H

NATIONAL JUNIOR COLLEGE, SINGAPORE
Senior High 2
Preliminary Examination
Higher 2

CANDIDATE NAME			
BIOLOGY CLASS	2bi2_____	REGISTRATION NUMBER	

Biology

9744/03

Paper 3 Long Structured and Free-response Questions

13 September 2024

2 hours

Candidates answer on the Question Paper.

Additional Materials: Answer Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, Biology class and registration number on all the work you hand in.
Write in dark blue or black pen.
You may use an HB for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Section A
Answer **all** questions in the spaces provided on the Question Paper.

Section B
Answer any **one** question in the separate Answer Booklet.

The use of an approved scientific calculator is expected, where appropriate. You may lose marks if you do not show your working or if you do not use appropriate units.

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

For Examiner's Use	
Section A	
1	**/30**
2	**/10**
3	**/10**
Section B	
4 or 5	**/25**
Total	**/75**

This document consists of **15** printed pages and **1** blank page.

Section A

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

1 Collagen is a key structural protein found in various tissues throughout the body. Its measurements can vary significantly depending on the type and function of the collagen. Type I collagen is the most abundant form.

Fig. 1.1 shows the structure of type 1 collagen fibrils.

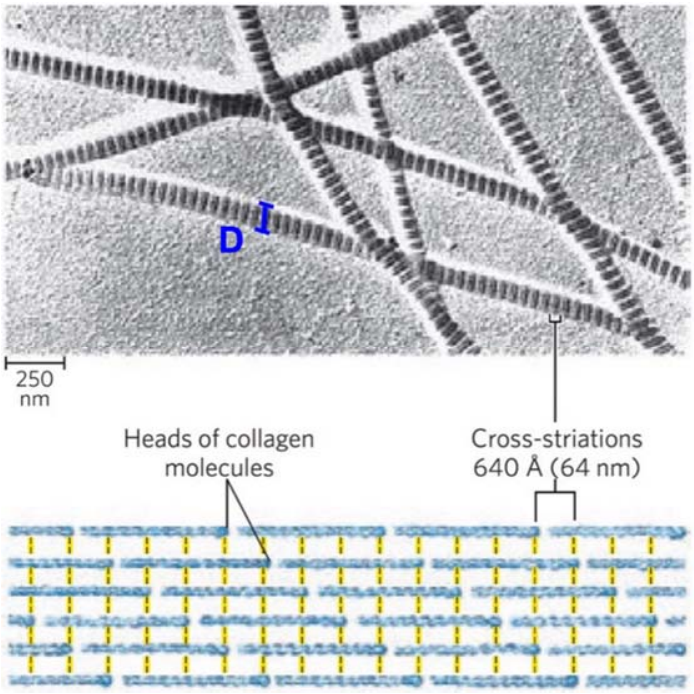

Fig. 1.1

(a) (i) Describe the molecular structure of collagen and explain how its structure relates to its function.

[5]

(ii) Use Fig. 1.1 to calculate the number of rows of collagen molecules found in the diameter of collagen fibril, **D**.

Assume that:

- the diameter of a collagen molecule is 1.5nm
- the length of hydrogen bond between two rows of collagen molecules is 3.0Å (angstroms).

Show your working clearly. Give your answer to the nearest whole number.

number of rows of collagen molecules in one collagen fibril = ...

[3]

(b) Osteogenesis imperfecta (OI) is a heritable disorder of connective tissues caused by abnormal synthesis or dysfunctional type I collagen. Each type 1 collagen molecule contains two COL1A1 polypeptides and one COL1A2 polypeptide.

A study was carried out to examine the mutations in *COL1A1* and *COL1A2* genes in patients with OI. PCR was carried out to amplify the genes in segments, and the resulting PCR product was used for DNA sequencing to identify the nucleotide sequence.

Fig. 1.2 shows a segment of *COL1A1* gene, with the 5' end starting at position 1.

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  1 tttgcccagg ctggagtgca atggtgtgat ctcggttcac tgcaaccccc gcctcctggg
 61 ttcaagtgat tctcctgcct cagcctccca agtagctggt actacaggcc catgccgcca
121 tgccgggcta atttttgtat ttttagtaga gatggagttt caccatgttg gctaggctgg
181 ggtctcaaac tctcgacctc aggtgatccg actgcctcag cctcccaaaa tgttgggatt
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Fig. 1.2

(i) Describe the principle and procedure of PCR.

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..... [4]

(ii) Use Fig. 1.2 to propose the sequence of the pair of primers used in PCR.

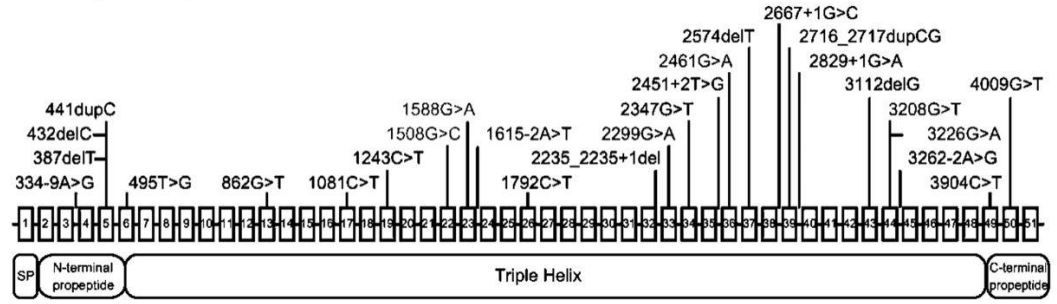
forward primer: 5' ..... 3'

reverse primer: 5' ..... 3'

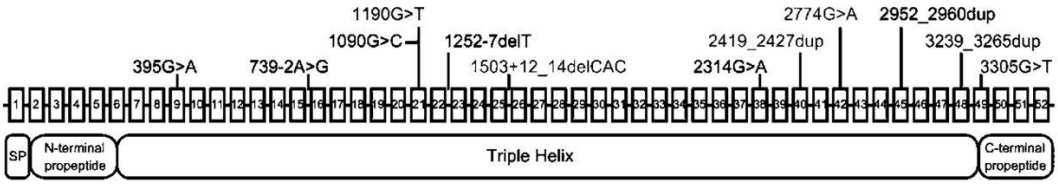
[2]

Fig. 1.3 shows the gene maps *COL1A1* and *COL1A2* genes with mutations annotated. The numbered box represents the numbered exon while each line between the boxes represents the intron between two exons. The types of mutations are represented by symbols “del”, “dup” and “>”.

COL1A1 gene map with mutations annotated



COL1A2 gene map with mutations annotated



legend for mutation annotation

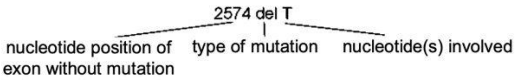


Fig. 1.3

(iii) With reference to Fig. 1.3, explain the effect of the mutations in exons and introns on type I collagen protein.

exons .....

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introns .....

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[5]

Osteogenesis imperfecta (OI) can also arise from *de novo* mutations (DNM), which refer to sequence alterations not found in parents.

Fig. 1.4 shows the pedigree of a family affected with OI. Patient 716 was diagnosed with OI at the age of 3 days. Her parents, individuals 710 and 711, are healthy without history of chronic or clinically significant diseases and are free of mutations known to cause OI. Her younger brother, individual 715, is normal and does not carry any mutation known to cause OI.

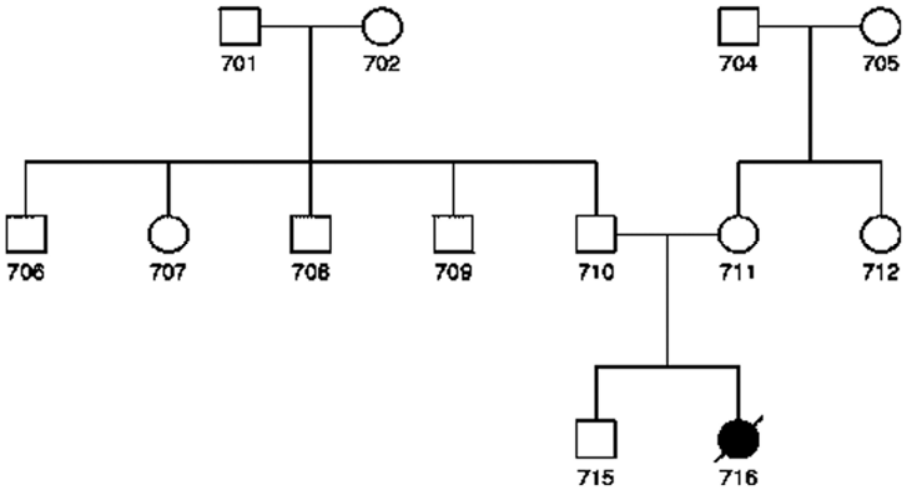

Fig. 1.4

(iv) Describe how genetic variation is produced in sperms under normal conditions.

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..... [3]

Fig. 1.5 shows how DNMs may be affected by gender and age.

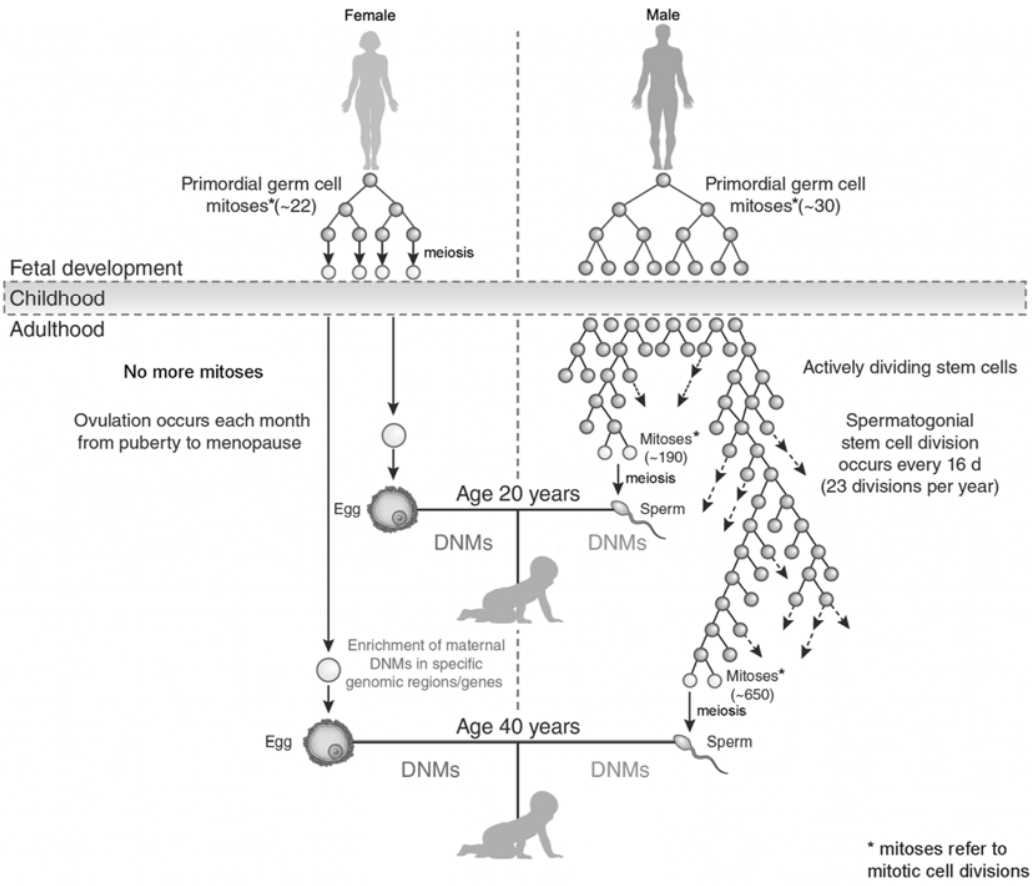

Fig. 1.5

(v) With reference to Fig. 1.4 and Fig. 1.5, explain how the OI condition is present in individual 716 but absent in individual 715 and their parents.

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..... [3]

(c) Type I collagen is the most abundant protein in the human body. It is degraded slowly and its replacement synthesis is low. However, during wound healing, the cells can increase the production of type I collagen by several hundred-fold.

Describe how the expression of type 1 collagen may be upregulated during wound healing.

[5]

[Total: 30]

2 Sahiwal cattle and Holstein Friesian cattle are known for their high milk yield.

Milk yield is affected by heat stress due to higher temperatures which results in protein misfolding within cells.

Cattle have several *hsp* genes that code for heat shock proteins (HSPs). The expression of HSPs increases in response to heat stress to help in refolding of proteins to their normal conformations.

Fig. 2.1 shows the relative expression of HSPs in the Sahiwal cattle and Holstein Friesian cattle during summer (S) and winter (W) seasons.

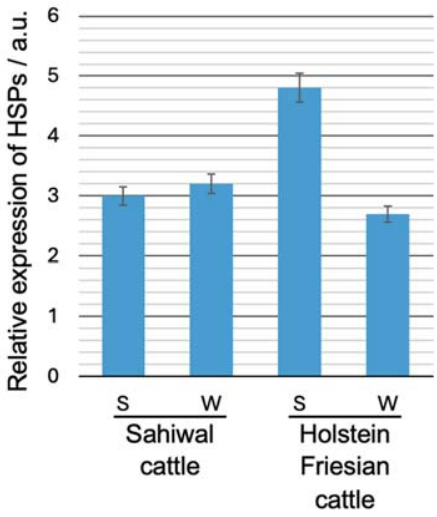

Fig. 2.1

(a) With reference to Fig. 2.1, describe the differences in the relative expression of HSPs in Sahiwal cattle and Holstein Friesian cattle.

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..... [3]

Holstein Friesian cattle are less heat tolerant than Sahiwal cattle and hence their milk yield is more affected by changing temperatures.

Fig. 2.2 shows the mean daily air temperature and the mean monthly milk yield per cow for Holstein Friesian cattle in Central Europe.

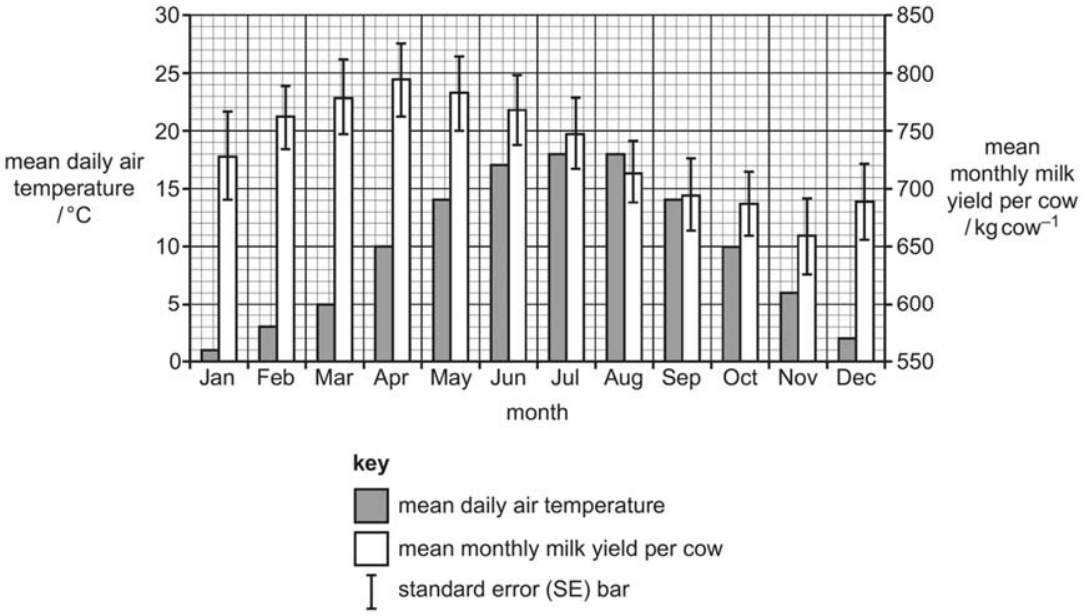

Fig. 2.2

(b) With reference to Fig. 2.2, describe the trends in air temperature and milk yield during summer from April to August.

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..... [2]

(c) Suggest reasons for the decrease in milk yield by Holstein Friesian cattle during summer.

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..... [2]

(d) Holstein Friesian cattle are the most common dairy cattle breed worldwide. However, there are rising concerns about the decreasing genetic diversity of the Holstein Friesian cattle populations due to intense directional selection practised in the last century.

Explain why low genetic diversity may decrease the long-term survival of Holstein Friesian cattle.

[3]

[Total: 10]

3 HIV-1 is the most common type of HIV. HIV-1 binds to CCR5 receptor on helper T lymphocytes.

Current treatment for HIV-1 involves the use of daily antiretroviral therapy (ART) to stop viral replication. Only 59% of HIV-positive individuals have access to ART.

Scientists found that two HIV-1-positive patients **P** and **Q** have no detectable HIV-1 after blood stem cell transplant (BSCT).

- Patient **P** was given two rounds of BSCTs, while patient **Q** was given one round of BSCT.
- All BSCTs came from a donor with helper T lymphocytes without the CCR5 receptor.
- In addition to BSCT, patient **P** had radiotherapy, while patient **Q** had chemotherapy. Both treatments are toxic.
- Both patients **P** and **Q** stopped receiving ART 16 months after BSCT.

18 months after stopping ART, both patients had no HIV-1 RNA in their plasma, no HIV-1 DNA in their helper T lymphocytes and no CCR5 on their helper T lymphocytes.

(a) Using the information provided, discuss the effectiveness of the use of BSCT to treat HIV-1 infections.

[5]

Currently, scientists are developing mRNA vaccines to prevent HIV infections.

To develop the vaccines, mRNAs coding for specific HIV proteins are introduced into the cells. The mRNAs used for vaccines must be stable so that they are not degraded before the proteins are produced.

Scientists modified the 5' cap of mRNAs to make them more stable than those with a normal GTP cap.

To test the effect of the modified caps, they introduced the same amount of each mRNA to different groups of cells. The mRNA half-life and the total amount of protein translated from the mRNAs were measured.

Table 3.1 shows the results.

Table 3.1

5' cap structure	mRNA half-life / hours after introduction into cells	total amount of protein translated from mRNA relative to amount with normal cap
no cap	1.41	0.011
normal cap	16.10	1.000
modified cap I	15.50	4.777
modified cap II	27.00	13.094
modified cap III	18.09	6.570

(b) (i) Identify the 5' cap structure that is most effective in stabilising the mRNA.

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[1]

(ii) After examining the results in Table 3.1, a student hypothesised that mRNA with modified cap I was translated more frequently than mRNA with the normal GTP cap.

Evaluate the validity of the student's hypothesis.

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[2]

(iii) Scientists can introduce either mRNA or DNA into cells to produce foreign proteins.

Explain why the introduction of mRNA is more likely to produce foreign proteins than the introduction of DNA.

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..... [2]

[Total: 10]

Section B

Answer **one** question in this section.

Write your answers on the separate answer booklet provided.

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

Your answers must be in continuous prose, where appropriate.

Your answers must be set out in section **(a)** and **(b)**, as indicated in the question.

4 **(a)** Describe the various roles of RNA in eukaryotes. [13]

(b) Explain the advantages of regulating gene expression at different levels in eukaryotes and suggest why prokaryotes have less complex gene regulation. [12]

[Total: 25]

5 **(a)** Describe the various roles of ATP in eukaryotes. [13]

(b) Explain the advantages of having cyclic processes in eukaryotes and suggest why some processes need to be non-cyclic. [12]

[Total: 25]

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