

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

A-level BIOLOGY

Paper 3

Monday 26 June 2017

Morning

Time allowed: 2 hours

Materials

For this paper you must have:

- a ruler with millimetre measurements
- a scientific calculator.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in **Section A**.
- Answer **one** question from **Section B**.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All work must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information

- The marks for the questions are shown in brackets.
- The maximum mark for this paper is 78.

For Examiner's Use

Question	Mark
1	
2	
3	
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6	
7	
TOTAL	



J U N 1 7 7 4 0 2 3 0 1

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ANSWER IN THE SPACES PROVIDED**



Section AAnswer **all** questions in this section.**0 1 . 1**

When a nerve impulse arrives at a synapse, it causes the release of neurotransmitter from vesicles in the presynaptic knob.

Describe how.

[3 marks]

The arrival of the nerve impulse (depolarisation of the presynaptic membrane) causes voltage-gated calcium ion (Ca^{2+}) channel proteins in the presynaptic membrane to open.

Calcium ions then enter the presynaptic knob by facilitated diffusion, down their concentration gradient.

The influx of calcium ions causes the synaptic vesicles to move towards and fuse with the presynaptic membrane, releasing the neurotransmitter into the synaptic cleft by exocytosis.

Question 1 continues on the next page

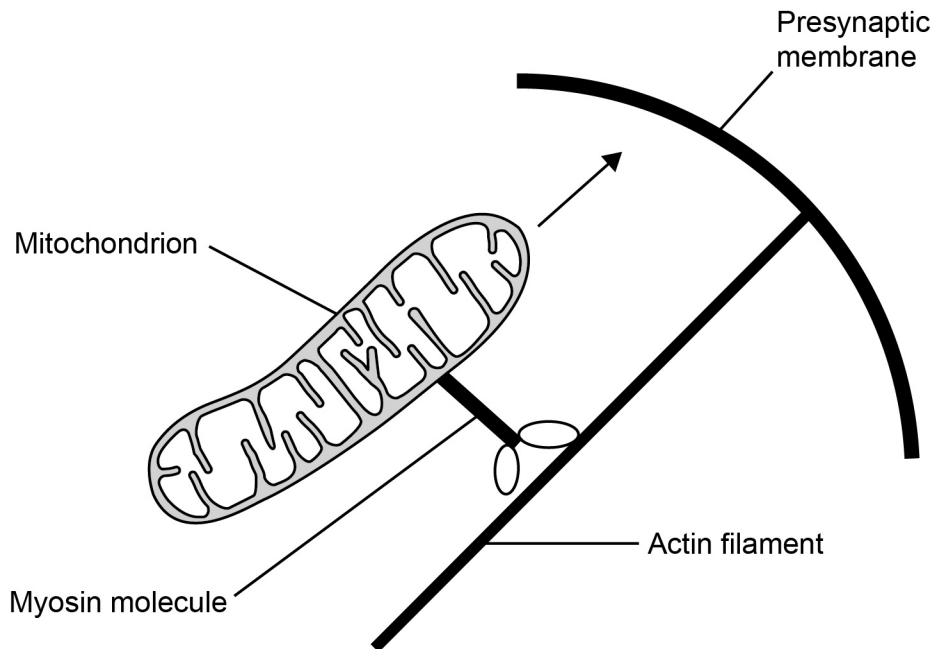
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0 1 . 2

The presynaptic knob contains actin filaments and myosin molecules.

The myosin molecules can attach to mitochondria and move them towards the presynaptic membrane, as shown in **Figure 1**.

Figure 1



Use your knowledge of how myosin and actin interact to suggest how the myosin molecule moves the mitochondrion towards the presynaptic membrane.

Do **not** include the roles of calcium ions and tropomyosin in your answer.

[2 marks]

The myosin head attaches to an actin filament, forming a cross-bridge, and then bends (changes angle) in a power stroke. This pulls the myosin, and the mitochondrion attached to it, along the actin filament. The head then detaches and another myosin head attaches further along the actin and bends, so the mitochondrion keeps moving towards the presynaptic membrane.



0 1 . 3

This movement of mitochondria happens when nerve impulses arrive at the synapse.

Suggest and explain **one** advantage of the movement of mitochondria towards the presynaptic membrane when nerve impulses arrive at the synapse.

[2 marks]

The mitochondria would supply more ATP close to where it is needed, as aerobic respiration in the mitochondria releases energy that is used to make ATP.

This ATP provides energy for moving the vesicles to the membrane, for the active transport of ions (e.g. pumping calcium ions back out of the knob), and for re-synthesising the neurotransmitter, e.g. reforming acetylcholine from choline and ethanoic acid that is reabsorbed.

7

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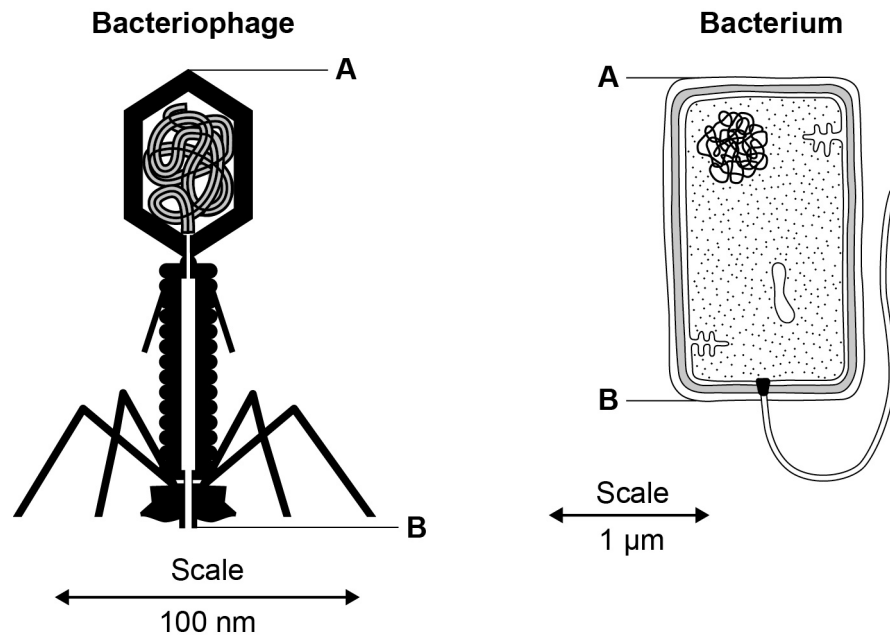


0 2

Bacteriophages are viruses that kill bacteria.

Figure 2 shows drawings of a bacteriophage and a bacterium.

Figure 2



0 2 . 1

Using **Figure 2** and your own knowledge, put a tick (✓) in the box next to the **only** correct statement about the structures of the bacteriophage and the bacterium.

[1 mark]

Both have ribosomes.

☐

Both have a cell-surface membrane.

☐

The bacteriophage has a capsid and the bacterium has a cell-surface membrane.

☒

The bacteriophage has a cell wall and the bacterium has a capsid.

☐


0 2 . 2

Using the scales in **Figure 2**, calculate how many times longer the bacterium is than the bacteriophage.

Use the distance between the points labelled **A** and **B** on each drawing in your calculations. Show your working.

[2 marks]

Bacteriophage: A to B = 61 mm, scale bar 100 nm = 40 mm

length = $61 / 40 \times 100 = 152.5 \text{ nm}$

Bacterium: A to B = 43 mm, scale bar 1 μm = 21 mm

length = $43 / 21 \times 1 = 2.05 \mu\text{m} = 2048 \text{ nm}$

$2048 / 152.5 = 13.4$

The bacterium is 13.4 times longer

Question 2 continues on the next page

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0 2 . 3

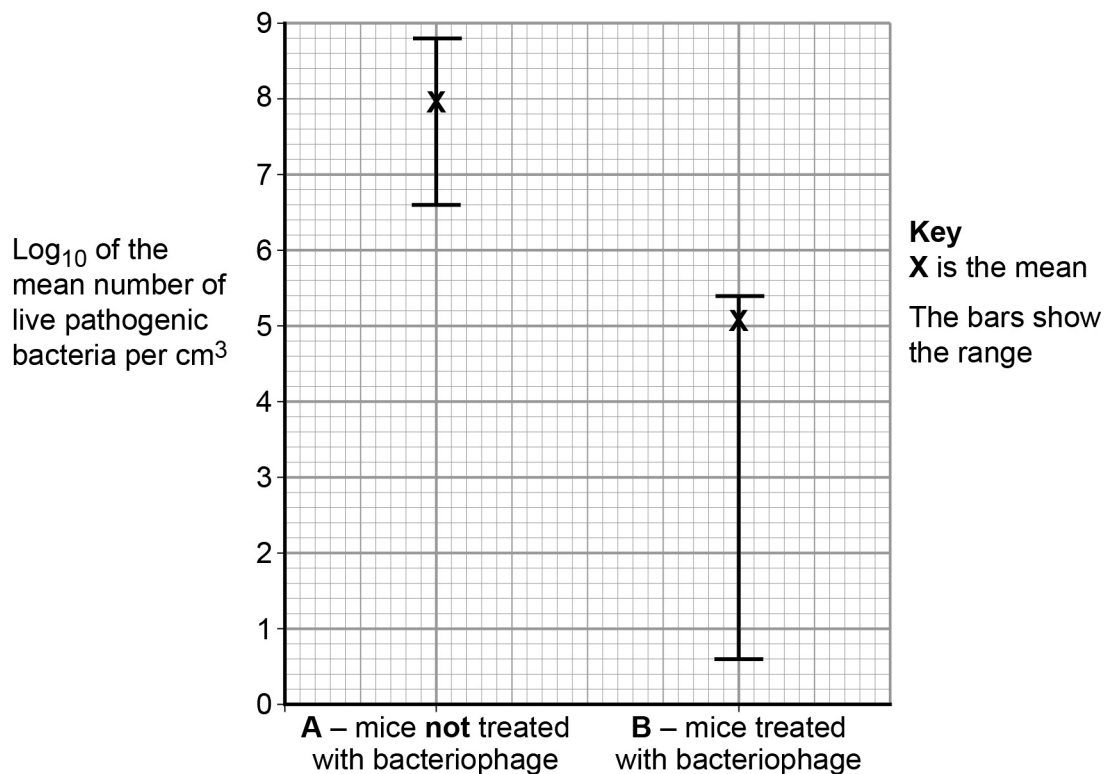
Scientists investigated the use of bacteriophages to treat lung infections caused by bacteria. They infected the lungs of mice with a pathogenic species of bacterium. The mice were then divided into two groups, **A** and **B**.

- The mice in group **A** were **not** treated with bacteriophage.
- The mice in group **B** were treated by breathing in a spray containing bacteriophage particles.

After 3 days, the scientists killed the mice and removed their lungs. They washed out each set of lungs with a set volume of liquid. The scientists determined the number of live bacteria in the liquid.

Figure 3 shows the scientists' results. **Figure 3** shows the mean and the range of the data about the mean for each group. Standard deviations of the means are **not** shown.

Figure 3



What would the scientists' null hypothesis be for this investigation?

[1 mark]

There will be no difference in the number of live bacteria in the lungs of treated mice (group B) and untreated mice (group A); the bacteriophage makes no difference to the number of live bacteria.



0 2 . 4

With some samples, the scientists decided they needed to carry out a series of dilutions of the sample before counting the bacteria.

Use evidence from **Figure 3** to explain why dilutions were necessary for some samples but not for others.

[2 marks]

The log scale shows a very large range in the number of bacteria, from about 4 ($10^{0.6}$) to about 631 million ($10^{8.8}$) bacteria per cm^3 .

Samples with very high numbers, such as the group A mean of about 100 million (10^8), would be too many to count, so they had to be diluted, but samples with low numbers, e.g. about 100 000 (10^5) in group B, were small enough to count without dilution.

0 2 . 5

Using only **Figure 3**, what can you conclude from these data about the effectiveness of the bacteriophage in treating this lung infection in mice?

Do **not** consider statistical analyses in your answer.

[3 marks]

The bacteriophage reduces the number of live bacteria in the lungs: the mean falls from about 10^8 in group A to about 10^5 bacteria per cm^3 in group B, about 1000 times fewer.

The ranges of the two groups do not overlap (A is from $10^{6.6}$ to $10^{8.8}$, B from $10^{0.6}$ to $10^{5.4}$), so every treated mouse had fewer bacteria than every untreated mouse.

However, the effect varies a lot between mice: some treated mice had a huge fall in bacteria but others only a small fall, and the bacteriophage did not reduce the bacteria to zero in any mouse, so it does not completely cure the infection.



0 3

Farmers use artificial fertilisers to maintain or increase yield from grain-producing crop plants such as wheat.

0 3 . 1

Artificial fertiliser is used to replace mineral ions removed from the land when crops are harvested. One of the mineral ions is nitrate.

Give **two** examples of biological molecules containing nitrogen that would be removed when a crop is harvested.

[2 marks]

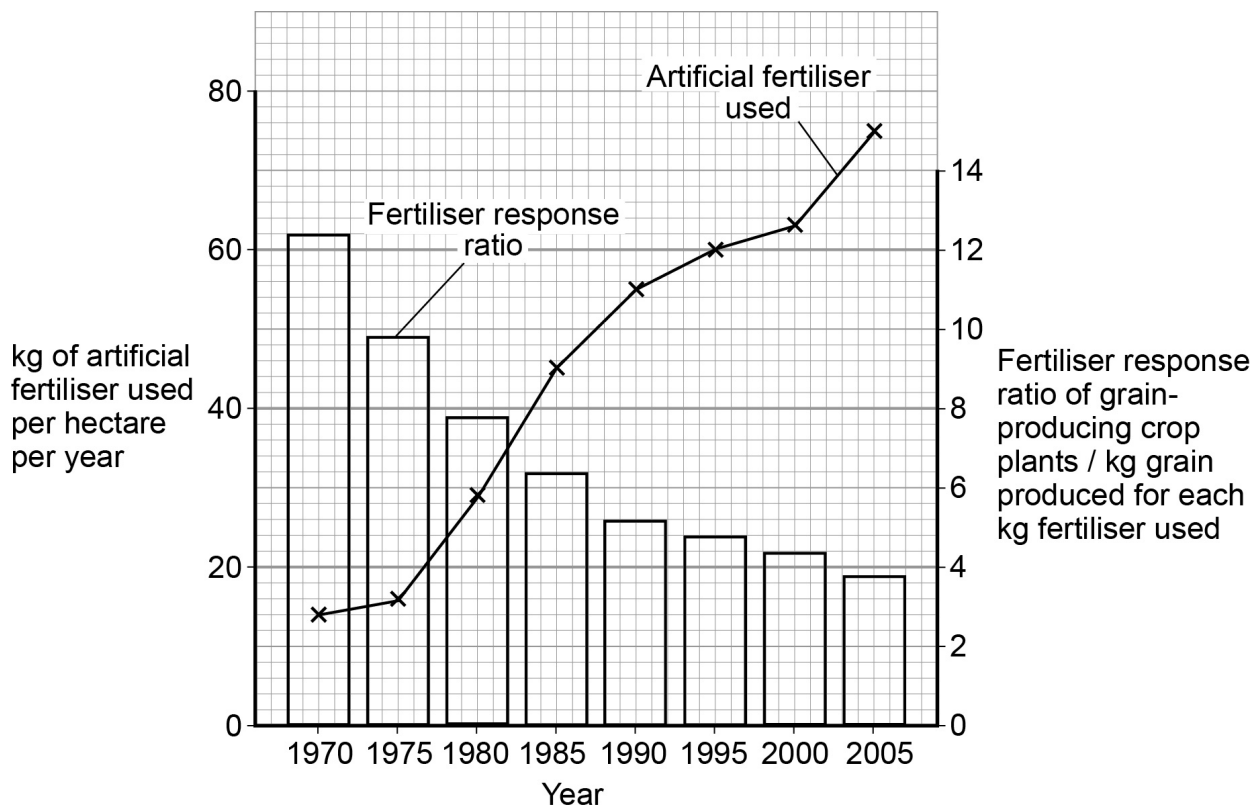
1 *Protein (amino acids)*

2 *DNA (nucleic acid / nucleotides)*

0 3 . 2

Scientists investigated changes in the use of artificial fertiliser in India between 1970 and 2005. They also investigated changes in the **fertiliser response ratio**. This ratio shows how many kg of grain are produced for each kg of fertiliser used.

Figure 4 shows their results in the form the scientists presented them.
(A hectare is a unit of area commonly used in agriculture)

Figure 4

Use these data to calculate the difference in the mass of grain produced per hectare in 1970 compared with 2005.

Show your working.

[2 marks]

1970: 14 kg fertiliser per hectare $\times$ ratio 12.4 = 173.6 kg grain per hectare

2005: 75 kg fertiliser per hectare $\times$ ratio 3.7 = 277.5 kg grain per hectare

Difference = 277.5 - 173.6 = 103.9

Difference 103.9 kg hectare⁻¹

0 3 . 3

Use the data in **Figure 4** to evaluate the use of artificial fertilisers on grain-producing crops in India.

[2 marks]

Over time more fertiliser was used (14 rising to 75 kg per hectare)

but the response ratio fell from 12.4 to 3.7, so fertiliser became less effective and less cost effective.

But this is only a correlation; it does not prove yield changes are due to fertiliser, as other factors (e.g. rainfall, crop variety) could be involved.

6

Turn over for the next question

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0 4

Ecologists investigated changes in grassland communities on large islands off the coast of Scotland between 1975 and 2010. On each island, they used data from a number of sites to determine the change in mean species richness and the change in mean index of diversity.

0 4 . 1

Table 1 shows plant species recorded at one site, on one island, in 1975.

Table 1

Species	Number of individuals
<i>Hydrocotyle vulgaris</i>	3
<i>Plantago maritima</i>	19
<i>Ranunculus acris</i>	3
<i>Hieracium pilosella</i>	3
<i>Calliergon cuspidatum</i>	10
<i>Prunella vulgaris</i>	16
<i>Pseudoscleropodium purum</i>	6

Calculate the index of diversity for this site using the formula:

$$d = \frac{N(N-1)}{\sum n(n-1)}$$

[2 marks]

$$N = 3 + 19 + 3 + 3 + 10 + 16 + 6 = 60$$

$$N(N - 1) = 60 \times 59 = 3540$$

$$\text{Sum of } n(n - 1) = 6 + 342 + 6 + 6 + 90 + 240 + 30 = 720$$

$$d = 3540 / 720 = 4.92$$

$$d = \underline{\quad 4.92 \quad}$$



0 4 . 2

Outline a method the ecologists could have used to determine the plant species richness at one site.

[3 marks]

Lay out two long tape measures at right angles to make a grid over the site, and use a random number generator (random number table) to select coordinates, so that the sampling positions are chosen at random and are not biased.

At each pair of coordinates, place a quadrat (e.g. a 1 m² frame quadrat).

Identify every plant species present inside each quadrat (using a key) and record them. Repeat for a large number of quadrats, e.g. 20 or more, and count the total number of different plant species found at the site to give the species richness.

Question 4 continues on the next page

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0 4 . 3

Some of the ecologists' results are shown in **Table 2**. They carried out a statistical test to find out whether any differences between the 1975 and 2010 means were significant. The values for P that they obtained are also shown in **Table 2**.

Table 2

Island	Change in mean species richness between 1975 and 2010	Value of P	Change in mean index of diversity between 1975 and 2010	Value of P
Islay	+8.89	≤ 0.001	+0.22	> 0.05
Colonsay	+14.70	≤ 0.001	+2.68	≤ 0.01
Harris	-5.13	≤ 0.001	-2.44	≤ 0.01

Do these data show that there were any significant changes in the grassland communities on these islands? Give reasons for your answer.

[3 marks]

Yes. Species richness increased significantly on Islay and Colonsay and fell significantly on Harris, because the probability of getting these differences by chance is less than 0.001 (0.1%), well below 0.05.

The index of diversity also changed significantly on Colonsay (increase) and Harris (decrease), as there is less than a 0.01 (1%) probability that these differences are due to chance.

However, the change in index of diversity on Islay (+0.22) is not significant, as there is a greater than 0.05 (5%) probability of getting this difference by chance.



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0 5 . 1

Name **two** enzymes involved in the semi-conservative replication of DNA.**[2 marks]**1 *DNA helicase*2 *DNA polymerase*

0 5 . 2

Sometimes, damage occurs during DNA replication. One enzyme involved in repairing damage to DNA is called ATR.

ATR works as follows.

- ATR phosphorylates other enzymes involved in repairing DNA.
- ATR **also** phosphorylates substrates required to repair DNA.

When ATR phosphorylates other enzymes, these enzymes become able to bind to their substrates.

Use your knowledge of enzyme structure to suggest why.

[2 marks]

Adding a phosphate group changes the tertiary structure of the enzyme (e.g. by changing the bonds between R groups), so the enzyme changes shape.

This forms the active site, or makes the active site complementary to the substrate, so the substrate can now fit and bind to it.



0 5 . 3

The enzyme-catalysed reactions activated by ATR only occur if the substrates have been phosphorylated.

Use your knowledge of energy changes in enzyme-catalysed reactions to suggest why.

[1 mark]

Phosphorylation makes the substrates more reactive (raises their energy level), which lowers the activation energy needed for the reaction, so the reaction can take place.

0 5 . 4

Sometimes, a mutagenic agent causes DNA to break. A different enzyme called ATM binds to the broken DNA. This leads to the activation of a protein coded for by a tumour suppressor gene. The effect of ATM binding is to stop cell division until DNA is repaired.

A mutation could result in a person having non-functional forms of the gene that produces ATM.

What can you predict about the possible effects of having a non-functional form of ATM?

[3 marks]

A non-functional ATM will not bind to the broken DNA, so the tumour suppressor protein is not activated and the tumour suppressor gene is not effective.

So the DNA is not repaired and the cell still has broken DNA, but cell division continues anyway, so cells divide uncontrollably and a tumour may form.

However, there may be no effect in a heterozygous person, because they are diploid and still have one functional ATM allele that can produce working ATM.

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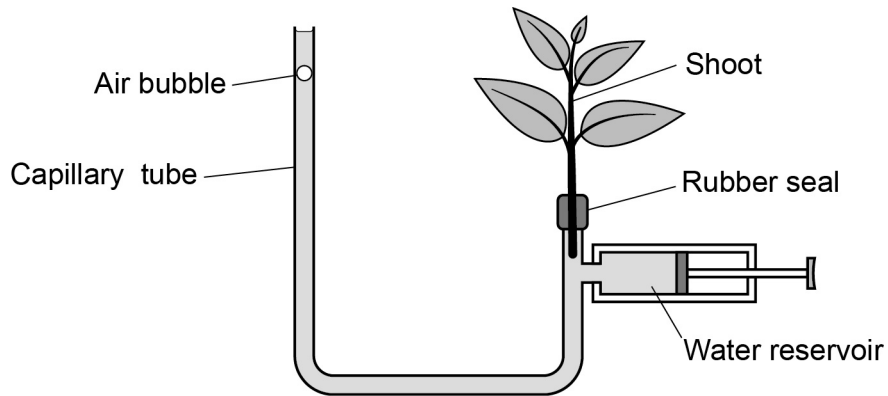
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0 6

A student used a potometer to measure the movement of water through the shoot of a plant. The potometer is shown in **Figure 5**. As water is lost from the shoot, it is replaced by water from the capillary tube.

Figure 5



0 6 . 1

In one experiment, the air bubble moved 7.5 mm in 15 minutes. The diameter of the capillary tube was 1.0 mm.

Calculate the rate of water uptake by the shoot in this experiment.

Give your answer in mm^3 per hour. Show your working.
(The area of a circle is found using the formula, $\text{area} = \pi r^2$)

[2 marks]

$$r = 1.0 / 2 = 0.5 \text{ mm}, \text{ area} = 3.14 \times 0.5^2 = 0.785 \text{ mm}^2$$

$$\text{volume in 15 min} = 0.785 \times 7.5 = 5.9 \text{ mm}^3$$

$$\text{rate} = 5.9 \times 4 = 23.6 \text{ mm}^3 \text{ per hour}$$

23.6 $\text{mm}^3 \text{ hour}^{-1}$



0 6 . 2

The student wanted to determine the rate of water loss per mm^2 of surface area of the leaves of the shoot in **Figure 5**.

Outline a method she could have used to find this rate. You should assume that all water loss from the shoot is from the leaves.

[3 marks]

Remove all the leaves from the shoot and draw around each leaf on graph paper, then count the squares (1 mm^2 each) to find the area of each leaf.

Multiply the area by two, because water is lost from both sides (upper and lower surfaces) of each leaf, and add these up to get the total surface area.

Divide the rate of water uptake from the potometer (in mm^3 per hour) by the total surface area of the leaves to give the rate of water loss per mm^2 .

0 6 . 3

The rate of water movement through a shoot in a potometer may not be the same as the rate of water movement through the shoot of a whole plant.

Suggest **one** reason why.

[1 mark]

The whole plant has roots that take up the water, but the cut shoot has none.

[Extra space]

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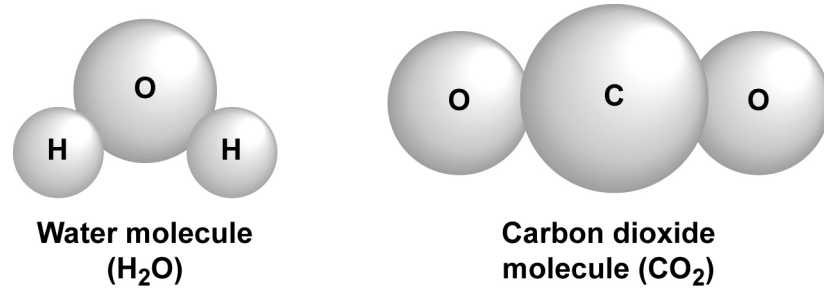


0 6 . 4

Aquaporins are channel proteins that allow the diffusion of water across membranes. One type of aquaporin, called PIP1, can also transport carbon dioxide molecules across membranes.

Figure 6 shows the structure of a water molecule and of a carbon dioxide molecule. They are drawn to the same scale.

Figure 6



Suggest **two** reasons why water molecules **and** carbon dioxide molecules can both pass through PIP1.

[2 marks]

- 1 *Both molecules are small and of similar size (similar height and width), so both fit through the channel of PIP1.*

[Extra space]

- 2 *Both molecules have a similar shape, so both can bind to / fit into the PIP1 channel.*

[Extra space]



0 6 . 5

The scientists first produced transgenic poplar trees. These trees all had a length of foreign DNA inserted into them. This DNA led to the production of single-stranded RNA that specifically inhibited expression of the gene for PIP1.

The scientists then measured the difference in the amount of PIP1 in leaves of transgenic poplars and in leaves of wild type poplars without the foreign DNA. The amount of PIP1 in the transgenic poplars was approximately 15% of that in the wild type poplars.

Using this information, what can you conclude about the effect of the foreign DNA in the transgenic poplar trees?

[3 marks]

The single-stranded RNA has a base sequence complementary to the mRNA for PIP1, so it binds to the PIP1 mRNA by complementary base pairing, which leads to the mRNA being destroyed.

So translation of PIP1 is prevented or reduced, which is why the transgenic poplars only had about 15% of the PIP1 of wild type trees.

With less PIP1, less water and carbon dioxide would cross the membranes, so this could reduce photosynthesis in the transgenic trees.

0 6 . 6

The transgenic poplars still produced some PIP1.
Suggest why.

[1 mark]

Not all of the PIP1 mRNA was bound by the single-stranded RNA (there was more mRNA than interfering RNA), so not all the mRNA was destroyed and some was translated.

Question 6 continues on the next page

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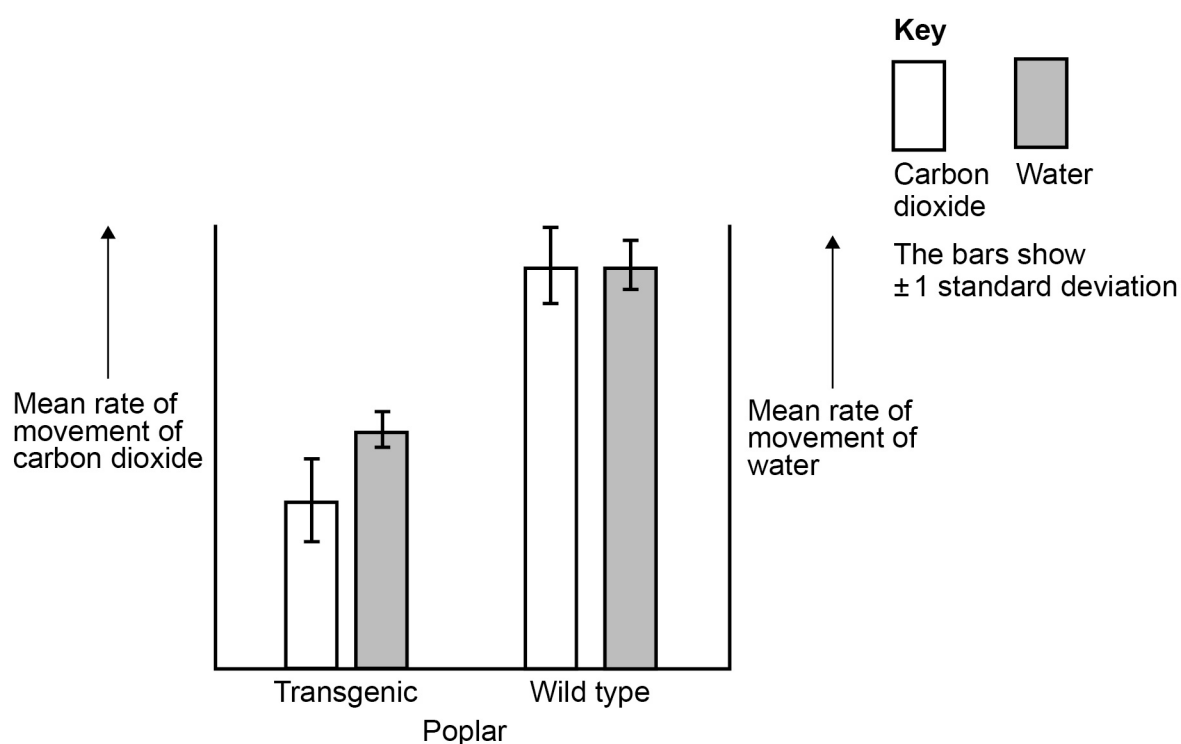
0 6 . 7

The scientists investigated the importance of PIP1 in the movement of water and carbon dioxide through the tissues of leaves of poplar trees.

They measured the mean rates of movement of carbon dioxide and water through the tissues of leaves of transgenic poplars and through the tissues of leaves of wild type poplars.

Their results are shown in **Figure 7**.

Figure 7



Using only **Figure 7**, evaluate the importance of PIP1 in the movement of carbon dioxide and water through leaves of poplar trees.

[3 marks]

The transgenic poplars, with less PIP1, have lower rates of movement of both carbon dioxide and water than the wild type, so PIP1 is important in the movement of both.

The ± 1 standard deviation bars of the transgenic and wild type trees do not overlap for either substance, so the differences are likely to be significant (although a statistical test is needed to confirm this).

Loss of PIP1 has a greater proportional effect on carbon dioxide movement than on water movement.

But movement of both does not stop, so not all the carbon dioxide and water moves through PIP1; some must diffuse by other routes, e.g. other aquaporins or through the phospholipid bilayer.

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Section B
Answer **one** question.

0 7

Write an essay on **one** of the topics below.

EITHER

0 7 . 1

The importance of nitrogen-containing substances in biological systems.

[25 marks]

OR

0 7 . 2

The importance of diffusion in organisms.

[25 marks]

07.2 The importance of diffusion in organisms

Diffusion is the net movement of molecules or ions from a region of higher concentration to a region of lower concentration, down a concentration gradient. It is a passive process, so it needs no ATP, and its rate depends on the surface area, the concentration gradient and the diffusion distance (Fick's law). Diffusion is essential in almost every part of an organism, from gas exchange and the absorption of food to the transmission of nerve impulses.

Gas exchange in all organisms depends on diffusion. In humans, oxygen diffuses from the air in the alveoli into the blood, and carbon dioxide diffuses the other way. The lungs are adapted to make this diffusion fast: millions of alveoli give a very large surface area, the alveolar epithelium and capillary endothelium are each only one cell thick so the diffusion pathway is short, and ventilation together with the constant flow of blood maintains a steep concentration gradient. In fish, the gill filaments and lamellae give a large surface area, and the counter-current flow of water and blood means that the blood



always meets water with a higher oxygen concentration, so a diffusion gradient is maintained along the whole lamella. Insects use a tracheal system, where oxygen diffuses down tracheae and tracheoles directly to the respiring cells. In the leaves of plants, carbon dioxide diffuses through the stomata and the air spaces of the spongy mesophyll to the photosynthesising cells. Where diffusion becomes less efficient, as in emphysema when alveolar walls are destroyed and the surface area falls, the person becomes breathless because not enough oxygen diffuses into the blood.

Diffusion is also important in the transport of substances across membranes. Small, non-polar molecules such as oxygen and carbon dioxide diffuse straight through the phospholipid bilayer. Larger or charged particles, such as glucose and ions, cannot pass through the hydrophobic core, so they move by facilitated diffusion through specific channel and carrier proteins. Water moves by osmosis, which is the diffusion of water from a higher to a lower water potential across a partially permeable membrane, often through aquaporins. In the ileum, glucose is absorbed by co-transport: sodium ions are actively pumped out of the epithelial cell into the blood, which keeps the sodium ion concentration inside the cell low, so sodium ions diffuse into the cell from the lumen through a co-transporter protein, bringing glucose with them. Glucose then moves into the blood by facilitated diffusion. Monoglycerides and fatty acids, released from micelles, diffuse across the membrane because they are lipid soluble. The villi and microvilli

Turn over ►

give a large surface area, and the constant blood flow keeps the gradient steep.

Diffusion plays a vital role in mass transport. Oxygen diffuses from red blood cells, through the capillary walls and tissue fluid, into respiring cells. In the tissues, the partial pressure of oxygen is low and the carbon dioxide concentration is high, so haemoglobin has a lower affinity for oxygen (the Bohr effect) and unloads oxygen, which then diffuses into cells. Capillaries are narrow and have thin walls so that the diffusion distance is short. In plants, the movement of water through the leaf depends on diffusion: water evaporates from mesophyll cells and the water vapour diffuses out of the stomata in transpiration, which creates the tension that pulls water up the xylem by cohesion-tension. In the phloem, the mass flow hypothesis depends on water moving by osmosis into the sieve tubes at the source and out at the sink.

The nervous system relies on diffusion of ions. At rest, the sodium-potassium pump creates concentration gradients of sodium and potassium ions across the axon membrane, giving a resting potential of about -70 mV. When a stimulus causes voltage-gated sodium ion channels to open, sodium ions diffuse rapidly into the axon, causing depolarisation and an action potential. Voltage-gated potassium ion channels then open and potassium ions diffuse out, causing repolarisation. In myelinated neurones, the depolarisation only occurs at the nodes of Ranvier, so the impulse jumps by saltatory conduction,



which is much faster. At a synapse, calcium ions diffuse into the presynaptic knob, causing vesicles to fuse with the membrane and release acetylcholine, which diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane. The synaptic cleft is very narrow, so diffusion across it is fast. Similarly, in muscle contraction, calcium ions released from the sarcoplasmic reticulum diffuse to the myofibrils, where they bind to troponin and move tropomyosin, allowing myosin heads to bind to actin.

Diffusion is important in the production of ATP in respiration and photosynthesis. In oxidative phosphorylation, the electron transport chain pumps protons into the intermembrane space of the mitochondrion, building up a high proton concentration. Protons then diffuse back into the matrix through ATP synthase by facilitated diffusion, and this flow provides the energy for ATP synthesis from ADP and inorganic phosphate (chemiosmosis). The same process happens across the thylakoid membranes in chloroplasts during the light-dependent reaction. Without this diffusion of protons, cells could not make enough ATP to provide energy for active transport, muscle contraction or protein synthesis. Oxygen also has to diffuse into mitochondria to act as the final electron acceptor.

Diffusion is also involved in the control of blood glucose and water potential. When blood glucose rises, glucose diffuses into the beta cells of the islets of Langerhans through carrier proteins, leading to insulin release. Insulin then causes more GLUT4 channel proteins to be

Turn over ►



inserted into the membranes of muscle and liver cells, so more glucose enters these cells by facilitated diffusion and blood glucose falls. In the kidney, the counter-current multiplier in the loop of Henle creates a low water potential in the medulla. When ADH is released, more aquaporins are inserted into the membranes of the collecting duct cells, so more water moves out of the filtrate by osmosis and is reabsorbed into the blood, producing concentrated urine. In plants, the growth hormone IAA diffuses from the shoot tip to the cells below, and its uneven distribution causes phototropism.

Beyond the specification, diffusion is important in cell signalling by nitric oxide (NO). Nitric oxide is a small, uncharged gas, so once it is made by endothelial cells lining blood vessels it diffuses straight through the cell-surface membranes into the neighbouring smooth muscle cells. There it activates the enzyme guanylyl cyclase, producing cyclic GMP, which causes the smooth muscle to relax, so the blood vessel dilates and blood pressure falls. This is the basis of glyceryl trinitrate treatment for angina, and of the drug sildenafil, which prolongs the effect of cyclic GMP. Because NO diffuses over only short distances before it breaks down, it acts as a local signal.

In conclusion, diffusion is essential to organisms at every level. It allows gas exchange and the absorption of digested food, delivers oxygen to respiring cells, underlies transpiration, allows nerve impulses and synaptic transmission, drives ATP synthesis by chemiosmosis and is involved in homeostasis. Because diffusion is only fast over short



distances, organisms have evolved large surface areas, thin exchange surfaces and mass transport systems to maintain steep concentration gradients, and much of their structure can be explained by the need to make diffusion efficient.

Turn over ►



[illegible]

[illegible]

[illegible]

25

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