1.10 Biology: Energy Transfers in Organisms

AQA 7402 · Calculator allowed · about 120 minutes · Write-in edition

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Glycolysis is the first stage of respiration and occurs in the cytoplasm of all living cells, whether or not oxygen is present.

(a) State the net number of ATP molecules produced per molecule of glucose during glycolysis, and explain why this net figure is lower than the total number of ATP molecules generated directly by substrate-level phosphorylation in this pathway. **(3)**

(b) Name the 3-carbon end product of glycolysis, and the coenzyme that becomes reduced during glycolysis. **(2)**

(c) Dr Chen measured 4.2 mol of ATP produced by substrate-level phosphorylation directly during glycolysis (before subtracting the ATP invested earlier in the pathway) from 1 mol of glucose. Explain why this value is inconsistent with accepted glycolysis stoichiometry, stating the expected value. **(2)**

(Total for Question 1 is 7 marks)

2 Required practical. Kwame used a respirometer to investigate the rate of oxygen uptake by germinating pea seeds at 25°C, following the required practical method. The respirometer had two identical tubes connected to a manometer: one containing the germinating peas plus soda lime, the other (the control tube) containing an equal volume of inert glass beads plus soda lime. The tubes were sealed and left to equilibrate before timing began.

(a) Explain the function of the soda lime in this investigation, and the purpose of the control tube. **(3)**

(b) After 10 minutes, the manometer fluid had moved 15 mm towards the respiring seeds. A repeat run using the control tube alone showed a movement of 2 mm in the same direction over the same time, due to a change in atmospheric pressure. Calculate the corrected distance moved by the manometer fluid due to oxygen uptake alone. **(1)**

(c) The internal diameter of the capillary tube was 2.0 mm. Using volume = $\pi * r^2 *$ length, calculate the volume of oxygen taken up by the seeds in 10 minutes, using the corrected distance from part (b). Give your answer to 3 significant figures. **(3)**

(d) The total mass of the germinating peas used was 3.0 g. Using your answer to part (c), calculate the rate of oxygen uptake per gram of seeds per minute. **(2)**

(e) Suggest one reason the calculated rate of oxygen consumption may be an underestimate of the true respiration rate of the seeds. **(1)**

(Total for Question 2 is 10 marks)

3 The respiratory quotient (RQ) is the ratio of the volume of CO_2 released to the volume of O_2 consumed during respiration in a given time: RQ = volume of CO_2 produced / volume of O_2 consumed.

(a) Aisha used a respirometer without soda lime to measure a student's gas exchange over 5 minutes: 250 cm^3 of O_2 was consumed and 250 cm^3 of CO_2 was produced. Calculate the RQ and state which type of respiratory substrate this value indicates is being used. **(2)**

(b) Explain, in terms of the chemical composition of the substrate molecules, why the RQ for lipid respiration (approximately 0.7) is lower than for carbohydrate respiration (RQ = 1.0). **(3)**

(c) A person's measured RQ was found to be 0.85. Suggest what this value indicates about the respiratory substrate(s) being used. **(2)**

(Total for Question 3 is 7 marks)

4 The light-dependent reactions of photosynthesis take place across the thylakoid membrane of the chloroplast.

(a) Describe how water is used in the light-dependent reactions, name this process, and give a balanced equation for it, including state symbols. **(3)**

(b) Explain how the light-dependent reactions generate a proton gradient across the thylakoid membrane, and how this gradient is used to synthesise ATP. **(4)**

(c) Cyclic photophosphorylation involves only photosystem I. State two ways in which cyclic photophosphorylation differs from non-cyclic photophosphorylation. **(2)**

(Total for Question 4 is 9 marks)

5 Required practical. Priya investigated the effect of light intensity on the rate of photosynthesis using immobilised algal beads (Chlorella suspended in alginate gel), following the required practical method. Beads containing the algae, together with hydrogencarbonate indicator solution, were sealed in test tubes and illuminated by a lamp placed at different distances. As the algae photosynthesised, the indicator changed colour according to the CO_2 concentration in solution, and the colour was measured using a colorimeter linked to a computer over a fixed 10-minute period.

(a) Explain why hydrogencarbonate indicator can be used to estimate the rate of photosynthesis in this investigation. **(2)**

(b) Priya placed the lamp at distances of 10 cm, 20 cm and 40 cm from the tube in turn. State the relationship between light intensity and distance from a point light source, and use it to calculate the light intensity at 40 cm relative to the intensity at 10 cm, taking the intensity at 10 cm as 1 arbitrary unit. **(3)**

(c) State three variables, other than the distance of the lamp from the tube, that should be controlled in this investigation to ensure it is a valid test. **(3)**

(d) The colorimeter readings showed no further change in colour beyond 40 cm from the lamp, even though CO_2 was known to still be present in solution. Suggest an explanation for this observation. **(2)**

(Total for Question 5 is 10 marks)

6 Pyruvate produced by glycolysis is actively transported into the mitochondrial matrix, where it undergoes the link reaction before entering the Krebs cycle.

(a) Describe the link reaction, including the type(s) of reaction involved and the products formed from one molecule of pyruvate. **(3)**

(b) State what happens to the 2-carbon acetyl group once it enters the Krebs cycle, and name the 4-carbon molecule regenerated at the end of one turn of the cycle that allows the cycle to continue. **(2)**

(c) One turn of the Krebs cycle produces 3 molecules of reduced NAD, 1 molecule of reduced FAD, 1 molecule of ATP (by substrate-level phosphorylation) and 2 molecules of CO_2. Each molecule of glucose yields two molecules of acetyl CoA, so the cycle turns twice per glucose. Calculate the total number of molecules of reduced NAD, reduced FAD and ATP produced directly by the Krebs cycle (excluding the link reaction) from one molecule of glucose. **(3)**

(d) Explain why the Krebs cycle is described as an aerobic process even though oxygen is not used directly in any of its reactions. **(1)**

(Total for Question 6 is 9 marks)

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7 Compare and explain how the chemiosmotic theory accounts for ATP synthesis during oxidative phosphorylation in the mitochondrion and during photophosphorylation in the chloroplast. In your answer, refer to the source of the proton gradient, the membrane across which the gradient is established, and the direction of proton flow through ATP synthase in each organelle.

(Total for Question 7 is 6 marks)

8 The light-independent reactions (Calvin cycle) occur in the stroma of the chloroplast.

(a) Name the enzyme that catalyses the fixation of carbon dioxide with ribulose bisphosphate (RuBP), and name the product formed. **(2)**

(b) Describe how glycerate 3-phosphate (GP) is converted to triose phosphate (TP), and how ribulose bisphosphate (RuBP) is regenerated. **(3)**

(c) To synthesise one molecule of glucose via the Calvin cycle, six molecules of CO_2 must be fixed. Fixing one molecule of CO_2 and converting the resulting GP to TP requires 3 molecules of ATP and 2 molecules of reduced NADP in total. Calculate the total number of molecules of ATP and of reduced NADP required to synthesise one molecule of glucose. Show your working. **(3)**

(d) A mutation in rubisco reduces its affinity for CO_2 relative to O_2. Suggest and explain the likely effect of this mutation on the rate of glucose synthesis in bright light, with a normal atmospheric CO_2 concentration. **(2)**

(Total for Question 8 is 10 marks)

9 A student investigated how the rate of photosynthesis in an aquatic plant varied with light intensity, at three different CO_2 concentrations (0.04%, 0.10% and 0.40%), with temperature held constant at 25°C throughout. At low light intensities the three data sets gave the same rate of photosynthesis, rising together in a straight line as light intensity increased. At higher light intensities, each data set levelled off (reached a plateau), with the 0.40% CO_2 data set plateauing at the highest rate, followed by 0.10%, then 0.04%.

(a) Explain why the three data sets give the same rate of photosynthesis at low light intensities, regardless of CO_2 concentration. **(2)**

(b) Explain why the data sets plateau at different rates, depending on CO_2 concentration, at high light intensity. **(2)**

(c) Predict and explain the effect on the plateau rate of the 0.40% CO_2 data set of raising the temperature from 25°C to 35°C, then further to 45°C, assuming light and CO_2 remain non-limiting throughout. **(3)**

(Total for Question 9 is 7 marks)

10 Reduced NAD and reduced FAD produced during glycolysis, the link reaction and the Krebs cycle deliver electrons to the electron transport chain on the inner mitochondrial membrane.

(a) Describe the roles of the electron transport chain and of oxygen in oxidative phosphorylation. **(4)**

(b) A student is given the following approximate conversion factors: each molecule of reduced NAD that enters the electron transport chain yields 2.5 molecules of ATP; each molecule of reduced FAD yields 1.5 molecules of ATP. Using a total per-glucose yield of 10 molecules of reduced NAD and 2 molecules of reduced FAD (from glycolysis, the link reaction and the Krebs cycle), and 4 molecules of ATP produced directly by substrate-level phosphorylation (2 from glycolysis and 2 from the Krebs cycle), calculate the theoretical maximum total number of ATP molecules produced per molecule of glucose. **(4)**

(c) Suggest why the actual ATP yield obtained in a living cell is usually lower than this calculated theoretical maximum. **(1)**

(Total for Question 10 is 9 marks)

Mark scheme · 1.10 Biology: Energy Transfers in Organisms

Question 1

(a) net ATP yield = 2 molecules of ATP per molecule of glucose **B1**

(a) 2 molecules of ATP are produced by substrate-level phosphorylation per molecule of triose phosphate, and 2 molecules of triose phosphate are formed per glucose, giving 4 ATP in total **B1**

(a) 2 molecules of ATP are used earlier in glycolysis to phosphorylate glucose and fructose 6-phosphate, so the net gain is 4 - 2 = 2 ATP **B1**

(a) Answer: Net ATP = 2 per glucose (4 produced by substrate-level phosphorylation, minus 2 invested earlier in the pathway).

(b) pyruvate (2 molecules per glucose) **B1**

(b) NAD, reduced to reduced NAD (NADH); 2 molecules per glucose **B1**

(b) Answer: Pyruvate; NAD (reduced to reduced NAD).

(c) the accepted stoichiometry is 4 mol ATP produced by substrate-level phosphorylation per mol of glucose (2 mol ATP per mol of triose phosphate, and 2 mol of triose phosphate per mol of glucose) **B1**

(c) 4.2 mol is inconsistent with this fixed stoichiometry, since the pathway can only produce whole-number multiples of ATP per triose phosphate (2 ATP each); a non-integer multiple such as 2.1 ATP per triose phosphate is not possible from a single glucose molecule following the defined reaction sequence, so the value likely reflects experimental or measurement error **B1**

(c) Answer: Expected value = 4 mol ATP; 4.2 mol is inconsistent with the fixed reaction stoichiometry and likely reflects experimental error.

Question 2

(a) soda lime absorbs the CO_2 produced by respiration, so any change in the volume/pressure of gas in the tube is due only to the uptake of oxygen **B1**

(a) the control tube corrects for changes in fluid movement caused by factors other than respiration, such as changes in atmospheric pressure or temperature during the experiment **B1**

(a) any movement of fluid recorded in the control tube can be subtracted from (or added to) the movement in the experimental tube, to give a corrected value due to respiration alone **B1**

(a) Answer: Soda lime removes CO_2 so fluid movement reflects O_2 uptake only; the control corrects for pressure/temperature changes unrelated to respiration.

(b) 13 mm (15 - 2), since the control's movement is an artefact unrelated to respiration and is subtracted from the test movement in the same direction) cao **B1**

(b) Answer: 13 mm.

(c) correct radius from diameter: r = 2.0/2 = 1.0 mm **M1**

(c) correct substitution: volume = $\pi * (1.0)^2 * 13$ (ecf from (b)) **M1**

(c) 40.8 mm^3 (0.0408 cm^3), awrt, ecf from (b) **A1**

(c) Answer: 40.8 mm^3 (0.0408 cm^3), to 3 significant figures.

(d) correct method: divides the volume from (c) by time (10 min), then by mass (3.0 g), ecf from (c) **M1**

(d) $1.36 * 10^{-3}$ cm^3 g^{-1} min^{-1} (0.00136 cm^3 g^{-1} min^{-1}), awrt, ecf from (c) **A1**

(d) Answer: 1.36×10^{-3} cm^3 g^{-1} min^{-1} (0.00136 cm^3 g^{-1} min^{-1}).

(e) accept any valid suggestion, e.g. heat released by respiration could warm and expand the gas in the tube, partially opposing the fluid movement and reducing the apparent volume change; or not all seeds used were respiring (e.g. some dormant or non-viable seeds were included), reducing the measured total; or some oxygen/CO_2 may dissolve in moisture on the seeds or apparatus rather than affecting the gas volume measured **B1**

(e) Answer: Any valid suggestion, e.g. respiratory heat expanding the gas and opposing fluid movement, or some seeds not actively respiring.

Question 3

(a) RQ = 250/250 = 1.0 cao **B1**

(a) indicates carbohydrate (e.g. glucose) is the primary respiratory substrate being used **B1**

(a) Answer: RQ = 1.0; indicates carbohydrate is the primary respiratory substrate.

(b) lipids contain a much higher proportion of hydrogen (and carbon) relative to oxygen than carbohydrates do, i.e. lipids are more reduced molecules **B1**

(b) fully oxidising this extra hydrogen to water requires relatively more oxygen to be consumed per molecule of substrate than for carbohydrate oxidation **B1**

(b) since RQ = CO_2 produced / O_2 consumed, this greater O_2 consumption relative to CO_2 produced gives a lower RQ (around 0.7) for lipids; carbohydrates already contain more oxygen in their structure, so relatively less additional O_2 is needed per CO_2 released, giving RQ = 1.0 **B1**

(b) Answer: Lipids are more reduced (higher H:O ratio) so need more O_2 per CO_2 released during oxidation, giving a lower RQ than carbohydrates.

(c) an RQ of 0.85 lies between the values for pure carbohydrate (1.0) and pure lipid (0.7) respiration **B1**

(c) this suggests the person is respiring using a mixture of both carbohydrate and lipid as respiratory substrates, rather than either exclusively **B1**

(c) Answer: RQ of 0.85 suggests a mixture of carbohydrate and lipid is being respired.

Question 4

(a) the process is called photolysis: light energy is used to split water molecules, associated with photosystem II **B1**

(a) products are protons (H^+), electrons and oxygen **B1**

(a) correctly balanced equation with state symbols: $2H_2O(l) -> 4H^+(aq) + 4e- + O_2(g)$ **B1**

(a) Answer: Photolysis: $2H_2O(l) -> 4H^+(aq) + 4e- + O_2(g)$

(b) excited electrons from photosystem II pass along a chain of electron carriers (the electron transport chain), releasing energy at each transfer **B1**

(b) this energy is used to actively pump protons (H^+) from the stroma into the thylakoid space (lumen), so [H^+] becomes higher in the lumen than in the stroma **B1**

(b) protons diffuse back into the stroma down their concentration (electrochemical) gradient through ATP synthase; this process is called chemiosmosis **B1**

(b) the flow of protons through ATP synthase drives the phosphorylation of ADP + inorganic phosphate (Pi) to form ATP (photophosphorylation) **B1**

(b) Answer: Electron transport pumps H^+ into the thylakoid lumen, building a gradient; H^+ flows back through ATP synthase (chemiosmosis), driving ADP + Pi -> ATP.

(c) cyclic involves only photosystem I, whereas non-cyclic involves both photosystem I and photosystem II (any two of these points, one mark each) **B1**

(c) cyclic does not involve photolysis of water and does not produce oxygen; cyclic produces only ATP (no reduced NADP), whereas non-cyclic produces both ATP and reduced NADP; in cyclic the electron returns to photosystem I, whereas in non-cyclic the electron passes to NADP+ and is not returned **B1**

(c) Answer: Any two of: cyclic uses only PSI (non-cyclic uses PSI and PSII); cyclic produces no reduced NADP and no oxygen; in cyclic the electron returns to PSI rather than reducing NADP+.

Question 5

(a) hydrogencarbonate indicator changes colour according to the concentration of dissolved CO_2 (e.g. yellow at high CO_2/more acidic, red at atmospheric CO_2, purple/magenta at low CO_2/more alkaline) **B1**

(a) as the algae photosynthesise they use up CO_2 (faster than it is released by their respiration), so the indicator changes colour towards purple; a greater colour change (measured by the colorimeter) in a given time indicates a higher rate of photosynthesis **B1**

(a) Answer: Indicator colour reflects dissolved CO_2; photosynthesis removes CO_2, shifting the colour towards purple, so the extent of colour change indicates the rate of photosynthesis.

(b) light intensity is inversely proportional to the square of the distance from the source (the inverse square law): I is proportional to $1/d^2$ **B1**

(b) correct substitution: $I(40)/I(10) = (10/40)^2 = (1/4)^2 = 1/16$ **M1**

(b) 0.0625 arbitrary units (1/16), i.e. 16 times lower than at 10 cm, cao **A1**

(b) Answer: 0.0625 arbitrary units (1/16 of the intensity at 10 cm).

(c) temperature (e.g. kept constant using a water bath) **B1**

(c) the volume/concentration of hydrogencarbonate indicator solution used in each tube **B1**

(c) the number/volume/density of algal beads used, the duration of illumination, or the wavelength/colour of light from the lamp (any one further valid variable not already credited) **B1**

(c) Answer: Any three of: temperature; volume/concentration of indicator; number or volume of algal beads; duration of illumination; wavelength of light used.

(d) at very low light intensity, light becomes so limiting that the rate of photosynthesis falls to approximately the same rate as (or below) the rate of respiration **B1**

(d) so there is no net uptake of CO_2 from solution (CO_2 released by respiration approximately balances CO_2 used in photosynthesis), even though CO_2 is still present, so the indicator colour does not change further **B1**

(d) Answer: Light becomes so limiting that photosynthesis rate falls to about the same as respiration rate, giving no net change in CO_2 and so no further colour change.

Question 6

(a) pyruvate is decarboxylated (loses a carbon as CO_2) and dehydrogenated (oxidised, loses hydrogen, reducing NAD to reduced NAD) **B1**

(a) the remaining 2-carbon acetate group combines with coenzyme A to form acetyl coenzyme A (acetyl CoA) **B1**

(a) products per pyruvate: 1 molecule of CO_2, 1 molecule of reduced NAD, 1 molecule of acetyl CoA (this reaction occurs twice per glucose, since 2 pyruvate molecules are produced by glycolysis) **B1**

(a) Answer: Pyruvate is decarboxylated and dehydrogenated to form acetyl CoA, CO_2 and reduced NAD (occurring twice per glucose).

(b) the acetyl group (2C) combines with oxaloacetate (4C) to form citrate (6C), which is then progressively decarboxylated and dehydrogenated around the cycle, releasing CO_2 and reducing NAD/FAD, with one substrate-level phosphorylation of ATP **B1**

(b) oxaloacetate is regenerated at the end of one turn, allowing it to combine with another molecule of acetyl CoA and the cycle to continue **B1**

(b) Answer: The acetyl group combines with oxaloacetate to form citrate; oxaloacetate is regenerated at the end of the cycle.

(c) correct method: multiplies each per-turn value by 2, since the cycle turns twice per glucose **M1**

(c) reduced NAD = 6 (3 * 2) and ATP = 2 (1 * 2) cao **A1**

(c) reduced FAD = 2 (1 * 2) cao **A1**

(c) Answer: Per glucose: 6 molecules of reduced NAD, 2 molecules of reduced FAD, 2 molecules of ATP (from the Krebs cycle alone).

(d) oxygen is required (as the final electron acceptor in oxidative phosphorylation) to regenerate oxidised NAD and FAD from the reduced NAD and reduced FAD produced by the Krebs cycle; without oxygen these coenzymes remain reduced and unavailable, so the Krebs cycle's dehydrogenase reactions cannot continue, and the cycle stops **B1**

(d) Answer: Oxygen is needed to regenerate oxidised NAD/FAD via oxidative phosphorylation; without it the Krebs cycle stops due to a lack of oxidised coenzyme.

Question 7

Level 3 A detailed and coherent explanation of chemiosmosis in both organelles is given, correctly identifying the source of protons, the membrane involved, and the direction of proton flow in each. A clear, accurate comparison is drawn between the two processes throughout, using appropriate biological terminology. **5-6**

Level 2 The explanation of chemiosmosis in at least one organelle is largely correct, and some valid comparison is attempted between the mitochondrion and chloroplast, but there are one or more inaccuracies or omissions. Terminology is mostly appropriate. **3-4**

Level 1 Basic, generalised statements are made about ATP synthesis and/or proton gradients, with limited reference to specific organelles and little or no valid comparison. Some relevant biological terms are used. **1-2**

Level 0 No relevant content, or the response does not address the question. **0**

Indicative content:

- In the mitochondrion, electron carriers of the electron transport chain use energy released as electrons (from reduced NAD and reduced FAD) pass along the chain to actively pump protons from the matrix into the intermembrane space
- In the chloroplast, an electron transport chain uses energy from electrons excited by light (photoactivation, following photolysis of water at photosystem II) to actively pump protons from the stroma into the thylakoid space (lumen)
- In the mitochondrion, oxygen is the final electron acceptor, combining with electrons and protons to form water; in non-cyclic photophosphorylation, NADP+ is the final electron acceptor, forming reduced NADP
- In both organelles, a proton (electrochemical) gradient is established across a membrane, with a higher H^+ concentration on one side than the other
- Protons diffuse back down their concentration gradient through ATP synthase: in the mitochondrion, from the intermembrane space into the matrix; in the chloroplast, from the thylakoid lumen into the stroma
- In both cases the flow of protons through ATP synthase causes a conformational change in the enzyme that catalyses the phosphorylation of ADP + Pi to ATP
- Both processes therefore use an electron transport chain to build a proton gradient and ATP synthase to convert that gradient into ATP by chemiosmosis
- The two processes differ in the source of high-energy electrons (light energy captured by chlorophyll in the chloroplast, versus oxidation of respiratory substrates via reduced NAD/FAD in the mitochondrion) and in the membrane and compartments involved (inner mitochondrial membrane/cristae versus thylakoid membrane)

Question 8

(a) rubisco (RuBP carboxylase) **B1**

(a) glycerate 3-phosphate (GP); 2 molecules of GP are formed per CO_2 fixed **B1**

(a) Answer: Rubisco; product = glycerate 3-phosphate (GP).

(b) GP is reduced (using ATP and reduced NADP from the light-dependent reactions) to form TP; this reaction produces ADP + Pi and NADP+ as by-products **B1**

(b) of every 6 molecules of TP produced, 5 are used, with further ATP, to regenerate 3 molecules of RuBP so the cycle can continue **B1**

(b) the remaining 1 molecule of TP (out of every 6) leaves the cycle and is used to synthesise other organic molecules, such as glucose **B1**

(b) Answer: GP + ATP + reduced NADP -> TP; most TP regenerates RuBP (using more ATP), while some TP is used to make glucose and other organic molecules.

(c) correct method: multiplies 6 (molecules of CO_2 fixed per glucose) by the ATP and reduced NADP required per CO_2 fixed (3 ATP and 2 reduced NADP) **M1**

(c) ATP required = 18 (6 * 3) cao **A1**

(c) reduced NADP required = 12 (6 * 2) cao **A1**

(c) Answer: 18 molecules of ATP and 12 molecules of reduced NADP.

(d) the rate of glucose synthesis would decrease, because rubisco would increasingly catalyse the oxygenation of RuBP instead of its carboxylation (photorespiration), reducing the proportion of RuBP converted to GP **B1**

(d) less GP is therefore available to be converted to TP, so less RuBP is regenerated and less TP is available for glucose synthesis, despite CO_2 and light both being available **B1**

(d) Answer: Rate of glucose synthesis decreases: more RuBP undergoes oxygenation (photorespiration) rather than carboxylation, reducing GP, TP and glucose formed.

Question 9

(a) at low light intensity, light is the limiting factor for all three CO_2 concentrations, restricting the rate of the light-dependent reactions (and so the supply of ATP and reduced NADP) **B1**

(a) since CO_2 concentration is not limiting at this low rate (more CO_2 is available than can be used), the rate is unaffected by CO_2 concentration, so the curves overlap **B1**

(a) Answer: Light is limiting at low intensity for all three CO_2 levels, so CO_2 concentration (which is not limiting) has no effect and the rates coincide.

(b) at high light intensity, light is no longer limiting, so CO_2 concentration (availability for the light-independent reactions/carbon fixation by rubisco) becomes the limiting factor **B1**

(b) a higher CO_2 concentration allows a higher maximum rate of carbon fixation before some other factor becomes limiting, giving a higher plateau **B1**

(b) Answer: Light is no longer limiting, so CO_2 concentration limits the rate; more CO_2 supports a higher maximum rate, hence a higher plateau.

(c) raising the temperature from 25 to 35°C would increase the plateau rate, because temperature was limiting the rate of enzyme-catalysed reactions (e.g. rubisco activity) below their optimum, and a higher temperature increases the kinetic energy and frequency of successful enzyme-substrate collisions **B1**

(c) with light and CO_2 both non-limiting, temperature becomes the limiting factor at 25-35°C, so the rate increases as temperature rises towards the enzymes' optimum **B1**

(c) raising the temperature further to 45°C would decrease the rate, as this is likely to be above the optimum temperature for the relevant enzymes (e.g. rubisco), causing denaturation (disruption of the tertiary structure/active site) and a fall in the rate of the light-independent reactions **B1**

(c) Answer: Rate increases from 25 to 35°C (temperature was limiting, below optimum); rate decreases at 45°C as enzymes such as rubisco begin to denature above their optimum.

Question 10

(a) electrons from reduced NAD/FAD pass along a series of electron carrier proteins in the electron transport chain, releasing energy at each transfer **B1**

(a) this energy is used to actively pump (transport) protons (H^+) from the matrix into the intermembrane space, creating a proton (electrochemical) gradient across the inner mitochondrial membrane **B1**

(a) protons diffuse back into the matrix through ATP synthase, down their concentration gradient (chemiosmosis), which catalyses the synthesis of ATP from ADP and Pi **B1**

(a) oxygen acts as the final electron acceptor at the end of the chain, combining with electrons and protons to form water; without oxygen the chain would back up and stop, halting oxidative phosphorylation **B1**

(a) Answer: Electrons pass along the chain, pumping H^+ to build a gradient; H^+ flows back through ATP synthase making ATP; oxygen accepts electrons at the end, forming water.

(b) ATP from reduced NAD = 10 * 2.5 = 25 **M1**

(b) ATP from reduced FAD = 2 * 1.5 = 3 **A1**

(b) adds oxidative phosphorylation total (25 + 3 = 28) to the substrate-level ATP (4) **M1**

(b) 32 ATP molecules per glucose cao (ecf from any correct NAD/FAD totals carried forward, e.g. from Q8(c)) **A1**

(b) Answer: 32 ATP molecules per glucose (theoretical maximum).

(c) some protons leak back across the inner mitochondrial membrane without passing through ATP synthase (proton leak), and/or some of the proton gradient's energy is used for other purposes, such as the active transport of pyruvate into the matrix, rather than solely for ATP synthesis (accept any other valid reason for inefficiency, e.g. heat loss) **B1**

(c) Answer: Some protons leak across the membrane without generating ATP, and some of the gradient's energy is used for other active transport, not only ATP synthesis.