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

GCE A LEVEL

A400U10-1

S23-A400U10-1

WEDNESDAY, 7 JUNE 2023 – AFTERNOON

BIOLOGY – A level component 1
Energy for Life

2 hours

For Examiner's use only		
Question	**Maximum Mark**	**Mark Awarded**
1.	**9**	
2.	**17**	
3.	**18**	
4.	**17**	
5.	**17**	
6.	**13**	
7.	**9**	
Total	**100**	

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ADDITIONAL MATERIALS

In addition to this paper you may require 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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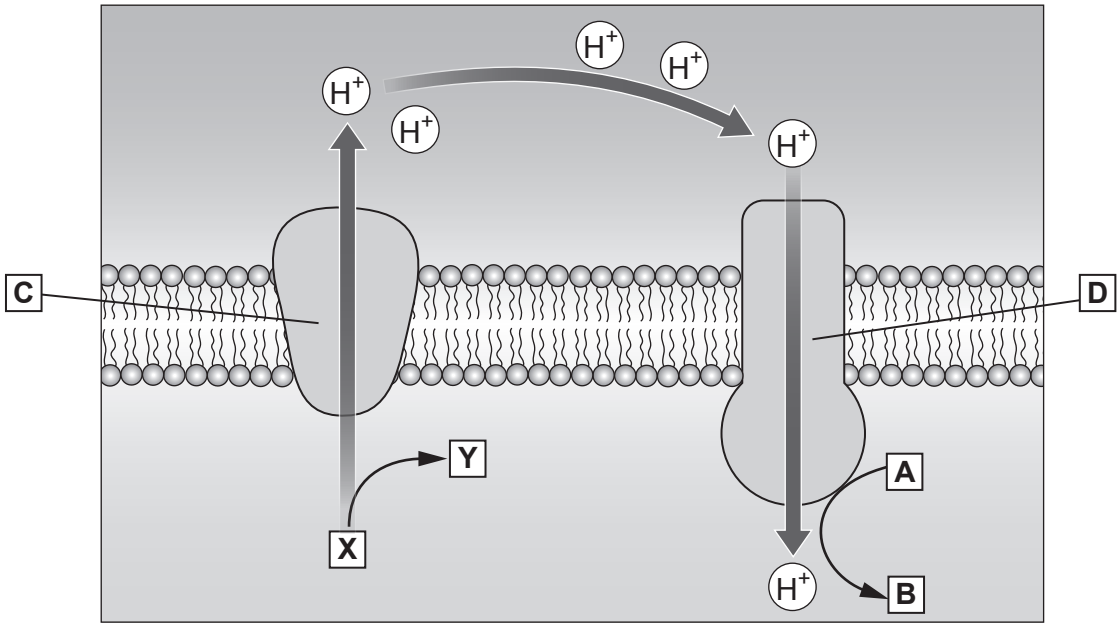
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Answer **all** questions.

1. ATP synthesis involves transferring energy from the flow of protons through an intrinsic protein complex. To enable the flow of protons through this protein complex, other structures are used to create a proton gradient across a membrane. This process is summarised in **Image 1.1**.

Image 1.1



(a) Use **Image 1.1** to answer the following questions.

(i) Name the following:

I. the **general** term for the protein labelled **C**. [1]

Proton pump (carrier protein)

II. the enzyme found in protein complex **D**. [1]

ATP synthetase (ATP synthase)

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(ii) Explain why protons are moved through structure **C** by a form of active transport but through structure **D** by facilitated diffusion. [2]

At C, protons are transported against their concentration gradient, from a lower to a higher concentration, so energy is needed (active transport).

At D, protons move down their concentration (electrochemical) gradient, from a higher to a lower concentration, through a channel in the protein, so it is facilitated diffusion.

(iii) **X** and **Y** represent a proton donor in two different forms.
Explain why **Y** is the oxidised form of the proton donor. [1]

Hydrogen (protons, H^+) have been removed from X, so Y has lost hydrogen and is the oxidised form.

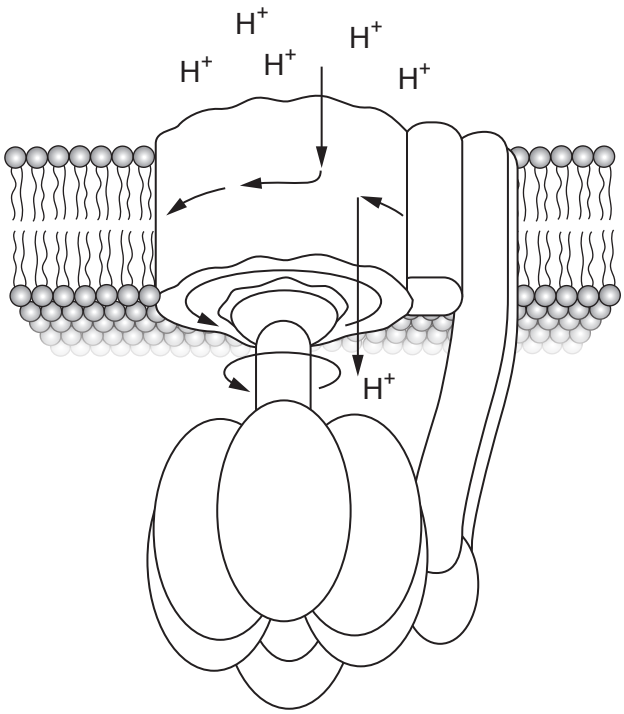
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(b) **Image 1.2** shows a model of the protein complex labelled **D** in **Image 1.1**. These structures are only found in two organelles of eukaryotic cells.

Image 1.2



(i) Name the **two** organelles in which structure **D** is found in eukaryotic cells and state precisely where it would be located in each of these organelles. [2]

Name of organelle	Location of structure **D**
Mitochondrion	*Inner mitochondrial membrane*
Chloroplast	*Thylakoid membrane*

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(ii) **Complete the boxes** below to show the reactants and products in the overall reaction that takes place in structure **D**. [1]

ADP	+	P_i	→	ATP

(iii) State if this reaction is endergonic or exergonic. Explain your answer. [1]

Endergonic, because energy is taken in and stored as a high energy bond is formed in ATP.

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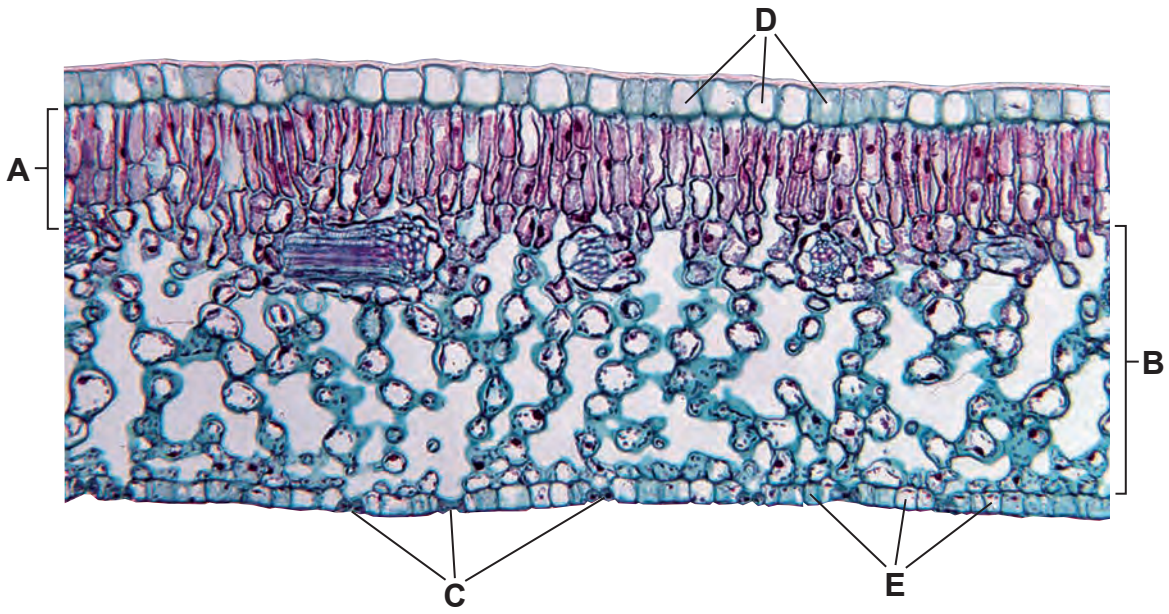
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2. During photosynthesis energy is transduced from light energy to chemical energy. This process takes place mainly in the leaves of a plant. The leaves show many adaptations to absorb the maximum amount of light energy.
Image 2.1 shows a transverse section through a leaf of a privet plant (*Ligustrum*).

Image 2.1



(a) (i) The tissue layer labelled **A** in **Image 2.1** is the main site of photosynthesis in the leaves of this plant. State the name given to this tissue layer. [1]

Palisade mesophyll

(ii) State **one** adaptation shown by tissue layer **B** in **Image 2.1**. Explain the function of this adaptation. [2]

Tissue B (spongy mesophyll) has large air spaces between the cells.

These enable gas exchange: diffusion of CO_2 to the palisade cells and of

O_2 and water vapour out through the stomata.

(iii) Name **one** organelle present in cells of tissue layers **A** and **B** and the structures labelled **C** but **not** present in the cells labelled **D** or **E**. [1]

Chloroplasts

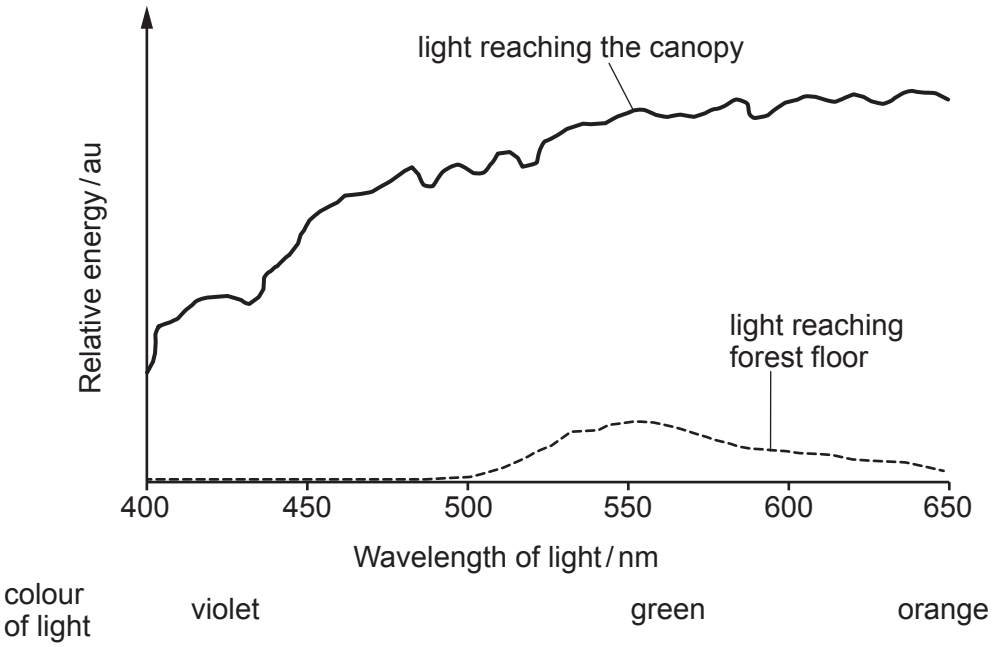
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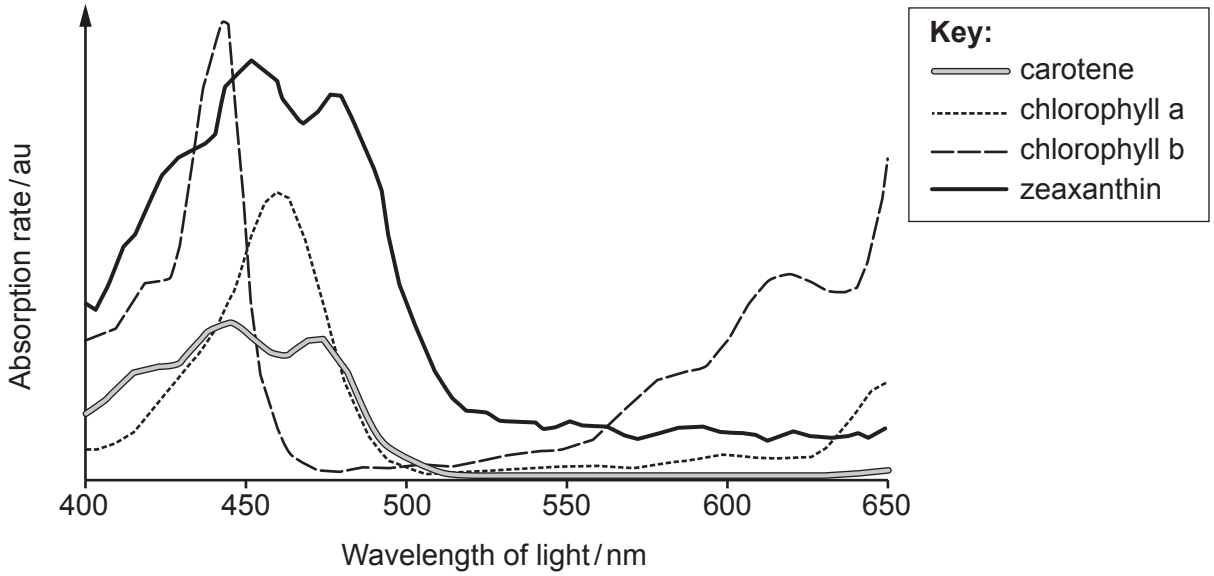
Green plants grow in a wide range of habitats but all need sufficient light to carry out photosynthesis. In shaded parts of a forest, most of the red and blue wavelengths of light are absorbed by leaves in the canopy and the light that reaches plants on the forest floor is mainly in the green/yellow region of the spectrum as shown in **Image 2.2**.

Image 2.2



To increase the efficiency of light absorption, chloroplasts contain a number of photosynthetic pigments. **Image 2.3** shows the absorption spectra of some photosynthetic pigments.

Image 2.3



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(b) Use all the information provided to suggest which **two** photosynthetic pigments might be found in higher concentrations in the leaves of plants growing on the floor of a forest compared to those in the canopy. Explain your answer. [3]

Zeaxanthin and chlorophyll b.

Most of the light reaching the forest floor is green / yellow light, between about 500 and 650 nm, as red and blue light has been absorbed by the canopy.

Zeaxanthin and chlorophyll b absorb most light at these wavelengths (chlorophyll b around 600 to 650 nm, zeaxanthin from 500 to 650 nm), so more light energy can be absorbed for photosynthesis.

(c) Intensity of light in some habitats is a limiting factor. Some plants respond to surviving in shade by growing larger leaves. In forests, trees fall into two main categories:

- those that can grow and survive in shade
- those that can only grow and survive in full sunlight, for example at the edges of a forest or in clearings.

Seeds were collected from two trees growing in a forest and germinated. They were then grown under low light intensity for ten days. The total leaf surface area of each seedling after ten days was recorded. Other environmental factors that could affect the growth of the seedlings were kept constant.

(i) State **three** factors that are required for the germination of seeds. [1]

Water

Oxygen

Suitable (warm) temperature

(ii) Explain why it was important that the seedlings were grown for **ten days** before the total leaf surface area was recorded. [1]

To give time for the leaves to develop and grow large enough to be measured.

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(iii) The total leaf surface area of the seedlings was determined using the following method:

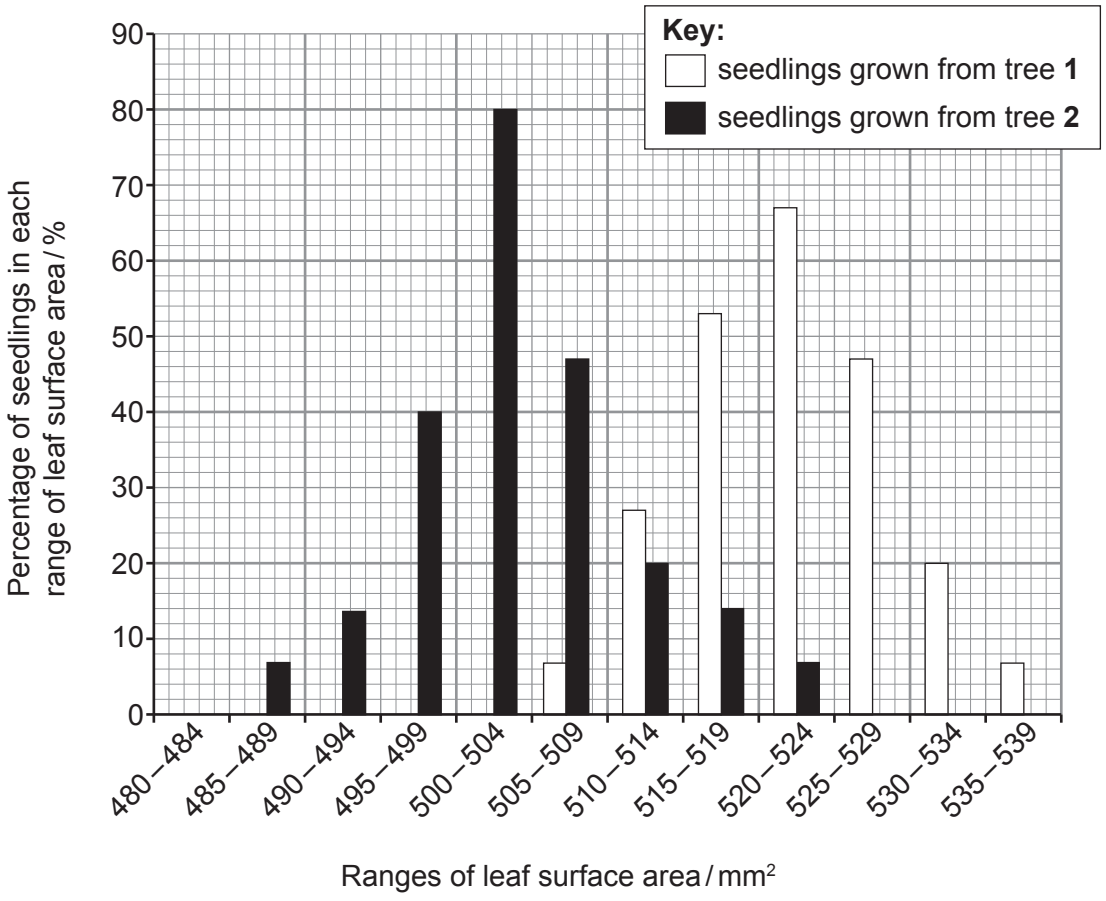
- cut out and weigh 1 cm^2 of leaf
- weigh all the leaves from the seedling
- divide the mass of the leaves by the mass of 1 cm^2 of leaf

Explain why this method provides a more accurate estimate of the total leaf surface area than drawing around each leaf on pieces of graph paper and then estimating the area covered by the leaf. [2]

Leaves are irregular in shape and may not be flat, so drawing around them is difficult and does not represent the actual area. Counting squares on graph paper needs judgement (part squares), so it is open to human error, whereas weighing gives quantitative data.

The total leaf surface area (to the nearest mm^2) of the seedlings grown from each tree was grouped into 5 mm^2 ranges and the percentage of the seedlings in each leaf range calculated. A frequency histogram was plotted of the results. This is shown in **Graph 2.4**.

Graph 2.4



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(d) (i) State the 5 mm^2 range of leaf surface area in which the modal value would be found for the seedlings grown from each tree. [1]

modal value tree **1** = 520 – 524 mm^2

modal value tree **2** = 500 – 504 mm^2

(ii) The mean leaf surface areas of the seedlings grown from each tree were:

Tree **1** 522 mm^2
Tree **2** 504 mm^2

With reference to the information provided give **two** ways in which the data from both trees show a normal distribution. [2]

For each tree the mode and the mean are in the same range (522 in 520 to 524, 504 in 500 to 504).

The values are evenly distributed (symmetrical) either side of the mean, giving a bell shaped curve.

(iii) Use **Graph 2.4** to conclude which tree was more likely to have been growing under the tree canopy. Use your knowledge of **leaf adaptations** to give **two** reasons to explain your answer. [3]

Tree 1, as its seedlings have a larger total leaf surface area (mode 520 to 524 mm^2 compared with 500 to 504 mm^2).

Shade leaves are larger so they can absorb more of the limited light available under the canopy.

Larger leaves contain more palisade mesophyll cells and so more chloroplasts and chlorophyll (photosynthetic pigment) to trap light.

They also have more stomata for gas exchange, so more CO_2 can diffuse in for photosynthesis.

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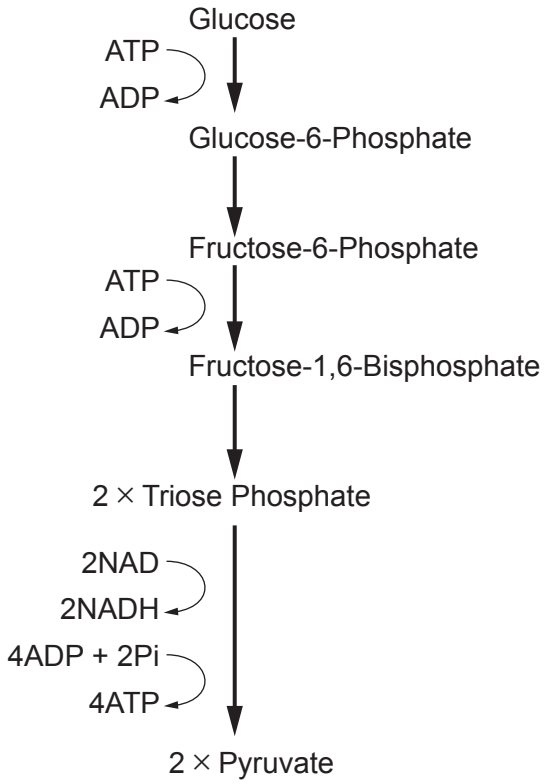
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3. Glycolysis is the first stage of respiration and is oxygen-independent. It takes place in the cytoplasm and enables a wide range of respiratory substrates to be used as energy sources.

Image 3.1 shows some stages of glycolysis.

Image 3.1



(a) The enzyme hexokinase catalyses the addition of a phosphate group to a molecule of glucose and can accept both alpha and beta glucose isomers as substrates. The enzyme acts through an induced fit mechanism.

(i) Describe the difference between the alpha (α) and beta (β) isomers of glucose. [1]

In alpha glucose the OH group on carbon 1 is below the ring; in beta glucose the OH on carbon 1 is above the ring.

(ii) Explain how the induced fit mechanism enables hexokinase to accept both isomers as substrates. [2]

The active site changes shape when the substrate binds, moulding around the substrate to form an enzyme-substrate complex.

Alpha and beta glucose have a very similar shape, so the flexible active site can fit around either isomer.

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(iii) Hexokinase includes a magnesium ion to catalyse the addition of a phosphate group to glucose.
State **one** other use of magnesium ions in eukaryotic cells. [1]

Magnesium is part of the chlorophyll molecule.

(b) Some ATP is produced directly in glycolysis. More ATP is produced as a result of glycolysis via the electron transport chain.

(i) Name the process by which ATP is produced directly in glycolysis. [1]

Substrate-level phosphorylation

(ii) Use **Image 3.1** to explain why there is a **net yield** of 2 ATP produced directly in glycolysis. [2]

2 ATP are used to phosphorylate glucose to glucose-6-phosphate and fructose-6-phosphate to fructose-1,6-bisphosphate.

4 ATP are produced when 2 triose phosphate are converted to 2 pyruvate, so the net yield is 4 – 2 = 2 ATP.

(iii) Identify **one** type of enzyme involved in the conversion of triose phosphate to pyruvate and state the function of this type of enzyme. [2]

Dehydrogenase.

It removes hydrogen from triose phosphate (oxidation of triose phosphate), passing it to NAD to form reduced NAD.

(iv) Describe what happens to pyruvate in animal cells under anaerobic conditions. [1]

Pyruvate is reduced (by reduced NAD) and converted to lactate (lactic acid).

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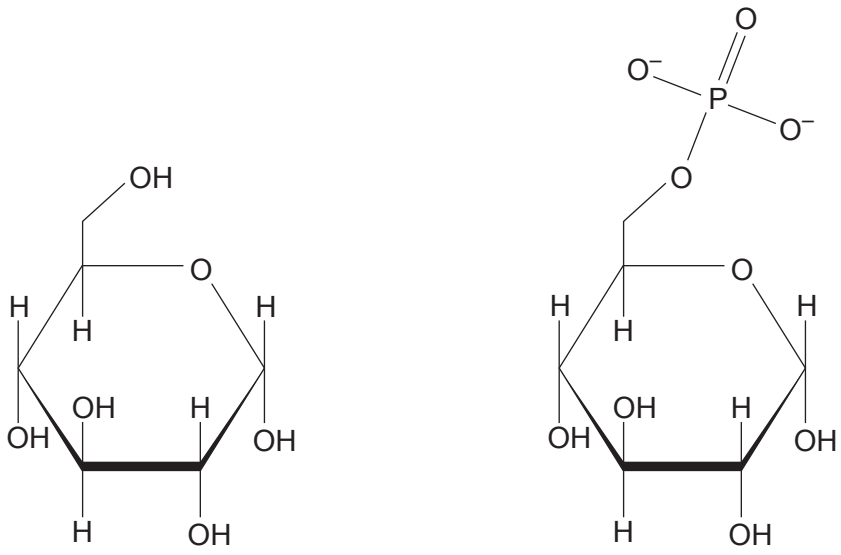
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(c) At rest, blood glucose concentration is usually low and hexokinase catalyses the conversion of glucose to glucose-6-phosphate. An increased concentration of glucose-6-phosphate inhibits hexokinase. **Image 3.2** shows the molecular structure of glucose and glucose-6-phosphate.

Image 3.2



glucose

glucose-6-phosphate

Use **Image 3.2** to conclude and explain how glucose-6-phosphate could inhibit hexokinase. [3]

Glucose-6-phosphate acts as a competitive inhibitor of hexokinase.

G6P has a similar shape and structure to glucose (the same ring with the same OH groups), with only an extra phosphate group.

So G6P can bind to and block the active site, forming an enzyme-inhibitor complex and preventing enzyme-substrate complexes forming.

This reduces the rate of formation of ES complexes, so the conversion of glucose to G6P slows down.

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(d) **Table 3.3** shows the blood glucose ranges for a non-diabetic, a pre-diabetic (high risk of developing diabetes) and a diabetic, 12 hours before eating and two hours after eating. The blood glucose concentrations are recorded as mg per decilitre (mg/dL).

Table 3.3

Time of glucose test	Blood glucose concentration / mg/dL		
	Non-diabetic	Pre-diabetic	Diabetic
12 hours before eating	< 100	100 to 125	≥ 126
two hours after eating	< 140	140 to 199	≥ 200

(i) Following 12 hours without eating, a blood test was carried out on an adult with a total blood volume of 4.8 dm^3 and total blood glucose mass of 4.6 g. Use the formula below to calculate the blood glucose concentration of this patient. **Give your answer to the nearest mg/dL.** [3]

$$\text{blood glucose concentration / mg/dL} = \frac{\text{mass of glucose (mg)}}{18} \times \frac{\text{volume of blood } (dm^3)}{10}$$

mass of glucose = 4.6 g = 4600 mg

concentration = (4600 ÷ 18) × (4.8 ÷ 10)

= 255.56 × 0.48 = 122.67

= 123 mg/dL (nearest mg/dL)

Blood glucose concentration = 123 mg/dL

(ii) The same patient was tested again two hours after eating. The result was 199 mg/dL.
Use the value of the blood glucose concentration two hours after eating to evaluate the risk of this patient developing diabetes. [2]

199 mg/dL is at the very top of the pre-diabetic range (140 to 199), only 1 mg/dL below the diabetic range (≥ 200). So the patient is at a very high risk of becoming diabetic.

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4. Instructions for setting up a new freshwater aquarium are given below.

- Fill the aquarium with water.
- Use an air pump to aerate the water and use an aquarium heater to reach a constant temperature of 28°C.
- Add a small amount of fish food every three days for at least 45 days (the fish food is added as a source of nitrogen compounds and bacteria which decay the food).
- Before each addition of food, test the water in the aquarium for the presence and concentration of ammonia, nitrite and nitrate.

IMPORTANT: Do not add fish until ammonia and nitrite are not detected in the water of the aquarium.

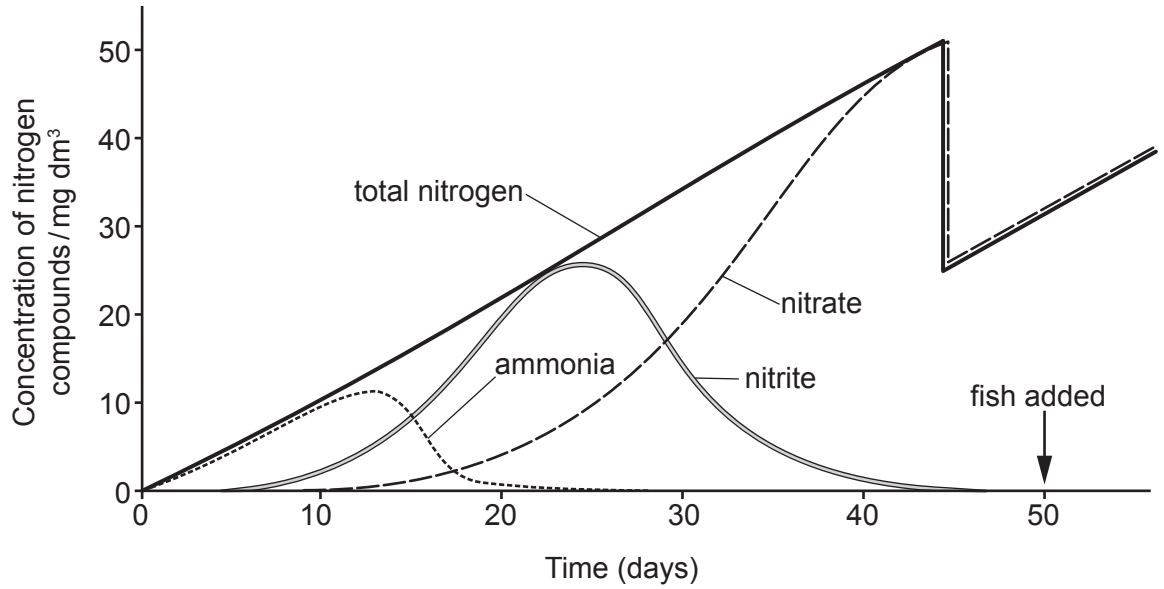
(a) (i) Name **two types** of compounds in the fish food that contain nitrogen atoms. [2]

Proteins / amino acids

Nucleic acids (DNA, RNA) / ATP

Graph 4 shows the concentration of three nitrogen-containing compounds found in the water samples from the aquarium.

Graph 4



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(ii) Use your knowledge of the nitrogen cycle to explain the sequence of the appearance of ammonia, nitrite and nitrate as shown in **Graph 4**. [4]

First, ammonia (ammonium, NH_4^+) is produced by bacteria (decomposers) breaking down proteins in the fish food: ammonification. Next, nitrite rises as ammonium is converted to nitrite (NO_2^-) by Nitrosomonas. Finally, nitrate appears as nitrite is converted to nitrate (NO_3^-) by Nitrobacter. These last two steps are nitrification by nitrifying bacteria, so ammonia peaks first, then nitrite, then nitrate.

(iii) Explain why the water was continually aerated. [2]

Aeration provides a source of oxygen and maintains aerobic conditions. Nitrifying bacteria are aerobic, so nitrification only takes place in aerobic conditions; it also prevents denitrification by denitrifying bacteria.

(iv) Suggest a possible explanation for the change in nitrate concentration at day 45. [1]

Some of the water was changed (removed and fresh water added) / the tank was cleaned.

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(b) Ammonia and nitrite ions are highly toxic; nitrate ions are less toxic but can still cause harm to fish in high concentrations.

(i) Suggest what would happen to the concentration of nitrate ions if plants were grown in the aquarium. Explain why this would happen. [2]

The nitrate concentration would decrease, as the plants absorb nitrate ions through their roots.

They use the nitrate to synthesise proteins (amino acids), nucleic acids and other nitrogen-containing compounds.

(ii) Suggest why the concentration of nitrogen containing compounds may increase if too many fish are introduced into an aquarium. [3]

More fish produce more excreta (urine, ammonia) and faeces (egesta), and more food is added; some fish may die.

These contain nitrogen-containing compounds such as urea, ammonia and proteins.

Nitrogen compounds are released when dead fish, uneaten food and faeces are decayed by decomposers.

(c) The aquarium was kept on a windowsill in bright sunlight. Two weeks after the introduction of fish to the aquarium the water turned green and the fish died. Suggest why the fish died and explain your answer. [3]

Bright sunlight and nitrate in the water caused an algal bloom (rapid growth of algae), turning the water green.

When the algae die, bacteria (decomposers) decay the dead algae, uneaten food and faeces and respire aerobically, using up the oxygen in the water.

The fish die as they cannot respire aerobically due to the lack of oxygen.

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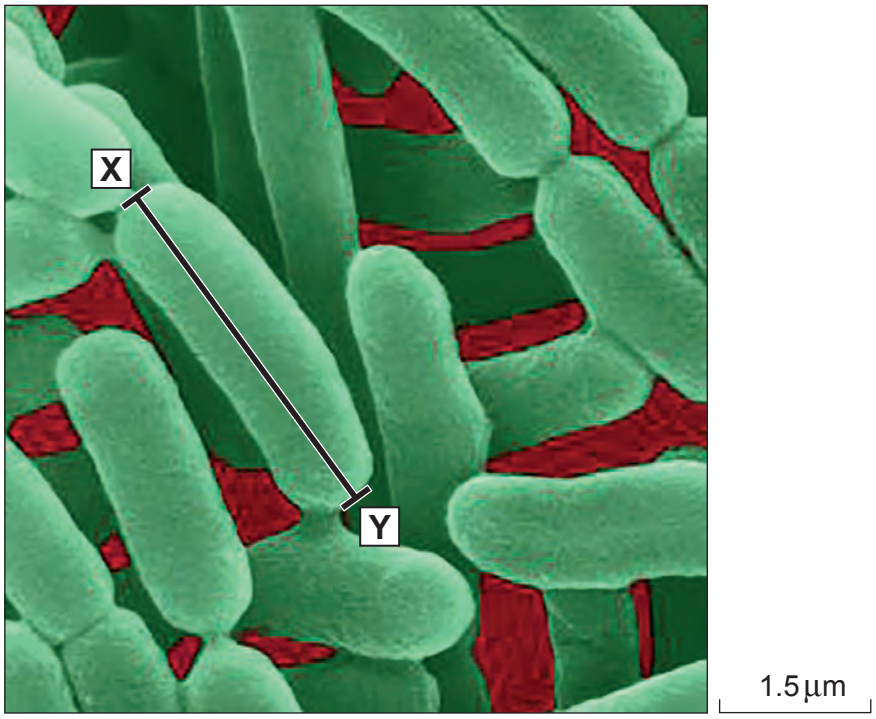
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5. *Salmonella enterica* is a bacterium with many different forms. Some forms of this bacterium are serious human pathogens, causing diarrhoea and vomiting; in some cases, infection with this pathogen can be fatal. **Image 5.1** shows a scanning electron micrograph (SEM) of some *Salmonella* bacteria.

Image 5.1



(a) Calculate the length of **one** bacterium along the line marked **X–Y** on **Image 5.1**. **Give your answer in µm to one decimal place.** [2]

X–Y on image = 49 mm; scale bar 20 mm = 1.5 µm

(49 ÷ 20) × 1.5 = 3.675 µm

Length of bacterium = 3.7 µm

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(b) A sample of faeces from a patient with diarrhoea and vomiting was examined for the presence of *Salmonella* bacteria. Rod-shaped bacteria were observed which stained red using Gram-staining. These bacteria were cultured and were found to be facultative anaerobes.

(i) State the term used to describe rod-shaped bacteria. [1]

Bacillus (bacilli)

(ii) Explain what is meant by the term facultative anaerobe. [1]

It can respire both aerobically and anaerobically, so it can survive with or without oxygen.

(iii) Explain what information about the **structure** of *Salmonella* bacteria is provided by the result of Gram-staining. [1]

It is Gram negative: the cell wall has an extra outer layer of lipopolysaccharide (thin peptidoglycan layer).

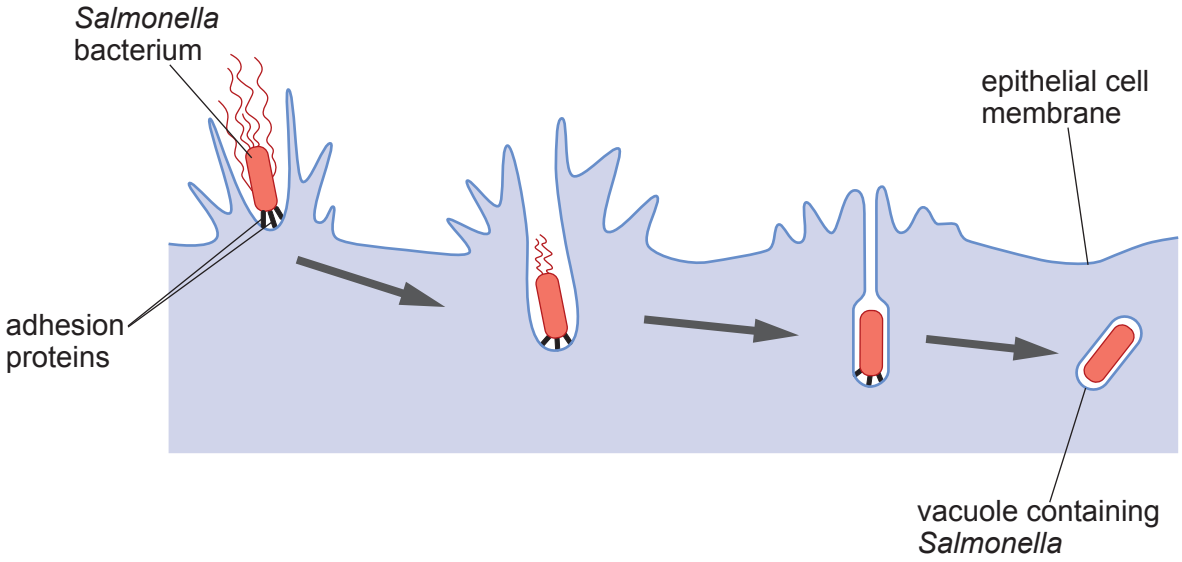
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Salmonella enterica is an intracellular pathogen. **Image 5.2** shows stages in the entry of *Salmonella* bacteria into an epithelial cell lining the gut.

Image 5.2



(c) Name the process by which these bacteria enter cells and explain why ATP is needed for this to take place. [2]

Endocytosis (phagocytosis).

ATP is needed as a source of energy to change the shape of the cell membrane, so it can surround the bacterium and form the vesicle / vacuole.

(d) *Salmonella* can be highly pathogenic and so strict aseptic conditions must be used when transferring samples containing this bacterium from the container with a faecal sample to an agar plate for culturing.
Describe and explain **two** precautions that must be taken when inoculating an agar plate with faeces that might contain *Salmonella*. [2]

Precaution	Explanation
Flame the inoculating loop until red hot before and after taking the sample	To sterilise it, killing any microorganisms present on the loop
Keep the Petri dish lid at an angle, open as little as possible	Reduces risk of contamination from airborne bacteria and spores

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(e) *Salmonella* infections are estimated to affect up to 1.3 billion people and are responsible for nearly 3 million deaths each year. Many foods have been found to contain low levels of *Salmonella* bacteria, including salad leaves and nuts.

One study carried out on one type of raw nut in the USA found the following results:

- 4153 samples were tested for the presence of viable *Salmonella* bacteria
- 101 of the samples tested positive for the bacteria

Calculate the percentage of samples that tested positive for *Salmonella*. **Give your answer to an appropriate number of decimal places.** [2]

(101 ÷ 4153) × 100 = 2.4320 %

Percentage with *Salmonella* = 2.4 %

(f) The most probable number (MPN) of bacteria in each of the 101 positive samples was estimated using the following method:

- 0.25 g of sample was broken down in 1 cm^3 of sterile culture medium and placed in a sterile, capped, tube
- the tube was incubated at 35°C for 24 hours
- the tube was tested for the presence of bacterial growth
- this method was repeated to give a total of 10 results for the sample

(i) Explain why this is a method of producing a viable count. [1]

It only counts bacteria that are alive and can divide and grow; dead bacteria cannot grow so are not counted.

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(ii) A total of 1010 tubes were prepared from the 101 samples of nuts that tested positive for *Salmonella*.
Of these, 260 tubes tested positive for the presence of *Salmonella* and 750 tested negative.

Use the formula below to calculate the MPN of *Salmonella* bacteria per gram in the food sample if each tube contained 0.25 g of nuts. [3]

$$\text{MPN } \textit{Salmonella} \text{ per gram} = \frac{P}{\sqrt{(N \times T)}}$$

where P = the number of tubes showing bacterial growth
N = the total mass (g) of sample tested in all of the negative tubes
T = the total mass (g) of sample in all of the tubes.

$N = 0.25 \times 750 = 187.5$ g

$T = 0.25 \times 1010 = 252.5$ g

$MPN = 260 \div \sqrt{(187.5 \times 252.5)}$

$= 260 \div \sqrt{47343.75} = 260 \div 217.6$

$= 1.195 = 1.2$ per g

MPN *Salmonella* = 1.2 g^{-1}

(iii) It has been estimated that a person needs to ingest 10^6 *Salmonella* bacteria to cause the symptoms of food poisoning.
Use your calculated value of the MPN of *Salmonella* to conclude whether eating this food puts a person at high risk of developing *Salmonella* food poisoning. [2]

There is a low risk (not a high risk) of food poisoning.

With about 1.2 Salmonella per gram, a person would need to eat about $10^6 \div 1.2 \approx 830\,000$ g (nearly 1000 kg) of nuts to ingest 10^6 bacteria, which is not possible.

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6. The first UK motorway opened in 1958 and was just over 13 km long. By 2017 there were 3800 km of motorway in the UK. Despite the high pollution levels on motorways, they have become havens for wildlife, especially plants, mainly because pedestrians are not allowed on motorways.

In some areas, the verges have been used to establish colonies of endangered species as part of local conservation efforts and some verges have been planted or seeded with wildflowers to increase biodiversity. Natural colonisation has also taken place with native species. Many wildflowers are adapted to growing in soils with low fertility. The soil at the edge of motorways is often of poor quality and provides ideal habitats for these plants.

(a) (i) During motorway construction the verges are usually left as bare soil. Explain why subsequent colonisation of these verges can be described as secondary succession. [2]

Soil is already present, so pioneer species do not need to form soil first.

Seeds, roots and other plant material are already present in the soil.

(ii) Long-term management of motorway verges often involves cutting the vegetation back to ground level in early Spring and again in August / September.

I. Explain why cutting the vegetation in this way on a regular basis prevents succession reaching a climax community. [1]

Shrubs and tree seedlings are cut down so cannot grow to full size,

so there is no seral progression.

II. The cut vegetation is removed from the verges. Conclude how this increases the biodiversity of wildflowers in motorway verges. [3]

Removing the cut vegetation prevents it being decayed on the

verges.

So decay products (nitrates, phosphates) do not enter the soil and

the soil fertility does not increase.

Wildflowers are adapted to low fertility soil, so they are not

outcompeted by fast growing grasses and more species survive.

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(b) Bees and wasps are important pollinators of plants grown to supply food for people and animals; 75% of food crops are pollinated by insects including bees and wasps. There has been an estimated 33.3% decrease in the population size of insects between 1980 and 2013.

A study was carried out in Europe to determine if road-side verges increase the biodiversity of bees and wasps. The method is summarised below:

- each sample site was divided into a grid
- using the grid, specialised traps of four different colours, white, yellow, turquoise and pink, were placed so as to avoid bias
- specimens of insects caught in the traps were stored in 96% ethanol and taken to a laboratory for identification

(i) Describe how the grid could have been used to reduce bias when placing the traps. [1]

Use a random number generator to give random coordinates on the grid and place the traps there.

(ii) Suggest why different coloured traps were used. [1]

Different species of bee and wasp are attracted to different coloured flowers, so the traps mimic flower colours.

(iii) Suggest **one** ethical and **one** ecological concern regarding the method used to store and identify the bees and wasps collected. [2]

ethical

The insects are killed by storing them in ethanol.

ecological

Removing insects reduces their numbers and biodiversity; some may be rare species or important pollinators.

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(iv) In this study, 14 roadside verges were sampled. Each site was bordered by arable land where a variety of crops were being grown.
Calculation of a diversity index indicated that there was a high biodiversity of bees and wasps present in the verges along this road.
It was concluded that roadside verges do increase the biodiversity of bees and wasps.

Use all the information provided, including the method used to collect the data, to evaluate this conclusion. [3]

There is no data on what the biodiversity was before the verges, or how it changed over time or season.

The verges were next to arable land, so insects could have come from the fields, and different crops at each site could affect results.

No sites without arable land were sampled, and only four trap colours at 14 sites is a small sample, so the conclusion is not valid.

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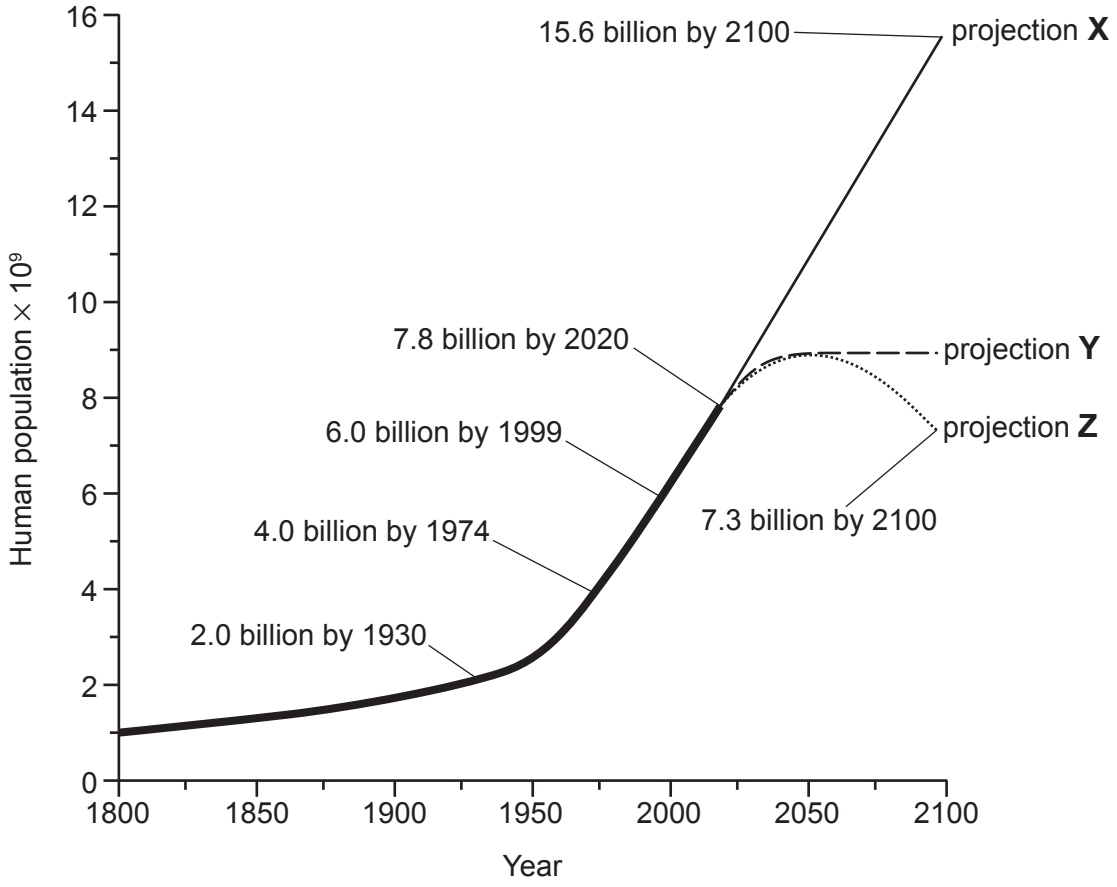
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7. **Graph 7** shows how the human population has changed since 1800. It also shows three projections of how the world population might change by the end of the 21st century.

Graph 7



At present, population scientists believe that projection **X** is the most likely world population by 2100.

State what is meant by density-dependent and density-independent factors and explain how these factors might account for the change in the human population growth curve between 1800 and 2020.
Use the population growth curves shown in **Graph 7** to explain what projections **X**, **Y** and **Z** represent in terms of human population size.
Suggest how the climate change planetary boundary might be affected if projection **Z** becomes reality. [9 QER]

Density-dependent factors are factors whose effect increases as the population size (density) increases, so they affect and are affected by the size of the population, for example food supply, disease, parasites and shelter.

Density-independent factors have the same effect whatever the population size,

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so they are not affected by population size, for example climate, floods or natural disasters.

Between 1800 and 2020 the human population increased from about 1 billion to 7.8 billion. Density-dependent factors have been reduced: better and more food from improved agriculture, lower levels of disease and parasites, better shelter and housing, and improved health care, vaccination, sanitation and a clean water supply. These mean that birth rate has been much greater than death rate and people survive and live longer, so the population grew exponentially, doubling from 2 billion in 1930 to 4 billion in 1974.

Projection X (15.6 billion by 2100) shows the population still in the log (exponential) phase, with the population doubling in unit time, because the birth rate remains greater than the death rate and people live longer.

Projection Y shows the population reaching the stationary phase at about 9 billion: the population plateaus at the carrying capacity, with no further change, because the birth rate (and survival) equals the death rate.

Projection Z shows the population entering the decline (death) phase, falling to 7.3 billion by 2100, because the birth rate is less than the death rate and people are not living as long, for example due to limited food or disease.

If projection Z becomes reality the population decreases. Fewer people need less energy, which reduces the need for fossil fuel combustion, so less CO_2 is emitted. Less land is needed for food and housing, so there is less deforestation and more afforestation, and trees act as carbon sinks absorbing more CO_2. Fewer animals are farmed and fewer paddy fields are needed, so less methane is released. Lower greenhouse gas emissions reduce the enhanced greenhouse effect, so we move closer to the safe operating level for the

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climate change planetary boundary and the effects of crossing it are reduced.

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