher flat baseline, stays flat until just before time II, rises to peak just after time II (slightly later/higher than cyanobacteria's peak), then declines steeply, dropping below the starting baseline by time IV. The Decomposers (dotted) curve starts at the lowest flat baseline, stays low through time II, then rises to peak between times II and III (later than both other curves), and declines gradually toward IV, remaining above its original baseline.]

Question 5

Microcystis aeruginosis is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, *M. aeruginosis* undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. *M. aeruginosis* has a short life span and is decomposed by aerobic bacteria and fungi. **Identify** the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between times I and II AND between times III and IV.

Question 5


Relative Concentration
I
II
III
IV
Time
Oxygen
Cyanobacteria
Decomposers

Solution 5

Mark scheme

- 2 points per time period. Time I–II: metabolic pathway = photosynthesis (1 point); organism = cyanobacteria (Microcystis aeruginosis) (1 point) — the bloom's photosynthesis raises dissolved oxygen as the cyanobacteria population rises to its peak at time II. Time III–IV: metabolic pathway = cellular respiration (1 point); organism = decomposers/fungi/bacteria (1 point) — after the bloom dies off, aerobic decomposers respiring the dead cyanobacteria consume oxygen, driving the oxygen concentration back down as the decomposer population rises.

Question 7

2017 ▪ Q7

Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.

Certain types of bacteria (e.g., *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.

(a) Identify the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque.

Question 7

(b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used.

Solution 7

(a)

Mark scheme

- Both points must come from the same row. Any one correctly matched pathway + acidic-product pair earns full credit: fermentation → (lactic) acid/lactate; OR anaerobic respiration → acid; OR glycolysis → (pyruvic) acid/pyruvate. S. mutans metabolizes sugar via this pathway, and the acidic product it generates lowers the pH in the anaerobic inner layers of plaque.

Solution 7

(b)

Mark scheme

- S. mutans decreases AND S. sanguinis increases — the alkaline toothpaste raises the pH between the teeth, removing the acidic environment that favored acid-tolerant S. mutans over the less acid-tolerant S. sanguinis.

Question 3

2016 ▪ Q3

[Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant. Line/area graph with y-axis "Percent Dry Weight" from 0 to 100 and x-axis "Time (weeks)" labeled May, June, July, August, with germination marked by an arrow at the start of May. Seven stacked bands (bottom to top at the start, May): Roots (largest band, filling most of the graph, shrinking from 100% at germination down to about 20–30% by June and staying around 20–30% through August), Stems (a thin band above roots), Leaves (a hatched band that grows from a small sliver at germination to become the dominant band by June–July, remaining large (roughly 40–60%) through July–August), Vegetative buds (a thin black band appearing briefly around late May–June, peaking near 45–50% total height around early June then narrowing and disappearing by July), Flowers (a dark gray band appearing from July onward, growing to roughly 15–25% of the total by August),

Question 3

Receptacles (a thin white band appearing in August above flowers), and Seeds (a stippled/dotted band appearing at the very top from late July through August, reaching the 100% line). The bands together always sum to 100% at every time point.] The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

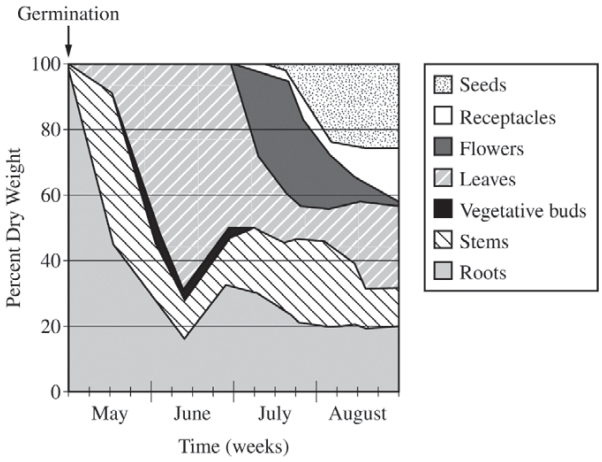
(a) Identify the direct source of the energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period.

(b) Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July.

Question 3

(c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants.

Question 3


Germination
100
80
60
40
20
0
Percent Dry Weight
May
June
July
August
Time (weeks)
Seeds
Receptacles
Flowers
Leaves
Vegetative buds
Stems
Roots

Solution 3

(a)

Mark scheme

- Direct source of energy during the first week of May (1 point): the seed - specifically its stored organic nutrients/carbohydrates. Plant part that grew the most during the same period (1 point): the roots.

Solution 3

(b)

Mark scheme

- Estimate (1 point): any value between 45 and 55 percent of total energy allocated to leaf growth on the first day of July, read from the stacked-area graph.

Solution 3

(c)

Mark scheme

- Proposed evolutionary advantage (1 point, any one): allocating a much greater percentage of energy to reproductive parts increases the annual plant's chance of reproducing before it dies (since it only lives one growing season); if it did not use this strategy, it would decrease the likelihood it would ever reproduce at all, whereas a perennial can afford to invest more in vegetative growth/storage because it gets multiple years/seasons to reproduce.

Question 2

2015 ▪ Q2

[Figure 1. Glycolysis and pyruvate oxidation: Glucose (chain of 6 circles) reacts with 2 ADP + 2 Pi and 2 NAD^+ to yield 2 ATP, 2 NADH, and 2 Pyruvate (chain of 3 circles). The 2 Pyruvate are converted to 2 CO_2, 2 NADH, and 2 Acetyl-CoA (chain of 2 circles).]

[Figure 2. Krebs cycle: 2 Acetyl-CoA (2 circles) enters a cycle; 2 OAA (4 circles) combines with it going into the cycle, producing 2 TCA (6 circles) coming out. Around the cycle: inputs 2 NADH and 2 $FADH_2$ feed in; outputs are 2 CO_2, 2 NADH (first turn), 2 GTP (bottom), and 2 CO_2, 2 NADH (second turn).]

[Figure 3. Electron transport chain: A membrane diagram showing Complex I, Complex II, Complex III, and Complex IV embedded in a phospholipid bilayer. NADH and NAD^+ enter at Complex I; 2 electrons ($2e^-$) pass from Complex I and Complex II to Complex III, then to Complex IV. H^+ ions are pumped across the membrane at

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Complex I, Complex III, and Complex IV (shown by upward H^+ arrows). At Complex IV, $\frac{1}{2}O_2$ combines (with H^+) to form H_2O.]
Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.
(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.
- Catabolism of glucose in glycolysis and pyruvate oxidation - Oxidation of intermediates in the Krebs cycle - Formation of a proton gradient by the electron transport chain

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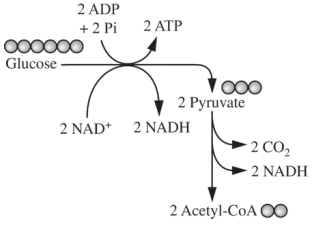


Figure 1. Glycolysis and pyruvate oxidation

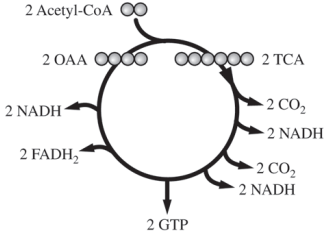
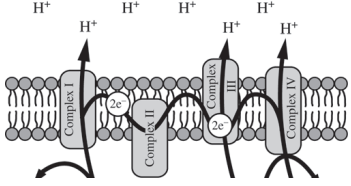


Figure 2. Krebs cycle



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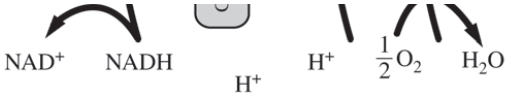

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(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

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(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

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(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

Solution 2

(a) Mark scheme

- 1 point per box, max 3 points. Catabolism of glucose in glycolysis and pyruvate oxidation: produces NADH for use in the electron transport chain (ETC), produces acetyl-CoA for entry into the Krebs cycle, and provides energy for substrate-level phosphorylation of ADP. Oxidation of intermediates in the Krebs cycle: produces NADH or FADH2 for use in the ETC, releases high-energy electrons for the ETC, provides energy to pump protons against their concentration gradient, and produces GTP via substrate-level phosphorylation of ADP. Formation of a proton gradient by the electron transport chain: the flow of protons through membrane-bound ATP synthase generates ATP, providing energy for oxidative phosphorylation of ADP.

Solution 2

(b) Mark scheme

- 1 point per box, max 3 points. Nearly all existing organisms perform glycolysis: the trait/gene/process originated early and was inherited/passed down/highly conserved because glycolysis provided a selective advantage passed on to descendants. Glycolysis occurs under anaerobic conditions: the origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis. Glycolysis occurs only in the cytosol: the origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis. Each observation is used to justify that glycolysis is ancient enough to trace to a common ancestor of all life.

Solution 2

(c)

Mark scheme

- 1 point per box, max 3 points. Calculate available energy in ATP: 30 mol ATP $\times$ 7.3 kcal/mol $=$ 219 kcal. Calculate efficiency: 219 kcal / 686 kcal $\approx$ 0.31–0.32, i.e., 31–32%. Describe fate of excess energy: the remaining energy ($686 - 219 \approx 467$ kcal) not captured in ATP is released as heat, which increases entropy.

Solution 2

(d)

Mark scheme

- 1 point for any valid, testable scientific question connecting the subcellular location of Krebs-cycle enzymes to the evolution of eukaryotes, e.g.: 'Since the Krebs cycle occurs in the "cytoplasm" of the mitochondria (the matrix), does this suggest that mitochondria were once free-living prokaryotes (i.e., arose via endosymbiosis)?' Any comparable question linking enzyme location to eukaryotic organelle origin earns the point.