Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A400U20-1

O20-A400U20-1

FRIDAY, 16 OCTOBER 2020 – MORNING

BIOLOGY – A level component 2

Continuity of Life

2 hours

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Question	**Maximum Mark**	**Mark Awarded**
1.	**14**	
2.	**14**	
3.	**14**	
4.	**18**	
5.	**16**	
6.	**15**	
7.	**9**	
Total	**100**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will need a calculator and a ruler.

INSTRUCTIONS TO CANDIDATES

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

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

Answer **all** questions.

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

INFORMATION FOR CANDIDATES

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

The assessment of the quality of extended response (QER) will take place in question **7**.

The quality of written communication will affect the awarding of marks.

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Answer **all** *questions.*

1. Gregor Mendel published his laws of heredity in 1866. He carried out breeding experiments using the garden pea, *Pisum sativum*. He investigated the inheritance of characteristics that had at least two distinct **forms** or **traits**. He developed varieties of peas that were **pure breeding** for the traits of each characteristic that he investigated. He determined that characteristics are inherited as '**units of inheritance**' and that while some units of inheritance always appear in the offspring produced from a cross, others did not.

(a) (i) State the term currently used in genetics to describe the **form** or **trait** of a characteristic. [1]

phenotype

(ii) Explain what is meant by the term **pure breeding**. [1]

When bred together, organisms of the same phenotype only ever produce offspring of that same phenotype, because they are homozygous.

(iii) Mendel's '**units of inheritance**' are now known as alleles. Explain why some characteristics always appear in the offspring produced from a cross, while others do not. [2]

A dominant allele is always expressed in the phenotype, as only one copy of the allele is needed (it is expressed in heterozygotes). A recessive allele is only expressed in the phenotype when both alleles in the pair are recessive (homozygous recessive), i.e. when the dominant allele is absent.

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Pea flowers are insect-pollinated and contain both female and male reproductive organs. In many of his experiments, Mendel prevented self-pollination and self-fertilisation by removing the male reproductive organs and cross-pollinating the flowers by hand. In other experiments he allowed plants to self-pollinate by preventing cross-pollination.

(b) (i) Name the male reproductive organs and explain how their removal would encourage cross-pollination. [2]

Stamens (anthers) are removed.

So no pollen is available from the same flower, making self-pollination impossible: pollen has to come from another flower or plant.

(ii) Suggest how Mendel could have prevented cross-pollination. Explain your answer. [1]

Enclose / isolate the flower in a bag to prevent insects transferring pollen from another flower.

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(c) In one experiment, Mendel crossed pure breeding pea plants which produced smooth, yellow peas with pure breeding plants that produced wrinkled, green peas. The $\mathbf{F_1}$ were allowed to self-fertilise. **Image 1.1** shows the $\mathbf{F_1}$ and $\mathbf{F_2}$ offspring produced in this experiment.

Image 1.1

Parent traits: smooth, yellow × wrinkled, green

F_1 trait all smooth yellow

F_2 traits

		Seed colour		
		yellow	**green**	**total**
Seed shape	**smooth**	311	106	417
	wrinkled	101	33	134
	total	412	139	551

(i) Calculate the ratio of the following combinations of traits found in the $\mathbf{F_2}$ offspring. **Give each value to one decimal place**. [2]

÷ 33: 311/33 = 9.4, 106/33 = 3.2, 101/33 = 3.1, 33/33 = 1.0

F_2 trait	smooth yellow		smooth green		wrinkled yellow		wrinkled green
F_2 ratio	9.4	:	3.2	:	3.1	:	1.0

(ii) Explain how these pure breeding parents produced the combinations of traits shown in the $\mathbf{F_2}$ offspring. [2]

F1 all smooth yellow, so smooth (S) and yellow (Y) are dominant; wrinkled (s) and green (y) are recessive.

SSYY × ssyy, so all F1 were heterozygous (SsYy) for each characteristic.

No linkage: the genes assort independently, giving SY, Sy, sY, sy gametes, so 9:3:3:1.

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(d) In the early 1900s, further genetic crosses were carried out to investigate inheritance in the garden pea. They studied two characters, flower colour – purple or red, and the shape of pollen grains – long or round. They crossed plants that were pure breeding for purple flowers and long pollen grains with plants pure breeding for red flowers and round pollen grains. The $\mathbf{F_1}$ were allowed to self-fertilise to produce the $\mathbf{F_2}$ generation. The results of this cross are shown in **table 1.2**.

Table 1.2

Characteristics	Number of offspring
purple flower, long pollen grains	4 831
purple flower, round pollen grains	390
red flower, long pollen grains	393
red flower, round pollen grains	1 338

(i) Suggest why this cross did not produce the same ratio of the combination of characters as found by Mendel in his experiment. [1]

The genes are linked: they are on the same chromosome, so they do not assort independently.

(ii) Using your knowledge of meiosis, explain how plants producing purple flowers and round pollen grains could have been produced in this cross. [2]

Crossing over between non-sister chromatids of homologous chromosomes at chiasmata during prophase I of meiosis.

This recombines the alleles, so recombinant gametes carrying the purple and round alleles together are produced.

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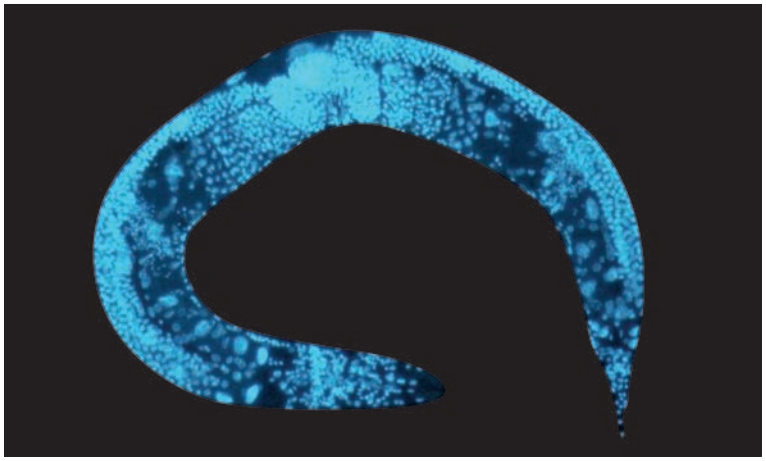
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2. *Caenorhabditis elegans* is a species of nematode worm found living free in soil. The adult worms are approximately 1 mm in length and contain only 959 body (somatic) cells.

Image 2.1 shows an adult *C. elegans* stained to show the position of the nuclei of each cell. The photograph was taken using a fluorescence microscope.

Image 2.1



(a) (i) When examining an organism using a microscope, describe **one** advantage and **one** disadvantage of staining the organism. [2]

Advantage

A stain provides contrast, so structures (e.g. nuclei) can be seen more clearly that would not otherwise be visible.

Disadvantage

The organism is usually killed or harmed in the staining process, as the stain can be toxic.

(ii) Suggest the power of the objective lens used to take the photograph shown in **image 2.1**. [1]

x 10 (low power)

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(b) Most *C. elegans* adults are hermaphrodite, possessing both male and female reproductive systems. The majority of zygotes are produced by self-fertilisation. This is followed by repeated cell divisions to produce the body cells.

(i) State the types of cell division involved in the production of the body cells and the gametes. [1]

body cells *mitosis*

gametes *meiosis*

(ii) Estimate the **minimum number** of cell divisions needed to produce the 959 body cells (somatic cells) found in the adult hermaphrodite nematode. [1]

$2^9 = 512$ (too few), $2^{10} = 1024 \geq 959$

Minimum number of cell divisions = *10*

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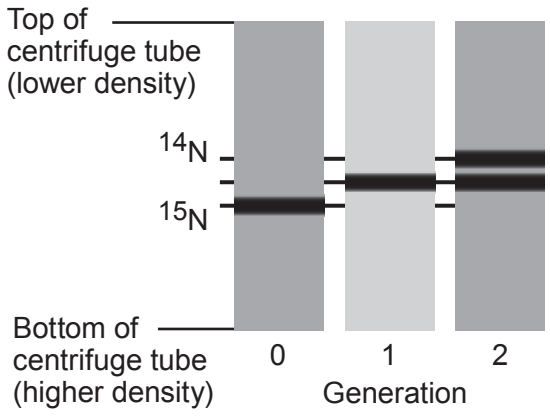
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(c) During the cell cycle, DNA has been shown to replicate semi-conservatively. Meselson and Stahl were the first scientists to prove this experimentally.

In their experiments they cultured bacteria with a nitrogen source containing only ^{15}N – a heavy isotope of nitrogen. The bacteria were then transferred to a culture medium containing ^{14}N – a light isotope of nitrogen. Samples of DNA were extracted from the initial ^{15}N culture (generation 0) and after one and two replications with ^{14}N (generations 1 and 2). The DNA from each sample was spun in an ultracentrifuge.

Image 2.2 shows the positions of the DNA in each sample.

Image 2.2



Explain how the evidence shown in **image 2.2** proved that DNA replicates semi-conservatively. [2]

Each original strand acts as a template, so each new DNA molecule contains one original strand and one new strand.

Generation 1: all the DNA is in one intermediate band, so every molecule has one ^{15}N strand and one ^{14}N strand.

Generation 2: half the DNA is intermediate and half is light (only ^{14}N).

Conservative replication would always keep a ^{15}N band at the bottom, and dispersive would give a single band at generation 2, so both are ruled out.

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(d) Mutations that occur during DNA replication can be responsible for causing cells to become cancerous by activating genes that prevent the control of cell division. However, cancerous growths (tumours) are very rare in *C. elegans* and only occur in the germ line cells.

(i) Name the genes that when mutated can trigger uncontrolled cell division and state the term used to describe the chemicals that can cause these mutations. [2]

Genes proto-oncogenes (oncogenes)

Term used to describe chemicals mutagens / carcinogens

(ii) Nearly all of the body cells are fully differentiated but some remain as stem cells and are responsible for the production of gametes.
Conclude why tumours only develop in the germ line cells and very rarely in the body cells of this organism. [2]

Body cells are fully differentiated and no longer divide, but germ line (stem) cells are not differentiated.

Only germ line cells can continue to divide by mitosis, so only they can accumulate mutations and divide uncontrollably to form a tumour.

(e) Scientists have used *C. elegans* to study epigenetic effects on genes that are involved in the control of the cell cycle and how these effects could trigger the development of cancers.

One form of epigenetic modification involves the methylation of cytosine bases in regions of genes that control the expression of that gene.

Explain how methylation could affect the quantity of a polypeptide produced, but not the structure of a polypeptide. [3]

Methylation of cytosine does not change the base sequence of the gene.

Methylation of the control region prevents transcription (RNA polymerase / transcription factors cannot bind), so the gene is not expressed: less or no mRNA is made, reducing the quantity of polypeptide.

Any mRNA that is made has the same base sequence, so translation produces the same amino acid sequence and the polypeptide structure is unchanged.

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3. Many plants, especially those which have been selectively bred to produce food for humans are polyploid, with several complete sets of chromosomes. For example, wild strawberries, are 2n = 14 but those grown commercially are octoploid, with eight sets of chromosomes.

(a) State how many chromosomes would be in the following cells during different stages of the life cycle of a commercially grown strawberry plant. [2]

a cell in the ovary wall ..56..

a pollen tube nucleus ..28..

a primary endosperm nucleus ..84..

Strawberries are often used as a source of DNA for extraction in a school laboratory. The following method was used to extract DNA from a strawberry.

1. Place a strawberry in a sealable plastic bag and crush.
2. Add 10 cm^3 of a mixture containing 1 cm^3 of detergent (pH 9), 0.1 g of salt and 10 cm^3 of water to the bag and mix thoroughly with the crushed strawberry.
3. Place the bag containing the strawberry mixture in a water bath at 60 °C for 15 minutes.
4. Cool the contents by placing the bag in a water bath of iced water.
5. Filter the mixture through a coffee filter paper into a clean beaker. Keep the filtrate.
6. Place 10 cm^3 of the filtrate in a boiling tube and add 2–3 drops of a protease enzyme and mix. Leave for 2 minutes.
7. Carefully pour ice-cold ethanol down the side of the tube to form a layer 1 cm deep on top of the filtrate. Let it stand for 3–4 minutes.
8. DNA precipitates into the ethanol. It should look cloudy. Using a glass rod, gently lift out some of the DNA.

(b) (i) Using **only** the information given, suggest why strawberries are often used as a source of DNA for extraction in a school setting. [1]

Strawberries are octoploid, so each cell has a large quantity of DNA,

making the DNA easier to see.

(ii) Coffee filter paper has a pore size of approximately 20 µm. Suggest why coffee filter paper is used rather than Grade 1 laboratory filter paper with a pore size of 11 µm. [1]

DNA is too large a molecule to fit through normal filter paper pores;

larger pores allow more DNA / filtrate to pass through.

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(iii) A protease is added to digest enzymes present in the cytoplasm of strawberry cells that could digest the DNA. Explain why you could not use **pepsin** as the protease when following this method. [2]

The detergent mixture is pH 9, so the solution is alkaline.

Pepsin has an optimum pH of 1 to 2 (acidic), so it would not be at its optimum conditions and would not work / be denatured at pH 9.

(c) In medicine, DNA samples can be taken from a developing foetus as part of pre-natal testing for genetic disorders. The quantity of DNA extracted is very small.
Identify and describe a method that can be used to increase the quantity of DNA available for analysis. [3]

Polymerase chain reaction (PCR).

Heat the DNA to 95 °C to break the hydrogen bonds and separate the two strands of DNA.

Cool to 50 to 60 °C to allow primers to bind (anneal) to the DNA strands.

Heat to 70 °C to allow thermally stable Taq DNA polymerase to add complementary nucleotides to make new strands.

Repeat the cycle many times, doubling the DNA each cycle.

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One genetic disorder that can be detected through analysis of foetal DNA is beta thalassaemia. This disorder is caused by a mutation to the gene coding for the beta-globin chain of adult haemoglobin. To date the only possible cures that have been trialled are stem cell therapy and gene therapy.

(d) In 2008, a child was born from an embryo produced by *in vitro* fertilisation. Before implantation the embryo was screened to ensure that it did not carry the gene for beta thalassaemia. Following the birth of the child, stem cells from the baby's umbilical cord were saved and transplanted to his brother who suffered from beta thalassaemia. These replaced the stem cells in his brother's bone marrow and red blood cells were then produced that had normal haemoglobin.

(i) Suggest why the treated child should still receive genetic counselling in the future before trying to become a parent. [2]

This was somatic stem cell therapy, not germ-line therapy: it treats the symptoms, but is not heritable.

The beta thalassaemia allele is still present in his germ-line cells / sperm, so he is still a carrier and could pass it on.

(ii) Suggest why there is opposition to producing one child specifically to treat a genetic disorder in another child. [1]

The child produced has no choice: he cannot give consent to being used as a donor.

(e) Gene therapy for beta thalassaemia has been trialled.
Suggest **one** advantage and **one** possible disadvantage of using a non-pathogenic virus as the vector for the beta-globin gene. [2]

Advantage: the virus would transfer the beta-globin gene directly into the host's (blood) stem cells.

Disadvantage: the virus could mutate and become pathogenic, or the gene could insert into another gene and inactivate it, or activate an oncogene; it may also cause an immune response.

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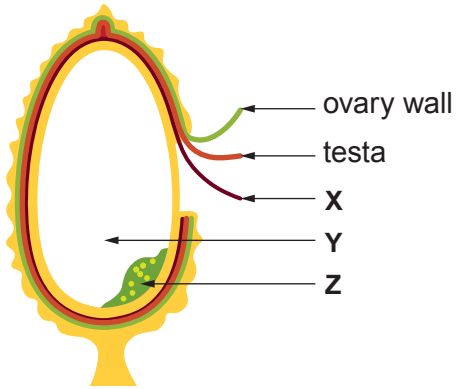
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4. Rice, *Oryza sativa*, is a staple food crop for over half of the world's population. It provides most of the carbohydrate intake for people in many countries. **Image 4.1** shows the structure of a rice grain.

Image 4.1



During processing of rice grains for consumption, most rice is 'polished' leaving only starch-containing tissue. This is called white rice. Brown rice retains fibre and protein-containing tissues.

(a) (i) Using the letters **X**, **Y** and **Z**, identify the following: [3]

I. the structure that would stain blue-black on application of iodine solution.

Y

II. the source of gibberellins during germination of a rice grain. Z

III. the main source of amino acids for a germinating rice grain. X

(ii) Most rice consumed in Asian countries is white rice. In some areas rice makes up 80 to 90% of the diet. Suggest how and why the processing of rice has led to reduced growth rates of children in some communities. [2]

Polishing removes layer X (the aleurone layer), which contains protein.

With 80 to 90% of the diet as white rice, children lack dietary protein,

which is needed for growth.

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Vitamin A deficiency is a world-wide problem. Rice can be genetically modified to include the gene coding for beta carotene which is then used in the production of vitamin A. This modified rice is yellow in colour and is called 'golden rice'.

In the first experiments to genetically modify rice, a pathogenic bacterium, *Agrobacterium tumefaciens*, was used to transfer the genes required to produce beta carotene into rice cells using modified plasmids.

(b) Name and describe the function of **two** enzymes that could have been used to produce the modified plasmids transferred to *A. tumefaciens*. [2]

Enzyme 1 restriction endonuclease

Function cuts the gene out of the (daffodil) DNA at specific base sequences, and cuts open the plasmid, leaving sticky ends.

Enzyme 2 DNA ligase

Function binds the DNA fragment containing the gene into the plasmid by forming phosphodiester bonds.

(c) One of the genes required for beta carotene synthesis was obtained from daffodil DNA. Due to the presence of introns in the daffodil gene, a better option might be to use a synthetic DNA sequence derived from mRNA rather than using a gene extracted directly from a daffodil chromosome.

(i) State what is meant by an *intron*. [1]

A region of non-coding DNA found between the coding regions (exons) of a gene.

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(ii) Explain how post transcriptional modification of mRNA (splicing) in eukaryotic cells provides evidence against the 'one gene one polypeptide' hypothesis. [2]

Pre-mRNA can be spliced in different ways: exons can also be removed during splicing, as well as introns.

So each mRNA has a different base sequence and codes for a different polypeptide: one gene can code for more than one polypeptide.

(iii) Explain why a synthetic DNA sequence derived from mRNA might be the better option for genetically modifying rice cells. [3]

Functional mRNA does not contain introns, as they have already been spliced out, so the synthetic DNA only contains exons (coding regions).

Bacteria such as A. tumefaciens cannot remove introns, so introns will not have to be spliced out.

Only a single DNA sequence is incorporated into the rice cells, so there is no risk of producing different mRNA / amino acid sequences.

(iv) Outline the process by which a synthetic daffodil gene could be prepared from mRNA. [3]

Extract mRNA from daffodil cells that are actively synthesising the required protein.

The mRNA is used as a template; reverse transcriptase makes a single-stranded DNA copy.

DNA polymerase then produces double-stranded cDNA, the synthetic gene.

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(d) The production of 'golden rice' is still in progress despite trials showing that humans can utilise the beta carotene contained in 'golden rice' to produce vitamin A. Suggest why people may still be opposed to the wide-scale growing and use of 'golden rice'. [2]

There are unknown side effects / health issues of eating a GM crop, and unknown effects on the environment.

There are concerns over the use of a pathogenic bacterium in gene transfer, and economic concerns.

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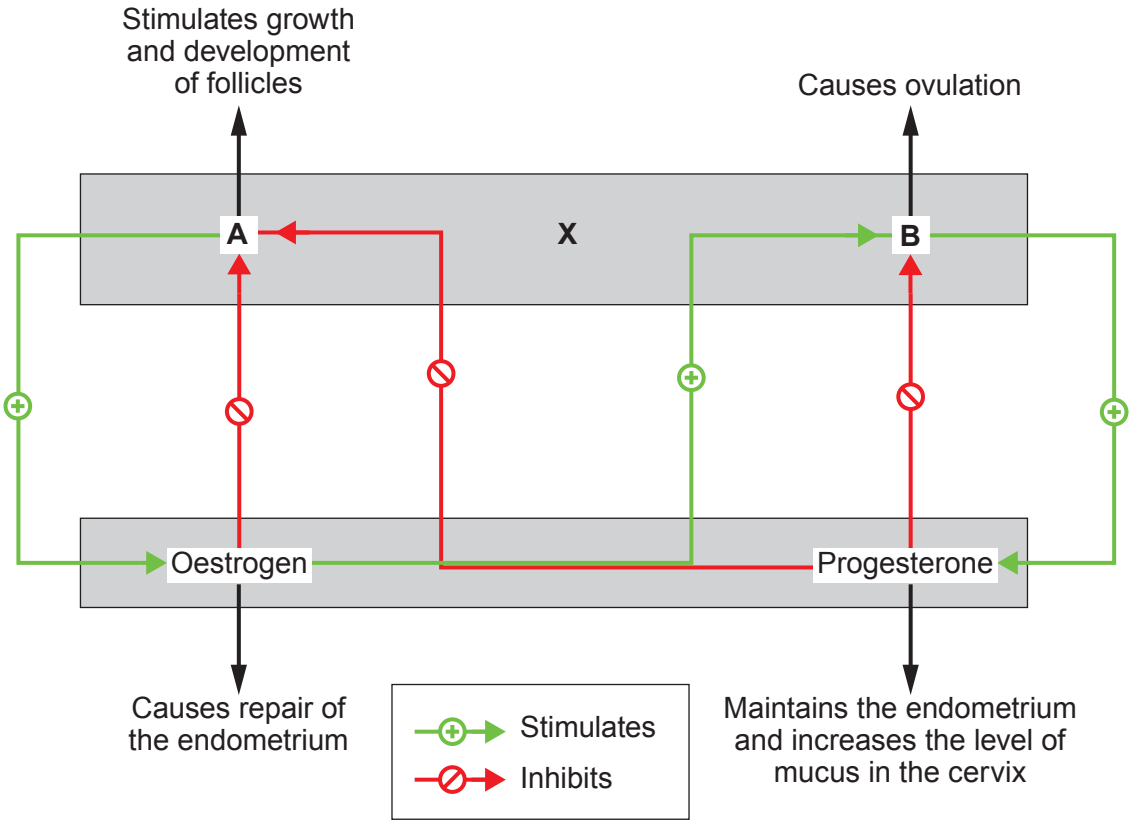
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5. The menstrual cycle is controlled by the interaction of a number of different hormones as shown in the flow chart in **image 5.1**.

Image 5.1



(a) (i) State the names of the hormones labelled **A** and **B** in **image 5.1** and the name of structure **X** where they are secreted into the blood. [2]

A follicle stimulating hormone (FSH)

B luteinising hormone (LH)

X anterior pituitary (gland)

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(ii) With reference to **image 5.1**, conclude how oestrogen and progesterone in the combined contraceptive pill, act to reduce the likelihood of fertilisation. [3]

Oestrogen and progesterone inhibit secretion of FSH (hormone A), so follicles do not develop and mature.

Progesterone inhibits secretion of LH (hormone B), so there is no LH surge and no ovulation.

Progesterone also increases the level of mucus in the cervix, so this blocks the entry of sperm.

Sperm production in human males is also dependent on the interaction of hormones **A** and **B** and their effects on different organs and tissues.

(b) State the following:

(i) the term used to describe the process of sperm production. [1]

spermatogenesis

(ii) the precise location of sperm production in human males. [1]

seminiferous tubules (in the testes)

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(c) Research into the development of a male contraceptive has focussed on reducing the production of spermatozoa. One possible method has been to increase the blood concentration of testosterone by administering a drug called TU.

One study involved 898 Chinese men between 20 and 45 years of age. All men starting the trial had fathered a child in the previous two years. Following an initial dose of 1000 mg, the men were all given an injection of 500 mg of TU each month for 30 months.

(i) Calculate the total mass of TU given to each man during the period of the trial. **Give your answer in grams.** [2]

1000 + (500 × 30) = 16 000 mg

16 000 mg ÷ 1000 = 16 g

mass of TU = 16 g

(ii) State **two** criteria that were used to select the men included in the trial. [2]

All had fathered a child in the previous two years.

All were Chinese men aged 20 to 45.

(iii) Semen samples were collected on a regular basis and the number of spermatozoa per cm^3 determined.
Of the original 898 men in the trial, 4.8% did not respond to the drug and remained fertile. Calculate the number of men who did respond to the drug. [2]

898 × 4.8/100 = 43.1 did not respond

898 − 43.1 = 854.9 ≈ 855

number of men who did respond to the drug = 855

(iv) The number of pregnancies in the partners of the men in the trial was also recorded. Suggest why sperm counts were carried out during the trial rather than relying on pregnancy rate alone as a measure of contraceptive success. [1]

Pregnancy rate measures both male and female fertility, and intercourse may not coincide with ovulation.

(d) Similar trials in other parts of the world have produced different degrees of success. Identify **two** changes to the study to validate the use of TU as a male contraceptive world-wide. Justify your suggested changes. [2]

Include men of different ethnicity (genetic make-up), as response to TU may differ.

Use a wider age group, as sperm production varies with age.

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6. Ferns are terrestrial, non-flowering plants that first appeared in the fossil record about 360 million years ago. They are similar to other terrestrial plants in that they have vascular systems for transport of water, ions and products of photosynthesis around the plant. **Image 6.1** shows the leaves of a fern plant.

Image 6.1



(a) (i) Name the vascular tissues you would expect to find in ferns. [1]

xylem and phloem

(ii) Ferns have chloroplasts with the same structure and photosynthetic pigments as flowering plants. Name **two** photosynthetic pigments found in ferns and state **precisely** where in the chloroplast you would expect to find them. [2]

Chlorophyll a and chlorophyll b, in the photosystems (antenna complex) in the thylakoid membranes.

(iii) Identify the type of nutrition found in ferns. [1]

photoautotrophic

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Classification of ferns was originally based on morphological features, but cross-fertilisation between unrelated species has produced hybrids that have often been classified as different species.

In recent years, analysis of the chloroplast genome has enabled botanists to identify hybrid forms as the chloroplast is inherited only from the female gamete.

Image 6.2 shows the gel electrophoresis of digested chloroplast DNA from four species of *Asplenium* fern. A DNA ladder was included to estimate the length of DNA fragments from the species of fern in number of base pairs.

Image 6.2

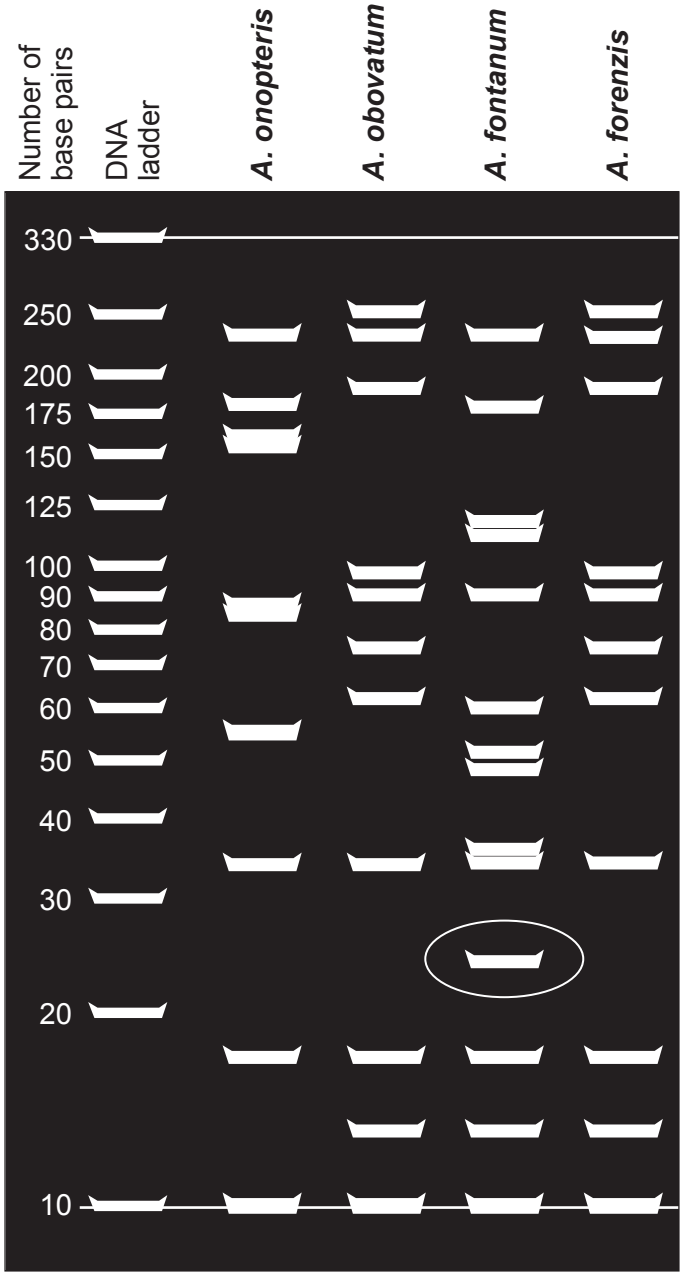


Table 6.3

number of base pairs	$\log_{10}$ number of base pairs	distance travelled / mm
10	1.00	128
20	1.30	103
30	1.47	88
40	1.60	78
50	1.70	70
60	1.78	63
70	1.85	57
80	1.90	53
90	1.95	48
100	2.00	44
125	2.10	36
150	2.18	30
175	2.24	25
200	2.30	19
250	2.40	10
330	2.52	0

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(b) (i) **Complete table 6.3** by calculating the $\log_{10}$ value of the number of base pairs in the DNA fragments in the DNA ladder. [1]

(ii) **Graph 6.4** shows some of the data from **table 6.3**.

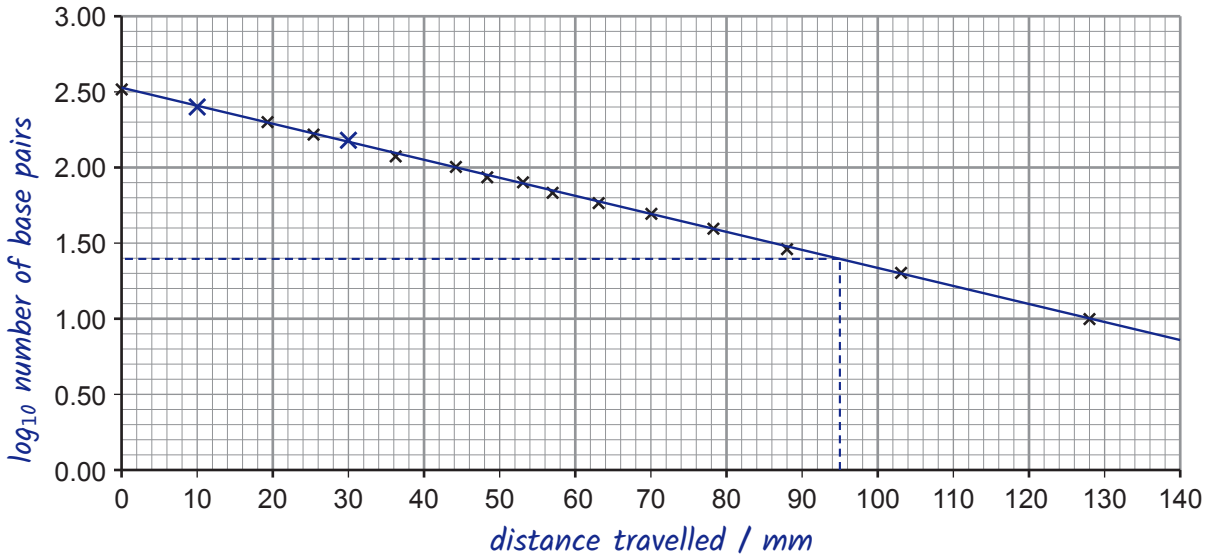
On **graph 6.4**:

I. label the axes [1]

II. plot the values for 10 mm and 30 mm [1]

III. draw a line of best fit through the plots. [1]

Graph 6.4



(iii) I. One fragment from *A. fontanum* has a circle drawn around it on the gel electrophoresis in **image 6.2**. This fragment travelled a distance of 95 mm. Use **graph 6.4** to estimate the $\log_{10}$ of the number of base pairs in this fragment. **Show how you estimated this value on graph 6.4**. [2]

$\log_{10}$ estimated number of base pairs in DNA fragment = 1.4

II. If $100 = 10^2$, then $\log_{10} 100 = 2$ and $10^2 = 100$.
Use this relationship and your answer to the previous question to determine the estimated number of base pairs in this fragment. [1]

$10^{1.4} = 25.1$

Estimated number of base pairs in DNA fragment = 25.1

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(iv) Suggest how you could modify the method to estimate the length of this DNA fragment more accurately. [1]

Include fragments in the DNA ladder between 20 and 30 base pairs in length.

(v) It is known that *A. forenzis* is a hybrid of *A. fontanum* and one of the other two species shown on the gel electrophoresis in **image 6.2**. Use the information given to conclude which species provided the female gamete to produce the hybrid *A. forenzis*. Explain your answer. [3]

A. obovatum provided the female gamete.

Chloroplast DNA is only inherited from the female gamete (the chloroplasts are in the cytoplasm of the egg).

The chloroplast DNA bands of A. forenzis match those of A. obovatum exactly, but not those of A. fontanum.

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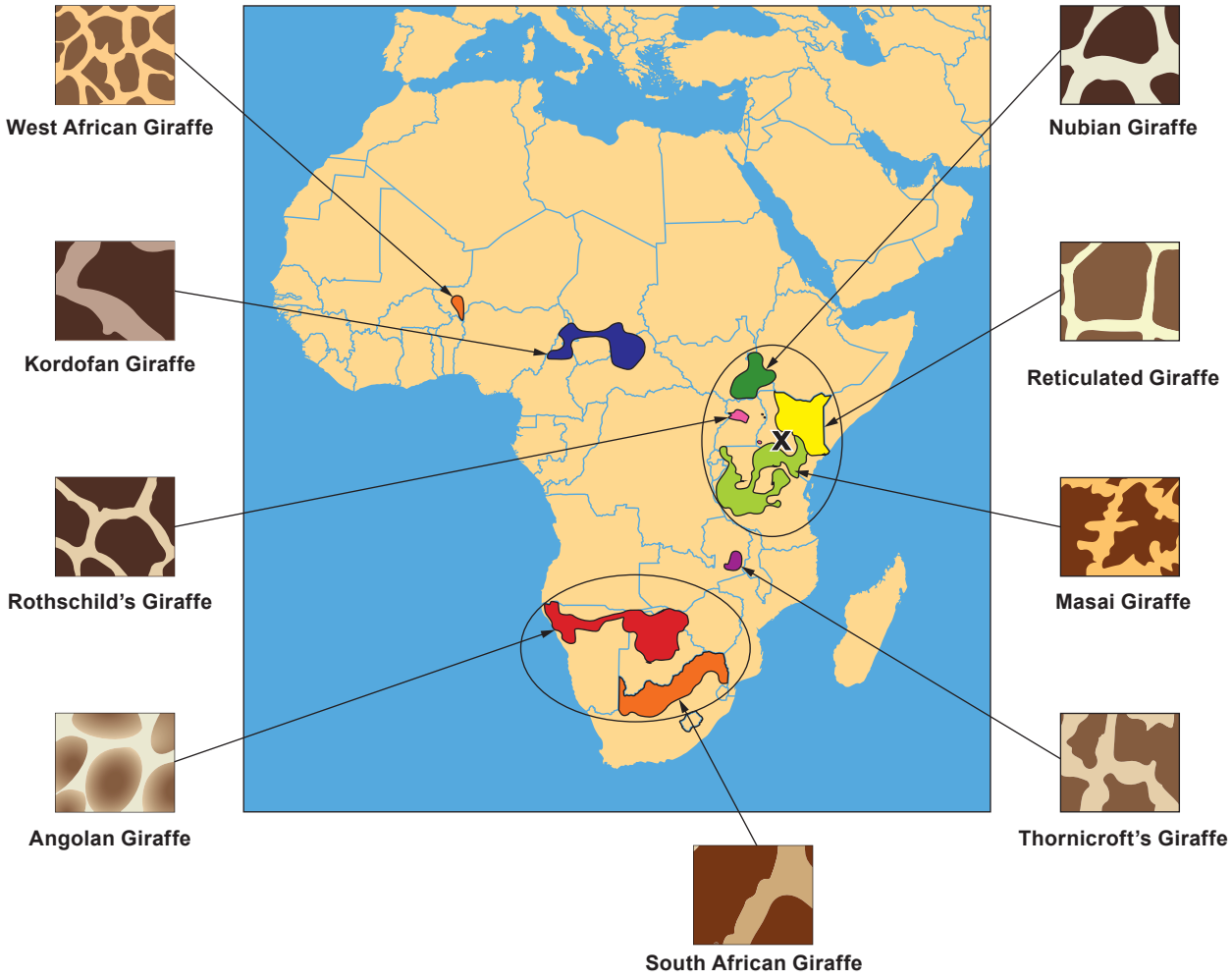
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7. Today, there are an estimated 1500 giraffes held in captivity and approximately 90000 in the wild. There are several different coat patterns that are similar to each other but are different in colouration and size of coloured areas in different populations. Giraffes live in a range of habitats ranging from sandy scrubland to dense forest.

Currently, only a single species of giraffe, *G. camelopardalis*, is recognised, but studies suggest that there may be up to nine species of giraffe. **Image 7.1** shows the current distribution of the proposed different species of giraffe together with their typical coat patterns.

Image 7.1



Giraffe populations are found in many parts of Africa. Some are now separated from other populations while others co-exist in the same parts of the continent (indicated by the oval shapes).

It has been suggested that different coat patterns evolved from a single ancestral form found in East Africa (marked **X** on the map). A number of different factors are believed to be responsible for the formation of the proposed different species of giraffe during the last million years.

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Use the information provided and your own knowledge to explain how evolution could have resulted in the appearance of different coat patterns. Explain how **two** different forms of speciation may have resulted in the development of different species of this animal. [9 QER]

Variation in coat colour and pattern in the ancestral population in East Africa (X) arose by random mutation, producing new alleles for coat pattern.

Giraffes live in different habitats, from sandy scrubland to dense forest.

Different coat patterns gave a competitive advantage in different habitats by providing camouflage from predators.

Individuals with the best adapted coat pattern for their habitat were more likely to survive and reproduce (survival of the fittest), passing the advantageous alleles on to their offspring. Over many generations the frequency of these alleles increased, so by natural selection different populations evolved different coat patterns.

Allopatric speciation: some groups of giraffe became geographically (physically) isolated, e.g. the West African giraffe and Thornicroft's giraffe, which are separated from the other populations, so there was no gene flow between them.

Each small isolated group had a gene pool that was not representative of the whole ancestral gene pool (founder effect), and genetic drift meant alleles that did not confer an advantage were lost from the gene pool.

Different environmental conditions gave different selection pressures in each area, favouring the survival of those with different advantageous alleles. The gene pools diverged until the populations could no longer interbreed to produce fertile offspring, so new species formed.

Sympatric speciation: giraffes living in the same area, such as the Reticulated, Masai, Nubian and Rothschild's giraffes within the oval in East Africa, or the Angolan and South African giraffes in the southern oval, diverged without geographical separation, through reproductive isolation.

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For example, behavioural isolation: giraffes are more likely to breed with animals of the same coat colour and pattern, or may have different courtship behaviour or breeding times; morphological differences such as size may also prevent mating. With no gene flow between these groups, mutation, natural selection and genetic drift caused their gene pools to diverge until they became reproductively isolated, separate species, even though they share the same area.

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