Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

1400U40-1

S25-1400U40-1

FRIDAY, 13 JUNE 2025 – MORNING

BIOLOGY – A2 unit 4
Variation, Inheritance and Options

2 hours

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**13**	
	2.	**15**	
	3.	**13**	
	4.	**9**	
	5.	**11**	
	6.	**9**	
Section B	**Option**	**20**	
	Total	**90**	

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ADDITIONAL MATERIALS

A calculator and a ruler.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.

Section **A**: 70 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks; Options. Answer **one option only**. You are advised to spend 25 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of quality of extended response (QER) will take place in question **6**. The quality of written communication will affect the awarding of marks.

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SECTION A

Answer **all** questions.

1. Himalayan balsam (*Impatiens glandulifera*) is a flowering plant. This invasive species was introduced to the UK in 1839 and in many places, threatens biodiversity by outcompeting native plant species.

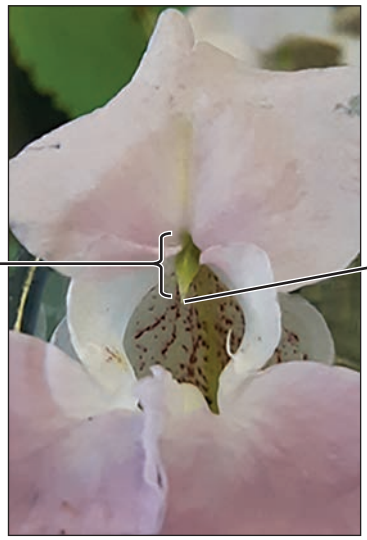
Images 1.1A and **1.1B** show Himalayan balsam flowers at different stages of development.

Image 1.1A Earlier stage of development

Stamens present

Image 1.1B Later stage of development

Stamens absent



(a) (i) Brightly coloured petals attract insects to the flowers.

Suggest **one** other feature, **not visible** in **Images 1.1A or B**, that may enable these flowers to attract insect pollinators. [1]

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Himalayan balsam flowers have several stamens and a single carpel. Early in the development of the flower, mature stamens cover an immature carpel. After producing pollen, the stamens degenerate and are absent by the time the carpel matures.

(ii) Use the information provided to describe how cross-pollination is ensured in Himalayan balsam. [2]

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(iii) Explain why cross-pollination is an advantage to a plant species colonising a new habitat. [2]

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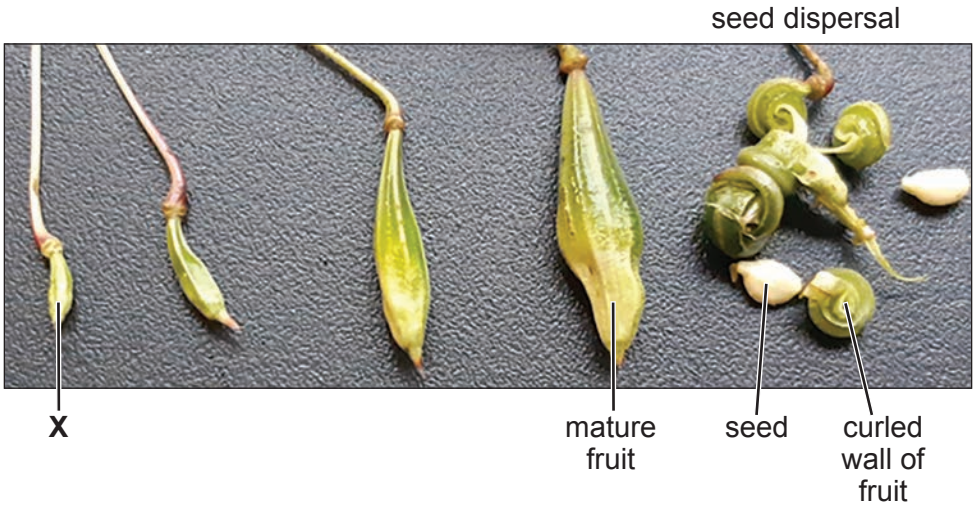
(b) Himalayan balsam fruit contains 4–14 seeds which are dispersed explosively when the fruit wall splits and curls.

Image 1.2 shows the development of Himalayan balsam fruit after fertilisation.

Image 1.2



(i) Structure **X** is part of the carpel. Identify structure **X**. [1]

.....

(ii) Flowering plants use a process of double fertilisation which produces a zygote and a primary endosperm nucleus within the ovule.

Complete Table 1.3 by stating the structures of the seed that develop from the structures within the ovule following fertilisation. [2]

Table 1.3

Structure within the ovule	Structure of the seed
Zygote	.....
Outer integument	.....

(iii) The primary endosperm nucleus becomes endosperm in the seeds of many flowering plants.

State **one** function of endosperm in seeds. [1]

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(c) Himalayan balsam plants grow in large numbers on land bordering rivers and canals, often near pathways. Seeds are dispersed as a result of the fruit's explosive mechanism which may disperse seeds up to six metres from the parent plant.

(i) With reference to the habitat, suggest **two** additional methods by which Himalayan balsam seeds may be dispersed. [2]

I. .....

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II. .....

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(ii) Explain why additional seed dispersal methods can be an advantage to this species. [2]

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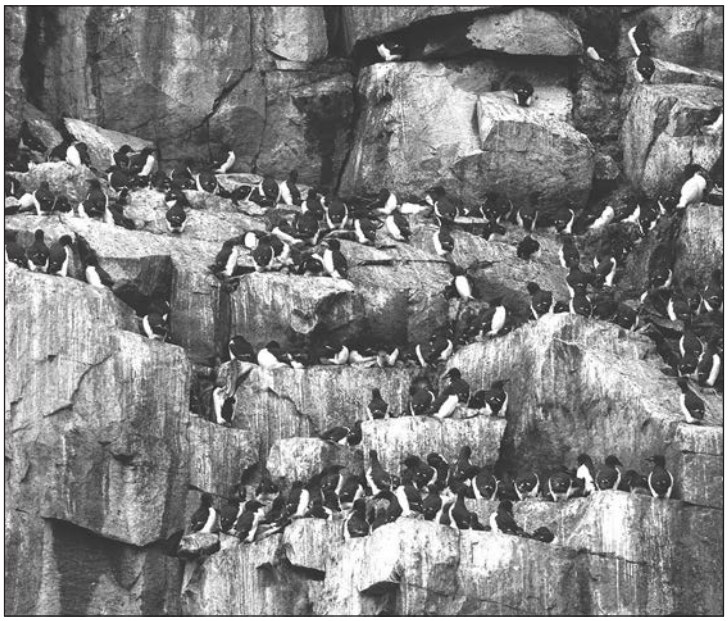
2. Guillemots (*Uria aalge*) are seabirds that live in large, densely populated colonies on sea cliffs throughout the British Isles. Females lay a single egg on a cliff ledge. The chick is fed on small fish caught by its parents until it flies from the ledge four weeks after hatching.

Image 2.1 shows part of a Guillemot colony.

Image 2.1



Guillemots have two polymorphic feather patterns referred to as morphs, shown in **Images 2.2A** and **2.2B**.

Image 2.2A Bridled morph

White ring and crescent pattern around the eyes

Image 2.2B Non-bridled morph

Head is completely black/brown

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(a) The feather pattern around the eyes is the effect of a single autosomal gene. The allele for the bridled phenotype is recessive.

(i) Define what is meant by the terms 'autosomal' and 'recessive'. [2]

Autosomal

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Recessive

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(ii) Bridled and non-bridled morphs are equally likely to mate. Regional variations in the frequency of bridled morphs exist in guillemot populations.
Thousands of guillemots nest on the crowded cliffs of the island of Westray (Orkney Islands, Northern Scotland).
A survey found that 16% of the population had the bridled phenotype.

I. Use the Hardy-Weinberg equations below to calculate the **frequency** of individuals that are **heterozygous** at this gene locus in the Westray guillemot population. **Show your calculations.** [4]

$p + q = 1$

$p^2 + 2pq + q^2 = 1$

Frequency of heterozygous individuals = ...

II. State **one** reason why the Hardy-Weinberg principle can be applied to the Westray guillemot population. [1]

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(iii) In the UK, the frequency of bridled individuals is significantly higher in populations living in a colder climate further north than in southern populations.

One theory suggests bridled birds possess a linked gene causing more aggressive behaviour that delays mating during the breeding season. As a result, egg laying and hatching take place later in Spring or early Summer.

Use the information provided to:

I. state **one** resource, on land, for which guillemots compete during the breeding season; [1]

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.....

II. suggest why a delay in mating provides a selective advantage for birds that live further north. [1]

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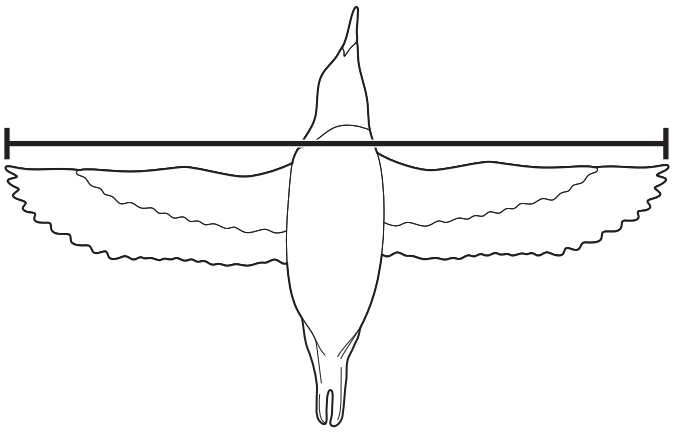
.....

(b) Scientists monitor the size and numbers of guillemots on Westray regularly. A large number of adult birds are caught and their wingspan measured before being released.

Wingspan is measured across both wings, shown in **Image 2.3**.

Image 2.3



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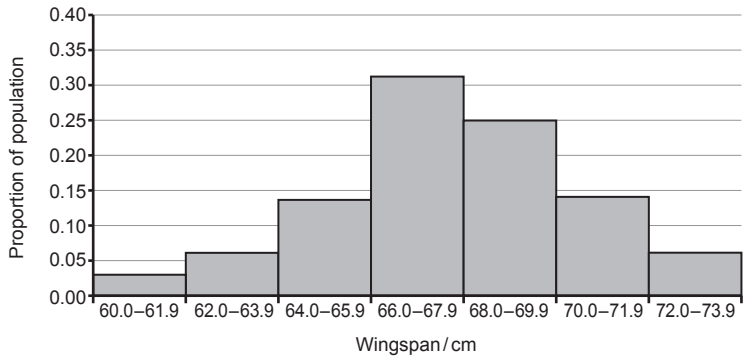
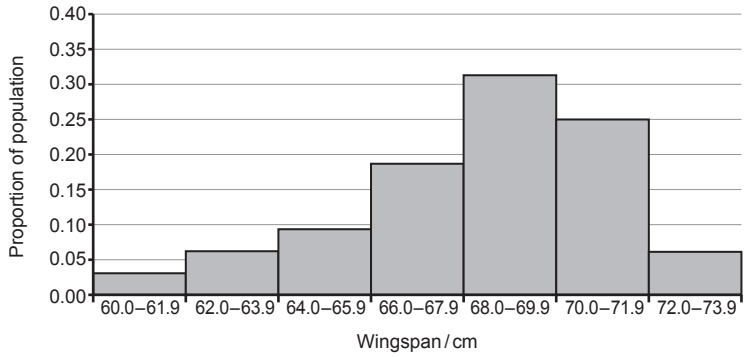
Graphs 2.4A and **2.4B** show the wingspan distribution of adult male guillemots as a proportion of the population on Westray during July 2008 and July 2018.

Graph 2.4A July 2008



Graph 2.4B July 2018



(i) State the type of variation illustrated by **Graph 2.4A**.
Describe how the genetic control of variation in wingspan differs from the genetic control of bridled feather pattern of guillemots. [2]

Type of variation

.....

Genetic control

.....

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(ii) Use **Graphs 2.4A** and **2.4B** to describe the change in the distribution of guillemot wingspan on Westray between 2008 and 2018. [1]

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(iii) Sand eels (a type of small fish) are a major food source for guillemots on Westray. Between 2008 and 2018, the sand eel population decreased significantly.

Use your knowledge of natural selection to suggest how the decrease in the sand eel population may have resulted in the change in wingspan distribution between 2008 and 2018. [3]

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3. Human lice, *Pediculus humanus*, are parasitic insects that feed by sucking blood through the skin of their host and may contribute to the spread of some diseases.

Images 3.1A and **3.1B** show two subspecies of lice that live on humans.

Image 3.1A

Head louse (*P. humanus capitis*)

Lives on hair on the scalp

Image 3.1B

Body louse (*P. humanus corporis*)

Lives on clothing

Human body hair became greatly reduced approximately 1.2 million years ago. Existing populations of *P. humanus* were then restricted to the hair on the scalp. Use of clothing created a new habitat into which some individuals of *P. humanus* migrated.

The separated group became isolated from those living on the scalp. This resulted in the divergence of two subspecies.

(a) Use the above information to explain how, over time, the two subspecies of *Pediculus* could evolve into two separate species. [3]

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(b) As the morphology of the two subspecies of *Pediculus* is similar, it is difficult to distinguish between them. By comparing base sequences of DNA from head lice and body lice, different subspecies can be identified accurately.

Before scientists could make comparisons, samples of DNA were amplified using the polymerase chain reaction (PCR). This process was carried out for each subspecies using apparatus known as a thermocycler.

The following were placed into a thermocycler:

- DNA sample
- Primers
- Free DNA nucleotides
- *Taq* DNA polymerase prepared in a buffer solution

Stages of this PCR method involved changing the temperature in the thermocycler as follows:

Stage 1: 95 °C for 30 seconds

Stage 2: 55 °C for 30 seconds

Stage 3: 70 °C for 45 seconds

These three stages were repeated for 30 cycles.

(i) Describe the effect of heating the DNA molecules to 95 °C during stage 1. [1]

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(ii) I. Describe the structure of a primer. [1]

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II. Explain the function of a primer within the PCR process. [1]

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(iii) *Taq* DNA polymerase is extracted from the bacterium *Thermus aquaticus*, which lives in hot springs.

Explain the reason for using DNA polymerase from this organism in the PCR cycle. [1]

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(iv) Use the formula below to calculate the number of copies of DNA that should be present in the thermocycler after 30 cycles of the PCR process if **one** molecule of DNA was present at the start. **Give your answer in standard form.** [2]

Number of copies of DNA = 2^n,
where n = the number of cycles.

Number of copies of DNA = ...

(v) After approximately 20 cycles, the production of DNA copies reaches a plateau.

Suggest **one** reason why the number of DNA copies may be fewer than expected after the number of cycles used in this procedure. [1]

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(c) (i) The genomes of both subspecies of *Pediculus* have been sequenced. Explain how this information might be used to benefit present day human populations that may be affected by these parasites. [1]

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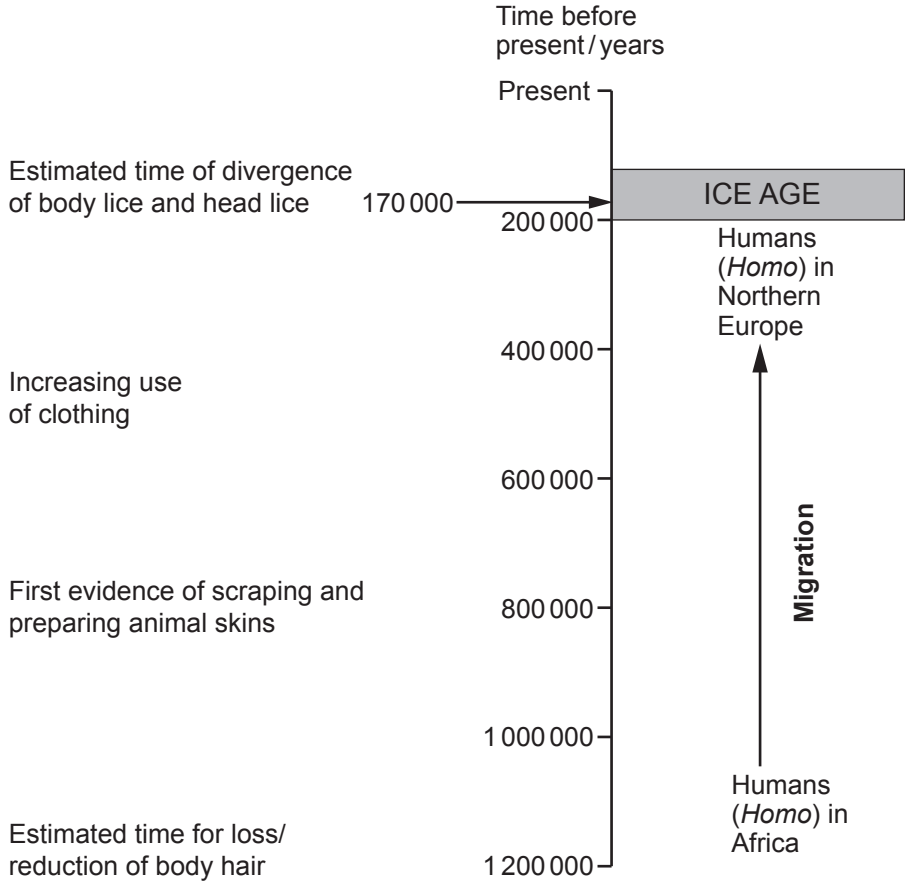
Image 3.2 represents a timeline in human (genus *Homo*) history and shows the estimated time of divergence of the two subspecies of *Pediculus*.

Image 3.2



(ii) Scientists concluded that the origin of body lice can be correlated with the use of clothing by humans.
Use the information in **Image 3.2** to:

I. explain **one** piece of evidence that supports this conclusion; [1]

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II. suggest a reason for the long time period between reduction of body hair and origin of body lice in humans. [1]

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4. The kittens in **Image 4** are female twins. They possess identical DNA sequences because they originated from the same zygote.
Their coat colouration is described as tortoiseshell, a combination of black and orange fur colour arranged in random patches.

Image 4

The gene that codes for this fur pigmentation is situated on the X chromosome.

Allele B codes for a pigment that produces black fur.

Allele O codes for a pigment that produces orange fur.

(a) (i) The parents of these twins have the following genotypes.

$$X^{B}Y \quad \text{and} \quad X^{O}X^{O}$$

I. State the **phenotype** of the parent with the homozygous genotype. [1]

.....

II. **Draw a genetic diagram** to show the possible results of a cross between the parents of the kittens shown in **Image 4**. [2]

III. Use your genetic diagram to determine the probability that these two parents will have offspring with the tortoiseshell phenotype. [1]

Probability of offspring being tortoiseshell = ...

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(ii) Explain why it is not possible to produce male tortoiseshell kittens. [1]

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(b) The kittens in **Image 4** are described as identical twins but their fur pattern is not identical.

Very early in the development of female mammalian embryos, one of the X chromosomes in each cell is inactivated.

After cell division, all the cells derived from that cell are affected in the same way.

In cats with the $X^B X^O$ genotype, hair follicle cells in which:

X^B is inactivated will produce orange fur,

X^O is inactivated will produce black fur.

(i) Use the information provided to explain why the pattern of coat colour is different in each twin kitten. [2]

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(ii) The DNA of the inactivated X chromosome is coiled more tightly around histone proteins.

Explain how this prevents gene expression. [1]

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(iii) Explain why the coat pattern of these two kittens can be described as epigenetic. [1]

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5. (a) Sickle cell disease is an inherited blood disorder caused by a mutation in the gene on chromosome 11 that codes for the β haemoglobin polypeptide.

In the normal allele (HB^A), the sixth DNA base triplet is CTC. This codes for the amino acid glutamate.

In the mutated allele (Hb^S), the sixth DNA base triplet is CAC. This codes for the amino acid valine.

(i) State the name of the type of mutation that gives rise to Hb^S. [1]

.....

Sickle haemoglobin causes red blood cells to twist out of shape. These cells transport oxygen less efficiently and break down sooner than normal red blood cells.

Images 5.1A and **5.1B** show the shape of a normal and a sickle red blood cell as seen using an electron microscope.

Image 5.1A Normal red blood cell

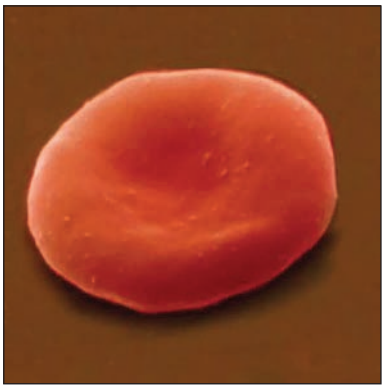

Image 5.1B Sickle red blood cell

Repeated transfusions of normal red blood cells are used to treat people who have sickle cell disease. This requires large numbers of cells from blood donors with correctly matched blood groups.

(ii) Mature red blood cells cannot reproduce, so cannot be cultured in a laboratory.

Explain why mature red blood cells cannot reproduce. [2]

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(b) Stem cells are present in bone marrow. They differentiate into different types of blood cells, including red blood cells which have a life span of four months.

Scientists have discovered how to induce mature white blood cells from donors to become stem cells in a laboratory. From these stem cells they have been able to produce red blood cells.

A trial was carried out to compare the effectiveness of donated and laboratory-produced red blood cells in treating the symptoms of sickle cell disease.

- Ten adult volunteers with sickle cell disease received a transfusion of red blood cells extracted from blood donors.
- Four months later, the trial was repeated with the same volunteers using transfusions of newly formed red blood cells produced in the laboratory from stem cells.
- The symptoms of sickle cell disease were monitored in each volunteer throughout the four months following each transfusion.

Results showed that transfusions of laboratory-produced red blood cells maintained a reduction in the symptoms of sickle cell disease for a longer period of time than donated red blood cells.

(i) I. Use the information above to explain why there was a four-month time interval between transfusions. [2]

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II. Suggest why laboratory-produced red blood cells reduced the symptoms of sickle cell disease for longer than donated red blood cells. [1]

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(ii) Explain why it was important to carry out each trial using the same volunteers. [1]

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(iii) Embryonic stem cells could provide an alternative source of stem cells. They have the ability to differentiate into any type of cell if given the correct chemical stimuli.

Give **one** reason why using stem cells derived from mature white blood cells is preferable to using embryonic stem cells for the purpose of producing red blood cells. [1]

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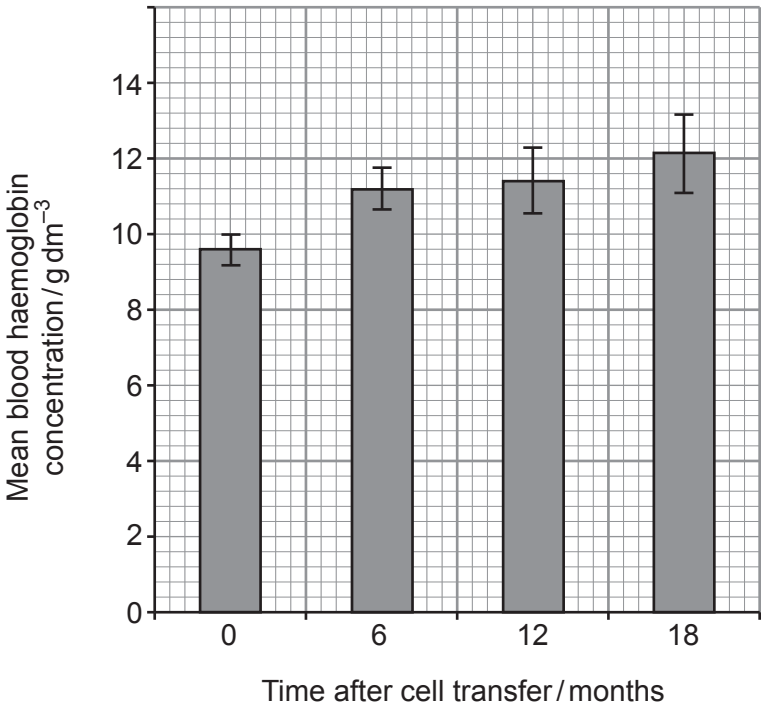
(c) Gene therapy can also be used in the treatment of sickle cell disease.

- Stem cells are extracted from the bone marrow of a volunteer with sickle cell disease.
- The mutated allele, Hb^S, is replaced with the normal Hb^A allele.
- These genetically altered stem cells are transferred back into the bone marrow of the same volunteer.
- Red blood cells that differentiate from the genetically altered stem cells should contain normal haemoglobin.

Graph 5.2 shows the mean haemoglobin concentration in blood after stem cell transfer for 15 adult volunteers with sickle cell disease. The bars in each column show the standard deviation from the mean.

Graph 5.2



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(i) The increase in blood haemoglobin concentration during the first six months following stem cell transfer is considered significant.
Use **Graph 5.2** to explain why the increase between **six** and **twelve** months is not considered significant. [1]

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(ii) Use the information provided to explain **one** advantage of this type of gene therapy as a treatment for sickle cell disease compared to the transfusion of red blood cells. [1]

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(iii) Suggest **one** potential disadvantage associated with the use of this gene therapy procedure for treating sickle cell disease. [1]

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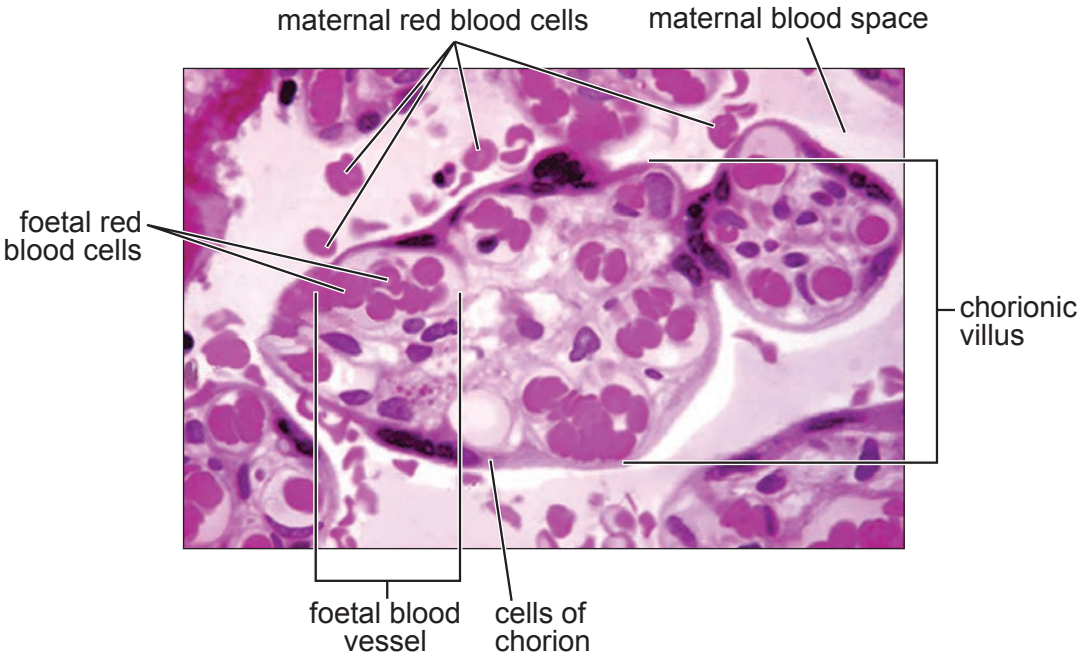
6. The human placenta is formed from the tissues of two genetically different individuals. It is the site of exchange of respiratory gases, nutrients and excretory products between maternal and foetal blood. There is no contact between the blood of the mother and foetus.

Image 6.1 is a photomicrograph showing a section through part of a placenta.

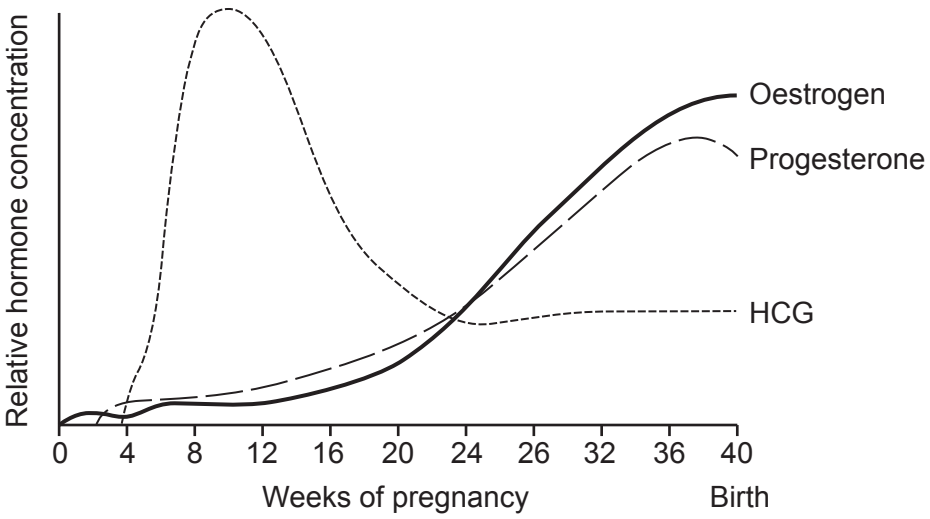
Image 6.1



The placenta secretes oestrogen, progesterone and HCG (human chorionic gonadotrophin) into the maternal bloodstream.

Graph 6.2 shows the relative concentrations of each of these three hormones in maternal blood during pregnancy.

Graph 6.2



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Use the information in **Image 6.1**, together with your knowledge of placental structure, to describe how efficient transfer of respiratory gases is achieved between maternal and foetal blood.

Explain why it is necessary to ensure that there is no direct contact between the blood of the mother and foetus.

With reference to **Graph 6.2**, describe the function of oestrogen, progesterone and HCG during pregnancy. [9 QER]

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SECTION B: OPTIONAL TOPICS

Option A: **Immunology and Disease** ☐

Option B: **Human Musculoskeletal Anatomy** ☐

Option C: **Neurobiology and Behaviour** ☐

Answer the question on **one topic only**.

Place a tick (✓) in **one** of the boxes above, to show which topic you are answering.

You are advised to spend about 25 minutes on this section.

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Option A: Immunology and Disease

7. Rabies is a viral disease transmitted to humans, usually by a bite from infected animals such as dogs. The virus contains RNA enclosed in a capsid made of proteins. The virus attacks the central nervous system causing inflammation of the brain and is often fatal.

The time period between contracting the disease and the start of symptoms is usually between one and three months. The time period depends on the distance the virus must travel along peripheral nerves to reach the central nervous system.

(a) (i) State the term used to describe an animal which carries and transmits an infectious pathogen into another living organism. [1]

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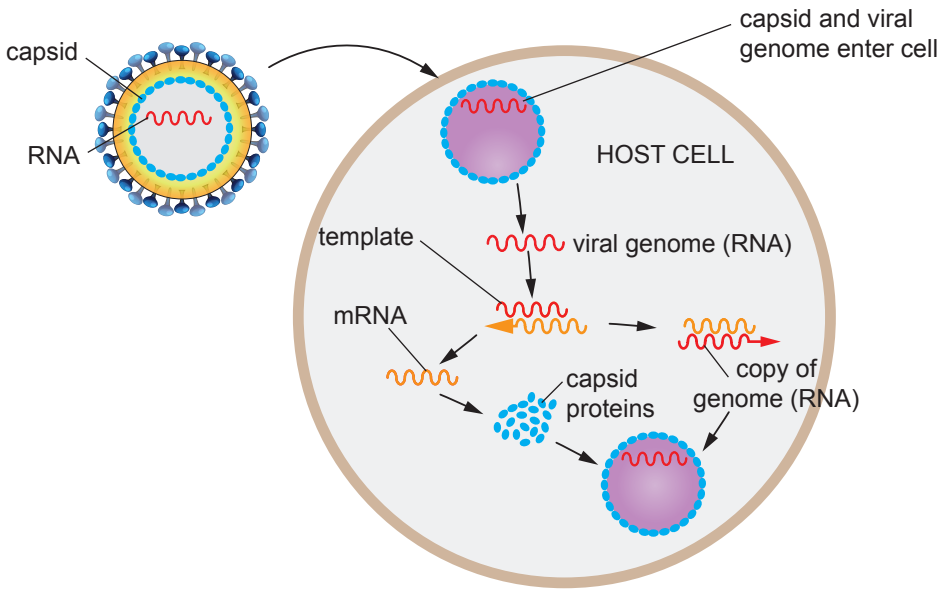
Following a bite from an infected animal, the rabies virus may enter the peripheral nervous system and migrate to the brain or may replicate in muscle tissue near the entry site.

Image 7.1 shows the replication of the virus inside an infected cell.

Image 7.1



(ii) Use **Image 7.1** and your own knowledge to describe how the rabies virus is replicated. [3]

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(b) Post-exposure prophylaxis (PEP) is the immediate treatment of a victim following a bite from an animal infected with rabies. This prevents virus entry into the central nervous system. PEP consists of:

- extensive washing and local treatment of the wound as soon as possible after exposure;
- the administration of rabies immunoglobulin (RIG);
- a course of rabies vaccine.

(i) RIG provides artificial passive immunity.
State what is meant by artificial passive immunity. [2]

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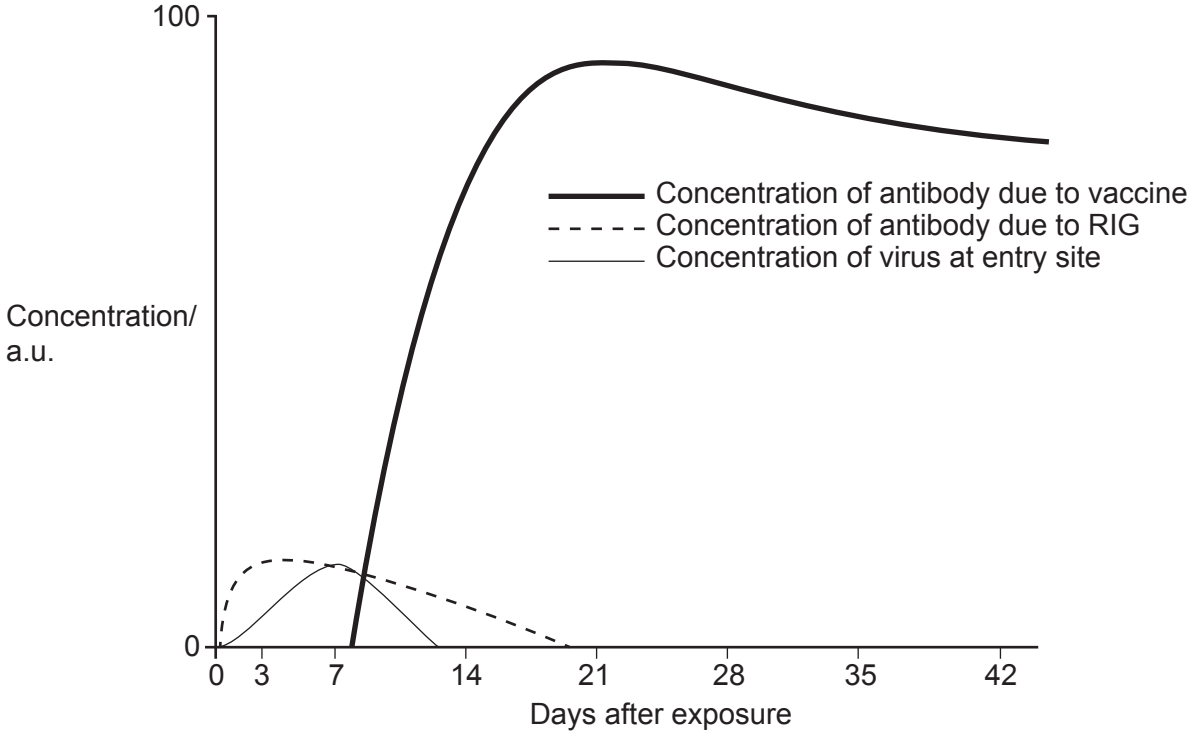
The rabies vaccine is given on days 0, 3, 7, 14 and 28 after exposure to the rabies virus. Scientists measured the concentration of virus at the entry site and the concentration of antibody in the blood following infection and subsequent treatment with vaccine and RIG. The results are shown in **Graph 7.2**.

Graph 7.2



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(ii) Use **Graph 7.2** to conclude why RIG is administered immediately after being bitten in addition to the rabies vaccine. [4]

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(iii) Individuals who have previously had the rabies vaccine are not given RIG but receive a booster shot of the vaccine. Suggest why these individuals:

I. are not given RIG; [2]

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II. receive a booster shot of the vaccine. [1]

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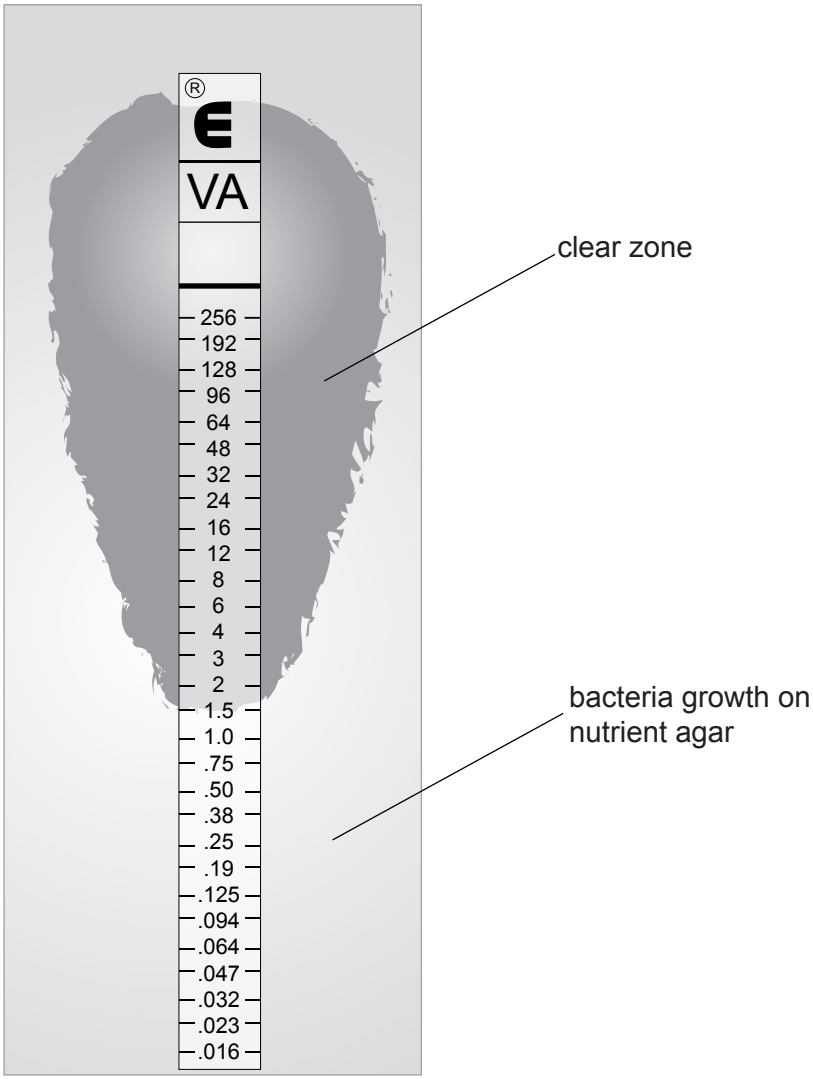
(c) Shigellosis is an infection of the intestines caused by *Shigella* bacteria. Treatment consists mainly of replacing fluids and salts lost because of diarrhoea. Antibiotics are only used in severe cases and are usually avoided in mild cases because many *Shigella* strains are becoming resistant to antibiotics such as azithromycin.

The strip shown in **Image 7.3** contains an accurately prepared gradient of azithromycin concentrations measured in $\mu g\,cm^{-3}$. It was placed on nutrient agar, which had bacteria growing on it.

Image 7.3



(i) Explain the shape of the clear zone. [2]

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(ii) The minimum inhibitory concentration is the lowest concentration of the antibiotic that is effective against the bacterium.
Use **Image 7.3** to determine the minimum inhibitory concentration. [1]

Minimum inhibitory concentration = ... $\mu g\,cm^{-3}$

(iii) The daily dose of azithromycin is $10\,mg\,kg^{-1}\,day^{-1}$.
A patient weighs 50 kg. Calculate the volume of a $40\,mg\,cm^{-3}$ concentration of azithromycin that should be prescribed per day for this patient. [2]

Volume = ... cm^3

(iv) State **one** advantage and **one** disadvantage of oral administration of azithromycin to treat *Shigella*. [2]

Advantage .....

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Disadvantage .....

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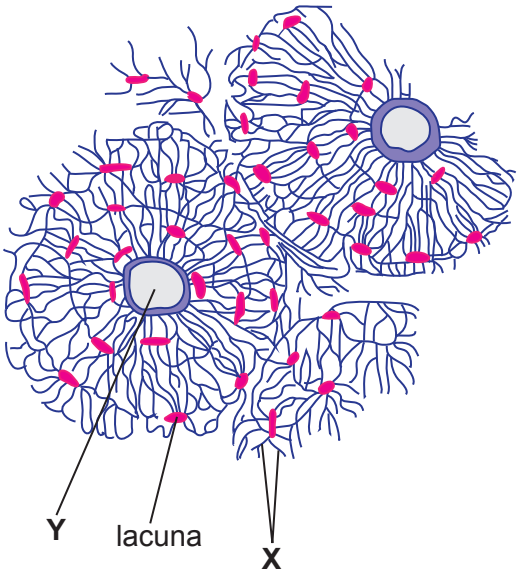
Option B: Human Musculoskeletal Anatomy

8. (a) **Image 8.1** shows a Haversian system.

Image 8.1



(i) Identify structures **X** and **Y** in **Image 8.1**. [1]

X .....

Y .....

(ii) State **two** structures found in **Y**. [1]

....

(b) Osteomalacia can be a result of a deficiency in the diet.

(i) Explain why treatments for osteomalacia include increasing the proportion of dairy products **and** oily fish in the diet. [3]

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Many of the symptoms of osteomalacia are similar to osteoporosis. Treatment for osteoporosis includes a good diet and exercise.

(ii) State what is meant by osteoporosis. [1]

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(iii) Explain why it is essential that treatment for osteoporosis in an older patient includes exercise. [3]

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(iv) A doctor carried out a bone density test on two different 50-year-old females to compare the bone density of a female with osteoporosis with a female who did not have osteoporosis. The female who did not have osteoporosis had a bone density of $0.95\,g\,cm^{-2}$, whereas the female with osteoporosis had a bone density of $0.71\,g\,cm^{-2}$.

Calculate the percentage difference in bone density for the female with osteoporosis compared to the female without osteoporosis. [2]

Percentage difference = ... %

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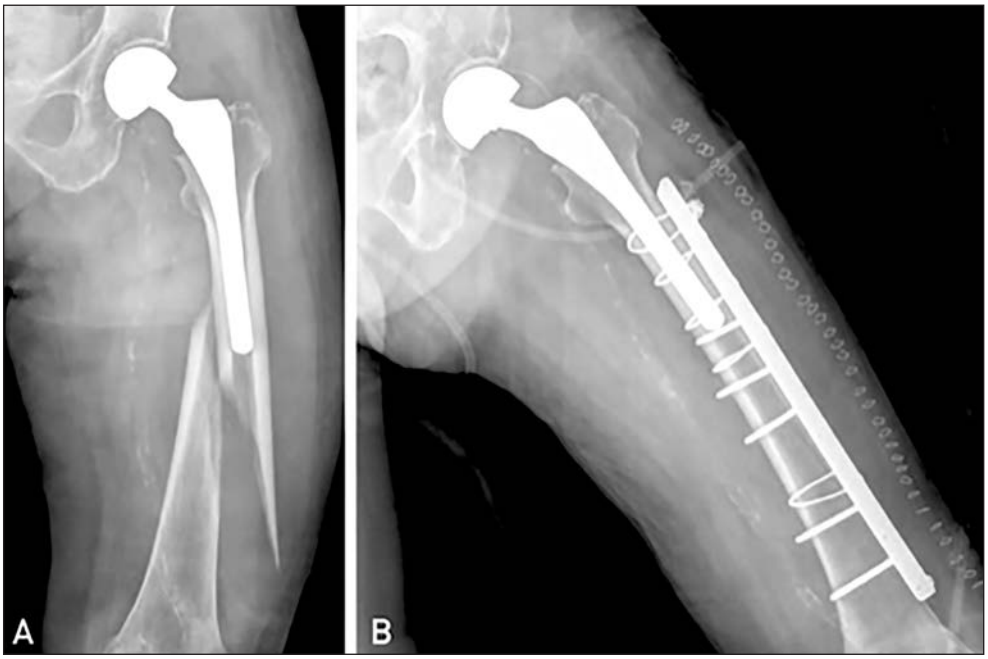
(c) Osteoarthritis is the most common disease of joints.

In severe cases of osteoarthritis, the joint must be replaced. If a person with a hip replacement falls, there is a very high risk of hip fractures. **Image 8.2A** shows an X-ray of a person with a hip replacement before treatment of the fracture. **Image 8.2B** shows an X-ray of the person after treatment of the fracture.

Image 8.2A **Image 8.2B**



Use your knowledge of fractures and the X-rays in **Images 8.2A** and **B** to:

(i) state the type of fracture; [1]

.....

(ii) describe how it was treated; [1]

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(iii) give **two** reasons why this treatment is necessary for hip fractures in particular. [2]

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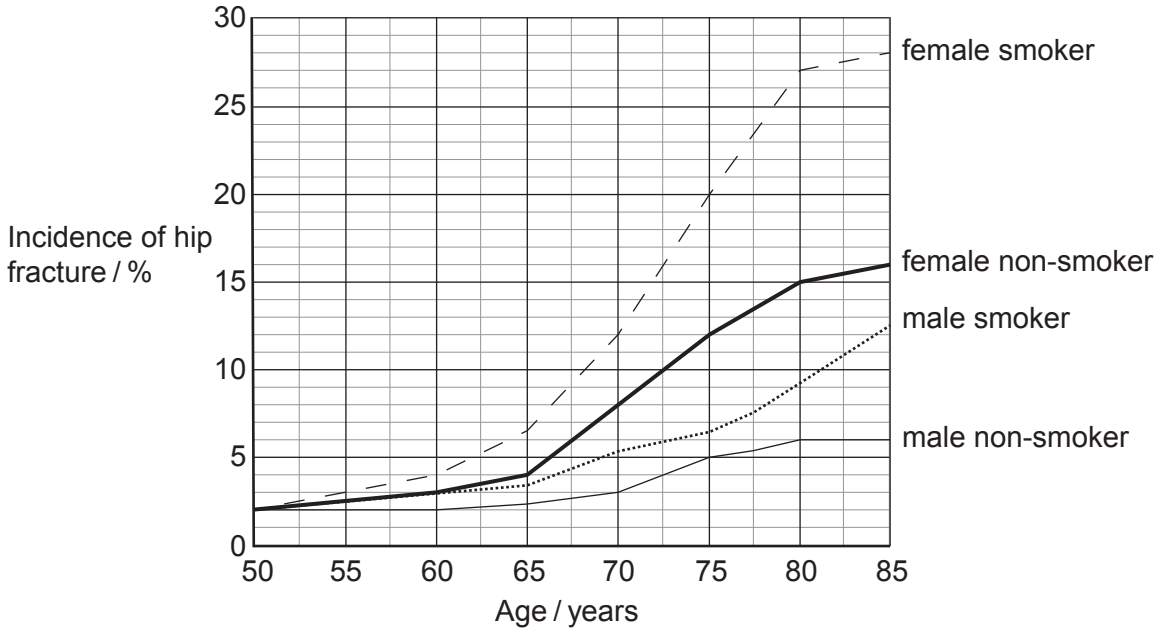
(d) A study was carried out in Wales to investigate the effect of smoking on the risk of hip fracture.

Data was collected on 2500 people aged 50–85 who were admitted to hospital with hip fractures. **Graph 8.3** shows their results.

Graph 8.3



(i) State **two** conclusions that can be drawn from **Graph 8.3** about the risk of hip fracture. [2]

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(ii) A similar study investigated the effect of smoking on the incidence of hip fracture across Europe. Data were collected from a number of hospitals and included 10 000 men and 10 000 women. As part of the study doctors also collected information on diet, family history and ethnicity.

I. Evaluate the reliability of the Welsh study in comparison to the European study. [2]

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II. Explain the significance of collecting data on diet, family history and ethnicity in this study. [1]

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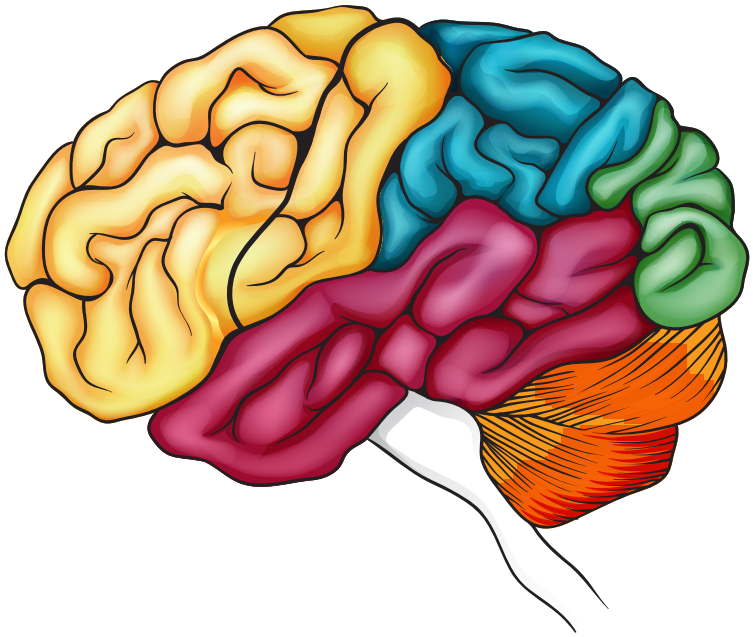
Option C: Neurobiology and Behaviour

9. **Image 9.1** shows the areas of the cerebral cortex.

Image 9.1



(a) (i) Use lines and the letters shown below to label the following structures in **Image 9.1**. [2]

W motor cortex

X sensory cortex

Y visual cortex

Z auditory cortex

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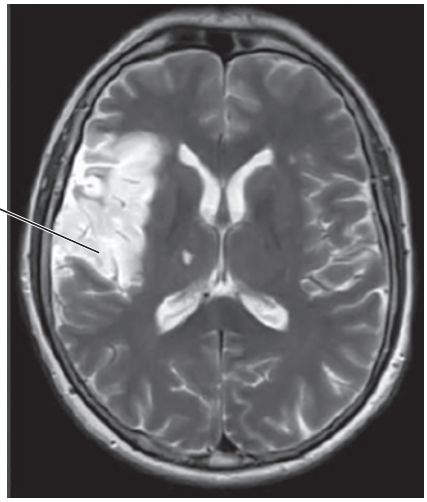
A stroke is an interruption to the blood flow in the brain. **Image 9.2** is an image of an MRI scan of an individual who has experienced a stroke. The white patch shows the area of the brain that is affected.

Image 9.2



(ii) The individual presented with the following symptoms: paralysis of the right arm and an inability to speak.
Conclude which **two** areas of the frontal lobe of the brain were affected. [2]

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(iii) Deduce which side of the brain was affected and explain your answer. [3]

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Strokes can also be diagnosed using CT scans. **Image 9.3A** shows an MRI scanner and **Image 9.3B** shows a CT scanner.

Image 9.3A

MRI scanner

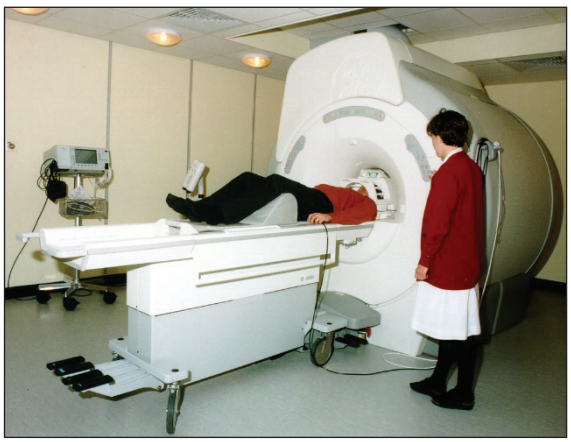

Image 9.3B

CT scanner

(iv) State **two** advantages of MRI scans over CT scans. Suggest why a CT scan would be more suitable for some patients. [3]

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(v) I. Use your knowledge of neuroplasticity to suggest how a 55-year-old individual who has suffered from a stroke can regain movement. [2]

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II. State why it is a slow process that requires a high number of repetitions of rehabilitation exercises. [2]

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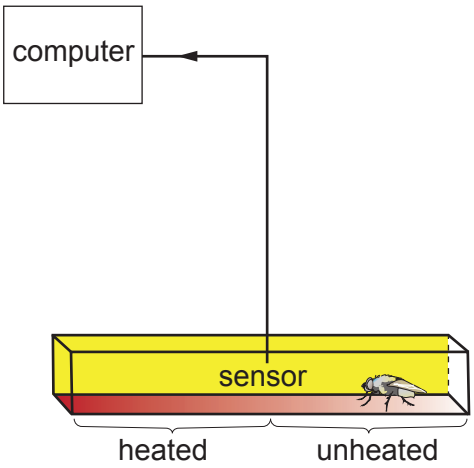
(b) Operant conditioning works for certain invertebrates, such as fruit flies, *Drosophila melanogaster*. Psychologists use a device known as a heat-box to investigate this. Conditioning in the heat-box is a process in which flies develop a preference for one side of an experimental chamber. This is shown in **Image 9.4**.

Image 9.4



During training, single flies walk freely back and forth in a narrow box in complete darkness. They are conditioned to avoid one half of the length of the box by being instantly heated on entering that half. The training cycle length can be varied.

The training is followed by a test period **without any heat**. During the test period, the position of the fly in the chamber is monitored by a sensor and the mean time the flies spend on the unheated side is calculated.

(i) Operant conditioning is a type of learned behaviour.
Define the terms operant conditioning and learned behaviour. [2]

Operant conditioning .....

.....

Learned behaviour .....

.....

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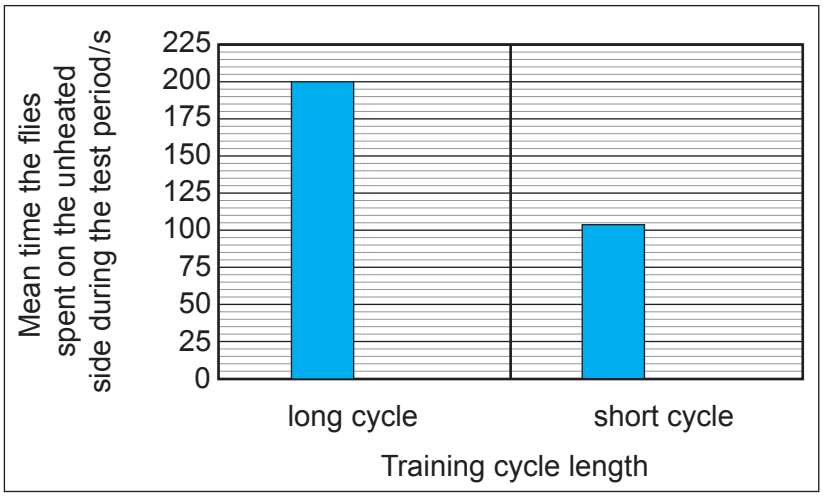
A study was carried out into the effect of training cycle length on learning in fruit flies. Short cycles contained 120 seconds of training, while long cycles contained 240 seconds of training. The study was repeated with two groups of 20 flies. The results are shown in **Graph 9.5**.

Graph 9.5



(ii) State the conclusion that can be drawn from **Graph 9.5**. [1]

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(iii) After long length training cycles the flies spent a mean time of 200 seconds on the unheated side of the chamber. After short length training cycles the flies spent 104 seconds of their time in the unheated side.
Calculate the percentage difference in the mean time the flies spent on the unheated side after long length training cycles compared to short length training cycles. [2]

Percentage difference = ... %

(iv) State how you could improve confidence in your conclusion. [1]

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