

Please check the examination details below before entering your candidate information

Candidate surname <i>StemUp Model Solution</i>		Other names	
Centre Number		Candidate Number	
Pearson Edexcel Level 3 GCE			
Monday 17 June 2019			
Morning (Time: 2 hours)		Paper Reference 9BN0/03	
Biology A (Salters-Nuffield) Advanced Paper 3: General and Practical Applications in Biology			
You must have: Calculator, HB pencil, ruler and a copy of the scientific article adapted from <i>The Biologist</i> (enclosed)			Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Show your working in any calculation questions and include units in your answer where appropriate.
- Answer the questions in the spaces provided
– *there may be more space than you need.*

Information

- The total mark for this paper is 100.
- The marks for **each** question are shown in brackets
– *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- In questions marked with an **asterisk (*)**, marks will be awarded for your ability to structure your answer **logically**, showing how the points that you make are related or follow on from each other where appropriate.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

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Answer ALL questions.

Write your answers in the spaces provided.

1 Many animals possess a heart and a circulatory system.

(a) Changes in the cardiac cycle can be observed by recording an electrocardiogram (ECG).

The ECG for a resting person is shown in the diagram.



Calculate the heart rate for this person.

(1)

$$R \text{ to } R \text{ interval} = 5 \text{ large squares} = 5 \times 0.2 = 1.0 \text{ s}$$

$$\text{heart rate} = 60 \div 1.0 = 60 \text{ beats per minute}$$

Answer 60 bpm



(b) Anabolic steroids stimulate muscle development.

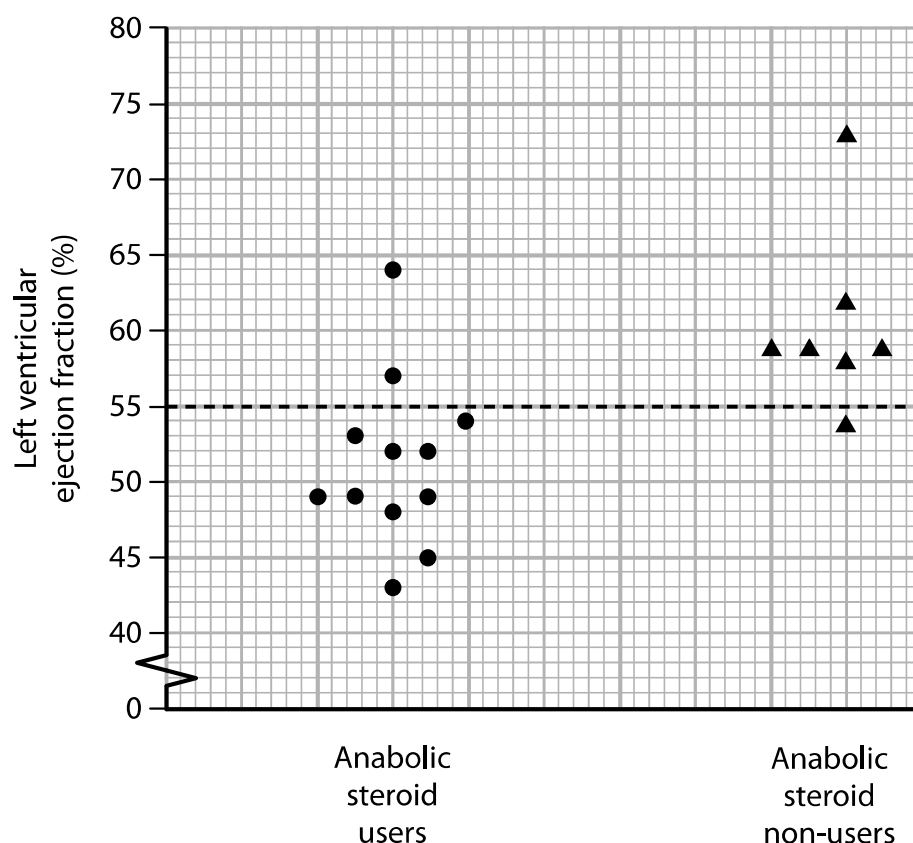
Some athletes use anabolic steroids in an attempt to improve their performance.

The effect of long-term anabolic steroid use on heart function has been investigated.

The left ventricular ejection fraction is the percentage of blood that leaves the left ventricle when it contracts.

The left ventricular ejection fraction for a healthy heart should be greater than 55%.

The results of a small study are shown in the graph.



(i) Analyse the data to determine the effect of anabolic steroid use on heart function. (2)

Anabolic steroid use reduces the left ventricular ejection fraction, so less blood leaves the left ventricle when it contracts (lower stroke volume and cardiac output).

10 out of 12 users (83%) have an ejection fraction below the healthy value of 55%, whereas only 1 of the 7 non-users is below 55%. The mean for users is about 51% compared with about 61% for non-users.



- (ii) Some drugs used to treat cancer have also been shown to reduce the ventricular ejection fraction.

Describe how the safe dose of a cancer drug could be determined.

(3)

First test the drug on cell cultures and animals, then on a small group of healthy volunteers, starting with a very low dose.

Then test the drug on a group of patients with cancer (a double-blind trial against a placebo or existing drug).

Gradually increase the dose and measure the ventricular ejection fraction of each person at each dose, to determine the highest dose that does not reduce the ventricular ejection fraction (does not cause side effects) but still treats the cancer.

(Total for Question 1 = 6 marks)

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2 The largest blood vessels in the body are the aorta and the vena cava.

(a) For one person, the cross-sectional area of the lumen of the aorta is 193.6 mm^2 .

The diameter of the lumen of the vena cava is 22.0 mm . Calculate the percentage increase in the cross-sectional area of the lumen of the vena cava compared with that of the aorta.

(2)

$$\text{radius of vena cava} = 22.0 \div 2 = 11.0 \text{ mm}$$

$$\text{area} = \pi r^2 = \pi \times 11.0^2 = 380.1 \text{ mm}^2$$

$$\begin{aligned} \% \text{ increase} &= (380.1 - 193.6) \div 193.6 \times 100 \\ &= 96.3 \% \end{aligned}$$

Answer 96.3 %

(b) The wall of the aorta is thicker than the wall of the vena cava.

Explain why there is a difference in the thickness of the walls of the aorta and the vena cava.

(2)

The aorta carries blood at high pressure straight from the left ventricle, so its wall has more collagen to withstand the high pressure without bursting.

It also has more elastic tissue to stretch and then recoil, smoothing the flow, and more smooth muscle to maintain pressure in the aorta. The vena cava carries blood at low pressure so it needs a thinner wall.



- (c) In some individuals, the wall of the aorta splits. This can result in rapid blood loss and death.

It has been suggested that this splitting is a result of a loss of tensile strength in the wall of the aorta.

Describe how the tensile strength of the aorta wall can be determined.

(3)

Cut a strip (or ring) of the aorta wall of known length and width, and measure the thickness of the piece of aorta with callipers, so the cross-sectional area can be calculated. Use repeats with the same dimensions.

Clamp one end of the strip and hang masses on the other end, adding masses one at a time until the aorta splits (breaks).

Convert the mass at which it splits into force ($N = kg \times 9.8$).

Tensile strength is determined by dividing the force by the cross-sectional area of the strip.

(Total for Question 2 = 7 marks)



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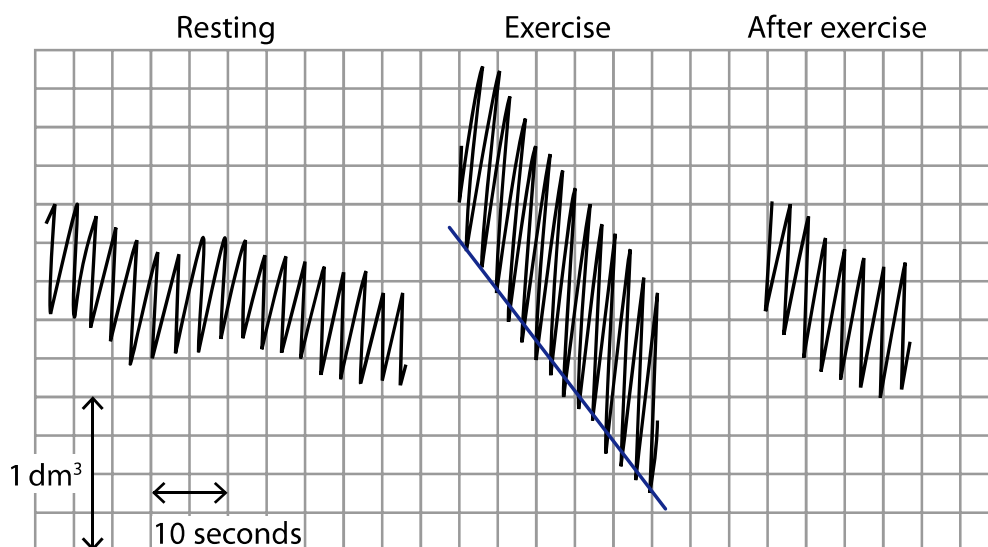
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3 The demand for oxygen changes during exercise.

The change in demand affects the breathing rate.

(a) Changes in breathing can be investigated using a spirometer.

Spirometer traces taken from the same individual before, during and two minutes after exercise are shown.



Calculate the rate of oxygen consumption during exercise.

(2)

gradient drawn along the troughs of the exercise trace:

volume falls 1 dm^3 (4 squares) in 15 s (3 squares)

rate = $1 \div 15 = 0.0667 \text{ dm}^3 \text{ s}^{-1}$

0.0667 $\text{dm}^3 \text{ s}^{-1}$



(b) Explain the effect of exercise on the changes in oxygen consumption.

(4)

Exercise increases oxygen consumption, because there is an increased rate of aerobic respiration in the muscle cells.

This is because more energy (ATP) is needed by the muscles for contraction.

During exercise some anaerobic respiration also produces lactate (lactic acid). After exercise oxygen is still required to convert the lactate back into pyruvate (and glucose) in the liver, repaying the oxygen debt.

So oxygen consumption after exercise is still higher than at rest, but it begins to decrease after exercise as the lactate is removed.

(c) At the start of exercise, breathing rate increases.

Explain how starting to exercise causes an increase in breathing rate.

(3)

Starting to exercise initiates nerve impulses from the motor cortex and from stretch receptors (proprioceptors) in the muscles and joints.

These impulses are sent to the ventilation centre (respiratory control centre) in the medulla oblongata.

This leads to increased impulses to the intercostal muscles and the diaphragm, so they contract more often and more strongly, increasing breathing rate.

(Total for Question 3 = 9 marks)



- 4 The earthworm, (*Lumbricus terrestris*), feeds on dead organic matter found in soil.



Soil pH is one of the abiotic factors that affects the population size of earthworms.

The populations of earthworms in fields with either acidic soil or alkaline soil have been investigated.

The results of this investigation are summarised in the table.

Sample	Earthworms in field with acidic soil		Earthworms in field with alkaline soil	
	Number per square metre	Mass per square metre / g m^{-2}	Number per square metre	Mass per square metre / g m^{-2}
1	80	184	723	1 164
2	59	110	1 613	1 968
3	106	253	354	439
4	31	70	728	961
5	121	238	214	233
6	75	139	874	1 739
7	97	149	668	1 096
8	138	309	121	213
9	63	95	791	1 455
10	63	84	497	736
Total	833	1 631	6 583	10 004



- (a) Deduce the effect of pH on the number and mass of earthworms in these two types of soil.

(4)

In the alkaline soil the number of earthworms is greater: a total of 6583 per square metre compared with 833 in acidic soil.

In the alkaline soil the total mass of earthworms is also greater: 10 004 g m⁻² compared with 1631 g m⁻².

However the mass of individual earthworms is less in alkaline soil: mean mass of one earthworm is 1.52 g in alkaline soil and 1.96 g in acidic soil.

Earthworms reproduce more in the alkaline soil, but the earthworms are smaller because there is greater competition for resources such as food.



(b) Describe a sampling method that could be used to collect the data in this table.

(4)

Choose an area of each field and use quadrats of a stated area, e.g. 1 m^2 (one square metre).

Place the quadrats randomly, using random numbers to generate co-ordinates on a grid laid out over each field. Take 10 samples in each field.

Use a standardised method to collect the earthworms, e.g. dig out the soil in the quadrat to the same depth (30 cm) and hand sort it for the same time.

Record the number of earthworms and the mass of the earthworms (count and weigh them) in each quadrat.

Record other soil variables at each quadrat, e.g. soil temperature, soil water content and humus content, and measure the soil pH with a pH probe.



- (c) Explain how differences between the mass of earthworms in these two soils could be shown to be statistically significant.

(3)

Find the mean mass of earthworms per square metre for each soil (and the standard deviation).

Use a t-test to calculate a t-value.

Compare the calculated t-value to the critical value for 18 degrees of freedom at a probability of 0.05 (5%). If the t-value is greater than the critical value the difference is significant and the null hypothesis is rejected.

(Total for Question 4 = 11 marks)



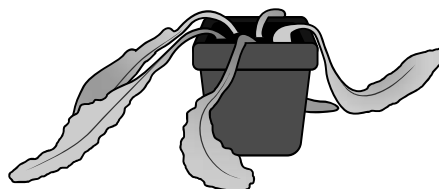
- 5 Lettuce plants usually grow upright. This is the 'upright' phenotype.

In one variety of lettuce the stem of the lettuce grows along the ground. This is the 'weary' phenotype.

These two phenotypes are shown in the diagram.



Upright



Weary

- (a) Inheritance of the weary phenotype has been investigated.

Scientists crossed weary lettuce plants with upright lettuce plants.
The F_1 generation produced from this cross were all upright.

In the second cross, two of the F_1 lettuce plants were crossed with each other to produce the F_2 generation.

The phenotypes of the F_2 generation and the results of a statistical test are shown in the table.

Number of offspring with weary phenotype	Number of offspring with upright phenotype	Chi-squared (χ^2)
159	414	2.31

Degrees of freedom	Probability		
	0.01	0.05	0.1
1	2.71	3.84	6.64
2	4.61	5.99	9.21
3	6.25	7.82	11.35
4	7.78	9.49	13.28



Justify the conclusion that the weary phenotype was inherited as a recessive trait.

(3)

None of the offspring from the cross between weary and upright lettuce had the weary phenotype: all the F_1 were upright, so the weary allele is masked by the dominant upright allele.

In the F_2 the ratio of weary to upright lettuce was about 1 : 3 (159 : 414, so 27.7% weary), which is the expected ratio for a cross between two heterozygotes when weary is recessive.

The chi-squared value of 2.31 is below the critical value of 3.84 (1 degree of freedom, $p = 0.05$), so the result is not statistically different from the expected 1 : 3 result and the null hypothesis can be accepted.

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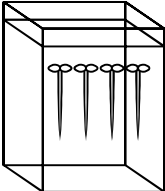
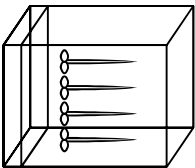
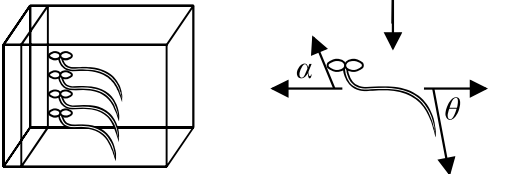
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- (b) The effect of gravity on the growth of lettuce plants with either upright or weedy phenotype was investigated.

The diagram shows the stages in this investigation.

Stage A 	Lettuce plants were grown until their stems were 15 cm long.
Stage B 	The lettuce plants were then placed in complete darkness and rotated so that they were at 90° to the direction of gravity.
Stage C 	The curvatures of the stems (α) and roots (θ) were measured for the next 23 days.

- (i) Explain why the plants were placed in a box in complete darkness.

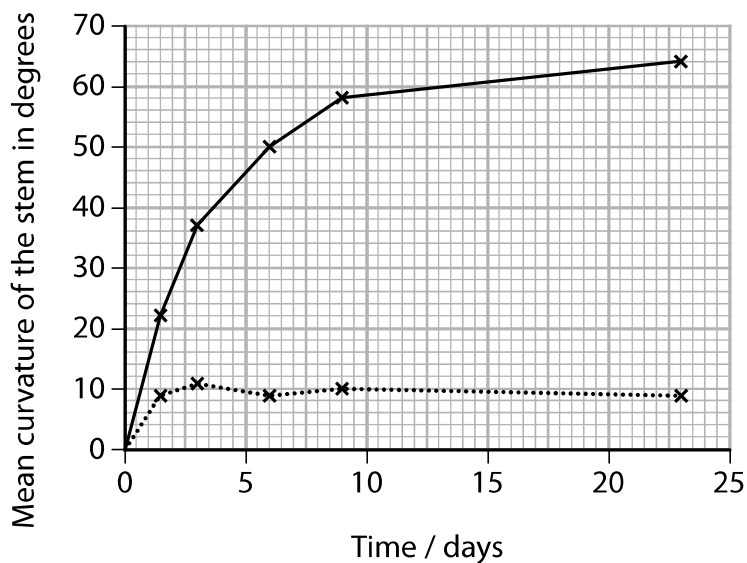
(3)

Plants respond to light: shoots show phototropic responses and grow towards light.

Light must therefore be excluded in order to study only the effects of gravity (geotropism).

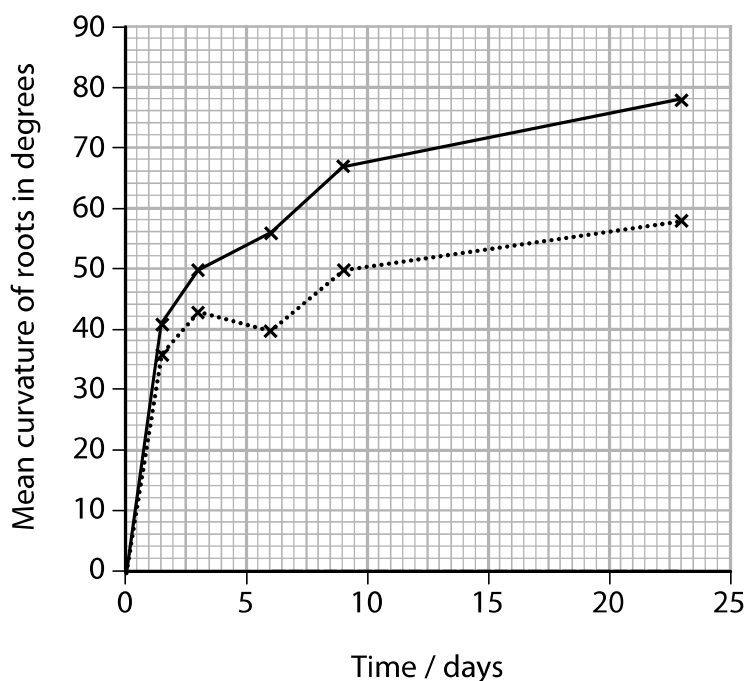
Putting the plants in complete darkness prevents light having an effect on the direction of growth, so light is controlled.

(ii) The mean curvatures of the stems and the roots are shown in the graphs.



Key

- x— upright lettuce rotated 90°
- x.... weary lettuce rotated 90°



Calculate the difference in the mean rate of curvature of the stems and roots of the weary lettuce plants over 23 days.

(2)

after 23 days: roots = 58°, stems = 9°

difference = 58 - 9 = 49°

rate = 49 ÷ 23 = 2.1 degrees per day

Answer 2.1 degrees per day



(iii) Explain why the stems of weary lettuce do not respond to gravity.

(2)

*The weary lettuce do not have the allele conferring the ability to respond to gravity
(they only have the alleles that confer a lack of response), so cells in the stem fail to
detect gravity.*

*So they do not produce (or redistribute) IAA (auxin), therefore there is no stimulation
of cell elongation on the side of the stem facing downwards.*

(Total for Question 5 = 10 marks)

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6 Enzymes control biochemical pathways.

Phosphofructokinase is an enzyme involved in controlling the rate of glycolysis.

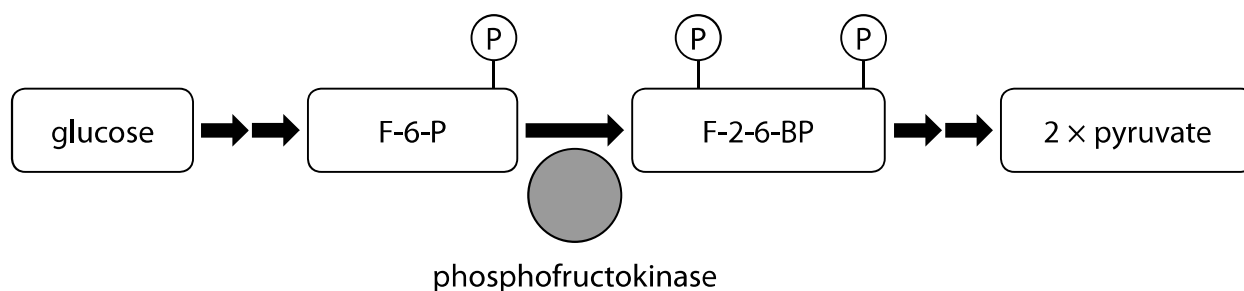
(a) State what is meant by the term enzyme.

(2)

A biological (protein) catalyst that lowers the activation energy of a reaction, increasing the rate of reaction without being used up.

(b) Phosphofructokinase is an enzyme that uses ATP to convert fructose-6-phosphate (F-6-P) into fructose-2,6-bisphosphate (F-2,6-BP).

The conversion of F-6-P by this enzyme is a rate-determining step in glycolysis. This is shown in the diagram.



(i) Explain why ATP is required for this reaction.

(3)

Hydrolysis of ATP to ADP and Pi releases energy.

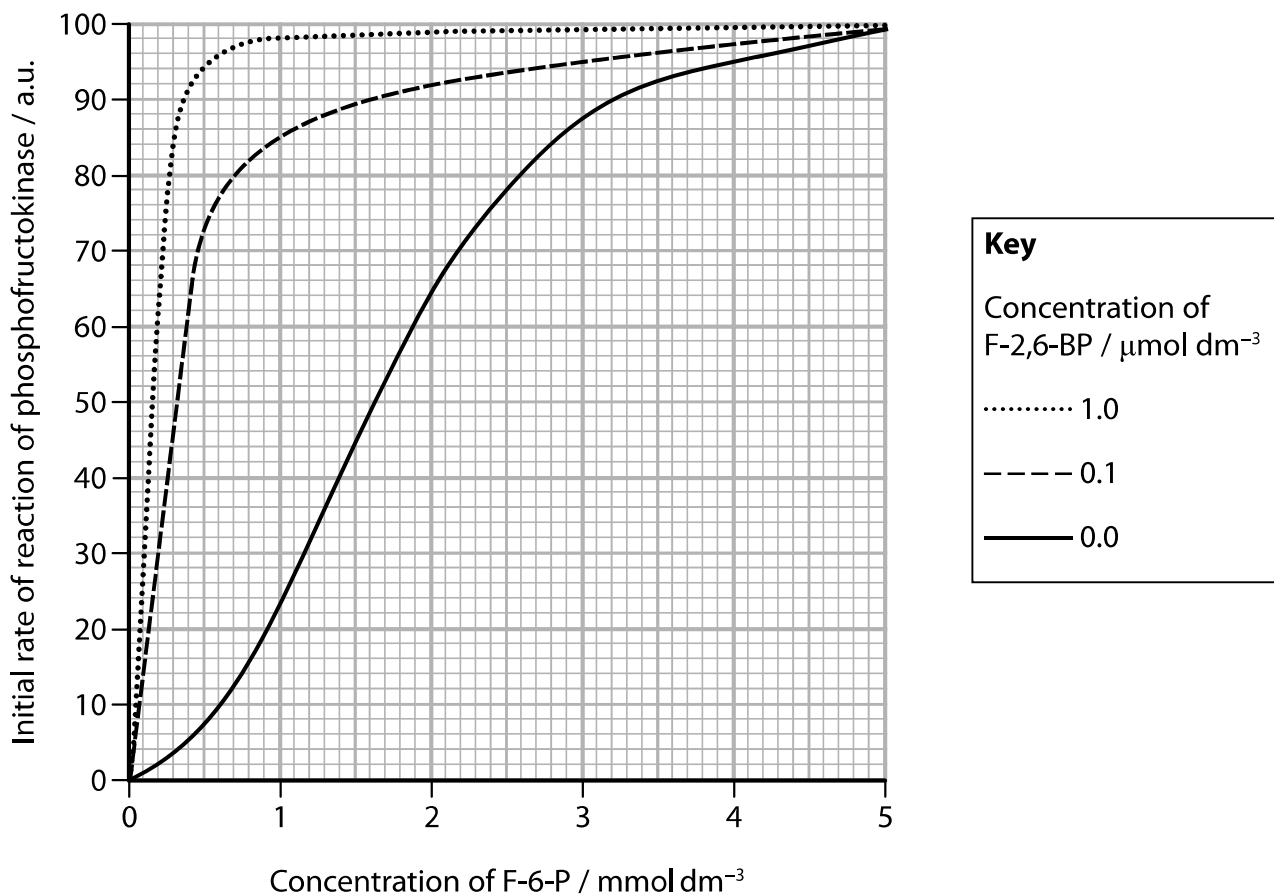
This provides the energy for the reaction, which requires energy.

ATP also provides the phosphate group for the phosphorylation of F-6-P, so that a second phosphate is added to make F-2,6-BP.

- (ii) The effect of substrate concentration on the initial rate of reaction of phosphofructokinase was investigated.

This investigation was repeated with the addition of two concentrations of F-2,6-BP.

The graph shows the results of this investigation.



Comment on the effects of F-6-P and F-2,6-BP concentrations on the rate of glycolysis.

(3)

As the concentration of F-6-P increases so does the initial rate of reaction of phosphofructokinase, so an increase in F-6-P will increase the rate of glycolysis, up to a maximum rate.

Increasing the concentration of F-2,6-BP also increases the rate (positive feedback on the enzyme), and reduces the concentration of F-6-P required to achieve the maximum rate of glycolysis.



(c) Glycolysis is inhibited by acidic conditions.

Devise an investigation to determine the effect of acidic conditions on the initial rate of reaction of phosphofructokinase.

(4)

Use pH buffers to give a range of pH values below 7, e.g. pH 4, 5, 6 and 7 as a control.

Mix the same volume and concentration of phosphofructokinase with F-6-P at an appropriate concentration, e.g. 2 mmol dm^{-3} , and provide an excess of ATP.

Control other variables: keep the enzyme concentration the same and keep the temperature constant at 37°C using a water bath.

Measure the quantity of F-2,6-BP produced per unit time (change in concentration in the first minute) to find the initial rate. Repeat three times at each pH and calculate means.

(Total for Question 6 = 12 marks)



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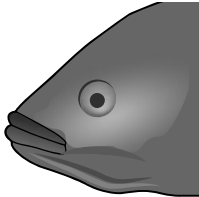
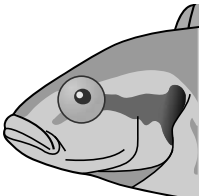
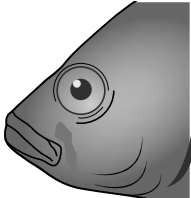


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- 7 More than 2000 different species of cichlid fish have been identified in lakes and rivers in Africa.

The different species of cichlid fish have evolved from a common ancestor over a short period of time.

The table shows some of the different species of cichlid fish found in lakes and rivers in Africa.

Species	Information	Mouth shape
<i>Oreochromis niloticus</i>	Lives in rivers across northern Africa. Herbivore feeding on plankton and plants. Lays eggs in gravel.	
<i>Neolamprologus brichardi</i>	Lives in shallow but steep rocky habitat in Lake Tanganyika. Carnivore feeding on small crustaceans and invertebrates. Lays eggs between rocks.	
<i>Astatotilapia burtoni</i>	Lives in muddy rivers flowing into Lake Tanganyika. Omnivore feeding on small fish, insect larvae, algae and plant debris. Lays eggs in gravel.	
<i>Pundamilia nyererei</i>	Lives in shallow water in Lake Victoria. Omnivore feeding on insect larvae and zooplankton. Lays eggs between rocks.	
<i>Maylandia zebra</i>	Lives in deep, clear waters of Lake Malawi. Herbivore feeding on plant material. Lays eggs in gravel.	



- (a) Describe how different species of cichlid fish have evolved in lakes and rivers in Africa. (5)

Random mutations are responsible for variation in the cichlid populations.

The lakes and rivers have different selection pressures, e.g. different water quality, food availability and substrate for egg laying.

Fish with an adaptation to their habitat survive, e.g. mouth shape suited to the food eaten (plankton, crustaceans or plants), or the behaviour of laying eggs in gravel or between rocks.

The fish that survive reproduce and pass on the beneficial alleles to their offspring, so allele frequencies change.

Reduced gene flow between populations: allopatric speciation of fish in different lakes or rivers (geographical isolation), and sympatric speciation of fish in the same lake.



*(b) The genomes of some species of cichlid fish have been sequenced and analysed.

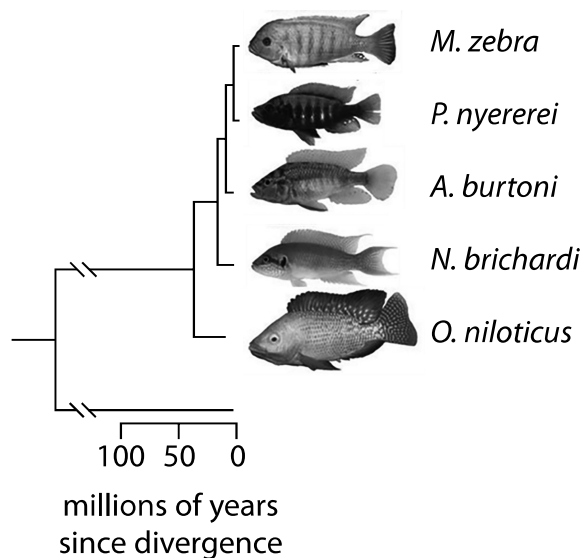
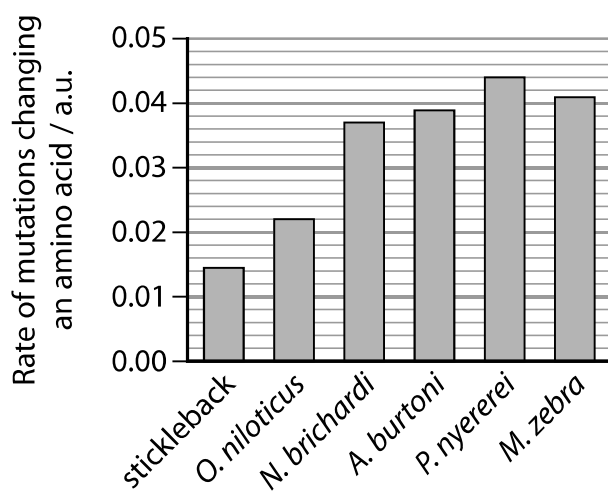
The data collected included:

- the rate at which genes have been duplicated to produce additional copies of genes on a chromosome
- the frequency of mutations in transcription factor binding sites
- the rate of mutations that result in a change of an amino acid in a protein.

This information was used to produce a phylogenetic tree.

A comparison was made with a stickleback, which is a slowly evolving fish.

Speed of evolution	Fish	Rate of gene duplication / a.u.	Number of mutations in transcription factor binding sites (compared to <i>O. niloticus</i>)
Rapidly evolving cichlid fish	<i>O. niloticus</i>	45	0
	<i>N. brichardi</i>	45	214
	<i>A. burtoni</i>	55	140
	<i>P. nyererei</i>	45	129
	<i>M. zebra</i>	60	142
Slowly evolving fish	stickleback	10	0



Analyse all the data provided to discuss how several species of cichlid fish have evolved over a short period of time.

(9)

Cichlid fish have a much higher rate of gene duplication (45 to 60 a.u.) than the slowly evolving stickleback (10 a.u.). Duplicated genes can mutate and take on new functions without losing the original function, so more alleles and new polygenic phenotypes appear in the gene pool.

The cichlids also have many mutations in transcription factor binding sites (129 to 214 compared with 0 in the stickleback and *O. niloticus*). These changes in regulatory sequences alter gene expression in different tissues, e.g. switching genes on in the jaw, so new phenotypes such as different mouth shapes or pigmentation can develop.

The rate of mutations changing an amino acid is higher in cichlids (about 0.022 to 0.044 a.u.) than in the stickleback (0.015). An altered amino acid changes the tertiary structure and so the protein function, e.g. enzymes that work at different pH or temperatures, or new digestive enzymes for new food types.

The variety of habitats provides many niches with different selection pressures. Fish with adaptations such as different mouth shapes exploit new food types and survive to pass on alleles. Changes in mouth shape and pigmentation allow mate choice and reproductive isolation, so speciation happens over a short time.

(Total for Question 7 = 14 marks)



8 The scientific article you have studied is adapted from *The Biologist*.

Use the information from the scientific article and your own knowledge to answer the following questions.

(a) State the meaning of the term stem cell (paragraph 1).

(2)

An undifferentiated cell that is capable of unlimited division (self-renewal) and can give rise to specialised cells.

(b) Describe how a 'single fertilised egg' can produce many different cell types (paragraph 2).

(3)

The fertilised egg divides by mitosis to give rise to many new genetically identical cells. Different sets of genes are activated (switched on) or switched off in different cells. Different proteins are synthesised, which determine the structure and function of each cell, resulting in differentiation into different cell types.

(c) Name the property shown by 'spontaneously beating regions' in cardiac muscle (paragraph 15).

(1)

myogenic



- (d) Mice used in research have a number of limitations (paragraph 6). Mice that are homozygous for a recessive trait are rare in the population, but can be produced in genetic crosses.

Explain how genetic crosses could be used to generate a mouse line expressing a recessive trait.

(3)

Screen a large population of mice to find mice carrying the recessive allele, then cross two heterozygous (carrier) mice, $Aa \times Aa$.

One quarter of the offspring are homozygous recessive (aa). Select the homozygous recessive mice expressing the trait.

Breed from these aa mice ($aa \times aa$) for subsequent generations, so all the offspring express the recessive trait.

- (e) Retinoic acid affects the expression of genes in embryonic stem cells (ESCs) leading to the development of neural tissues (paragraph 11).

Explain how chemicals such as retinoic acid could affect gene expression.

(3)

Retinoic acid acts as (or activates) a transcription factor, by entering the cell and binding to a receptor.

The transcription factor binds to regulator regions of DNA, such as the promoter, allowing RNA polymerase to bind.

This allows the transcription of the gene, the production of mRNA, so the gene is expressed (or the converse if it acts as a repressor).



- (f) The Zika virus can cause microcephaly. This condition is a result of brain tissue not developing in the foetus (paragraphs 20 and 21).

Explain how the Zika virus can cause microcephaly.

(3)

The Zika virus binds to receptors on neural cells (brain cells) in the foetus.

The virus, or its genetic material, is taken into the cell.

The virus replicates inside the cells using the host cell machinery.

This causes the neural cells to die (burst) and inhibits replication of neural cells, and new viruses spread to other neural cells, so less brain tissue develops.

- (g) Tissue rejection can occur in organs transplanted from other individuals (paragraph 22).

Explain how the immune system is involved in tissue rejection.

(4)

The proteins on the donated cells, tissues or organs act as antigens and are recognised as foreign (non-self).

These antigens are presented by macrophages (antigen presenting cells).

This leads to activation of T helper cells, which release cytokines.

This leads to activation of T killer (cytotoxic T) cells, and of B cells which become plasma cells that produce antibodies.

This results in destruction of the transplanted tissue.



(h) Human cells can be grown in monolayers using tissue culture (Figure 1).

Devise a procedure to investigate the effect of temperature on the growth rate of a monolayer of human cells.

(5)

Set up several flasks of the same cell line, each with the same number of cells in the same volume of culture medium that provides nutrients (glucose, amino acids).

Use aseptic technique throughout, e.g. sterile flasks and pipettes, working in a laminar flow cabinet, to prevent contamination of the cell culture.

Control temperature by placing flasks in incubators set at a range of temperatures, e.g. 25, 30, 35, 37 and 40 °C.

Control another abiotic factor, e.g. the carbon dioxide concentration at 5% and the pH of the medium.

Culture the cells at each temperature for the same stated period, e.g. 48 hours.

Measure growth by counting the number of cells with a haemocytometer (or measuring area of the monolayer) at the beginning and end. Repeat three times at each temperature and calculate the mean growth rate.



- (i) Describe how a gastruloid differs from an organoid (paragraphs 21, 26 and 28).

(2)

Gastruloids show a greater extent of differentiation (more types of cell) and develop the three germ layers, like an embryo, whereas an organoid is only a single organ.

The cells in gastruloids are organised along an axis with left to right patterning.

- (j) Describe two ethical issues concerning the use of human embryonic stem cells in research (paragraph 32).

(2)

Embryonic stem cells have the potential to develop into a human being, so harvesting them destroys embryos (potential life).

The embryo is unable to give consent to being used in research.



- (k) Explain the advantages of using iPSCs compared to ESCs for the production of transplant material (paragraphs 33 and 34).

(3)

iPSCs are obtained from the patient, so they avoid the ethical issues associated with the use and destruction of embryos.

Transplant material from iPSCs will be genetically identical and have the same antigens as the patient, so it will not trigger an immune response and be rejected.

iPSCs can be collected when needed, and there is no need to produce embryos to collect them.

(Total for Question 8 = 31 marks)

TOTAL FOR PAPER = 100 MARKS



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