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A-Level · Biology

AB5D Energy Transfers in and between Organisms: Depth and Exam Drill

AQA 7402 · Calculator allowed · about 140 minutes

Total Marks

Name: ________________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

1 This question assesses core definitions and simple recall about energy carriers and processes in organisms.

(a) State the name of the molecule that acts as the main immediate energy currency in cells. **(1)**

(b) Give the term for the process in which glucose is broken down to release energy in the absence of oxygen. **(1)**

(c) Name the organelle where oxidative phosphorylation occurs in eukaryotic cells. **(1)**

(d) State one example of an abiotic factor that can reduce the rate of photosynthesis in plants. **(1)**

(Total for Question 1 is 4 marks)

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2 This question concerns respiratory energy yield and rates. A sample of actively respiring yeast is provided in a sealed respirometer chamber with glucose substrate. The chamber has internal volume 250 cm3. Over 5.0 minutes the drop in internal oxygen partial pressure corresponds to 8.0×10^{-3} mol of O2 consumed. Assume aerobic respiration of glucose is C6H12O6 + 6O2 -> 6CO2 + 6H2O and that each mole of O2 consumed in oxidative phosphorylation leads to synthesis of 2.5 mol ATP (the P:O ratio for NADH-linked respiration).

(a) Calculate the mean rate of oxygen consumption in mol s^{-1} for the yeast sample over the 5.0 minute period. **(2)**

(b) Using the respiratory stoichiometry and P:O ratio given, calculate the total number of moles of ATP synthesised in the chamber over the 5.0 minute period. **(3)**

(c) Estimate the mean ATP synthesis rate in mol s^{-1} in this sample and the rate expressed in micromol s^{-1} (1 micromol = 1.0×10^{-6} mol). **(3)**

(d) State one experimental factor that could cause the measured O2 consumption to underestimate true ATP synthesis rate in the cells, and briefly explain why. **(2)**

(Total for Question 2 is 10 marks)

3 Photosynthetic efficiency and rates. A leaf disk experiment measures net photosynthetic O2 production. At 400 micromol m^{-2} s^{-1} photon flux, a leaf area of 0.020 m2 produces 1.80 x 10^{-4} mol O2 in 10 minutes. Assume 4 photons are required to produce one O2 in the light reactions (minimum quantum requirement).

(a) Calculate the total number of photons incident on the leaf area during the 10 minute period. **(3)**

(b) Using the quantum requirement given, calculate the theoretical maximum mol of O2 that could be produced from the incident photons and compare with the observed 1.80 x 10^{-4} mol O2. Hence calculate the light-use efficiency defined as (observed O2 / theoretical max O2) x 100%. Give the efficiency to 2 significant figures. **(4)**

(c) State one biological factor that could explain why observed O2 production is much lower than theoretical maximum. **(1)**

(Total for Question 3 is 8 marks)

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4 Biomass and transfer efficiency in a simple food chain. A grassland plot produces 6.50 x 10^{3} kJ m^{-2} yr^{-1} of net primary production (biomass energy). Herbivores grazing this plot consume 18% of the plant biomass. Of the plant biomass consumed, 30% is assimilated and the rest is egested. Of assimilated energy, 40% is used for respiration and the remainder is available for growth and reproduction (secondary production).

(a) Calculate the amount of plant biomass energy (in kJ m^{-2} yr^{-1}) that is ingested by herbivores. **(2)**

(b) Calculate the assimilated energy and the energy lost as egested material (kJ m^{-2} yr^{-1}). **(3)**

(c) Calculate the secondary production (growth and reproduction energy) available to the herbivore population after respiration losses. **(3)**

(Total for Question 4 is 8 marks)

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5 Uncertainty and significant figures in biomass transfer measurements. A student measures plant biomass energy as 6.50 x 10^{3} kJ m^{-2} yr^{-1} with an absolute uncertainty of ± 1.5 x 10^{2} kJ m^{-2} yr^{-1}. Using values from question 4, calculate the propagated uncertainty (absolute) in the amount of plant biomass energy ingested by herbivores (ingested = NPP x 0.18). Give your final ingested value with its absolute uncertainty and state the appropriate number of significant figures.

(a) Calculate the ingested value and its absolute uncertainty propagated from the NPP measurement. Use linear propagation for multiplication: absolute uncertainty in product = factor x absolute uncertainty in NPP. **(6)**

(b) Explain briefly why percentage uncertainty is a more useful comparison than absolute uncertainty when comparing the reliability of two biomass measurements of different magnitudes. **(3)**

(Total for Question 5 is 9 marks)

6 Experiment design and analysis: measuring effect of temperature on rate of respiration in plant tissue. A student measures CO2 production (as a proxy for respiration) from 5 g leaf samples at four temperatures: 10, 20, 30 and 40 degrees C. Recorded mean CO2 production rates are 0.015, 0.028, 0.051 and 0.032 micromol s^{-1} respectively (each mean from three replicates).

(a) Calculate the Q10 value for respiration between 10 and 20 degrees C using the mean rates provided. Give your answer to 2 significant figures. **(3)**

(b) Calculate the Q10 value between 20 and 30 degrees C and comment briefly on how Q10 changes across the temperature range studied. **(3)**

(c) Suggest one experimental improvement to make the Q10 estimates more reliable and briefly justify your suggestion. **(1)**

(Total for Question 6 is 7 marks)

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7 Levels of response question. Evaluate how human activities can alter the efficiency of energy transfer through a terrestrial ecosystem. In your answer consider both direct effects on primary productivity and indirect effects on trophic transfer efficiency. Use examples where appropriate.

(Total for Question 7 is 6 marks)

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8 ATP hydrolysis and coupling. Describe the mechanism by which ATP hydrolysis can be coupled to an endergonic transport process across a cell membrane. Your answer should include the role of enzyme conformational change and the fate of phosphate and ADP.

(a) Give the sequence of events in a P-type ATPase that uses ATP to pump ions against their concentration gradient, including ATP binding, phosphorylation, conformational change, ion release, and dephosphorylation. **(6)**

(b) State one reason why coupling via phosphorylation is advantageous compared with simply allowing ions to flow down their electrochemical gradient. **(2)**

(Total for Question 8 is 8 marks)

9 Synoptic question linking ecology and cellular energetics. An agricultural scientist proposes planting a nitrogen-fixing crop in rotation with wheat to increase long-term wheat yields. Discuss quantitatively and qualitatively how adding nitrogen-fixing plants could change net primary productivity, the assimilation efficiency of herbivores grazing on the system, and the potential secondary production in a simple model where NPP increases by 20% and plant tissue nitrogen concentration rises so that assimilation efficiency of herbivores increases from 30% to 36%. Use the baseline values from question 4 (original NPP = 6500 kJ m^{-2} yr^{-1}, herbivore consumption fraction = 0.18, respiration fraction of assimilated energy unchanged at 40%).

(a) Calculate the new NPP, the new ingested energy by herbivores, the assimilated energy with increased assimilation efficiency, and the resulting secondary production after respiration. Show calculations and give final numeric values (kJ m^{-2} yr^{-1}). **(6)**

(b) Briefly evaluate two ecological trade-offs or unintended consequences of introducing nitrogen-fixing crops that the scientist should consider beyond the direct increases in NPP and secondary production. **(4)**

(Total for Question 9 is 10 marks)

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10 Data interpretation: a researcher reports yearly energy budgets for two meadow management strategies A and B. Strategy A yields NPP = 5200 kJ m^{-2} yr^{-1} with herbivore consumption fraction 0.22 and assimilation efficiency 0.32. Strategy B yields NPP = 6000 kJ m^{-2} yr^{-1} with herbivore consumption fraction 0.15 and assimilation efficiency 0.38. Respiration fraction of assimilated energy is 45% for both strategies. Which strategy produces greater secondary production per m^2 yr^{-1}? Show calculations and give the difference between strategies in kJ m^{-2} yr^{-1}. Conclude which strategy is better if the goal is to maximise secondary production available to herbivores.

(a) Calculate secondary production for strategy A and strategy B, showing intermediate steps (ingested, assimilated, then secondary production). **(4)**

(b) Calculate the difference in secondary production and state which strategy is better for maximising herbivore secondary production. **(2)**

(Total for Question 10 is 6 marks)

Mark scheme · AB5D Energy Transfers in and between Organisms: Depth and Exam Drill

Question 1

- (a) **B1** ATP
- **(a) Answer: ATP**
- (b) **B1** anaerobic respiration or fermentation
- **(b) Answer: Anaerobic respiration**
- (c) **B1** mitochondrion or mitochondria
- **(c) Answer: Mitochondrion**
- (d) **B1** any one correct abiotic factor such as low light intensity, low carbon dioxide concentration, low temperature, or water shortage
- **(d) Answer: Low light intensity**

Question 2

- (a) **M1** method: divide moles consumed by total time in seconds, i.e. $8.0 \times 10^{-3} / (5.0 \times 60)$
- (a) **A1** 2.67×10^{-5} mol s^{-1} cao
- **(a) Answer: 2.67×10^{-5} mol s^{-1}**
- (b) **M1** method: ATP moles = (moles O2 consumed) x (ATP produced per O2) = $8.0 \times 10^{-3} \times 2.5$
- (b) **M1** evaluate product to 2 sf or 3 sf
- (b) **A1** 2.00×10^{-2} mol ATP, cao
- **(b) Answer: 2.00×10^{-2} mol ATP**
- (c) **M1** divide moles ATP (2.00×10^{-2}) by time in seconds (300 s)
- (c) **M1** correct numerical evaluation to give mol s^{-1}
- (c) **A1** 6.67×10^{-5} mol s^{-1} and 66.7 micromol s^{-1}, cao
- **(c) Answer: 6.67×10^{-5} mol s^{-1}; 66.7 micromol s^{-1}**
- (d) **B1** any one correct factor such as some oxygen used for non-ATP producing processes (e.g. reactive oxygen species formation), or leakage of O2 in apparatus, or cells performing anaerobic metabolism concurrently
- (d) **B1** brief explanation linked to factor, e.g. leakage causes measured O2 decrease to be smaller than true consumption or non-ATP uses mean less ATP per O2
- **(d) Answer: Leakage of O2 from the chamber, so measured O2 decrease is smaller than true cellular O2 consumption.**

Question 3

- (a) **M1** method: photons per second per m2 x area x time = photon flux x area x time
- (a) **M1** substitute: 400 micromol m^{-2} s^{-1} = 400×10^{-6} mol m^{-2} s^{-1}; time = 600 s
- (a) **A1** 4.80×10^{-3} mol photons, cao
- **(a) Answer: 4.80×10^{-3} mol photons**
- (b) **M1** method: theoretical O2 = mol photons / 4
- (b) **M1** calculate theoretical O2 = $4.80 \times 10^{-3} / 4 = 1.20 \times 10^{-3}$ mol
- (b) **M1** efficiency = (observed/theoretical) x 100 = $(1.80 \times 10^{-4} / 1.20 \times 10^{-3}) \times 100$
- (b) **A1** 15% (to 2 sf), cao
- **(b) Answer: 15%**
- (c) **B1** possible factors such as photoprotection dissipating energy as heat, inefficiencies in electron transport, photorespiration, limited CO2, or respiration concurrent with photosynthesis
- **(c) Answer: Photorespiration reduces net O2 production.**

Question 4

- (a) **M1** method: ingested = NPP x fraction consumed = $6.50 \times 10^3 \times 0.18$
- (a) **A1** 1170 kJ m^{-2} yr^{-1}, cao
- **(a) Answer: 1170 kJ m^{-2} yr^{-1}**
- (b) **M1** assimilated = ingested x assimilation fraction = 1170 x 0.30
- (b) **M1** egested = ingested - assimilated
- (b) **A1** assimilated = 351 kJ m^{-2} yr^{-1}; egested = 819 kJ m^{-2} yr^{-1}, cao
- **(b) Answer: Assimilated = 351 kJ m^{-2} yr^{-1}; Egested = 819 kJ m^{-2} yr^{-1}**
- (c) **M1** method: secondary production = assimilated x (1 - respiration fraction) = 351 x 0.60
- (c) **M1** numerical evaluation
- (c) **A1** 210.6 kJ m^{-2} yr^{-1} (accept 211 kJ m^{-2} yr^{-1} to 3 sf), cao
- **(c) Answer: 210.6 kJ m^{-2} yr^{-1}**

Question 5

- (a) **M1** calculate ingested: 6500 x 0.18 = 1170 kJ m^{-2} yr^{-1}
- (a) **M1** method for absolute uncertainty: uncertainty_ingested = 0.18 x uncertainty_{NPP}
- (a) **M1** substitute uncertainty: 0.18 x 150 = 27 kJ m^{-2} yr^{-1}
- (a) **M1** state ingested with uncertainty before rounding: 1170 ± 27
- (a) **M1** determine appropriate significant figures consistent with uncertainty (uncertainty to 2 s.f. or 1 s.f.) and round value accordingly
- (a) **A1** 1170 ± 27 kJ m^{-2} yr^{-1} (round to 3 significant figures for value and 2 significant figures for uncertainty) cao
- **(a) Answer: 1170 ± 27 kJ m^{-2} yr^{-1}**
- (b) **B1** percentage uncertainty normalises uncertainty to the magnitude of the measurement
- (b) **B1** therefore allows comparison of relative precision between values of different sizes
- (b) **B1** brief example or statement linking to decision making or comparing data reliability gains the third mark
- **(b) Answer: Percentage uncertainty normalises the error to the measurement size so one can compare relative precision; for example 27/1170 is about 2.3% compared with a 150/6500 = 2.3% for the original measurement.**

Question 6

- (a) **M1** method: Q10 = rate at higher temp / rate at lower temp for 10 degree interval = 0.028 / 0.015
- (a) **M1** numerical evaluation
- (a) **A1** 1.9 (to 2 s.f.), cao
- **(a) Answer: 1.9**
- (b) **M1** method: Q10 = 0.051 / 0.028
- (b) **M1** numerical evaluation
- (b) **A1** 1.8 and comment that Q10 decreases slightly or is similar, and respiration drops at 40 degrees indicating enzyme denaturation or stress, cao
- **(b) Answer: Q10 between 20 and 30 degrees C = 1.8. Q10 is similar to between 10 and 20 degrees C but respiration decreases at 40 degrees C suggesting enzymes begin to denature.**
- (c) **B1** one sensible improvement with brief justification, e.g. increase number of replicates to reduce random error, control humidity to prevent desiccation, ensure rapid equilibration time at each temperature so measurements reflect steady-state rates
- **(c) Answer: Increase replicates to at least five per temperature to reduce random error and give more reliable mean rates for Q10 calculation.**

Question 7

- **Level 3** (5-6): Detailed, balanced evaluation. Points include clear explanation of mechanisms by which human activities alter net primary productivity and trophic transfer efficiency, supported by relevant examples, and considered judgement about overall impact and magnitude. Quality of written communication is good.
- **Level 2** (3-4): Some evaluation with explanation of at least one mechanism and an example. Connections between primary productivity and transfer efficiency made but limited in breadth or depth.
- **Level 1** (0-2): Simple statements or descriptions with limited linkage, little or no evaluation, or unsupported assertions.
- **Indicative content:**
  - Direct effects on primary productivity: nutrient enrichment from fertiliser increases primary productivity but may cause algal blooms, eutrophication and reduced light penetration; habitat destruction and deforestation reduce plant biomass and NPP.
  - Indirect effects on trophic transfer: selective removal of predators or herbivores changes community structure and trophic efficiencies; intensive agriculture often increases harvestable secondary production per unit area but reduces energy passed to higher trophic levels by removing biomass (harvesting) and reducing biodiversity.
  - Mechanistic links: increased NPP may raise energy available to herbivores but higher respiration losses from stressed plants or higher plant tissue C:N may lower assimilation efficiency; pesticides reduce assimilation and increase egestion due to digestive disruption.
  - Examples: conversion of rainforest to pasture decreases total NPP and lowers transfer efficiency to top predators; well-managed agroecosystems can increase short-term secondary production but usually reduce ecosystem transfer efficiency and resilience.
  - Balanced judgement: human activities can both increase and decrease efficiency; overall often reduce long-term ecosystem transfer efficiency and biodiversity, with short-term gains in yield.

Question 8

- (a) **M1** ATP binds to the transporter on the cytosolic side and is hydrolysed with transfer of phosphate to the protein (phosphorylation)
- (a) **M1** phosphorylation induces a conformational change in the transporter that reduces affinity for the bound ion on the cytosolic side and increases affinity on the extracellular side (or vice versa)
- (a) **M1** ion is released on the other side of the membrane against its concentration gradient
- (a) **M1** ADP is released and the phosphate remains transiently on the pump
- (a) **M1** dephosphorylation returns the pump to its original conformation ready for another cycle
- (a) **M1** overall coupling: chemical energy from ATP hydrolysis is converted into work of moving ions, with phosphate acting to stabilise the high-energy conformational state
- **(a) Answer: ATP binds and is hydrolysed, phosphorylating the pump and causing a conformational change that moves the ion across the membrane; ADP is released and later dephosphorylation restores the original conformation.**
- (b) **B1** allows active transport against a gradient to maintain cellular ion homeostasis, enabling processes like nutrient uptake or membrane potential maintenance
- (b) **B1** provides an energy-controlled and regulatable mechanism rather than passive uncontrolled flow
- **(b) Answer: It allows active transport of ions against their gradient, maintaining homeostasis and enabling controlled, regulated transport.**

Question 9

- (a) **M1** calculate new NPP = 6500 x 1.20 = 7800 kJ m^{-2} yr^{-1}
- (a) **M1** calculate ingested = 7800 x 0.18
- (a) **M1** calculate assimilated using new assimilation 0.36
- (a) **M1** calculate secondary production = assimilated x (1 - respiration fraction 0.40)
- (a) **M1** correct numerical evaluation of ingested and assimilated and secondary production
- (a) **A1** answers: new NPP 7800; ingested 1404; assimilated 505.44; secondary production 303.26 kJ m^{-2} yr^{-1} (awrt)
- **(a) Answer: New NPP = 7800 kJ m^{-2} yr^{-1}; Ingested = 1404 kJ m^{-2} yr^{-1}; Assimilated = 505.4 kJ m^{-2} yr^{-1}; Secondary production = 303.3 kJ m^{-2} yr^{-1}**
- (b) **B1** one trade-off such as increased risk of nitrate leaching and water pollution if nitrogen enters soil beyond plant uptake
- (b) **B1** explain consequence for ecosystem services or biodiversity
- (b) **B1** second trade-off such as changes in plant community composition favouring legumes over native species, altering food web and reducing long-term resilience
- (b) **B1** brief explanation of how this affects long-term productivity or trophic transfer efficiency
- **(b) Answer: Trade-offs include nitrate leaching causing eutrophication of waterways and potential loss of biodiversity from favouring legumes, which can alter food-web structure and reduce resilience.**

Question 10

- (a) **M1** calculate ingested A = 5200 x 0.22 = 1144
- (a) **M1** calculate assimilated A = 1144 x 0.32 = 366.08
- (a) **M1** calculate secondary production A = 366.08 x (1 - 0.45) = 201.34
- (a) **M1** repeat for B with correct numbers: ingested B = 6000 x 0.15 = 900; assimilated B = 900 x 0.38 = 342; secondary production B = 342 x 0.55 = 188.1
- **(a) Answer: Strategy A secondary production = 201.3 kJ m^{-2} yr^{-1}; Strategy B secondary production = 188.1 kJ m^{-2} yr^{-1}**
- (b) **M1** compute difference = 201.34 - 188.1 = 13.24
- (b) **A1** Strategy A is better by 13.2 kJ m^{-2} yr^{-1}, cao
- **(b) Answer: Strategy A is better by 13.2 kJ m^{-2} yr^{-1}.**