H2

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level

CANDIDATE NAME									
CENTRE NUMBER	S					INDEX NUMBER			

0123456789

BIOLOGY **9477/03**

Paper 3 Long Structured and Free-response Questions **For examination from 2026**

SPECIMEN PAPER **2 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Section A: answer **all** questions.
- Section B: answer **one** question.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and index number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- Do **not** write on any bar codes.
- You may use an approved calculator.

INFORMATION

- The total mark for this paper is 75.
- The number of marks for each question or part question is shown in brackets [ ].

Singapore Examinations and Assessment Board

CAMBRIDGE International Education

[Turn over

Section A

Answer **all** the questions in this section.

1 In 1987, Cann, Stoneking and Wilson published the suggestion that all modern humans are descended from one woman, who became known as Mitochondrial Eve. They claimed this woman lived in Africa between 150 000 and 200 000 years ago.

Their suggestion was based on the analysis of mitochondrial DNA (mtDNA) of 147 people taken from all racial groups. In 2000, Ingman and his co-workers carried out a similar study based on a sample of 53 people of different races using improved techniques and arrived at a similar conclusion.

In each case, the investigation was carried out by studying the nucleotide sequence of the DNA of the mtDNA of each person. mtDNA is circular and contains 37 genes. These genes code for some of the proteins present on the inner mitochondrial membrane.

(a) Mitochondria are only found in eukaryotic cells but mtDNA shares similarities with the genomes of prokaryotes.

(i) State **one** way in which a typical prokaryotic genome and a typical eukaryotic genome are similar.

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..... [1]

(ii) List **three** ways in which a typical prokaryotic genome and a typical eukaryotic genome are different.

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..... [3]

(iii) Scientists have suggested that mitochondria may have originated as independent (free-living) prokaryotic cells that became engulfed by primitive eukaryotic cells in a process similar to endocytosis. These cells continued to function inside the cells that had engulfed them.

Describe **two** features of mitochondria that provide support for any parts of this hypothesis.

1 .....

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2 .....

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.....

[2]

(iv) The mtDNA genes do **not** code for the proteins found in the mitochondrial matrix.

Name **and** outline **two** respiratory processes that depend on the proteins found in the mitochondrial matrix.

name of process 1 .....

outline .....

.....

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name of process 2 .....

outline .....

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[6]

(v) In 2002, Ingman set out to try to replicate the work of Cann, Stoneking and Wilson.

State **one** reason why repeating the work of others is an important part of scientific research.

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.....[1]

(b) The features of mtDNA that make it particularly useful for this type of study include:

- little or no genetic recombination occurs in mtDNA
- mtDNA has a higher mutation rate than chromosomal DNA
- mtDNA is passed to offspring only from the mother (maternal inheritance).

(i) Little or no genetic recombination occurs in mtDNA because mtDNA does **not** take part in meiosis.

Explain how meiosis leads to genetic recombination in the nuclear DNA of eukaryotes.

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..... [4]

(ii) Suggest **one** reason why a higher mutation rate is useful for this type of study.

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..... [1]

(iii) Suggest **one** reason why maternal inheritance of mtDNA is useful for this type of study.

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..... [1]

(c) The calculation that Mitochondrial Eve lived between 150 000 and 200 000 years ago is based on the idea of a mean rate of mutation of DNA. The mean rate of mutation of DNA can be estimated by comparing the differences in nucleotide sequences between similar species whose time of speciation can be deduced from fossil evidence. Once known, the mean rate of mutation of DNA can be used to estimate how long ago different species shared a common ancestor, based on the number of differences between their nucleotide sequences.

Mitochondrial Eve was a modern human, *Homo sapiens*. Her descendants arrived in Europe over 40 000 years ago. Neanderthals, another primate similar to modern humans, were already present. By about 30 000 years ago, the Neanderthals had become extinct.

Figure 1.1 shows the nucleotide base sequence of a short fragment of DNA from a modern human and the corresponding base sequences from a Neanderthal and four other primate species. Chimpanzee, orangutan and gorilla are species of ape, while the macaque is a type of monkey.

primate species	nucleotide base sequence
modern human	CCCAATACGCAAAATTAACCCCCTAATAAAATTAATTAACCACTCA
Neanderthal	CCCAATACGCAAAATTAACCCCCTAATAAAATTAATTAACCACTCA
chimpanzee	CCCAACACGCAAAATTAACCCCCTAATAAAATTAATTAATCACTCA
orangutan	CTCAACACGTAAAATCAACCCCCTAATAAAATTAATCAACCACTCA
gorilla	CCCTATACGCAAAACTAACCCCCTAACAAAACTAATTAACCACTCA
macaque	TCCAATACGCAAATCCAACCCACTAACAAAAATAATTAATCGCTCC

Figure 1.1

To obtain the Neanderthal DNA sequence, a small quantity of degraded DNA was first extracted from the fossilised bones of a Neanderthal. PCR was used to provide sufficient material to allow sequencing of some of the Neanderthal mtDNA, including the sequence shown in Figure 1.1.

(i) Describe **and** explain how PCR increases the quantity of DNA for analysis.

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..... [3]

(ii) Complete the list in Table 1.1 to place the primates from Figure 1.1 in order of the closeness of their evolutionary relationship to humans.

Table 1.1

modern human	close evolutionary relationship
	distant evolutionary relationship

[1]

(iii) Explain how you used the information in Figure 1.1 to work out your answer to **1(c)(ii)**.

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..... [2]

(iv) Explain why orangutans and gorillas are considered to be different biological species.

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..... [2]

(d) In 1997, Krings and his co-workers carried out research on variation in primate mtDNA. They analysed the nucleotide sequence of the mtDNA of:

- 994 diverse modern humans
- one Neanderthal fossil
- nine chimpanzees.

They compared the nucleotide sequences of each of these 1004 samples of mtDNA with each of the 994 modern human nucleotide sequences. In this way they were able to make comparisons between the mtDNA of:

- pairs of different modern human individuals
- the Neanderthal and different modern human individuals
- the chimpanzees and different modern human individuals.

The number of differences in the nucleotide sequence for each pair-wise comparison was then recorded. These differences in mtDNA have little or no effect on mitochondrial function.

The results of these comparisons are shown in Figure 1.2.

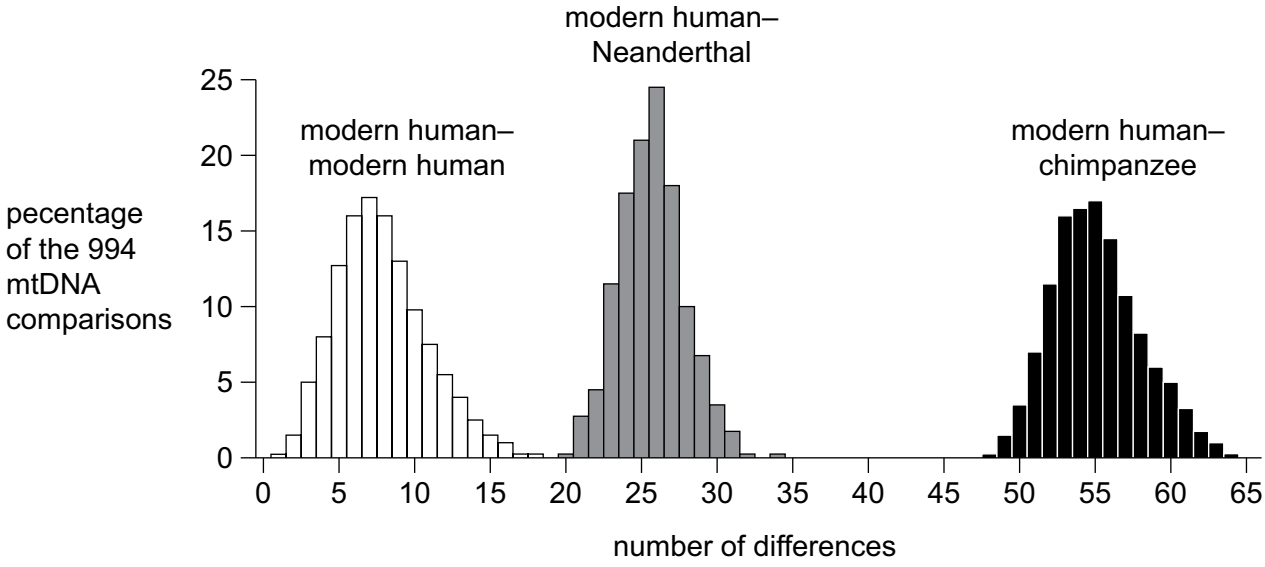

Figure 1.2

(i) Each type of comparison in Figure 1.2 shows the same pattern of genetic variation.

Name this pattern of genetic variation.

..... [1]

(ii) Describe **and** explain the results shown in Figure 1.2.

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..... [4]

[Total: 32]

2 Trees remove carbon dioxide from the atmosphere and store this carbon in their biomass in the long term. This long-term storage of carbon is called carbon sequestration.

(a) The carbon sequestered in a tree is not in the form of carbon dioxide.

Identify **three** biomolecules in which carbon may be sequestered in a tree.

1 .....

2 .....

3 .....

[3]

(b) Singapore has a high density of urban trees and plants, earning it the description 'garden city'. It also has a busy road network.

The rain tree, *Samanea saman*, is the commonest urban tree species in Singapore.

Table 2.1 shows the number of rain trees located along roads and in parks in Singapore and the rate at which the trees sequester carbon in tonnes per year. One tonne is equivalent to 1000 kg.

Table 2.1

location	**number of rain trees**	**rate of carbon sequestration / tonnes year^{-1}**
roads	26 226	487
parks	2 356	44

For the rain trees located along roads and in parks in Singapore, calculate the mean mass of carbon sequestered by a single rain tree in one year.

Show your working and give your answer in kilograms (kg) to three **significant** figures.

mean mass of carbon sequestered = ... kg [2]

(c) (i) In total, Singapore's urban trees sequester 3872 tonnes of the element carbon per year.

This helps offset carbon dioxide emissions from human activities like burning fossil fuels in the engines of cars.

There are about 600 000 cars in Singapore.

Each car is estimated to emit 4.04 tonnes of carbon dioxide per year.

27% of the mass of carbon dioxide is carbon.

Use the data provided to calculate the percentage of the element carbon released into the atmosphere by cars in Singapore that is offset by the urban trees.

Show your working.

.....% [3]

(ii) With reference to your answer to **2(c)(i)** and any other relevant aspects, comment on the benefits to the environment of planting urban trees in Singapore.

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..... [3]

[Total: 11]

3 Lymphoid stem cells are a subset of blood stem cells that give rise to the B lymphocytes and T lymphocytes of the immune system.

(a) (i) State the level of potency of lymphoid stem cells.

..... [1]

(ii) Outline **two** defining features of stem cells.

.....

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..... [2]

(b) (i) Blood stem cell transplants may be given to people suffering from leukaemia. Leukaemia is a cancer that affects white blood cells.

Figure 3.1 shows the number of blood stem cell transplants carried out in one area of the world between 1984 and 2005.

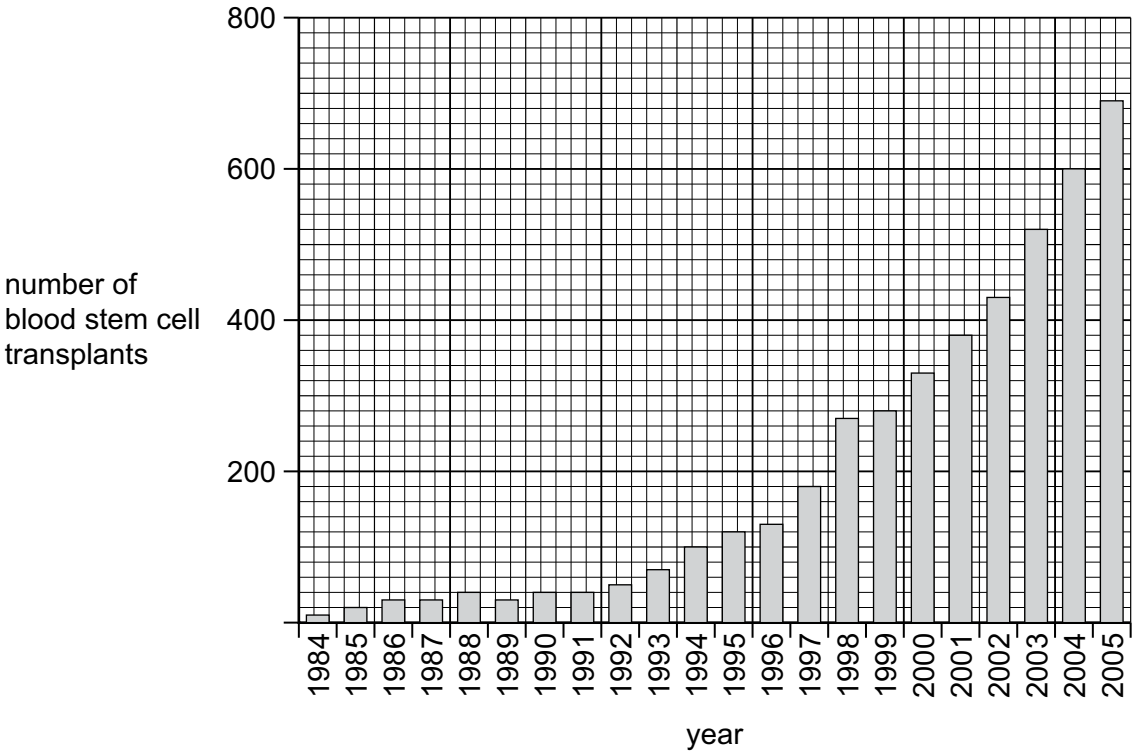

Figure 3.1

Calculate the mean yearly rate of increase in blood stem cell transplants from 1990 to 2005 for this area of the world.

Show your working and give your answer to **two** significant figures.

mean yearly rate of increase = ... $year^{-1}$ [2]

(ii) Outline **two** types of genetic change that can result in cells becoming cancerous.

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..... [4]

(c) Figure 3.2 shows a simplified outline of the process that results in the formation of plasma cells from lymphoid stem cells.

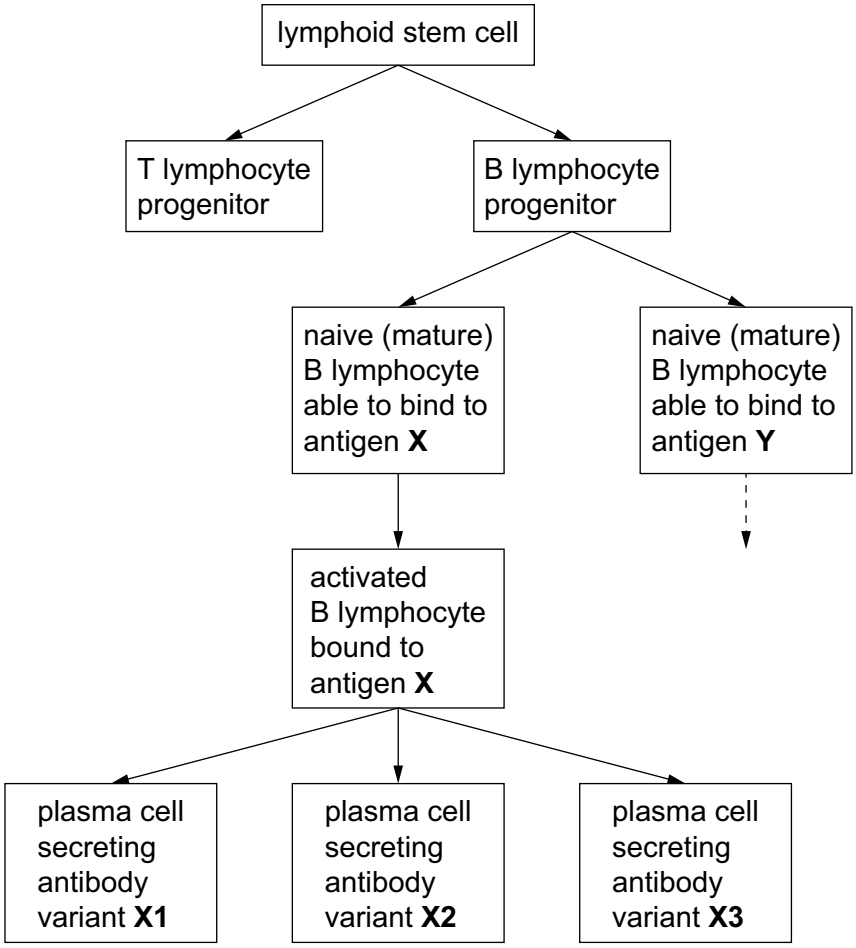

Figure 3.2

Name precisely the **genetic** process occurring in:

(i) B lymphocyte progenitors, to give naive B lymphocytes capable of recognising **different** antigens

..... [1]

(ii) activated B lymphocytes, to give plasma cells that secrete IgG antibodies instead of membrane-bound IgM antibodies that are produced earlier in the process

..... [1]

(iii) activated B lymphocytes, to give sub-clones of plasma cells that vary slightly in the ability of their antibodies to bind antigen **X**.

..... [1]

[Total: 12]

Section B

Answer **one** question in this section.

Your answer should be illustrated by large, clearly labelled diagrams, where appropriate.

Your answer must be in continuous prose, where appropriate.

EITHER

4 With reference to named examples, describe the different roles of proteins in living organisms. [20]

OR

5 With reference to a wide range of examples relevant to prokaryotes, eukaryotes and viruses, outline different ways in which molecules can enter cells. [20]

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