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Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level BIOLOGY

Paper 3

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.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Show all your working.
- 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	
4	
5	
6	
7	
TOTAL	



Section A

Answer **all** questions in this section.

You are advised to spend no more than 1 hour and 15 minutes on this section.

0	1
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In one species of squirrel, *Sciurus carolinensis*, fur colour is controlled by one gene, with two codominant alleles. C^G represents the allele for grey fur colour, and C^B represents the allele for black fur colour.

Table 1 shows the three possible phenotypes.

Table 1

Genotype	Phenotype
$C^G C^G$	Grey fur
$C^G C^B$	Brown-black fur
$C^B C^B$	Black fur

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In a population of 34 *S. carolinensis*, 2 had black fur.

Use the Hardy–Weinberg equation to estimate how many squirrels in this population had brown-black fur. Show your working.

[2 marks]

$$q^2 = \text{frequency of } C^B C^B = 2 \div 34 = 0.0588$$

$$q = \text{square root of } 0.0588 = 0.243, \quad p = 1 - 0.243 = 0.757$$

$$2pq = 2 \times 0.757 \times 0.243 = 0.368 \text{ (36.8\%)}$$

$$\text{Number with brown-black fur} = 0.368 \times 34 = 12.5$$

Answer 12



0 1 . 2

The actual number of squirrels in this population that had brown-black fur was 16.

Use all of the information to calculate the **actual** frequency of the C^G allele.

Do **not** use the Hardy–Weinberg equation in your calculation.

Give your answer to 2 decimal places.

[1 mark]

$$\text{Grey} = 34 - 16 - 2 = 16; C^G \text{ alleles} = (16 \times 2) + 16 = 48$$

$$\text{Total alleles} = 34 \times 2 = 68; 48 \div 68 = 0.7059$$

Answer 0.71

0 1 . 3

S. carolinensis were first introduced to the UK from North America in the 1870s. They are now widely distributed across the UK.

S. carolinensis from both North America and the UK show exactly the same genotypic and phenotypic variation. An identical mutation causing black fur has also been found in several other species closely related to *S. carolinensis*.

Use this information to deduce which **one** of the following conclusions is most likely true.

Tick (✓) **one** box.

[1 mark]

- A** The mutation that caused black fur happened after *S. carolinensis* was introduced to the UK from North America.
- B** The mutation that caused black fur happened in a common ancestor of *S. carolinensis* and other closely related species.
- C** The mutation that caused black fur happened independently in *S. carolinensis* and all other closely related species.
- D** The phenotypic variation shown in *S. carolinensis* and other closely related species is caused by genetic drift.

☐
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Question 1 continues on the next page

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The mutation that caused the C^B allele was due to a 24 base-pair deletion from the C^G allele.

0 1 . 4

The protein coded for by the C^B allele is 306 amino acids long.

Calculate the percentage reduction in size of the protein coded for by the C^B allele compared with the protein coded for by the C^G allele.

Give your answer to 3 significant figures and show your working.

[2 marks]

$$24 \text{ bases} \div 3 = 8 \text{ amino acids fewer}$$

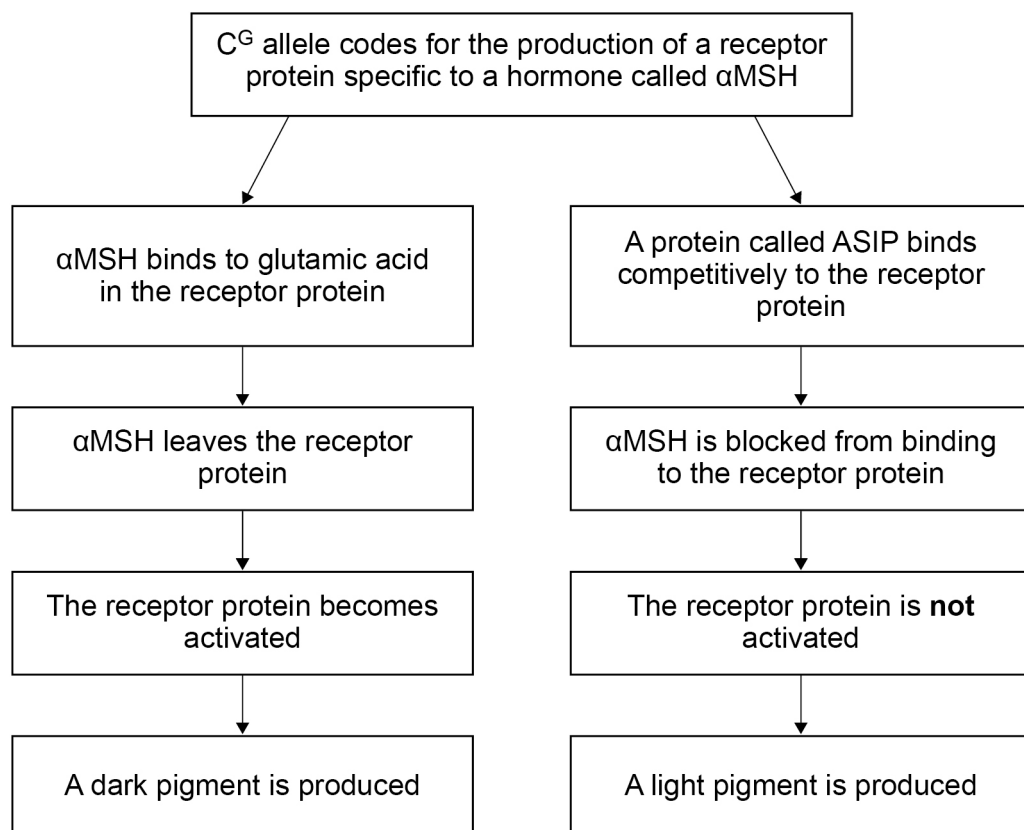
$$C^G \text{ protein} = 306 + 8 = 314 \text{ amino acids}$$

$$(8 \div 314) \times 100 = 2.548\%$$

Answer 2.55%

In *S. carolinensis*, fur colour depends on the distribution and relative amounts of light pigments and dark pigments in the hairs of the fur. **Figure 1** shows how the protein produced from the C^G allele can result in the production of a light pigment or a dark pigment.

Figure 1



The deletion mutation in the C^B allele results in the production of a receptor protein that does not have glutamic acid. The lack of glutamic acid in the receptor protein has the same effect as α MSH leaving the receptor protein.

0	1	5
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Use **Figure 1** and this information to suggest why *S. carolinensis* with the genotype $C^B C^B$ have black fur rather than grey fur.

[3 marks]

The lack of glutamic acid means the receptor protein is permanently activated, because it does not need alpha-MSH to bind to it and then leave it in order to become activated.

Also, the changed shape of the receptor means ASIP may no longer be able to bind to it competitively, so ASIP cannot stop activation.

So only the dark pigment is produced in the hairs, giving black fur.

9

Turn over for the next question

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0 2 . 1

Describe how the human immunodeficiency virus (HIV) is replicated **once inside** helper T cells (T_H cells).

[4 marks]

Inside the T_H cell, the viral RNA is converted into DNA by the enzyme reverse transcriptase.

This DNA is then inserted (integrated) into the DNA of the helper T cell's chromosome / genome in the nucleus.

The viral DNA is transcribed by RNA polymerase into HIV mRNA (and viral RNA).

The HIV mRNA is translated on the host cell's ribosomes into new viral proteins, such as capsid proteins and enzymes, which are assembled with the RNA into new virus particles that bud out of the cell.



HIV-1 is the most common type of HIV. HIV-1 binds to a receptor on T_H cells called CCR5.

Current treatment for HIV-1 involves the use of daily antiretroviral therapy (ART) to stop the virus being replicated. Only 59% of HIV-positive individuals have access to ART.

Scientists have found that two HIV-1-positive patients (**P** and **Q**) have gone into remission (have no detectable HIV-1). This happened after a blood stem cell transplant (BSCT).

- Patient **P** was given **two** BSCTs, and patient **Q** was given **one** BSCT.
- All BSCTs came from a donor with T_H cells **without** the CCR5 receptor.
- In addition, patient **P** had radiotherapy, and patient **Q** had chemotherapy. Both of these treatments are toxic.
- **Both** patients (**P** and **Q**) stopped receiving ART 16 months after BSCT.

18 months after stopping ART, **both** patients had **no** HIV-1 RNA in their plasma, **no** HIV-1 DNA in their T_H cells and **no** CCR5 on their T_H cells.

0	2	2
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Use the information given to evaluate the use of BSCT to treat HIV infections.

[5 marks]

For: both patients have no HIV-1 RNA or DNA detectable, so BSCT could be a cure. Their T_H cells now have no CCR5, so there is nothing for HIV-1 to bind to and they should not be infected in the future.

Patient Q needed only one transplant, and both patients no longer need daily ART, which only 59% of people can access.

Against: both patients also had toxic radiotherapy or chemotherapy, so we do not know if BSCT alone is effective or which treatment caused remission.

It has only been tried in two people, so we do not know if it works in everyone, and only for 18 months, so it may not be long term.

It only applies to HIV-1; HIV may mutate to bind a different receptor, the stem cells may be rejected and there may be few suitable donors without CCR5.

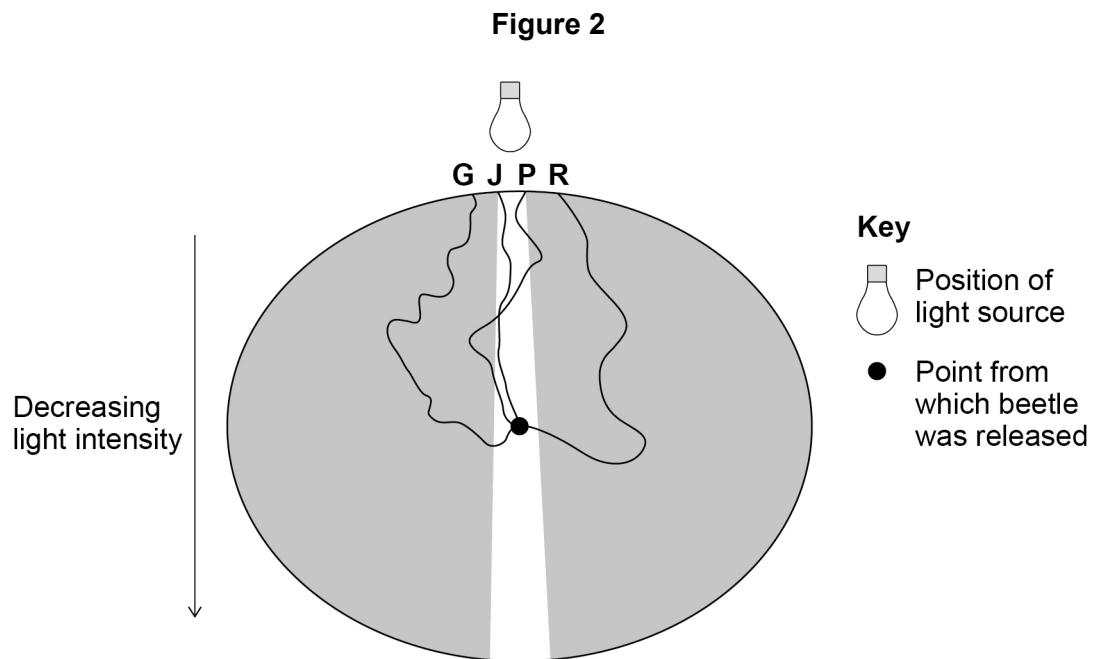


0 3

Scientists investigated movement in adult pine beetles. Adult beetles emerge from cracks in tree bark.

The scientists released a newly emerged adult beetle, **G**, from the centre of a sample area that had a single light source coming from one direction. They made a drawing of the beetle's path of walking. They repeated this with three more beetles, **J**, **P** and **R**.

Figure 2 shows the scientists' results.



0 3 1

Name the type of behaviour shown by beetles **G**, **J**, **P** and **R**, and suggest **one** advantage to adult beetles of the type of behaviour shown.

[2 marks]

Behaviour (Positive photo)taxis

Advantage It helps the beetles disperse away from where they emerged,
so there is less competition for food and space, and a better chance of
finding a mate.



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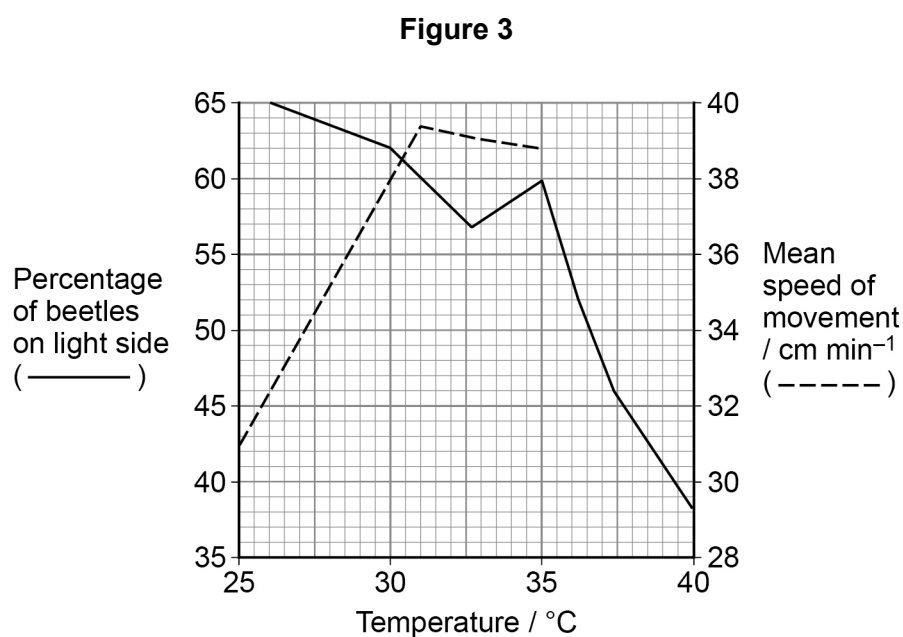


At higher temperatures and higher light intensities, adult pine beetles normally

- move more
- fly rather than walk.

When preparing to fly, these adult beetles walk slowly. The scientists investigated the movement of adult beetles at different temperatures, and in the light and the dark. They created a box that was half in the light and half in the dark. They released an adult beetle at the midpoint of the central dividing line between light and dark areas. They recorded the path of the beetle's movement and its location after 5 minutes. They recorded the path of the beetle's movement and its location after 5 minutes. From this, they calculated the mean speed of movement. They repeated the experiment with many beetles and at several temperatures.

Figure 3 shows the scientists' results.



0 3 . 2

After studying these experiments, a student concluded:

- there is a significant change in movement between 35 °C and 37.5 °C
- between 35 °C and 37.5 °C, more beetles move away from the light
- between 35 °C and 37.5 °C, more beetles have a slower walking speed.

Suggest reasons why these conclusions might **not** be valid.

[3 marks]

No statistical test was done, so we do not know if the change between 35 and 37.5 °C is significant.

Between 35 and 36.5 °C more than half of the beetles were still on the light side.

Speed was not recorded above 35 °C (none at 37.5 °C), so we cannot say anything about speed there; the slowing also started before 35 °C.

The y-axis shows mean speed of movement, which may include flying, not only walking, and a mean could hide some beetles walking very fast while others stay still. Slower movement may be due to preparing to fly rather than temperature.

5

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0 4

Freshwater marshes have one of the highest rates of gross primary production (*GPP*) and net primary production (*NPP*) of all ecosystems.

Carbon use efficiency (*CUE*) is the ratio of *NPP*:*GPP*. Freshwater marshes have a high *CUE*.

0 4 . 1

Use your knowledge of *NPP* to explain why freshwater marshes have a high *CUE* and the advantage of this.

Do **not** refer to abiotic factors in your answer.

[2 marks]

Explanation Low respiration, so less energy is lost from *GPP*.

Advantage More growth / biomass, so more energy for consumers.

0 4 . 2

Freshwater marsh soils are normally waterlogged. This creates anaerobic conditions.

Use your knowledge of the nitrogen cycle to suggest why these soils contain relatively high concentrations of ammonium compounds and low concentrations of nitrite ions and nitrate ions.

[2 marks]

Nitrifying bacteria need oxygen (aerobic conditions), so in waterlogged

soil there is less nitrification: less oxidation of ammonium ions to nitrite ions and then to nitrate ions, so ammonium builds up.

Denitrifying bacteria are anaerobic, so there is more denitrification: more nitrate is reduced to nitrogen gas, so nitrite and nitrate concentrations stay low.



A student investigated the growth rate of a freshwater marsh plant.

The growth rate (R) of a plant can be determined using this equation.

$$R = \frac{(\ln W_2 - \ln W_1)}{t}$$

Where

$\ln$ = natural logarithm

t = duration of the investigation in days

W_1 = plant biomass at the start of the investigation

W_2 = plant biomass at the end of the investigation

The student used the equation above; however, she substituted height for biomass. This was because she did not want to destroy the plants to measure their biomass.

0 4 . 3

State the assumption the student has made **and** suggest why this assumption might **not** be valid.

[2 marks]

She has assumed that height is directly proportional to biomass.

This may not be valid because the plant may put biomass into other growth, such as roots, wider leaves or flowers and seeds, which height does not measure; some increase in height may also be due to water gain.

0 4 . 4

At the end of the investigation, the student noted the freshwater marsh plant had grown 268 mm in height, and now measured 387 mm. She calculated the rate of growth (R) to be $0.097 \text{ mm m}^{-1} \text{ day}^{-1}$

Use this information and, **substituting height for biomass**, use the equation to calculate the duration of the student's investigation.

Give your answer to the nearest full day. Show your working.

[2 marks]

$$W_1 = 387 - 268 = 119 \text{ mm}, \quad W_2 = 387 \text{ mm}$$

$$t = (\ln 387 - \ln 119) \div 0.097 = (5.958 - 4.779) \div 0.097 = 12.16$$

12

days

8

Turn over ►



0 5 . 1

The action of endopeptidases and exopeptidases can increase the rate of protein digestion. Describe how.

[2 marks]

Endopeptidases hydrolyse internal peptide bonds within the polypeptide, and exopeptidases hydrolyse the peptide bonds at the ends of the polypeptide, removing single amino acids (and dipeptides).

Endopeptidases therefore create many more ends (more surface area) for the exopeptidases to act on, so hydrolysis is faster.

0 5 . 2

As humans age, there is a decrease in body protein.

Give the name of **one** body protein that could have resulted in:

[2 marks]

reduced muscle power *Myosin (or actin)*

reduced immunity *Antibodies*

Scientists investigated the effect of two types of dietary protein on the ability of old men to produce body proteins.

Table 2 shows information about the two types of dietary protein investigated.

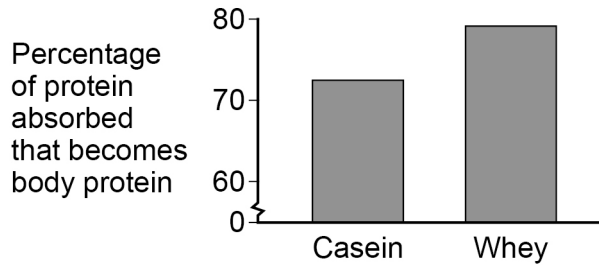
Table 2

Physiological factor	Name of dietary protein	
	Casein	Whey
Rate of absorption of dietary protein / mmol dm^{-3} amino acids in blood plasma h^{-1}	3.05	4.33
Stimulation of protein synthesis	Higher rate	Lower rate
Breakdown of body proteins	No effect	Inhibitory effect



Figure 4 shows the percentage of protein absorbed that becomes body protein in old men following a meal of casein or whey.

Figure 4



A statistical test confirmed that the difference between the results shown in **Figure 4** was significant.

0 5 . 3

Suggest which type of dietary protein would be better for old men to eat to cause a **net** gain of body proteins. Use the information provided to explain your answer.

[3 marks]

Whey would be better.

Whey is absorbed faster than casein: 4.33 compared with 3.05 mmol dm⁻³ amino acids in plasma per hour.

Although whey stimulates protein synthesis at a lower rate than casein, it still stimulates protein synthesis.

Whey also inhibits the breakdown of body proteins, whereas casein has no effect on breakdown.

Figure 4 shows a significantly higher percentage of absorbed protein becomes body protein with whey (about 79%) than with casein (about 72%), so overall there is a net gain.

7

Turn over ►



0 6

Plants transport sucrose from leaves to other tissues for growth and storage. SUT1 is a sucrose co-transporter protein.

Scientists investigated whether the cells of tobacco plant leaves used SUT1 to transport sucrose to other tissues.

0 6 . 1

The scientists used a radioactively labelled DNA probe to show that the cells of tobacco plant leaves contained the *SUT1* gene.

Describe how they would do this.

Do **not** include PCR in your answer.

[4 marks]

Extract DNA from the tobacco leaf cells and cut it into fragments

using restriction endonucleases (restriction enzymes).

Separate the DNA fragments by size using gel electrophoresis.

Treat the DNA (e.g. with alkali or heat) to separate it into single strands so that the bases are exposed, and transfer it onto a nylon membrane.

*Add the radioactively labelled DNA probe, which has a base sequence complementary to part of the *SUT1* gene, so it hybridises (base pairs) with the *SUT1* gene if present. Wash off any unbound probe.*

*Use autoradiography (place X-ray / photographic film over the membrane) to show where the bound probe is; a band shows the *SUT1* gene is present.*



0 6 . 2

To study the role of SUT1 in tobacco plants, scientists reduced the expression of the *SUT1* gene.

When the *SUT1* gene is transcribed, the SUT1 mRNA produced is called 'sense' SUT1 mRNA. The scientists genetically modified plants by inserting an **extra** gene so that this **also** allowed the production of 'antisense' SUT1 mRNA.

The scientists had two types of tobacco plants:

- type **A** – plants that were genetically modified
- type **B** – plants that were **not** genetically modified.

Suggest how the production of 'antisense' SUT1 mRNA in type **A** plants would reduce the expression of the *SUT1* gene.

[4 marks]

The antisense SUT1 mRNA has a base sequence that is complementary to the sense SUT1 mRNA.

So the antisense mRNA binds (base pairs) to the sense mRNA, forming double-stranded RNA.

Ribosomes are then unable to bind to the sense mRNA (and the double-stranded RNA may be broken down).

So translation of the SUT1 mRNA is prevented or reduced, and less SUT1 protein is produced.

Question 6 continues on the next page

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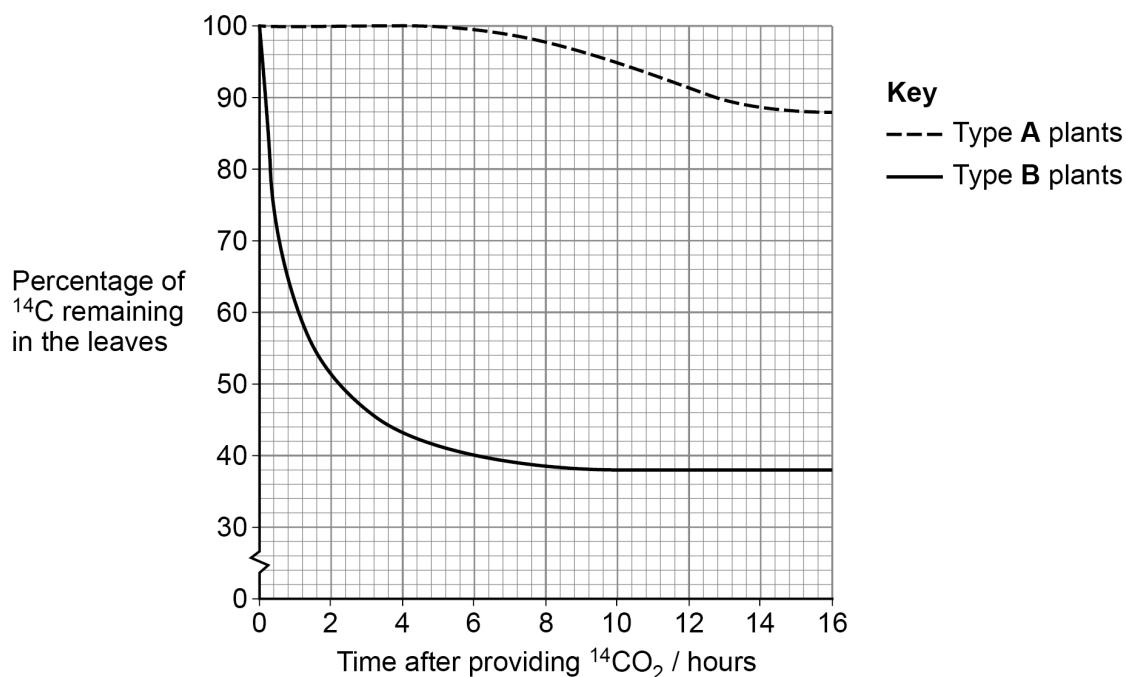
0 6 . 3

The scientists hypothesised that lower rates of sucrose transport from leaves would cause reduced growth.

To test this hypothesis, the scientists provided leaves of type **A** and type **B** plants with labelled carbon dioxide ($^{14}\text{CO}_2$). To estimate sucrose transport out of leaves, they measured the percentage of ^{14}C remaining in the leaves for 16 hours.

Figure 5 shows their results.

Figure 5



Calculate the ratio of percentage of ^{14}C remaining in leaves of type **B** to type **A** plants 16 hours after providing $^{14}\text{CO}_2$

[1 mark]

Type B = 38%, type A = 88%

$$38 \div 88 = 0.43$$

Answer 0.43 : 1



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In type **B** plants, the percentage of ^{14}C remaining in the leaves does not reach zero per cent, as shown in **Figure 5**.

Suggest **two** reasons why.

[2 marks]

1 Some of the ^{14}C is used to make cellulose for cell walls (or lipids / proteins), which stay in the leaf.

2 Some ^{14}C is converted into starch, which stays in the leaf, or is still in GP / triose phosphate / RuBP in the Calvin cycle.

Question 6 continues on the next page

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The scientists measured physiological differences between type **A** plants and type **B** plants.

Table 3 shows the scientists' results as they presented them.

Table 3

Physiological factor	Type of tobacco plant	
	Type A	Type B
Rate of sucrose transport from leaf cells / $\mu\text{mol m}^{-2} \text{ s}^{-1}$	0.1	3.7
Leaf sucrose concentration / mmol m^{-2}	22	4
Ratio of shoot:root dry mass	6:1	2:1
Rate of photosynthesis / $\mu\text{mol glucose m}^{-2} \text{ s}^{-1}$	4	14



Sucrose is able to inhibit the production and activity of rubisco in leaves of a plant. Type **A** plants have decreased dry mass compared with type **B** plants.

0 6 . 5

Use all the information to suggest **and** explain how the physiological factors in **Table 3** would contribute to the decreased dry mass observed in type **A** plants.

[4 marks]

Type A plants have reduced SUT1 expression, so less SUT1 protein and less sucrose is exported from leaf cells (0.1 compared with $3.7 \mu\text{mol m}^{-2} \text{s}^{-1}$), so the leaf sucrose concentration builds up (22 compared with 4 mmol m^{-2}).

The high sucrose concentration inhibits the production and activity of rubisco, so less CO_2 combines with RuBP and less GP is made, so the light-independent reaction (Calvin cycle) slows. This is why photosynthesis is only 4 compared with $14 \mu\text{mol m}^{-2} \text{s}^{-1}$.

Less sucrose is transported to the roots, so the roots do not grow as much, shown by the larger shoot:root ratio of $6:1$ compared with $2:1$.

With smaller roots, less water and fewer mineral ions (e.g. nitrate for proteins) are absorbed for growth and photosynthesis.

Less photosynthesis and less growth mean less dry mass is produced in type A plants.

15

Turn over for Section B

Turn over ►



Section BAnswer **one** question.

You are advised to spend no more than 45 minutes on this section.

0 7Write an essay on **one** of the topics below.**Either****0 7 . 1**

The importance of complementary shapes of molecules in organisms

[25 marks]**Or****0 7 . 2**

The importance of ions in metabolic processes

[25 marks]*07.1 The importance of complementary shapes of molecules in organisms**Many of the most important processes in living organisms depend on one**molecule fitting another because their shapes are complementary. This**allows molecules to recognise each other specifically, so that reactions,**signals and the copying of information happen only where and when**they should. In this essay I will explain how complementary shapes are**important in enzyme action, DNA and protein synthesis, the immune**system, cell signalling by hormones and nerves, and muscle contraction.**Enzymes are globular proteins whose tertiary structure, held by hydrogen**bonds, ionic bonds and disulfide bridges between R groups, produces an**active site with a specific shape. Only a substrate with a complementary**shape can bind to form an enzyme-substrate complex. In the induced-fit**model the active site changes shape slightly as the substrate binds,**putting strain on bonds and lowering the activation energy, so reactions**happen quickly at body temperature. This is important because it means**each enzyme catalyses only one reaction, allowing metabolism to be*

controlled. For example, in digestion amylase hydrolyses starch into maltose, and maltase, a membrane-bound disaccharidase on the ileum epithelium, hydrolyses maltose into glucose, which can then be absorbed by co-transport. Complementary shape also explains enzyme inhibition: a competitive inhibitor has a similar shape to the substrate and binds to the active site, while a non-competitive inhibitor binds at an allosteric site and changes the shape of the active site so the substrate no longer fits. End-product inhibition uses this to regulate metabolic pathways. If high temperature or extreme pH breaks the bonds in the tertiary structure, the enzyme is denatured, the active site is no longer complementary and the reaction stops.

The structure of DNA depends on complementary base pairing. Adenine pairs with thymine by two hydrogen bonds and guanine with cytosine by three, because a purine and a pyrimidine fit together across the double helix. This is vitally important because it allows DNA to be copied accurately by semi-conservative replication. DNA helicase breaks the hydrogen bonds, and free DNA nucleotides line up opposite their complementary bases on each template strand. DNA polymerase, whose active site is complementary to the 3' end of the growing strand, joins them by condensation reactions, so it can only work in the 5' to 3' direction. As a result, each daughter cell produced by mitosis receives an identical copy of the genetic information.

Complementary shapes are also essential in protein synthesis. During transcription, RNA nucleotides pair with complementary bases on the template strand to form pre-mRNA, which is spliced to mRNA. In translation, each tRNA carries an anticodon that is complementary to a codon on the mRNA, so the correct amino acid is brought to the

Turn over ►



ribosome in the correct order, and peptide bonds join them. The sequence of amino acids then determines how the polypeptide folds into its final shape. A gene mutation such as a substitution or deletion can change the amino acid sequence, so the protein may fold differently and lose its complementary shape, for example an enzyme whose active site no longer fits its substrate. Gene expression is also controlled by complementary shapes: transcription factors bind to specific base sequences in the promoter region, and oestrogen activates a transcription factor by binding to a complementary site on it. In RNA interference, siRNA is complementary to a specific mRNA, so the mRNA is broken down and not translated. Complementary DNA probes are used in genetic screening to find specific alleles, such as mutated BRCA1 alleles. The immune system depends entirely on complementary shapes. Antigens are proteins or glycoproteins on the surface of cells, and each lymphocyte has receptors complementary to only one antigen. When a phagocyte presents a pathogen's antigens, only the helper T cell with complementary receptors binds, and it stimulates the specific B cell to divide by mitosis in clonal selection. The plasma cells produced secrete antibodies, which have a variable region with a binding site complementary to the antigen. Antibodies form antigen-antibody complexes and cause agglutination, so phagocytes can engulf many pathogens at once. Memory cells with the same receptors allow a faster secondary response, which is why vaccination works. This specificity is important because it allows the body to distinguish self from non-self. However, antigenic variability means that if the antigen's shape changes, existing antibodies and memory cells are no longer complementary, which is why new influenza vaccines are needed each year. Monoclonal



antibodies use complementary binding in pregnancy tests and the ELISA test, and to target drugs to cancer cells.

Communication between cells relies on receptors with shapes complementary to their signalling molecules. In the control of blood glucose, insulin binds to complementary receptors on the cell-surface membranes of liver and muscle cells, causing vesicles containing glucose channel proteins to fuse with the membrane, so more glucose is taken up and converted to glycogen. Glucagon binds to different receptors on liver cells, activating adenylate cyclase to produce cyclic AMP, which activates protein kinase and leads to glycogenolysis. Because only cells with the right receptors respond, a hormone in the blood affects only its target cells. In type 2 diabetes the receptors respond less to insulin, so blood glucose stays high. Similarly, ADH binds to receptors on cells of the collecting duct, so that more aquaporins are inserted into the membrane and more water is reabsorbed by osmosis. Membrane transport proteins also have complementary binding sites, for example the sodium-glucose co-transporter in the ileum binds both sodium ions and glucose.

At a cholinergic synapse, acetylcholine diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane that are complementary to it. This opens sodium ion channels, causing depolarisation, and if threshold is reached an action potential is generated. Acetylcholinesterase has an active site complementary to acetylcholine and hydrolyses it, so the signal stops and the receptors are freed. This is important because it ensures impulses travel in one direction only and do not continue indefinitely. Many drugs work because their shape is complementary to receptors: some mimic a

Turn over ►

neurotransmitter and stimulate the receptor, while others block it.

Muscle contraction also depends on complementary shapes. When an action potential reaches a muscle fibre, calcium ions are released from the sarcoplasmic reticulum and bind to troponin, which moves tropomyosin away from the binding sites on actin. The heads of myosin molecules have a shape complementary to these binding sites, so actomyosin cross-bridges form and the myosin heads pull the actin filaments along in the sliding filament mechanism. ATP binds to the myosin head, causing it to detach, and ATP hydrolase hydrolyses the ATP to recock the head. Without these complementary shapes, animals could not move to find food or escape predators. ATP synthase in mitochondria and chloroplasts is another example, as its shape allows ADP and inorganic phosphate to be joined as protons diffuse through it, producing the ATP needed for contraction.

Beyond the specification, the importance of complementary shapes is shown by the antibiotic penicillin. Penicillin has a shape similar to the substrate of the bacterial enzyme transpeptidase, which forms cross-links between peptidoglycan chains in the cell wall. Penicillin binds permanently to the active site, acting as an irreversible competitive inhibitor, so the wall is weakened and the bacterium bursts by osmotic lysis. Human cells have no cell wall, so they are unaffected. Some bacteria have evolved enzymes called penicillinases, whose active sites are complementary to penicillin and break it down; this is a cause of antibiotic resistance. Another example is the SARS-CoV-2 virus, whose spike protein is complementary to the ACE2 receptor on human cells, allowing the virus to enter them. Most COVID-19 vaccines cause the body to make antibodies complementary to this spike protein.



In conclusion, complementary shapes of molecules are essential to life.

They give enzymes their specificity, allow DNA to be copied and

expressed accurately, let the immune system recognise and destroy

pathogens, allow hormones and neurotransmitters to act only on target

cells, and make muscle contraction possible. When the shape of a

molecule changes, through denaturation or mutation, its function is lost,

showing how important complementary shapes are in organisms.

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25



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