



Rewarding Learning

ADVANCED
General Certificate of Education
2025

Centre Number

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Biology

StemUp Model Solution

Assessment Unit A2 2

assessing

Biochemistry, Genetics and
Evolutionary Trends



[ABY21]

ABY21

FRIDAY 13 JUNE, MORNING

TIME

2 hours 15 minutes.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

You must answer the questions in the spaces provided.

Do not write outside the boxed area on each page or on blank pages.

Complete questions in black ink and use a dark HB pencil for drawings and graphs.

Do not write with a gel pen.

Answer **all nine** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100. Section A carries 82 marks. Section B carries 18 marks. Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.

You may use a scientific calculator.

You are reminded of the need for good English and clear presentation in your answers.

Use accurate scientific terminology in all answers.

You should spend approximately **25 minutes** on Section B.

You are expected to answer Section B in continuous prose.

Quality of written communication will be assessed in Section B.

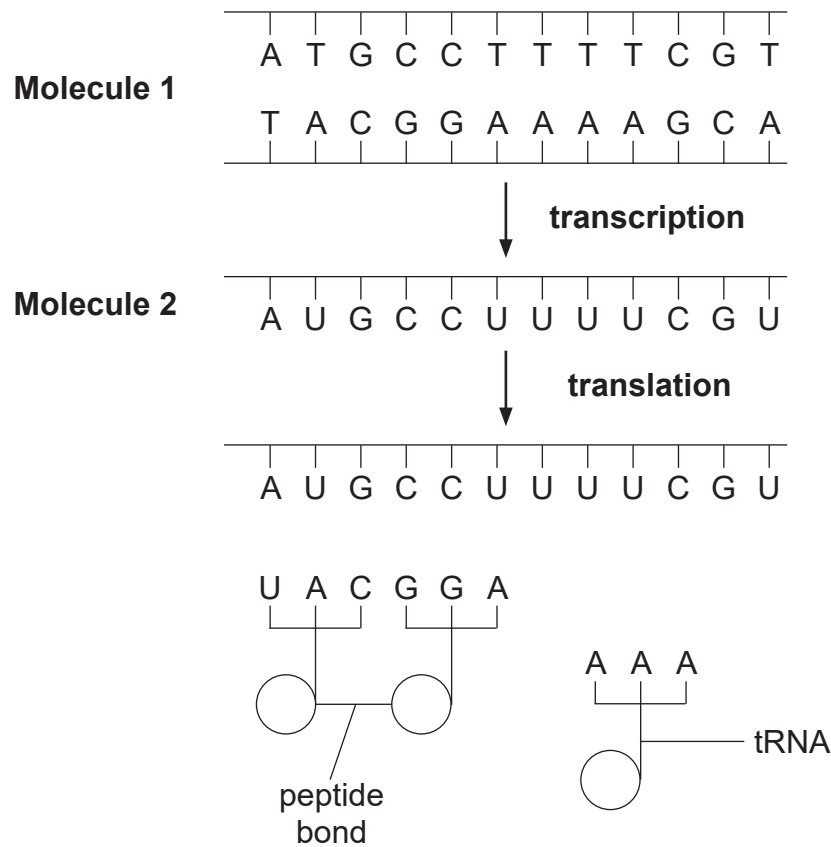
Statistics Sheets are provided for use with this paper.

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Section A

- 1 (a) Some stages in the synthesis of a protein are represented in the diagram below.



Source: Principal Examiner

- (i) Identify **molecules 1 and 2** in the above diagram.

Molecule 1: DNA (template / antisense strand)

Molecule 2: mRNA (messenger RNA)

[2]

- (ii) Name **one** enzyme involved in the process of transcription.

RNA polymerase

[1]



- (b) Some codons and the amino acids for which they code are shown in the table below.

Codon	Amino acid
UUU	Phe
AUG	Met
CGU	Arg
CGG	Arg
CCU	Pro
UGA	No amino acid

- (i) Explain what is meant by a triplet code.

Three adjacent bases (a codon) code for one amino acid.

[1]

- (ii) Suggest the role of the codon UGA in protein synthesis.

It is a stop codon, so it terminates translation / protein synthesis.

[1]

The codons CGU and CGG both code for the amino acid Arg.

- (iii) State the term used to describe this feature of the genetic code.

Degenerate (code)

[1]

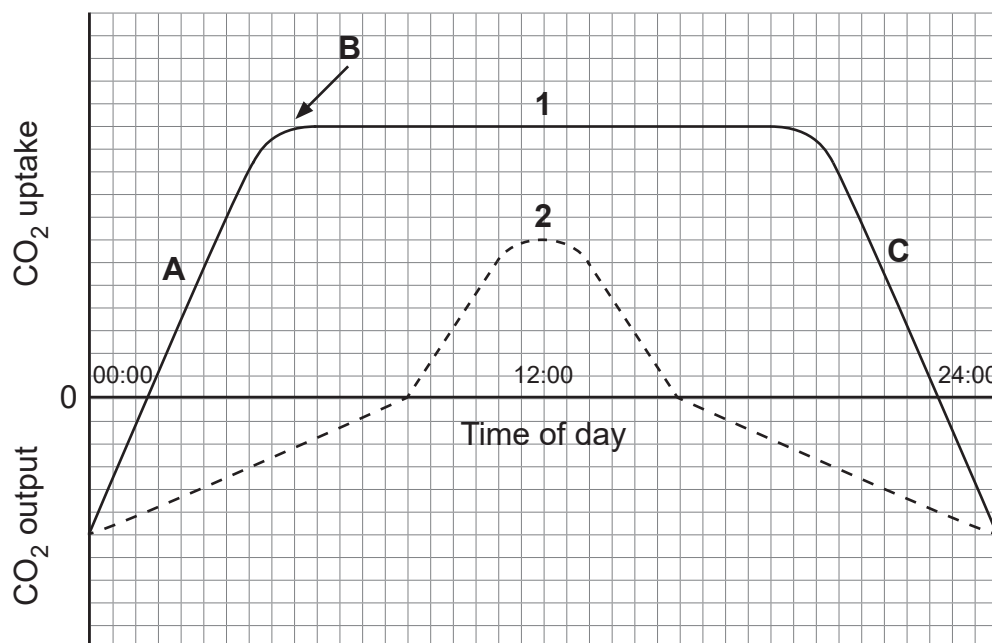
[Turn over]



2 Plants photosynthesise and respire during the daytime.

Lines **1** and **2** on the graph below represent measurements of carbon dioxide (CO_2) taken over a 24-hour period.

The graph shows data from the same plant in two different seasons (line **1** = summer, line **2** = winter).



Source: Principal Examiner

(a) The region labelled **A** on graph line **1** is due to the effect of increasing light intensity on photosynthesis. However, both light intensity and temperature increase up to 12:00 noon.

(i) Account for the constant CO_2 uptake after point **B** on graph line **1**.

Another factor such as carbon dioxide concentration (or the amount of rubisco) is now limiting, so the rate cannot increase further. [1]



- (ii) Using your understanding of the light-dependent and light-independent stages of photosynthesis, explain why the rate of CO_2 uptake decreases at C in graph 1.

Light intensity falls in the evening, so the light-dependent reactions slow down and less ATP and reduced NADP (NADPH) are produced.

So the light-independent reactions (Calvin cycle) slow, GP cannot be reduced to TP and RuBP is not regenerated, so less CO_2 is fixed by RuBP.

[2]

- (iii) Explain the evidence from the graph that indicates that net photosynthesis rather than gross photosynthesis is represented by the data.

The graph shows CO_2 output (values below zero) at night / when light is low.

This shows respiration is taking place, so the CO_2 uptake measured is photosynthesis minus respiration, i.e. net photosynthesis.

[2]

The line labelled 2 represents measurements taken during winter.

- (b) Using only the information provided, explain why a farmer would expect a greater yield from a crop plant grown in summer than in winter.

The area above the x-axis (net CO_2 uptake / net production) is much greater for line 1 in summer than line 2 in winter.

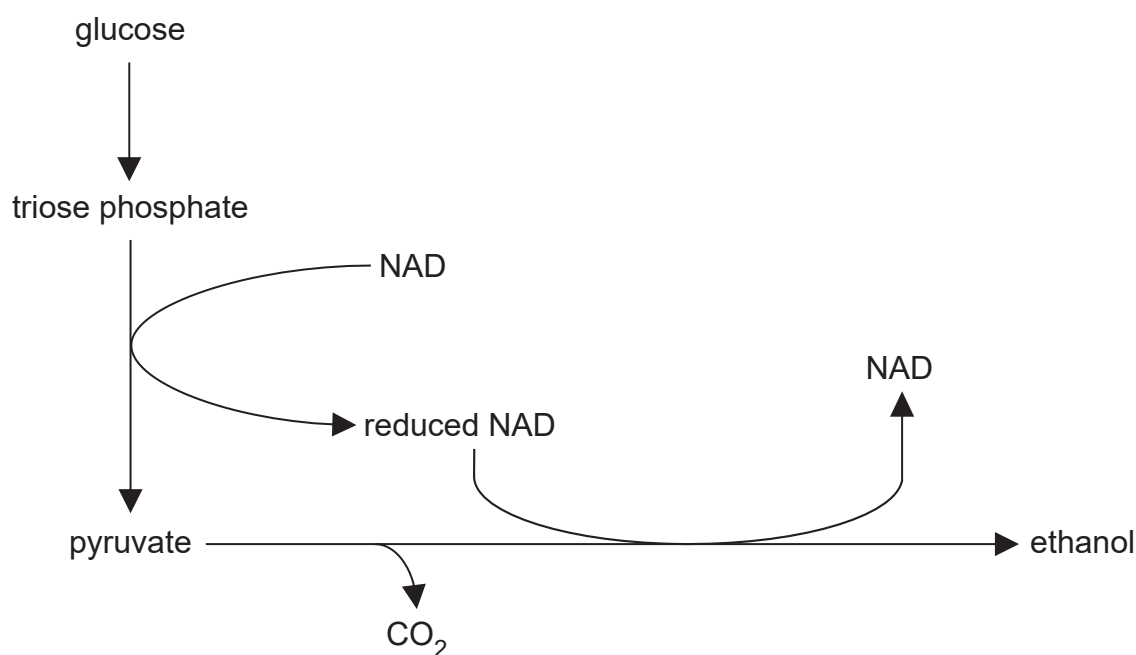
So more carbohydrate is produced and available for growth in summer, giving a greater yield.

[2]

[Turn over]



3 The diagram below represents a respiratory pathway in a plant.



Source: Principal Examiner

(a) (i) State the name of the metabolic pathway that converts glucose to pyruvate.

Glycolysis

[1]

(ii) Identify the type of respiration shown above, using evidence from the diagram to support your answer.

Anaerobic respiration (alcoholic fermentation).

Evidence: ethanol and CO₂ are produced from pyruvate, and reduced

NAD is reoxidised to NAD without oxygen.

[2]



(iii) The pathway shown occurs in plant roots, particularly in waterlogged soil.

Suggest how the pathway shown is an adaptation in this environment.

Waterlogged soil is low in oxygen, so aerobic respiration in root cells cannot occur.

This pathway regenerates NAD so glycolysis can continue, producing some ATP (2 per glucose) for root cells to stay alive, e.g. for active transport.

[2]

There is a net gain of 2 ATP molecules in the metabolic pathway from glucose to pyruvate.

(b) Account for this net ATP production.

2 ATP are used to phosphorylate glucose at the start, and 4 ATP are produced by substrate-level phosphorylation when triose phosphate is converted to pyruvate, so net gain = $4 - 2 = 2$ ATP.

[1]

[Turn over]



- (c) The respiratory quotient (RQ) value can be used to determine both the type of respiration occurring in tissue and the respiratory substrate being respired.

In an investigation, some plant tissue was found to have a RQ value of 1.0.

- (i) Identify the substrate being respired.

Glucose (carbohydrate)

[1]

- (ii) State the equation used to calculate the RQ value.

$$RQ = \text{volume of } CO_2 \text{ produced} \div \text{volume of } O_2 \text{ consumed}$$

$$RQ = CO_2 \text{ produced} / O_2 \text{ consumed}$$

[1]

- (iii) During the investigation, the tissue used 50 mm^3 of oxygen.

Using the equation in (c)(ii) and the information provided, calculate the volume of carbon dioxide produced by the tissue.

Show your working out.

$$1.0 = CO_2 \text{ produced} \div 50$$

$$CO_2 \text{ produced} = 1.0 \times 50$$

$$= 50 \text{ mm}^3$$

50 mm^3 [2]



- 4 The phylum Arthropoda consists of several classes, including Insecta (insects) and Arachnida (arachnids).

The photographs below show an insect and an arachnid.



Source: J. Napier



Source: Principal Examiner

- (a) (i) Identify **one** feature visible in the photographs which confirms that both animals are arthropods.

Jointed limbs / jointed legs [1]

- (ii) Identify **one** feature visible in the photographs which suggests these animals belong to different classes.

The insect has 6 legs but the arachnid (spider) has 8 legs. [1]

Arthropods show bilateral symmetry.

- (iii) Define the term bilateral symmetry.

The body can be divided into two identical (mirror-image) halves,
by only one plane, i.e. along the central axis (left and right sides are
mirror images).

[2]

[Turn over]



Insects are the most successful animal group on Earth. This is due in part to the ability to fly.

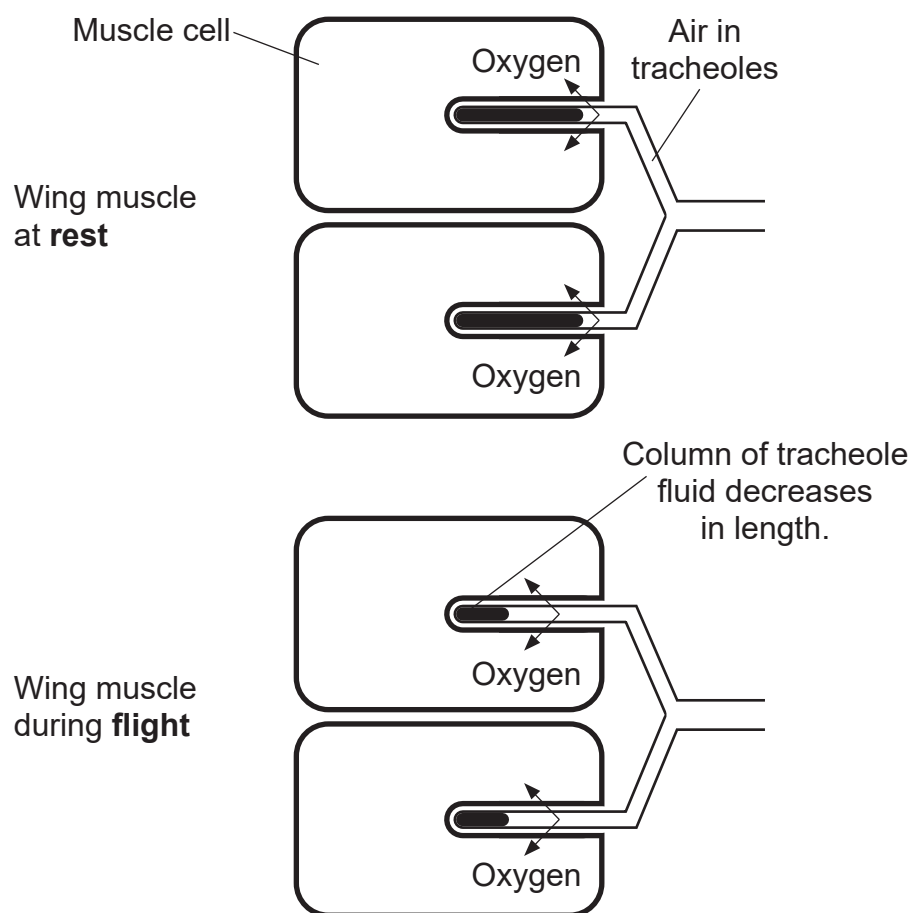
(b) (i) Suggest how their ability to fly has contributed to the success of insects.

Flight lets insects escape ground-based predators, reach food such as nectar, and disperse to colonise new habitats.

[1]

Flying puts a high respiratory demand on the insect, so an efficient mechanism for the delivery of oxygen to wing muscles is essential.

The diagram below represents the system of tubes called tracheoles which deliver oxygen directly to the wing muscle cells from the air outside.



Source: Principal Examiner



- (ii) Using the diagram, suggest how a decrease in the length of tracheole fluid allows wing muscles to maintain higher rates of respiration.

With less fluid, air reaches further into the tracheoles, increasing the surface area in contact with muscle cells for gas exchange.

Oxygen diffuses faster through air than fluid, so more oxygen diffuses to the muscle cells for aerobic respiration.

[2]

- (iii) Describe the role of oxygen in aerobic respiration.

Oxygen is the final electron (and hydrogen) acceptor at the end of the electron transport chain, combining with electrons and H^+ to form water.

This allows electrons to keep flowing so oxidative phosphorylation (ATP synthesis by ATP synthase) can continue.

[2]

[Turn over]



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5 Plant leaves can have different adaptations allowing them to maximise growth.

For example, so-called 'sun' and 'shade' leaves are adapted for different light conditions.

One adaptation is the increased thickness of sun leaves compared to shade leaves. Researchers studied some other leaf adaptations in the common nettle (*Urtica dioica*) growing in different light conditions.

Their observations are shown in the table below.

Leaf feature	Sun leaves	Shade leaves
Colour	Light green	Dark green
Mean length / cm	4.70	7.90
Mean width / cm	4.69	7.67
Mean mass per unit area / g cm ⁻²	0.52	0.13

Source: Adapted from Science and Plants for Schools, Field Studies Council

- (a) (i) Identify **one** similarity and **one** difference in the data for mean length and mean width shown by the two types of leaves.

Similarity For each leaf type, mean length and mean width are approximately the same (leaves are roughly as wide as long).

Difference Shade leaves have a much greater mean length and width than sun leaves (7.90 and 7.67 cm vs 4.70 and 4.69 cm). [2]

- (ii) Suggest how the darker green colour is achieved in shade leaves and explain the benefit of this.

Shade leaves have more chloroplasts per cell / produce more chlorophyll.

This allows them to absorb a higher percentage of the limited light available, so the rate of photosynthesis is maintained in low light.

[2]

[Turn over]



- (b) A t-test can be used to determine if there is a significant difference between the mean leaf masses per unit area of the sun and shade leaves.

- (i) State an appropriate null hypothesis.

There is no significant difference between the mean leaf mass per unit area of sun leaves and shade leaves.

[1]

- (ii) Use the data in the table below to complete the t-test.

	Sun leaves	Shade leaves
Number in sample (n)	32	30
Mean leaf mass per unit area / g cm^{-2} ($\bar{x}$)	0.52	0.13
Standard deviation (error) of the mean ($\hat{\sigma}_{\bar{x}}$)	0.03	0.04

Source: Adapted from Science and Plants for Schools, Field Studies Council

Show your working out.

$$t = (\bar{x}_1 - \bar{x}_2) \div \sqrt{(\hat{\sigma}_{x_1})^2 + (\hat{\sigma}_{x_2})^2}$$

$$\bar{x}_1 - \bar{x}_2 = 0.52 - 0.13 = 0.39$$

$$\sqrt{(0.03^2 + 0.04^2)} = \sqrt{(0.0009 + 0.0016)} = \sqrt{0.0025} = 0.05$$

$$t = 0.39 \div 0.05 = 7.8$$

$$t = \underline{7.8} \quad [3]$$



(iii) State the number of degrees of freedom.

$$60 \quad (32 + 30 - 2)$$

[1]

(iv) State the probability of the t-value you have calculated and comment on what this means.

$$p < 0.001, \text{ since } t = 7.8 \text{ exceeds } 3.460 \text{ at } 60 \text{ d.f.}$$

The difference in means is highly significant (under 0.1% chance it is random).

[2]

(v) State the decision regarding the null hypothesis.

Explain your reasoning.

Reject the null hypothesis.

Because $p < 0.05$: $t = 7.8$ exceeds the critical value of 2.000 at $p = 0.05$.

[2]

[Turn over]



- (c) Using the information provided and your knowledge, suggest and explain how sun leaves are adapted for growing in high-light environments.

Sun leaves are small, since there is plenty of light so a large surface area is not needed to absorb enough light, and small leaves reduce shading of the lower leaves.

Small leaves also have fewer stomata, so less water is lost by transpiration in the hot, bright conditions.

They are lighter green, with less chlorophyll needed as light is not limiting, and the lighter colour reduces the heating effect of the sun.

Sun leaves are thicker (greater mass per unit area), with more palisade layers for photosynthesis and a thicker cuticle, which also reduces water loss.

[4]





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[Turn over



- 6 The human genome consists of about 3 billion base pairs. However, only around 10% of this is coding DNA.

The CFTR gene is 200 kilobases (kb) long, of which 6.5kb are coding.

- (a) Calculate the percentage of the CFTR gene which is **non-coding**.

Show your working out.

$$\text{non-coding} = 200 - 6.5 = 193.5 \text{ kb}$$

$$\% \text{ non-coding} = 193.5 \div 200 \times 100$$

$$= 96.75$$

$$\underline{\hspace{2cm} 96.75 \hspace{2cm}} \% \text{ [2]}$$

Areas within non-coding regions of DNA can have many repeated base sequences. A repeated sequence of 9–100 base pairs is called a 'minisatellite'.

- (b) Suggest why mutations in the minisatellite region will have little or no effect on the individual.

Minisatellites are in non-coding regions, so a mutation does not change

the amino acid sequence of any protein (no effect on phenotype).

\hspace{10cm} [1]



- (c) While the repeat sequence in a minisatellite is 9–100 base pairs long, shorter repeated sequences are also found in the non-coding DNA.

These repeats are 2–8 base pairs long and called ‘microsatellites’.

Across the human population, the number of repeats of microsatellites is much more variable than for minisatellites. Microsatellite analysis is used on samples taken from crime scenes.

- (i) Using the information provided, explain the advantage of comparing microsatellite DNA rather than minisatellite DNA in crime scene analysis.

The number of microsatellite repeats is much more variable between people,
so a microsatellite profile is more likely to be unique and can distinguish between individuals more reliably.

[2]

- (ii) Explain why it is preferable to use microsatellites from several different chromosomes when identifying an individual.

Using several chromosomes gives a greater number of independent repeated sequences to compare,
so the probability of two people sharing the same profile by chance is much smaller, reducing identification error.

[2]

[Turn over]



(d) The diagram below represents a DNA fingerprint obtained from an individual.



Source: Principal Examiner

- (i) Name the type of enzyme used to prepare DNA for this process and explain its role.

Restriction endonucleases (restriction enzymes).

They cut the DNA into fragments at specific base sequences

(recognition sites), giving fragments of different lengths.

[2]

- (ii) Using the diagram above, identify the band containing the longest DNA fragments and explain your answer.

Band 5

Explanation *Larger fragments move more slowly through the gel, so band 5 has migrated the shortest distance from the well.*

[2]



Various methods can be used to make DNA fragments visible. In this case, a dye was used to stain the DNA.

(iii) Band **3** is more darkly stained than the other bands.

Suggest what this indicates about band **3**.

*Band 3 contains the most DNA, i.e. the greatest number of
fragments of that length.*

[1]



- 7 Two genes involved in determining eye colour in humans are denoted **B/b** and **G/g**. Both the **B** and **G** alleles code for the production of the dark pigment melanin in the iris of the eye, and are dominant to the recessive alleles which will result in the absence of melanin.

When two heterozygous individuals (**BbGg**) reproduce, five phenotypic classes of eye colour are possible in the offspring.

BBGG will result in dark-brown eyes, while **bbgg** will result in blue eyes. The other three phenotypes in order of decreasing darkness (mid-brown, light-brown and hazel) are dependent on the overall number of dominant alleles in the genotype.

- (a) (i) Complete the following genetic diagram to show the cross between two heterozygous individuals with light-brown eyes.

Parental phenotypes: light-brown eyes × light-brown eyes

Parental genotypes: **BbGg** × **BbGg**

Gametes: *BG, Bg, bG, bg* × *BG, Bg, bG, bg*

	<i>BG</i>	<i>Bg</i>	<i>bG</i>	<i>bg</i>
<i>BG</i>	<i>BBGG</i>	<i>BBGg</i>	<i>BbGG</i>	<i>BbGg</i>
<i>Bg</i>	<i>BBGg</i>	<i>BBgg</i>	<i>BbGg</i>	<i>Bbgg</i>
<i>bG</i>	<i>BbGG</i>	<i>BbGg</i>	<i>bbGG</i>	<i>bbGg</i>
<i>bg</i>	<i>BbGg</i>	<i>Bbgg</i>	<i>bbGg</i>	<i>bbgg</i>

Phenotypes: 4 dominant alleles = dark-brown, 3 = mid-brown, 2 = light-brown, 1 = hazel, 0 = blue

Offspring phenotype	Dark-brown	Mid-brown	Light-brown	Hazel	Blue
Expected ratio	<i>1</i>	<i>4</i>	<i>6</i>	<i>4</i>	<i>1</i>

[5]



- (ii) Explain why the observed ratio may differ from the expected ratio.

Fertilisation is random (and independent assortment in meiosis is random), so the observed numbers differ by chance, especially with small numbers of offspring.

[1]

Polygenic inheritance arises from the control of an organism's phenotype by several interacting genes. The greater the number of interacting genes, the greater the number of phenotypes produced.

- (b) State the type of variation most likely to involve polygenic inheritance.

Continuous variation

[1]

[Turn over]



- 8 (a) Lactase is an enzyme which digests lactose, the sugar found in milk. Babies must produce lactase to consume a milk-based diet.

Following the introduction of solid food (weaning), some children produce less lactase due to reduced activity of the lactase-producing gene. However, other children exhibit 'lactase persistence', since the gene responsible remains fully active and produces lactase.

- (i) Suggest why there is reduced activity of the lactase-producing gene as some children get older.

After weaning, milk is no longer the main part of the diet, so

lactase is not needed and the gene is switched off (reduced

consumption of milk).

[1]

The mutation resulting in lactase persistence occurred in humans around 8000 to 10000 years ago. This is around the time that human groups began farming animals such as cattle.

- (ii) Suggest why the occurrence of this mutation was of benefit to those humans who began farming.

The mutation allows individuals to continue producing lactase into

adulthood, so they can digest lactose in milk.

Farmers kept cattle, so their diet likely included more milk and

dairy, a valuable source of energy and nutrients, so those with the

mutation had a selective advantage.

[2]



Gene sequencing has shown that those with lactase persistence have a single base difference in their genome.

(iii) The single base difference that causes lactase persistence is an example of a SNP (single nucleotide polymorphism).

State **two** differences between an epigenetic change and a SNP.

1. An epigenetic change involves no change in the base sequence

(e.g. methylation of DNA); a SNP changes one base.

2. An epigenetic change alters gene expression and is usually not inherited; a SNP is inherited.

[2]



- (b) Researchers have studied lactase persistence in ancient and modern human populations. They analysed DNA from human remains of both ancient and modern human populations.

The table below summarises some of their findings. The lactase persistence allele is dominant (M).

Estimated age of samples	Number of individuals	Genotype frequency			Lactase persistence phenotype frequency
		mm	Mm	MM	
8500–7500 years	8	1.00	0.00	0.00	0.00
1000–800 years	18	0.28	0.44	0.28	0.72
Modern humans	450	0.15	0.48	0.37	0.85

Source: Ancient DNA Analysis Reveals High Frequency of European Lactase Persistence Allele (T-13910) in Medieval Central Europe | PLOS One
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- (i) Suggest why only eight samples were analysed for humans who lived 8500–7500 years ago.

There are very few human remains from that time available, and few contain enough intact DNA.

[1]

- (ii) PCR was used before analysis of the DNA took place.

Suggest why this was necessary.

To amplify the small amount of (degraded) ancient DNA, giving a large enough sample of DNA for analysis.

[1]



- (c) (i) Using your knowledge of the Hardy-Weinberg equation, calculate the frequency of the recessive allele (m) in the sample of the modern humans.

Show your working out.

$$q^2 = \text{frequency of } mm = 0.15$$

$$q = \sqrt{0.15} = 0.387$$

$$q = 0.39$$

0.39 [2]

- (ii) Calculate the number of heterozygous individuals in the sample of modern humans.

Show your working out.

$$\text{Heterozygous (Mm) frequency} = 0.48 (= 2pq)$$

$$\text{number} = 0.48 \times 450$$

$$= 216$$

216 [2]

[Turn over]



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- (iii) Using the information provided, suggest an explanation for the increase in the frequency of the lactase persistence phenotype over time.

Gene mutation produced the M allele, which gave lactase persistence and enabled better nutrition from milk.

Farming created a selection pressure favouring the M allele, so individuals with it survived and reproduced more, passing on M and increasing its frequency.

[2]

- (iv) Suggest why the data provided for modern humans is the most likely to meet the requirements of Hardy-Weinberg calculations.

Modern humans give a very large sample / population size (450), so chance effects are small.

[1]

[Turn over]



Section B

In this question you will be assessed on the quality of your written communication skills including the use of specialist scientific terms.

- 9 Selection is an important process which maintains populations, but also changes populations so that new species develop.

(a) Describe the process of stabilising selection, including the type of environment in which it occurs and its impact on a population. [6]

(b) Variation in a population allows for selection.

State how such variation may arise and discuss how directional selection may result in speciation. [12]

- (a) Describe the process of stabilising selection, including the type of environment in which it occurs and its impact on a population.

Stabilising selection is a type of natural selection that favours the average (intermediate) phenotypes in a population and selects against individuals with extreme traits at both ends of the range.

It occurs in a stable, unchanging environment where the existing average traits are already optimal (best adapted). An example is human birth mass, where babies of average mass have the highest survival rate, while very small or very large babies are less likely to survive.

Individuals with traits near the average have a higher survival rate and greater reproductive success, so they pass on their alleles to the next generation more often, while alleles for extreme phenotypes are removed.

As a result, the proportion of average individuals increases over



generations and the distribution curve becomes narrower around the same mean (the mode does not shift).

This leads to reduced genetic variation in the population. Because there is reduced variation around the average, stabilising selection decreases the potential for evolutionary change.

[Turn over]



(b) Variation in a population allows for selection.

State how such variation may arise and discuss how directional selection may result in speciation.

Variation arises from meiosis. During meiosis I, crossing over between non-sister chromatids of homologous chromosomes at chiasmata produces new combinations of alleles, and independent assortment of homologous pairs produces gametes with different combinations of maternal and paternal chromosomes.

Cross fertilisation, the random fusion of gametes from two different parents, further increases variation.

Gene mutation, a change in the base sequence of DNA such as a substitution, insertion or deletion, can produce new alleles. Chromosome mutation, a change in the structure or number of chromosomes such as polyploidy or non-disjunction, can also occur. Mutations may give rise to



a new phenotype.

Directional selection occurs in a changing environment. It favours one extreme variant, so individuals with the extreme trait are better adapted and have a higher survival rate and greater reproductive success. They pass on their alleles, resulting in an increased allele and phenotype frequency in the population, so the mean (mode) shifts in the direction of that extreme, a modal shift. This occurs over a significant time period, i.e. many generations.

A species is a group of individuals capable of interbreeding to produce fertile offspring. Speciation can occur when a population is split by geographical isolation, leading to allopatric speciation. For example, a population of squirrels may be separated by the formation of the Grand Canyon, or a group of finches may colonise different islands, as with Darwin's finches on the Galapagos.

Each isolated population experiences different selection pressures in its own environment, so directional selection acts differently on each, together with different mutations. No gene flow occurs between them, so the gene pools change and genetic divergence arises from the geographical isolation. Eventually reproductive isolation develops, so even if the populations meet again they can no longer interbreed to produce fertile offspring. Examples of reproductive isolation include different courtship behaviour or breeding seasons (behavioural and seasonal isolation), incompatible genitalia

[Turn over



(mechanical isolation), or hybrid sterility, as in the mule produced from a horse and a donkey.

Reproductive isolation maintains the genetic divergence, so the two populations are now separate species.





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Question Number	Marks
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Examiner Number

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ADVANCED
General Certificate of Education

Biology

Statistical Formulae and Tables

Statistics Sheets

Statistical Formulae and Tables

1 Definition of Symbols

n = sample size

$\bar{x}$ = sample mean

$\hat{\sigma}$ = estimate of the standard deviation

These parameters are obtained using a calculator with statistical functions, remembering to use the function for $\hat{\sigma}$ – which may be designated a different symbol on the calculator – with $(n - 1)$ denominator.

2 Practical Formulae

2.1 Estimation of the standard deviation (error) of the mean ($\hat{\sigma}_{\bar{x}}$)

$$\hat{\sigma}_{\bar{x}} = \sqrt{\frac{\hat{\sigma}^2}{n}}$$

2.2 Confidence limits for population mean

$$\bar{x} \pm t \sqrt{\frac{\hat{\sigma}^2}{n}}$$

which can be rewritten, in terms of $\hat{\sigma}_{\bar{x}}$, as

$$\bar{x} \pm t(\hat{\sigma}_{\bar{x}})$$

where t is taken from t tables for the appropriate probability and $n - 1$ degrees of freedom.

3 Tests of significance

3.1 Student's *t* test

Different samples are denoted by subscripts; thus, for example, $\bar{x}_1$ and $\bar{x}_2$ are the sample means of sample 1 and sample 2 respectively.

The following formula for t is that to be used:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\hat{\sigma}_1^2}{n_1} + \frac{\hat{\sigma}_2^2}{n_2}}}$$

which can be rewritten, in terms of $\hat{\sigma}_{\bar{x}}$, as

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\hat{\sigma}_{\bar{x}_1}^2 + \hat{\sigma}_{\bar{x}_2}^2}}$$

with $n_1 + n_2 - 2$ degrees of freedom.

3.2 Chi squared test

Using the symbols O = observed frequency, E = expected frequency and Σ = the sum of

$$\chi^2 = \Sigma \frac{(O - E)^2}{E}$$

with $n - 1$ degrees of freedom (where n is the number of categories).

Table 1 Student's t values

d.f.	$p = 0.1$	0.05	0.02	0.01	0.002	0.001
1	6.314	12.706	31.821	63.657	318.31	636.62
2	2.920	4.303	6.965	9.925	22.327	31.598
3	2.353	3.182	4.541	5.841	10.214	12.924
4	2.132	2.776	3.747	4.604	7.173	8.610
5	2.015	2.571	3.365	4.032	5.893	6.869
6	1.943	2.447	3.143	3.707	5.208	5.959
7	1.895	2.365	2.998	3.499	4.785	5.408
8	1.860	2.306	2.896	3.355	4.501	5.041
9	1.833	2.262	2.821	3.250	4.297	4.781
10	1.812	2.228	2.764	3.169	4.144	4.587
11	1.796	2.201	2.718	3.106	4.025	4.437
12	1.782	2.179	2.681	3.055	3.930	4.318
13	1.771	2.160	2.650	3.012	3.852	4.221
14	1.761	2.145	2.624	2.977	3.787	4.140
15	1.753	2.131	2.602	2.947	3.733	4.073
16	1.746	2.120	2.583	2.921	3.686	4.015
17	1.740	2.110	2.567	2.898	3.646	3.965
18	1.734	2.101	2.552	2.878	3.610	3.922
19	1.729	2.093	2.539	2.861	3.579	3.883
20	1.725	2.086	2.528	2.845	3.552	3.850
21	1.721	2.080	2.518	2.831	3.527	3.819
22	1.717	2.074	2.508	2.819	3.505	3.792
23	1.714	2.069	2.500	2.807	3.485	3.767
24	1.711	2.064	2.492	2.797	3.467	3.745
25	1.708	2.060	2.485	2.787	3.450	3.725
26	1.706	2.056	2.479	2.779	3.435	3.707
27	1.703	2.052	2.473	2.771	3.421	3.690
28	1.701	2.048	2.467	2.763	3.408	3.674
29	1.699	2.045	2.462	2.756	3.396	3.659
30	1.697	2.042	2.457	2.750	3.385	3.646
40	1.684	2.021	2.423	2.704	3.307	3.551
60	1.671	2.000	2.390	2.660	3.232	3.460
120	1.658	1.980	2.358	2.617	3.160	3.373
∞	1.645	1.960	2.326	2.576	3.090	3.291

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Table 2 χ^2 values

d.f.	$p = 0.900$	0.500	0.100	0.050	0.010	0.001
1	0.016	0.455	2.71	3.84	6.63	10.83
2	0.211	1.39	4.61	5.99	9.21	13.82
3	0.584	2.37	6.25	7.81	11.34	16.27
4	1.06	3.36	7.78	9.49	13.28	18.47
5	1.61	4.35	9.24	11.07	15.09	20.52
6	2.20	5.35	10.64	12.59	16.81	22.46
7	2.83	6.35	12.02	14.07	18.48	24.32
8	3.49	7.34	13.36	15.51	20.09	26.13
9	4.17	8.34	14.68	16.92	21.67	27.88
10	4.87	9.34	15.99	18.31	23.21	29.59
11	5.58	10.34	17.28	19.68	24.73	31.26
12	6.30	11.34	18.55	21.03	26.22	32.91
13	7.04	12.34	19.81	22.36	27.69	34.53
14	7.79	13.34	21.06	23.68	29.14	36.12
15	8.55	14.34	22.31	25.00	30.58	37.70
16	9.31	15.34	23.54	26.30	32.00	39.25
17	10.09	16.34	24.77	27.59	33.41	40.79
18	10.86	17.34	25.99	28.87	34.81	42.31
19	11.65	18.34	27.20	30.14	36.19	43.82
20	12.44	19.34	28.41	31.41	37.57	45.32
21	13.24	20.34	29.62	32.67	38.93	46.80
22	14.04	21.34	30.81	33.92	40.29	48.27
23	14.85	22.34	32.01	35.17	41.64	49.73
24	15.66	23.34	33.20	36.42	42.98	51.18
25	16.47	24.34	34.38	37.65	44.31	52.62
26	17.29	25.34	35.56	38.89	45.64	54.05
27	18.11	26.34	36.74	40.11	46.96	55.48
28	18.94	27.34	37.92	41.34	48.28	56.89
29	19.77	28.34	39.09	42.56	49.59	58.30
30	20.60	29.34	40.26	43.77	50.89	59.70
40	29.05	39.34	51.81	55.76	63.69	73.40
50	37.69	49.33	63.17	67.50	76.15	86.66
60	46.46	59.33	74.40	79.08	88.38	99.61
70	55.33	69.33	85.53	90.53	100.43	112.32
80	64.28	79.33	96.58	101.88	112.33	124.84
90	73.29	89.33	107.57	113.15	124.12	137.21
100	82.36	99.33	118.50	123.34	135.81	149.45

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COUNCIL FOR THE CURRICULUM EXAMINATIONS AND ASSESSMENT

29 Clarendon Road, Clarendon Dock, Belfast BT1 3BG

☎ +44 (0)28 9026 1200

☎ +44 (0)28 9026 1234

☎ +44 (0)28 9024 2063

✉ info@ccea.org.uk

🌐 www.ccea.org.uk

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