Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A400U10-1

S25-A400U10-1

THURSDAY, 5 JUNE 2025 – AFTERNOON

BIOLOGY – A level component 1
Energy for Life

2 hours

For Examiner's use only		
Question	**Maximum Mark**	**Mark Awarded**
1.	**12**	
2.	**14**	
3.	**17**	
4.	**21**	
5.	**19**	
6.	**8**	
7.	**9**	
Total	**100**	

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01

ADDITIONAL MATERIALS

A calculator and a ruler.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **7**.

The quality of written communication will affect the awarding of marks.

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Answer **all** questions.

1. The oxidation of respiratory substrates is catalysed by enzymes. In a series of reactions hydrogen ions are produced which are transferred to the hydrogen carriers involved in respiration. These carriers then deliver hydrogen to the site of ATP synthesis.

(a) (i) Name **two** hydrogen carriers that are involved in aerobic respiration in mitochondria. [1]

NAD FAD

(ii) Describe the role of hydrogen ions in ATP synthesis. [3]

Hydrogen ions (protons) are pumped into the intermembrane space, so they flow (diffuse) down their electrochemical (concentration) gradient from the intermembrane space back into the matrix.

They pass through ATP synthase (ATP synthetase) in the inner mitochondrial membrane.

The flow of protons provides the energy for ATP synthase to join ADP + P_i → ATP.

(iii) Explain why the two hydrogen carriers involved in aerobic respiration result in the synthesis of different numbers of ATP molecules. [2]

Reduced NAD delivers its hydrogen at the start of the electron transport chain, so its electrons pass three proton pumps, but reduced FAD delivers them further along, so they pass only two proton pumps.

So different numbers of protons are pumped into the intermembrane space: NAD gives 3 ATP and FAD gives 2 ATP.

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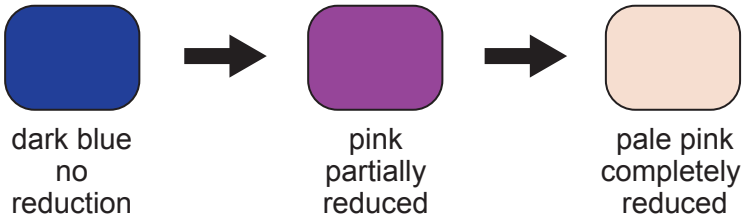
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(b) Resazurin dye changes colour when it is reduced and will change colour in the presence of respiring cells. If resazurin is present it will be reduced by hydrogen and changes colour from dark blue to pink to pale pink as shown in **Image 1.1**.

Image 1.1



Students used resazurin to investigate the action of dehydrogenase in yeast. They set up a thermostatically controlled water bath at 35 °C. Two test tubes were prepared as follows and left in the water bath for five minutes:

Test tube **A**: 3 cm^3 of boiled 2.5% yeast suspension + 3 cm^3 of 5% glucose solution
Test tube **B**: 3 cm^3 of 2.5% yeast suspension + 3 cm^3 of 5% glucose solution

After five minutes, 3 cm^3 of 0.01% resazurin was added to test tubes **A** and **B**. The resazurin solution was at the same temperature as the yeast and glucose mixture.

(i) Explain why the resazurin was brought to the same temperature as the yeast and glucose mixtures before mixing. [1]

So that a change in temperature does not affect the enzyme (dehydrogenase) activity, the kinetic energy of the molecules or the rate of reaction.

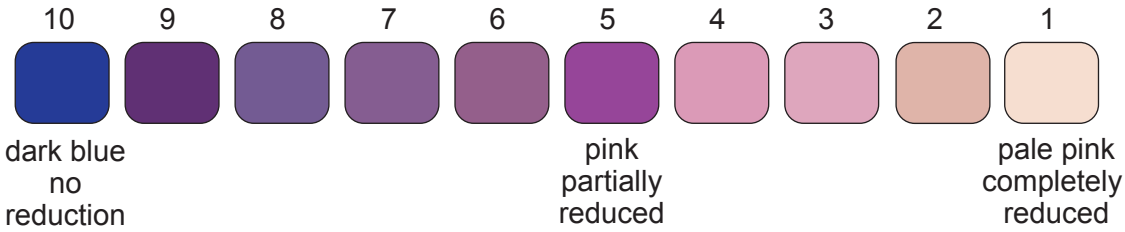
(ii) Explain the purpose of test tube **A**. [2]

It acts as a control: boiling denatures the dehydrogenase enzymes in the yeast.

It shows that the change in colour in tube B is due to the dehydrogenase enzymes (respiration) in the living yeast.

The colour of the contents of each test tube was recorded every three minutes for a period of 30 minutes. The colour of each tube was matched to the colour chart shown in **Image 1.2**. The numbers indicate the extent of reduction of resazurin, with 10 indicating no reduction.

Image 1.2



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Table 1.3 shows one student's results.

Table 1.3

Time / minutes	Extent of reduction of resazurin / au	
	test tube **A**	test tube **B**
0	10	8
3	10	8
6	10	7
9	10	6
12	10	5
15	10	4
18	10	3
21	10	2
24	10	1
27	10	1
30	10	1

The results of other students varied considerably from those shown in the table.

(iii) I. Use all the information given to identify and explain how **one** limitation in this investigation could account for the variation in the results of other students.

[2]

The colours were matched to the chart by eye, and colour vision is subjective.

So different students would judge the same shade differently and record different colours (results).

II. Suggest and explain **one** improvement that would provide results that are more accurate. [1]

Use a colorimeter to measure the colour (absorbance), as this gives objective, quantitative data.

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2. (a) *Streptococcus mutans* is one of at least 25 species of streptococcus bacteria found in the human mouth. A chain of *S. mutans* cells following Gram staining is shown in **Image 2.1**.

Image 2.1



(i) Classification of the different streptococcus bacteria is tentative as all these species appear similar after Gram staining.
Explain the meaning of the term **tentative** when referring to classification. [1]

It is based on the information (evidence) available at the time, so it is not fixed and can change.

(ii) Explain how **one** biochemical method of analysis could be used to distinguish between the different species of *Streptococcus*. [2]

DNA sequencing: sequence a gene (e.g. the 16S rRNA gene) from each species.

Compare the DNA base sequences; the more differences in the base sequence, the less closely related (the more different) the species are.

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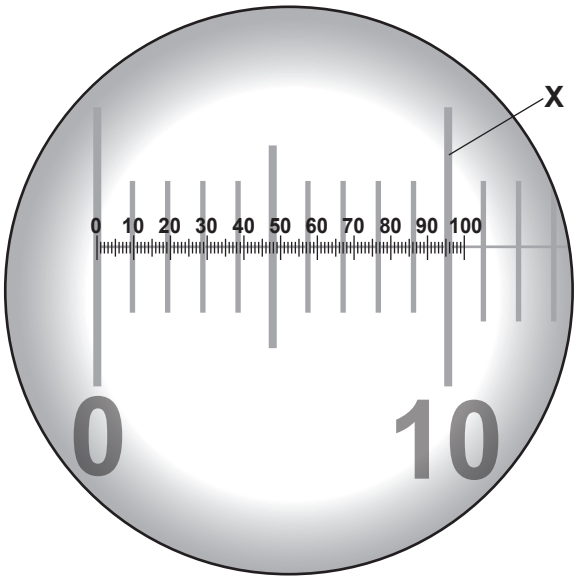
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(b) A microscope was used to measure the diameter of one of the bacteria shown in **Image 2.1**. The microscope was first calibrated using an eyepiece graticule and a stage micrometer. Divisions marked on the stage micrometer have a constant value of 0.01 mm but the value of one eyepiece unit (epu) varies depending on the magnification of the objective lens.

Image 2.2 shows how a stage micrometer and eyepiece graticule would appear when viewed down a microscope at high magnification.

Image 2.2



(i) Name scale **X** in **Image 2.2**. [1]

stage micrometer

(ii) At this magnification it was calculated that 1 epu = 1.05 µm.
The diameter of one of the bacteria in **Image 2.1** was measured at 2 epu.
Calculate the actual diameter of this bacterium. [1]

2 epu × 1.05 µm = 2.10 µm

Diameter of bacterium = *2.10* µm

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(c) In humans, *S. mutans* is most prevalent on the surface of teeth and is one of the main organisms responsible for tooth decay.
S. mutans can convert sucrose into two main products:

- lactic acid
- dextran – a sticky polysaccharide

S. mutans can also metabolise other sugars, including glucose, fructose and lactose to produce lactic acid.
Image 2.3 shows a cavity in a human premolar caused by tooth decay.

Image 2.3



(i) With reference to the habitat of this species of bacteria and its metabolism of sugars, conclude whether *S. mutans* is an aerobe, an obligate anaerobe or a facultative anaerobe. Explain your answer. [3]

S. mutans is a facultative anaerobe.

It produces lactic acid from sugars, so it respires anaerobically (lactate fermentation), e.g. in the low oxygen conditions under the sticky dextran layer on teeth.

But oxygen is present in the mouth (air is breathed in) and the bacteria still survive there, so they can also respire aerobically.

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(ii) Use the information provided to explain why **not** brushing your teeth can increase the risk of cavity formation. [2]

Dextran sticks to the teeth and traps the bacteria and lactic acid, so if teeth are not brushed the bacteria and lactic acid remain on the teeth and are not removed.

The lactic acid corrodes (dissolves) the tooth enamel, forming a cavity.

(d) Dextran solutions are used to treat cases of very low blood pressure caused by excessive blood loss. When dextran solutions are injected into the blood, they significantly reduce the plasma solute potential.
Use your knowledge of tissue fluid formation and osmosis to conclude how dextran solutions help to restore blood pressure. [4]

Dextran lowers the solute potential and so lowers (makes more negative) the water potential of the plasma.

At the arterial end of the capillary the water potential of the blood is lower than normal, so less water leaves the plasma and less tissue fluid is formed.

At the venous end the water potential of the plasma is lower than that of the tissue fluid, so more water moves by osmosis from the tissue fluid back into the capillaries (more tissue fluid is reabsorbed).

This increases the blood volume (the amount of water in the blood), which restores (increases) the blood pressure.

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3. For healthy and productive growth, plants require a range of minerals.
Calcium, sulphur, nitrogen, phosphorus and magnesium are termed macronutrients, as plants require relatively high levels of them.
Some elements are only required in low levels; these are called micronutrients.

(a) (i) State which **two** of the macronutrients listed above are required to produce the amino acids involved in cross-linking polypeptide chains. [2]

nitrogen sulphur

(ii) State **one** role of each of the following elements **in plants**. [2]

calcium strengthens plant cell walls (calcium pectate)

magnesium a component of chlorophyll

(b) An experiment was carried out to investigate the effects of some micronutrient deficiencies on duckweed (*Lemna minor*). This is a simple, aquatic plant that floats on the surface of ponds. It grows rapidly and individual plants can be counted easily. **Image 3.1** shows some *L. minor* plants.

Image 3.1



Five different nutrient media were tested. One contained complete nutrient medium containing all the minerals required for healthy growth. The others contained the same nutrient medium but with a source of one micronutrient omitted. The method used to set up the culture vessels is described below.

- wrap the sides of a 250 cm^3 beaker with aluminium foil to prevent entry of light
- place 150 cm^3 of nutrient medium in the beaker
- place two *L. minor* plants on the surface of the nutrient medium
- cover the top of the beaker with clear plastic film
- place the beaker in a room kept at a constant 20 °C under continuous light
- after 14 days
  1. record the colour of the leaves on a scale of 0–5 where 0 is complete chlorosis and 5 is normal dark green
  2. record the size of the leaves as T = tiny, S = small, M = medium and L = large
  3. harvest the plants and dry to constant mass
- repeat the whole experiment to gain five sets of data and calculate mean results for each nutrient medium tested

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(i) The beaker was wrapped in aluminium foil to reduce the growth of algae in the nutrient medium.
Explain how this increases the validity of the investigation. [2]

Algae would use (compete for) the minerals in the nutrient medium, so would limit (restrict) the growth of the duckweed.

Reducing algae means only the omitted micronutrient affects growth, so the results are valid.

(ii) Explain **one** reason why the top of the beaker was covered with clear plastic film. [2]

The film is clear to allow light in for photosynthesis by the duckweed.

It also prevents evaporation of water, so the concentration of the nutrient medium is maintained.

(iii) Suggest the colour of leaves given a leaf colour score of 0. [1]

yellow

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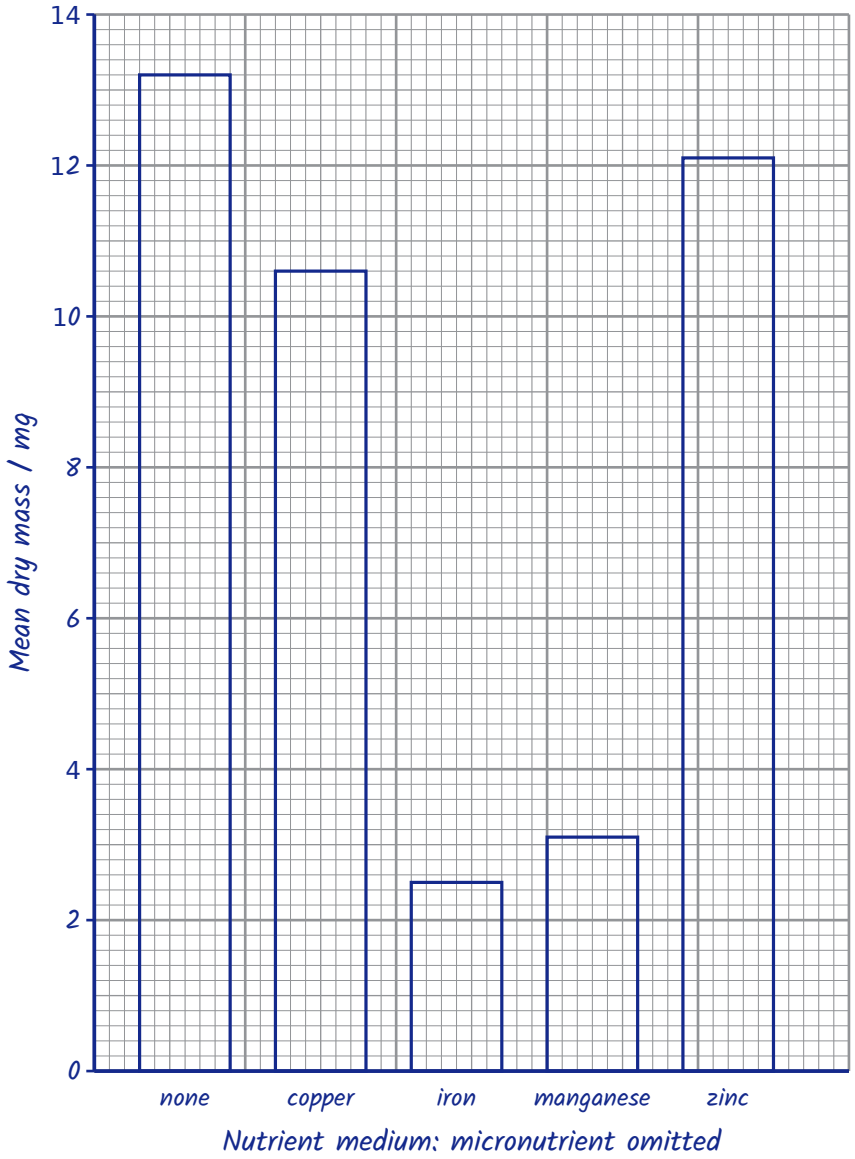
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The results of the experiment are shown in **Table 3.2**.

Table 3.2

Nutrient medium – micronutrient omitted	Mean results		
	dry mass / mg	leaf colour score	leaf size
none	13.2	5	L
copper	10.6	4	M
iron	2.5	1	S
manganese	3.1	2	T
zinc	12.1	4	M

(iv) Use **Table 3.2** to plot a **bar chart** of the mean dry mass of *L. minor* harvested for each nutrient medium on the grid below. [3]



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(v) Iron is essential for the transfer of electrons from photosystem I to the final electron acceptor.
Manganese is involved in reactions that result in the photolysis of water.

Use the information above and your knowledge of the light-dependent and light-independent stages of photosynthesis to explain why a deficiency of iron and manganese results in a major decrease in growth of *L. minor* plants. [5]

Manganese deficiency means less photolysis of water, so fewer protons (H^+) are released and fewer electrons for the electron transport chain. So less ATP is synthesised (by photophosphorylation / chemiosmosis). Iron deficiency means fewer electrons are transferred from photosystem I to NADP (the final electron acceptor), so less reduced NADP (NADPH) is produced. In the light-independent stage (Calvin cycle) less ATP and reduced NADP are available to reduce GP to triose phosphate (TP), so less TP is produced. Less ATP also reduces the regeneration of RuBP (ribulose bisphosphate), so less carbon fixation by rubisco and less GP is formed. So less glucose for respiration and fewer amino acids for protein synthesis, so less growth.

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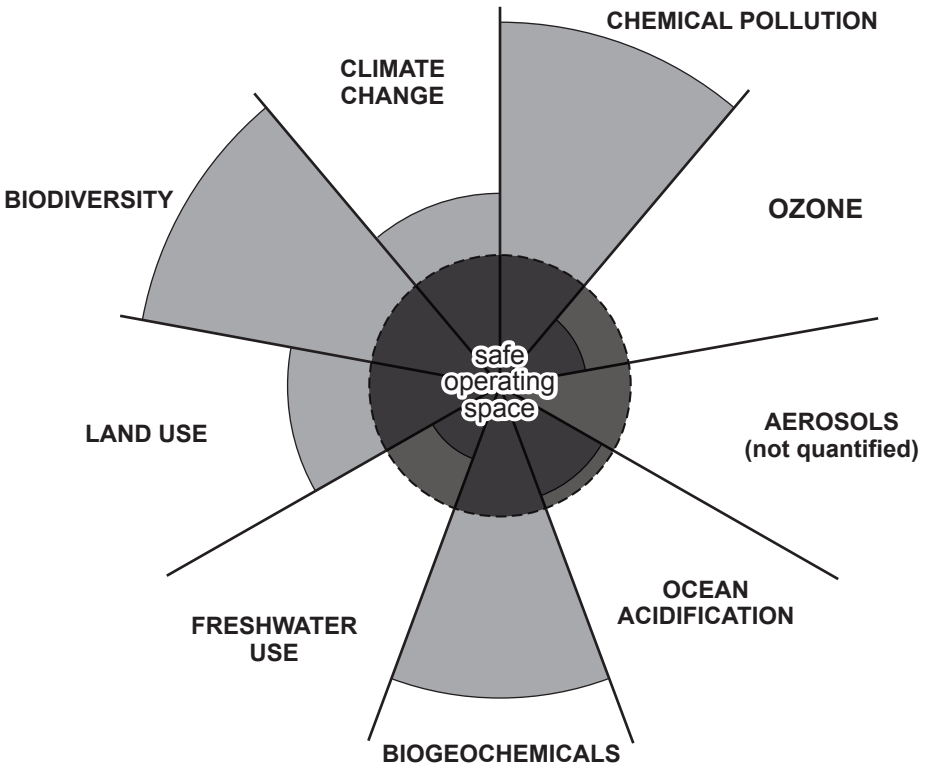
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4. (a) Planetary boundaries represent the central concept in an Earth system framework proposed by scientists. **Image 4.1** shows the status of the nine planetary boundaries in 2022.

Image 4.1



(i) State the expected consequence of crossing the safe threshold for any planetary boundary. [1]

There is a risk of abrupt, irreversible environmental change (damage to the planet).

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(ii) The threshold for climate change has been crossed. This has been linked to human activities, including deforestation.
With reference to the role of **photoautotrophs** and **saprotrophs** in the carbon cycle, explain how deforestation could account for the status of the climate change planetary boundary shown in **Image 4.1**. [4]

Deforestation removes photoautotrophs (trees), so less photosynthesis takes place.

This reduces the natural removal of CO_2 from the atmosphere.

More dead organic matter (felled trees, branches, roots) is decayed by saprotrophs.

Respiration by the saprotrophs releases more CO_2, so more CO_2 is released by decay than is removed by photosynthesis.

The increased atmospheric CO_2 is a greenhouse gas linked to climate change (global warming), so the climate change boundary has been crossed.

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Question continued overleaf

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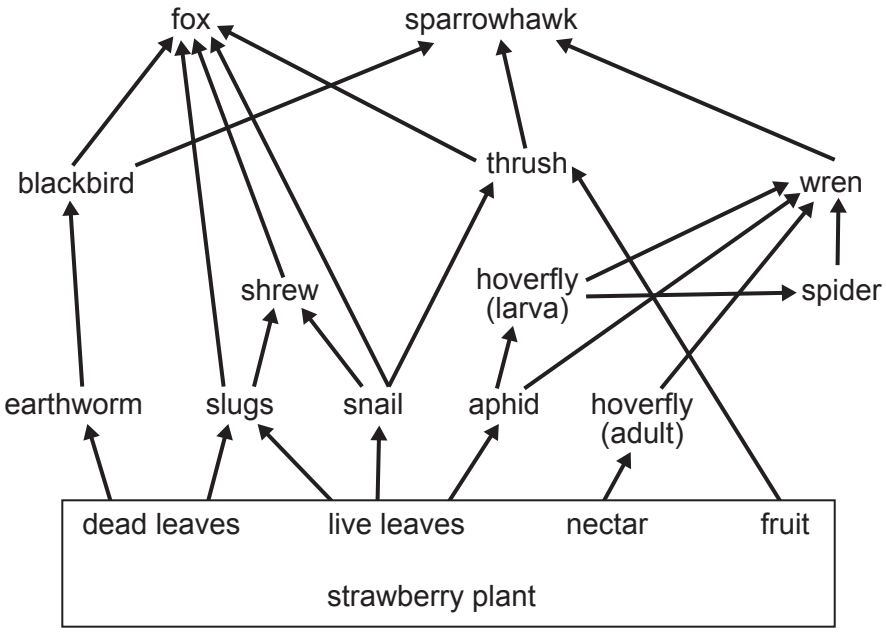
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(b) The chemical pollution boundary includes a wide variety of chemicals released into the environment by humans. To meet the demands of an increasing human population, intensive farming is used to increase food production.

'Aphide' is a pesticide which is sprayed onto a wide range of crops to control aphids. Aphids feed on the contents of phloem sieve tubes and can spread fungal disease between plants.

Image 4.2 shows the feeding relationships in a community of interdependent species that includes aphids.

Image 4.2



(i) State what the arrows represent in **Image 4.2**. [1]

direction of energy transfer from one trophic level to the next

(ii) Identify the following in **Image 4.2**:

I. an organism that is both a herbivore and a detritivore [1]

slugs

II. an omnivore [1]

thrush

(iii) Identify the original source of the energy transferred between organisms. [1]

the Sun (sunlight)

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(c) 'Aphide' acts by inhibiting the hydrolysis of acetylcholine in synapses. At low concentrations 'Aphide' affects only aphids. In high concentrations it can affect aphid predators and other organisms, including humans.

(i) Use the information given to explain why it is recommended that all fruit and vegetables should be washed before being eaten. [2]

Pesticide residue may remain on the produce, so humans could ingest a toxic (harmful) level of 'Aphide'.

Acetylcholine would not be broken down, so levels in the synapse stay high, affecting synaptic transmission (continued muscle contraction).

(ii) In rats, it was found that the maximum 'safe' daily intake of 'Aphide' was $0.035\,mg\,kg^{-1}$. This is the highest dose that could be ingested daily without causing adverse effects to health.
Calculate the total mass of 'Aphide' that an adult human weighing 95 kg could ingest per day with no impact to their health.
Give your answer in grams and in standard form. [3]

mass = 95 kg × 0.035 mg kg^{-1} = 3.325 mg day^{-1}

3.325 mg ÷ 1000 = 0.003325 g

= 3.325×10^{-3} g day^{-1}

Total mass of 'Aphide' = 3.325×10^{-3} g day^{-1}

(iii) Suggest **one** disadvantage **to humans** of using rats to determine the maximum 'safe' daily intake of 'Aphide' for a human. [1]

Rats are genetically different to humans, so may respond differently (have different tolerances).

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(d) The presence and concentration of 'Aphide' can be monitored using a biosensor. This includes immobilised molecules of the enzyme laccase.

(i) State **two** advantages of using **immobilised enzymes** in a biosensor. [2]

I. *The enzyme can be reused (recovered and used again), so it is cheaper.*

II. *It is more stable over a wider range of temperature and pH.*

(ii) Laccase is a soluble, globular protein. A ribbon diagram of its structure is shown in **Image 4.3**.

Image 4.3



Identify the secondary protein structure labelled **X** in **Image 4.3** and name the type of bond involved in maintaining this structure. [2]

X = *alpha (α) helix*

Bond = *hydrogen bonds*

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(iii) There are over 350 000 **synthetic** chemicals in production globally. At present only a very small fraction of these can be identified using biosensors.
Use your knowledge of enzymes to suggest why it is proving difficult to develop biosensors to identify these chemicals. [2]

Enzymes are specific to one substrate (complementary active site), so a different enzyme is needed for each chemical tested.

Enzymes may not exist naturally for synthetic chemicals, and making artificial enzymes takes time.

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5. In eukaryotic cells most of the ATP is synthesised in the mitochondria. Only a small number of ATP molecules are synthesised in the cytoplasm.

(a) (i) Name the stage of respiration that takes place in the cytoplasm. [1]

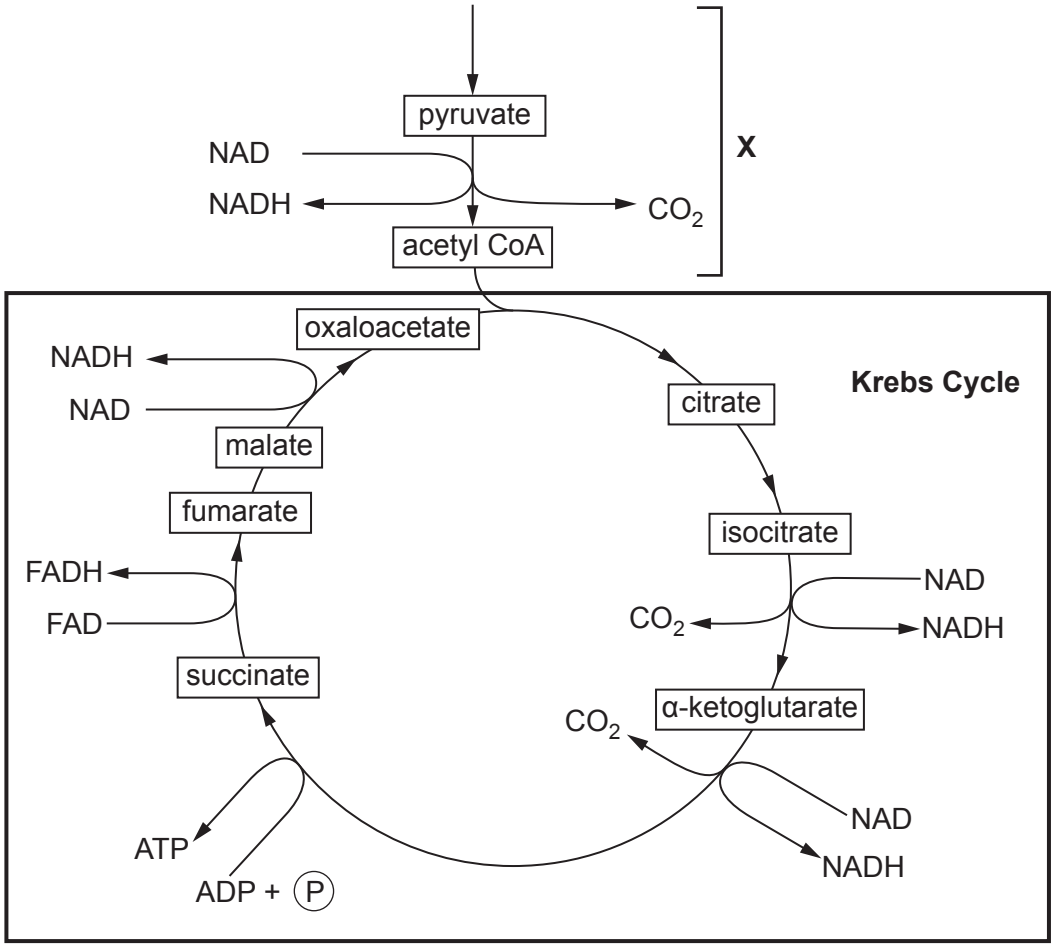
glycolysis

(ii) State the type of reaction that produces ATP in the cytoplasm. [1]

substrate-level phosphorylation

Image 5.1 shows the stages of respiration that take place in the mitochondria.

Image 5.1



(iii) Name **two** types of enzyme involved in the conversion of pyruvate to acetyl CoA in the stage labelled **X** in **Image 5.1**. [1]

decarboxylase *dehydrogenase*

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(iv) Triacetin is a triglyceride that can be used as an alternative respiratory substrate to glucose. From each molecule of triacetin, four molecules of acetyl CoA are formed.
Use **Image 5.1** and your knowledge of aerobic respiration to calculate the number of molecules of ATP that could be synthesised as a result of the breakdown of one molecule of triacetin. [2]

per Krebs cycle: 3 NADH = 9 ATP, 1 FADH = 2 ATP, 1 ATP (SLP) = 12 ATP

4 acetyl CoA, so 4 cycles: 12 × 4 = 48 ATP (36 + 8 + 4)

Number of molecules of ATP = 48

Question continued overleaf

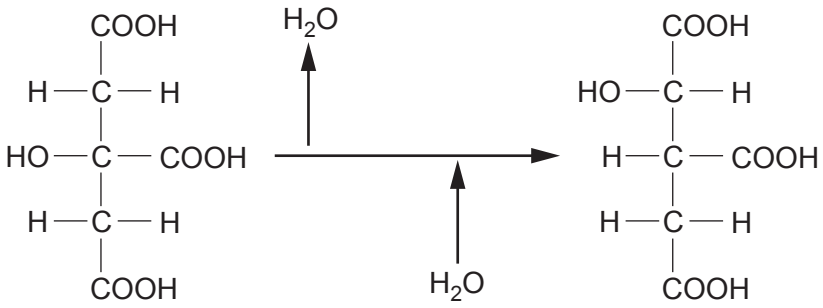
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(b) **Image 5.2** shows the formulae of citrate and isocitrate, two of the molecules formed during Krebs cycle.

Image 5.2



citrate **isocitrate**

(i) Explain why the molecules shown in **Image 5.2** are structural isomers. [1]

They have the same molecular formula (same number of each atom) but a different arrangement of atoms (different structural formula).

(ii) Both citrate and isocitrate contain three of the same functional group.
This functional group is also found in amino acids.
State the name and formula of this functional group. [1]

Name carboxyl (carboxylic acid) group

Formula COOH

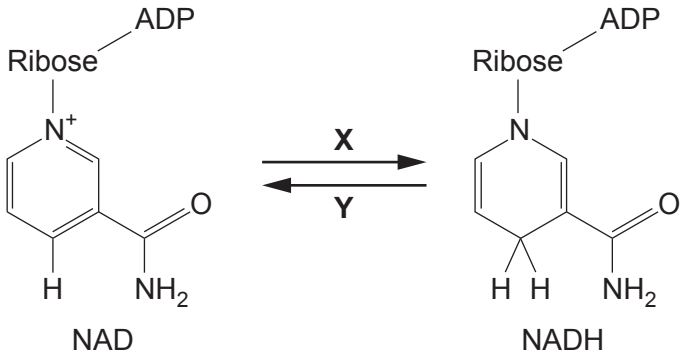
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(c) Isocitrate is converted to α-ketoglutarate by the enzyme isocitrate dehydrogenase (IDH). NAD is also converted to NADH in this reaction as shown in **Image 5.3**.

Image 5.3



NAD NADH

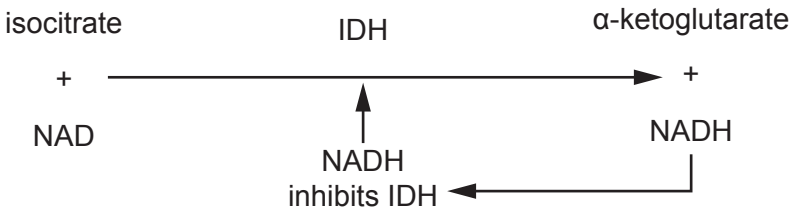
(i) Use information from **Image 5.3** to state whether NAD is being oxidised or reduced in the reaction labelled **X**. Explain your answer. [2]

NAD is reduced.

Hydrogen (H^+ and electrons) is added: NADH has an extra H on the ring and the N has lost its positive charge.

(ii) **Image 5.4** shows the conversion of isocitrate to α-ketoglutarate.

Image 5.4



Use information from **Images 5.3** and **5.4** to explain how NADH can act as a competitive inhibitor of IDH and regulate the production of α-ketoglutarate. [3]

NADH has a similar shape to NAD, so it can fit into the active site of IDH.

It blocks the active site, preventing the formation of enzyme-substrate complexes between IDH and NAD (isocitrate).

So increased production of NADH decreases the production of α-ketoglutarate (negative feedback).

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(d) An investigation was carried out to determine how the concentration of NADH affects the rate at which isocitrate is converted to α-ketoglutarate.
The same concentration of IDH was used throughout. All solutions were at pH 7.4 and 25 °C.

(i) Explain how **and** why the pH was maintained at pH 7.4. [2]

Using a buffer solution of pH 7.4, because a change in pH changes the shape of the active site of IDH and affects its ability to bind to NAD (isocitrate).

The inhibitory effect of NADH on the activity of IDH is given as percent inhibition (I%).
Table 5.5 shows the rates of reaction of IDH and I% for a range of NADH concentrations.

Table 5.5

Concentration of NADH / μmol dm^{-3}	Rate of reaction / μmol minute^{-1} mg^{-1} IDH	I% (percentage inhibition) / %
0	79	0
25	64	19
50	51	35
100	39	51
150	25	68
200	16	80
250	10	87
300	7	91

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(ii) Use the following equation and data from **Table 5.5** to calculate the percentage inhibition (I%) for a concentration of 50 μmol NADH. [2]

$$I\% = \frac{(V_0 - V)}{V_0} \times 100$$

where V_0 = the rate of reaction in the absence of NADH,
and V = the rate of reaction in the presence of NADH

I% = (79 − 51) ÷ 79 × 100

= 28 ÷ 79 × 100 = 35.4

I% = *35*

(iii) The rate at which NADH transports hydrogen to the electron transport chain increases as the concentration of ATP in the matrix decreases. ATP cannot be stored in cells. However, demand for ATP varies at different times of the day and the rate of ATP synthesis varies to meet demand.

Suggest how the inhibitory effect of NADH on IDH is involved in regulating the rate at which ATP is synthesised when **an organism's activity levels are low**. [3]

When activity is low, less ATP is used, so the concentration of ATP in the matrix increases.

So the rate at which NADH delivers hydrogen to the electron transport chain decreases and the concentration of NADH increases.

This causes increased inhibition of IDH, so the rate at which NADH (and FADH) is produced in the Krebs cycle is reduced.

So fewer H^+ are pumped into the intermembrane space, a lower proton gradient is established, and the rate of ATP synthesis decreases to match demand.

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6. In any ecosystem, population numbers vary over time due to many factors. These factors can be biotic or abiotic and their effects can be density dependent or density independent. Increasing human pressures on the environment have increased the risk of extinction for many species.

(a) (i) State the term used to describe a species that is at risk of extinction. [1]

endangered

(ii) **Table 6.1** lists three factors that could affect the size of a population.

Table 6.1

Factor	Abiotic	Biotic	Density-dependent	Density-independent
Atmospheric temperature	✓			✓
Disease		✓	✓	
Drought	✓			✓

Place a tick (✓) in **two** boxes in each row in **Table 6.1** to correctly identify if these factors are **abiotic** or **biotic** and whether their effects are **density-dependent** or **density-independent**. [2]

(b) The population size of many species is now monitored to inform political decisions that could support conservation. The data collected is used to predict the time taken for a species to be no longer at risk of extinction.

The numbers of African elephants (*Loxodonta africana*) decreased rapidly in the 20th century, largely due to human activities. Conservation efforts are helping to restore population numbers in some areas of Africa.

(i) Suggest **two** human activities that could have contributed to the decline in the number of African elephants. [1]

poaching (hunting for ivory)

habitat destruction (deforestation)

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(ii) Under optimal conditions, African elephants have a generation time of 22 years. This is the time taken for a population to double in number.
Generation time (G) is calculated using the formula:

$$\text{Generation time (G)} = \frac{t}{3.3 \times \log_{10}\left(\frac{N_{final}}{N_{start}}\right)}$$

where:

t = time
N_{final} = the final number of individuals in the population
N_{start} = the initial number of individuals in the population

Use the formula above to estimate the time it would take for a starting population of 10 elephants to reach a population of 1000.
Give your answer to two significant figures. [3]

$22 = t \div (3.3 \times \log_{10}(1000 \div 10))$

$\log_{10}(100) = 2$, so $3.3 \times 2 = 6.6$

$t = 22 \times 6.6 = 145.2$ years

$= 150$ years (2 s.f.)

Time taken to reach final population of 1000 = 150 years

(iii) One conservation method used has been to set up enclosed areas where elephants are protected.
If the area is not enclosed, it could lead to a decrease in the time taken to reach the target population of 1000 elephants. Suggest why. [1]

Elephants could migrate into the area (immigration), so numbers increase faster than by breeding alone.

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7. Succession is the change in structure and species composition of a community over time. Primary succession from bare rock to a mature community can take hundreds of years. Secondary succession, for example, following the felling of trees, takes far less time.

Forests are habitats that can support a high level of biodiversity. In some countries, forests are given nature conservation status and are unmanaged. There is limited harvesting of wood and no clearance of dead wood or undergrowth. This helps to preserve habitats.

In managed forests, secondary succession is encouraged by the regular felling of trees. The removal of dead and decaying wood and undergrowth in these forests reduces the spread of disease.

Evidence suggests that by using sustainable forest management practices, the demand for timber and the need for conservation can be met.

Table 7 compares data from an unmanaged nature conservation forest and a managed timber production forest. Both forests contained similar tree species.

Table 7

	Type of forest	
	unmanaged nature conservation forest	sustainably managed timber production forest
increase in volume of wood / m^3 hectare^{-1} year^{-1}	2	15
maximum volume of wood / m^3 hectare^{-1}	624	757
time for trees to reach felling height / years	175	50
useful wood harvest / million m^3 year^{-1}	10–15	56–86
carbon storage / tonnes CO_2 hectare^{-1} year^{-1}	0.4	3.2–3.5
increase in species biodiversity over time / %	0	0.005

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Use correct terminology to describe the stages in primary succession that could result in the initial formation of a forest from bare rock.
Explain why biodiversity increases as the forest community matures.
With reference to the information opposite, explain how managed forest succession can meet the need for timber production and be of benefit to the environment. [9 QER]

Primary succession begins with the colonisation of bare rock by pioneer species such as lichens and mosses, which can tolerate harsh abiotic conditions. They weather the rock and, when they die, their decay by saprotrophs adds organic matter, forming a thin soil.

This allows pioneer plants such as annuals to grow, followed by perennials and grasses, then shrubs as the soil deepens and holds more water and minerals.

Each community changes the abiotic conditions, making them more suitable for the next species, which outcompete the previous ones. Each stage is called a sere (seral stage). Finally trees grow and a forest forms the climax community.

Biodiversity increases as the forest community matures because the total number of organisms and the number of plant species (species richness) increase. More plant species and biomass give an increased net primary productivity, so there is more food for animals and the food webs become wider and more complex. The layers of the forest (canopy, shrub layer, field layer, leaf litter) provide many more habitats and ecological niches, so more species of animals can live there. Decay of dead organisms increases soil formation and soil fertility, and the tree cover gives shade and shelter so there is less variation in abiotic factors such as soil moisture content and temperature, so more species can survive.

Table 7 shows that managed forest succession meets the need for timber. In the managed forest the trees grow faster: the volume of wood increases by 15 m^3 $hectare^{-1}$ $year^{-1}$ compared with only 2 in the unmanaged forest, and the maximum volume of wood is greater (757 compared with 624 m^3 $hectare^{-1}$).

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Trees take only 50 years to reach felling height instead of 175 years, so they can be felled and replanted more often, giving a much greater useful wood harvest (56 to 86 million m^3 $year^{-1}$ compared with 10 to 15).

Managed succession also benefits the environment. Removing dead and decaying wood and undergrowth reduces the spread of disease, so fewer trees die. The rapidly growing young trees photosynthesise more, so carbon storage is much higher (3.2 to 3.5 compared with 0.4 tonnes CO_2 $hectare^{-1}$ $year^{-1}$), and with less decay less CO_2 is released by saprotrophs, which helps to reduce climate change. Regular felling keeps parts of the forest at earlier seral stages, so there is a slight increase in species biodiversity over time (0.005% compared with 0% in the unmanaged forest). So sustainable management meets the demand for timber while also conserving the environment.

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