



VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
2025
HIGHER 2

NAME:

CT CLASS:

BIOLOGY

9744 / 03

Paper 3 Long Structured and Free-response Questions

18/09/2025

2 hour

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name and CT class in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil 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 space provided on the Question Paper.

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 bracket [] at the end of each question or part question.

Question	Marks
Section A	
1	
2	
3	
Section B	
Total	

This document consists of **20** printed pages.

[Turn over]

Section A

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

- 1 (a) Outline the roles of oxygen in aerobic respiration.

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..... [3]

- (b) Air contains a mixture of gases, which include approximately 78% nitrogen, 21% oxygen and 0.03% carbon dioxide. Fluctuations in these levels have occurred multiple times in the evolution of Earth's atmosphere. It is known that Earth was once without oxygen, but the gas began to accumulate in the atmosphere around 2.3 billion years ago. The increased presence of oxygen gave rise to a more efficient energy source in the form of aerobic metabolism, producing 16–18 times more adenosine triphosphate (ATP) per hexose sugar than anaerobic metabolism.

Multicellular organisms require efficient oxygen transport systems because the process of simple diffusion is too slow and inefficient to reach all cells within their large bodies, which have a small surface-area-to-volume ratio. Invertebrates like molluscs and arthropods make use of a protein called haemocyanin to transport oxygen throughout their bodies. It is an extracellular protein not contained within cells, but is instead dissolved freely in the haemolymph, which is the invertebrate equivalent of blood.

Haemocyanin is made up of a dimer or hexamer of subunit proteins depending on the species, with each subunit containing two copper ions to bind to one oxygen molecule. Fig. 1.1 shows the structure of a haemocyanin subunit, as well as the arrangement of the oxygen binding site in haemocyanin made up of six histidine amino acid residues (His) and the two copper ions.

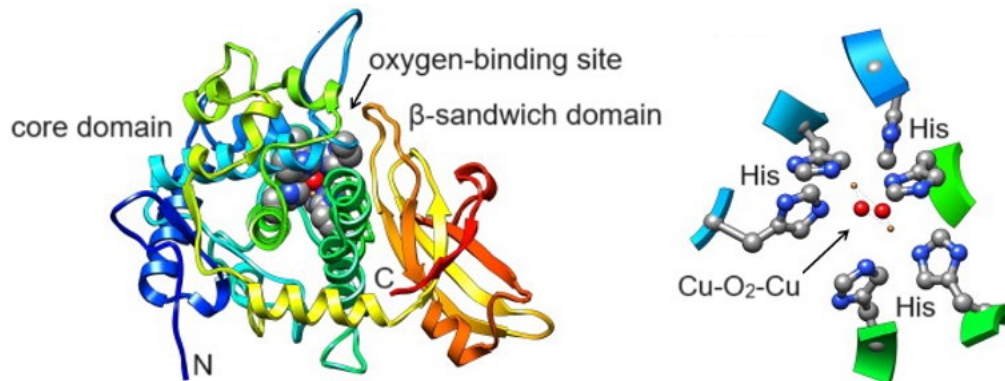


Fig. 1.1

With reference to the information provided,

- (i) state the highest level of organisation of haemocyanin.

..... [1]

- (ii) explain how the oxygen binding site of each haemocyanin subunit is formed.

.....

 [2]

(c) The amino acid sequences of a portion of the core domain of the haemocyanin subunit from four different invertebrate species have been compared. Fig. 1.2 shows the results.

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species 1  LGGASKPKKAASKAPTKKPKATPVKKAKKKLAATPKKAAPGGTAAPGGTAACHA
species 2  LHGASKAKKAAPKAPTKKPKATGGKKAKKKLAATPKKAAPLGTAAPGGTAACVA
species 3  LGGASKPKKAASKAPTKKPKATPVKKAKPKLAATPKKAAPGGTAAPGGTAACHA
species 4  LGGASKPKGAASKAPTKKPKATPVKKAKKKSAATPKKAPPGGTAAHGGTAACHA

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Fig. 1.2

Using information in Fig. 1.2,

(i) explain how the results shown support Darwin's theory of evolution.

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..... [3]

(ii) draw a phylogenetic tree that shows the evolutionary history of the four invertebrate species.

(iii) Recent studies have concluded that species 1 and 2 diverged 2.6 million years ago.

Calculate the mutation rate of haemocyanin. Show your working in the space below.
Leave your answer in **three** significant figures.

..... x 10⁻⁶ mutations per year [1]

(iv) With reference to the genetic code, suggest how the answer in (c)(iii) may be an underestimate.

.....

 [2]

(d) Haemocyanin has demonstrated anti-cancer properties as it has been shown to stimulate apoptosis in tumour cells in experiments, reducing the mass of tumours in mouse models, as well as the number of viable cells in cancer cell cultures.

Cancer formation involves the accumulation of different mutations. Some mutations are described as dominant mutations, while others are described as recessive mutations.

(i) Outline a type of mutation in cancer formation that is described as dominant.

.....
 [1]

(ii) Explain why this type of mutation is described as dominant.

.....

 [2]

- (e) In human, the protein that transports oxygen is haemoglobin. Haemoglobin A (HbA) is the most abundant type of haemoglobin in adults, making up 95–98% of total haemoglobin. A variant of haemoglobin known as foetal haemoglobin (HbF) is found in human foetus. It is produced in the foetus at around six weeks of pregnancy, and its levels remain high after birth until the baby is roughly two to four months old.

Fig. 1.3 shows the affinity of the two types of haemoglobin.

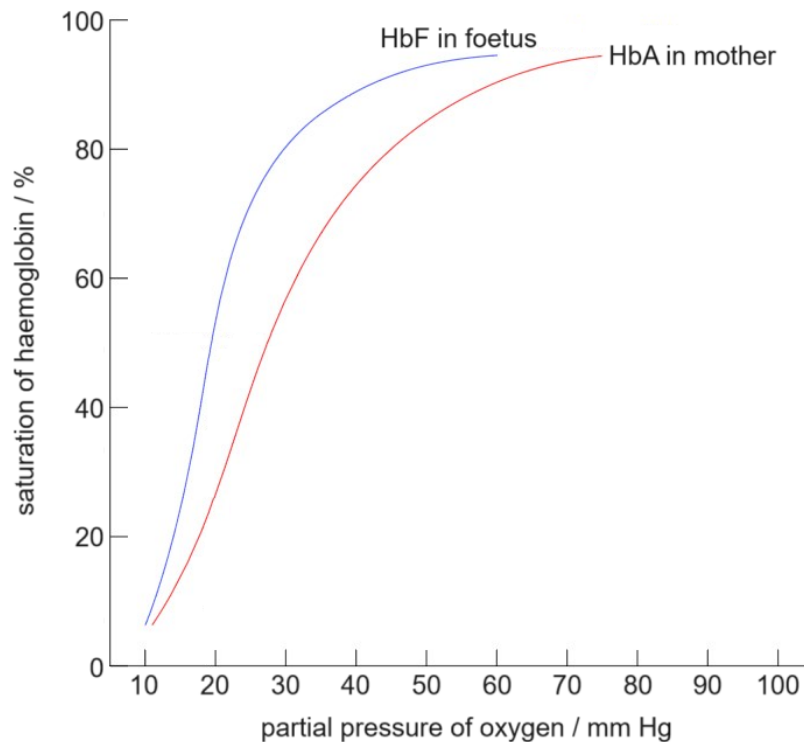


Fig. 1.3

With reference to Fig. 1.3,

- (i) compare the affinity of the two types of haemoglobin at 30 mm Hg of oxygen.

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 [1]

- (ii) suggest an advantage of the foetus expressing HbF.

.....
 [1]

- (f) HbA is made up of two α -chains and two β -chains, while HbF is made up of two α -chains and two γ -chains. After birth, the expression of the γ -chains is switched off, and the baby's body then begins to express the β -chains.

The regulation of expression of the γ -chains involves two proteins, BCL11a and ZBTB7a. They bind to promoter sequence of the γ -chain during the transition from foetal to adult haemoglobins. Disrupting the binding of these proteins is shown to increase HbF levels and is being developed as a therapeutic strategy for genetic blood disorders like sickle cell disease and β -thalassemia.

- (i) State the level of control of gene expression involving BCL11a and ZBTB7a proteins.

..... [1]

- (ii) Suggest a structural similarity between BCL11a protein and a general transcription factor.

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..... [1]

- (iii) Suggest how BCL11a and ZBTB7a proteins regulate the expression of the γ -chains.

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..... [1]

- (iv) Outline how cells can reduce the intracellular concentration of BCL11a and ZBTB7a proteins after they are synthesised.

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..... [2]

(g) Fig. 1.4 shows the effect of oxygen levels on the affinity of HbA to oxygen under normal conditions (solid line), as well as the effects of different conditions (dotted lines).

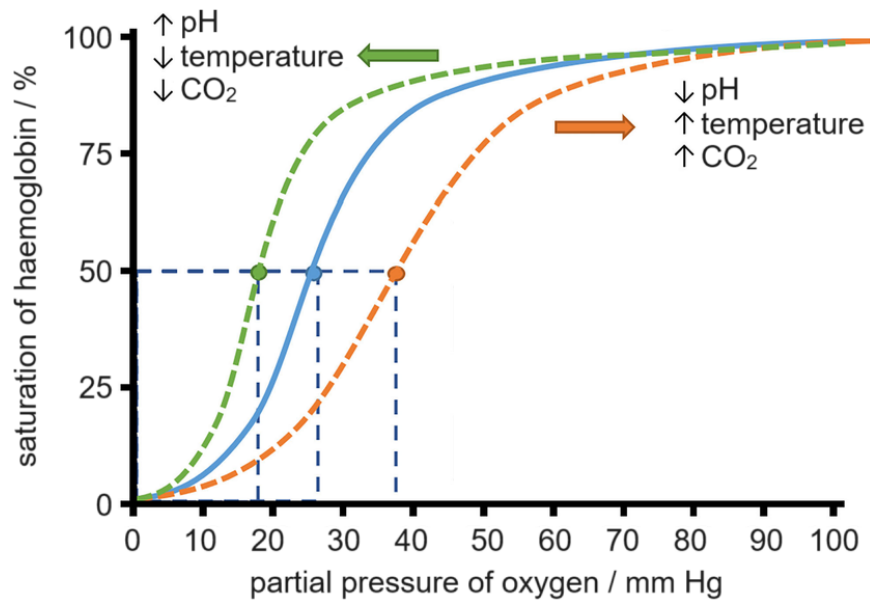


Fig. 1.4

With reference to Fig. 1.4,

- (i) explain the effect of increasing oxygen level on oxygen affinity of HbA in normal conditions.

[4]

(ii) suggest how HbA supplies oxygen to tissues undergoing high level of activities.

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..... [2]

[Total: 30]

- 2 From the 1920s until the 1970s, insulin obtained from animals was used to treat diabetes. Since the late 1970s, insulin has been produced by genetic engineering.

The production of human insulin by genetic engineering involves the use of plasmids and the bacterium *Escherichia coli*.

Multiple copies of the human insulin gene are mixed with cut plasmids. After that, some of the plasmids, now containing the human insulin gene, are taken up by host bacteria, which will lead to the expression of human insulin in these bacteria.

Fig. 2.1 shows:

- a cut plasmid and the human insulin gene
- a plasmid containing the human insulin gene after mixing.

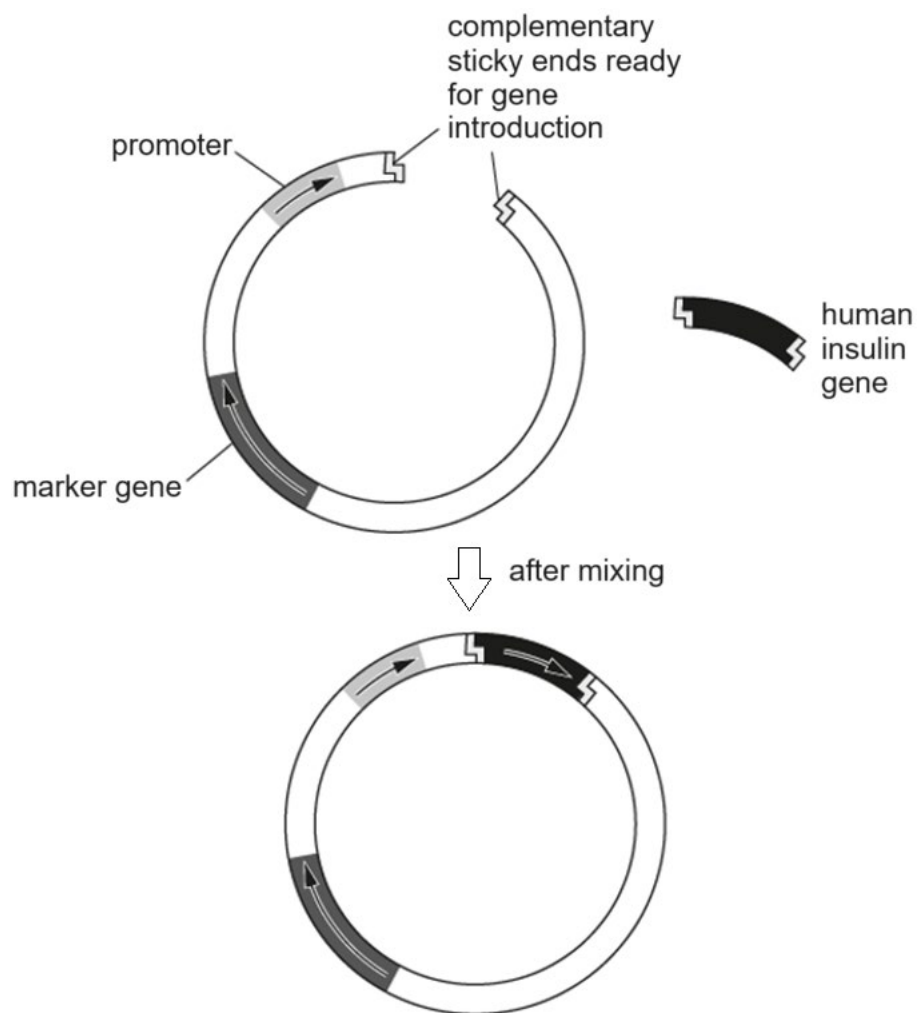


Fig. 2.1

(a) With reference to Fig. 2.1, explain why a promoter is often present on the plasmid.

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..... [1]

(b) Suggest the advantages of using genetic engineering to produce human insulin compared to insulin obtained from animals.

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..... [2]

(c) During early research, when the plasmid as shown in Fig. 2.1 was first introduced into the *E. coli*, non-functional human insulin was produced.

Explain why there was no functional insulin **and** suggest what improvement was needed in order for functional insulin to be expressed in *E. coli*.

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..... [3]

- (d) In addition to plasmids, the human insulin gene may also be packaged into bacteriophage particles for delivery into *E. coli*.

Fig. 2.2 shows direct plasmid uptake compared to bacteriophage-mediated delivery.

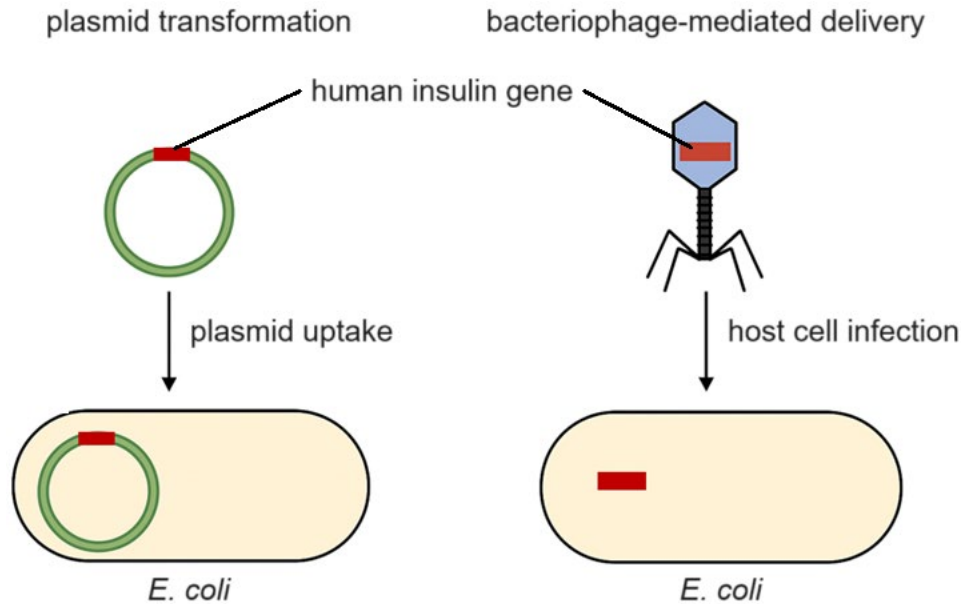


Fig. 2.2

State whether a virulent or temperate phage would be used **and** explain how it could be engineered to deliver the insulin gene into bacteria.

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..... [4]

[Total: 10]

Question 3 starts on page 14.

- 3 Bees are well known as the main pollinator of the world and are estimated to contribute to the pollination of 75% of all major food crops.

There have been warnings on the impacts of climate change on bees. The Inter-governmental Panel on Climate Change (IPCC) reported a projection of 3°C rise in surface air temperature by 2100 under the intermediate greenhouse gas emission scenario SSP2–4.5. However, it is projected to increase by 6°C under the worst-case emission scenario SSP5–8.5.

(a) Explain how greenhouse gas emission leads to the rise in surface air temperature.

.....
 [1]

(b) During winter (December to February), there are few flowers available for bees to forage, hence bees undergo an adaptation of hibernation referred to as 'overwintering'. During late fall (November), queen bees stop giving birth to forager bees and begin raising winter bees, which have larger body fat content. Once temperatures drop below approximately 10°C, the bees hibernate through winter and minimise heat loss by clustering inside their hive in a massive huddle. In early spring (March), these bees emerge from their colony in search for food.

To investigate the effects of climate change on the emergence of bees after overwintering, scientists subjected *Osmia bicornis*, a species of mason bee, to 3 different conditions:

- control – based on the daily temperatures reported for that day (used as the baseline for the other 2 conditions)
- SSP2–4.5 – 3°C higher than the baseline
- SSP5–8.5 – 6°C higher than the baseline

The results of the investigation are shown in Table. 3.1. The emergence timing is defined as the number of ordinal days since the 1st of January. The weight loss is defined as the percentage of body mass lost relative to the starting body mass measured upon hatching from their cocoons. Bees of similar starting body mass were selected for this investigation.

Table 3.1

	control			SSP2–4.5			SSP5–8.5		
variable (unit)	n	mean	std. error	n	mean	std. error	n	mean	std. error
emergence timing (ordinal days)	166	103	0.51	159	85.7	0.82	156	63.9	1
mean temperature at emergence (°C)	166	16.4	0.1	159	16.3	0.2	156	16	0.2
mean weight loss at emergence (%)	166	9.43	0.18	159	11	0.24	156	13.5	0.26

- (i) With reference to Table 3.1, discuss the impact of a 3°C rise in temperature on the population of bees.

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..... [4]

- (ii) Explain how the results in Table 3.1 highlight the importance of immediate efforts to reduce greenhouse gas emissions from human activities.

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..... [3]

- (c) Although many crops rely on insect pollination, only about 25% of global production does, as major staples like cereals do not depend on insects. Hence, should pollinators like bees become extinct, crop yield is expected to decline only by 5-8%.

Explain why it is still important to protect the bees from effects of climate change.

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..... [2]

[Total: 10]

Section B

Answer **one** question in this section.

Write your answers on the lined paper provided at the end of this Question Paper.

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 parts **(a)** and **(b)**, as indicated in the question.

- 4 (a)** Describe how insulin regulates blood glucose level. [13]

- (b)** Glucose serves as the primary respiratory substrate within cells. It undergoes a series of chemical reactions, primarily in the cytoplasm and mitochondria, to generate ATP, the main energy currency of the cell. This process, known as cellular respiration, involves both anaerobic (without oxygen) and aerobic (with oxygen) stages.

Discuss, with named examples, the importance of conformation in respiration. [12]

[Total: 25]

- 5 (a)** Describe how the genomes of viruses are inherited through the reproductive cycle of a lambda phage. [13]

- (b)** Proteins perform a vast range of functions in cells, from catalysing metabolic reactions to providing structural support. In order to become functional, a protein must be synthesised accurately, folded correctly, and sometimes modified after translation.

Discuss, with named examples, the involvement of covalent bonds in the synthesis of a functional protein. [12]

[Total: 25]

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