NANYANG JUNIOR COLLEGE
JC 2 Preliminary Examination
Higher 2

CANDIDATE NAME

CLASS

BIOLOGY

9744/02

Paper 2 Structured Questions

14 September 2023

Candidates answer on the Question Paper.

No Additional Materials are required.

2 hours

READ THESE INSTRUCTIONS FIRST

Write your name and CT on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions in the spaces provided on the Question Paper

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 no use appropriate units.

At the end of the examination, fasten all your work securely together.

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

For Examiner's Use	
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9	
10	
Total	

This document consists of **24** printed pages.

[Turn over

Answer **all** the questions.

1 Polysaccharides, such as glycogen, are composed of thousands of monomers.

Oligosaccharides are carbohydrates that contain three to ten monomers in their chain.

Nystose is one example of an oligosaccharide. The structure of nystose is shown in Fig. 1.1.

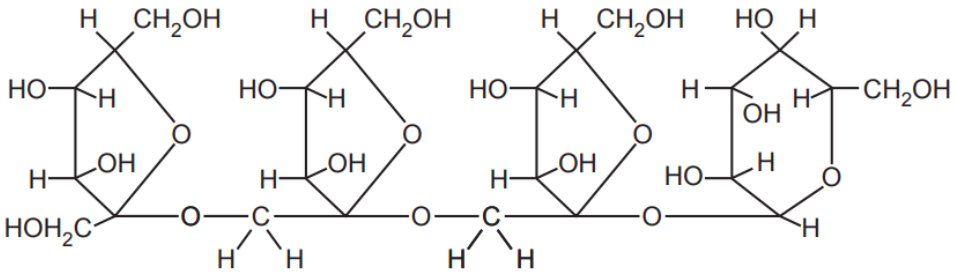

Fig 1.1

(a) State three differences between the structures of nystose and glycogen, **other** than the number of monomers in the molecules.

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[3]

(b) One of the enzymes involved in glycogen synthesis is glycogen synthase. The monomer of the glycogen polymer is α-glucose.

(i) Draw the ring form of α-glucose in the space provided.

(ii)

[2]

(iii) The gene coding for glycogen synthase is known as *GYS1*. Glycogen synthase catalyses the formation of a covalent bond between two α-glucose molecules during glycogen synthesis.

Name the type of bond formed.

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[1]

(iv) Glycogen branching enzyme is another enzyme that is required for glycogen synthesis.

Suggest why glycogen branching enzyme is needed in addition to glycogen synthase.

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[1]

(c) Table 1.1 shows three functions of cell structures that are involved in the synthesis of glycogen synthase.

Complete Table 1.1 by naming the cell structure that carries out the function listed.

Table 1.1

function	name of cell structure
assembles ribosomes for polypeptide synthesis	
synthesizes ATP to provide a supply of energy for the transcription of *GYS1*	
folds and modifies synthesized polypeptide to produce functioning glycogen synthase	

[3]

[Total: 10]

2 There are a number of mutations affecting the production of fetal haemoglobin, HbF, and normal adult haemoglobin, HbA.

- The Hb^A allele codes for the normal β-globin polypeptide of haemoglobin.
- The Hb^S allele, caused by a base substitution mutation, codes for an abnormal β-globin polypeptide.

The abnormal haemoglobin molecules (HbS) form fibres in low partial pressures of oxygen (pO_2). The fibres cause red blood cells to become sickle shaped and the cells can block blood capillaries.

Individuals with adult haemoglobin molecules that are all abnormal (HbS) have sickle cell anaemia. This is a painful chronic condition that can be life-threatening.

(a) Explain why this mutation causes the HbS to form fibres.

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[2]

(b) Fetal haemoglobin, HbF, is produced by the fetus until just before birth, when adult haemoglobin begins to be made.

By the age of six months, adult haemoglobin has replaced most of the HbF. This change occurs when the genes coding for HbF are switched off and the genes coding for adult haemoglobin are switched on.

- A base substitution, British-198, causes fetal haemoglobin to continue to be produced.
- Normally by the age of six months, the concentration of HbF reduces to less than 1% of total haemoglobin.
- With the British-198 mutation, the concentration of HbF may be as high as 20% of total haemoglobin in an adult.
- HbF has a higher affinity for oxygen at low pO_2 than adult haemoglobin. Individuals who have both sickle cell anaemia and British-198 mutation have reduced symptoms of sickle cell anaemia.

Suggest why having the British-198 mutation reduces the symptoms of sickle cell anaemia.

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[2]

(c) Gel electrophoresis can be carried out to test individuals for the different versions of haemoglobin: HbA, HbS and HbF.

- A buffer with alkaline pH is used to make all haemoglobin molecules negatively charged.
- HbS molecules have an additional positive charge compared to HbA.

(i) Describe and explain how gel electrophoresis is used to diagnose sickle cell anaemia.

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[4]

(ii) Four individuals had their haemoglobin analysed by gel electrophoresis. One of the individuals was heterozygous for the Hb^A and Hb^S alleles and had a condition known as sickle cell trait (SCT).

Some of the results are shown in Fig. 2.1. In Fig. 2.1, lane 1 and lane 5 are complete.

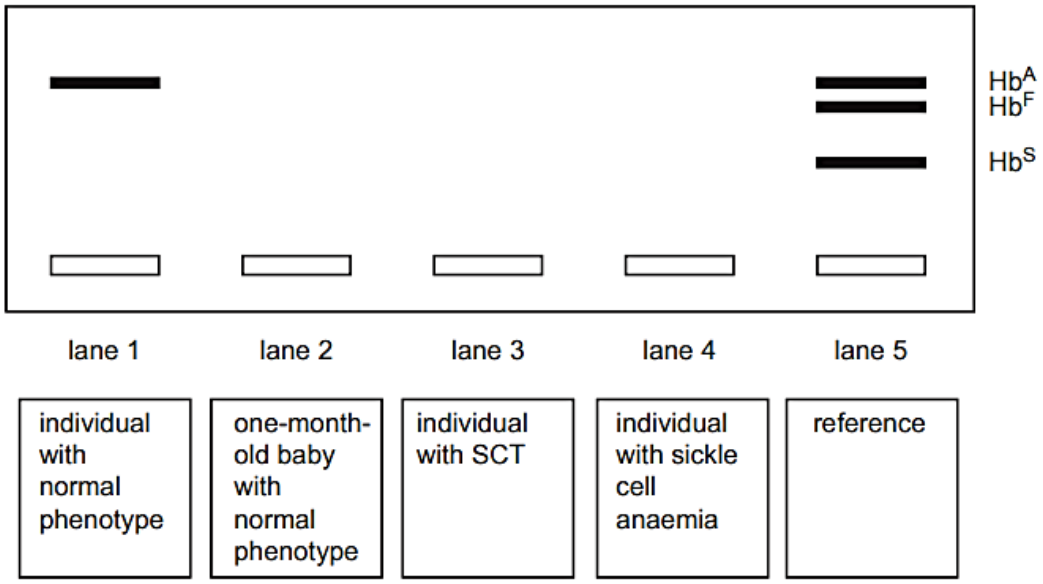

Fig. 2.1

Predict the results for the individuals analysed, by adding bands to lanes 2, 3 and 4 on Fig. 2.1. [2]

[Total: 10]

3 **(a)** The house mouse, *Mus musculus*, has a diploid number of 40 chromosomes. Fig. 3.1 shows 6 of these chromosomes.

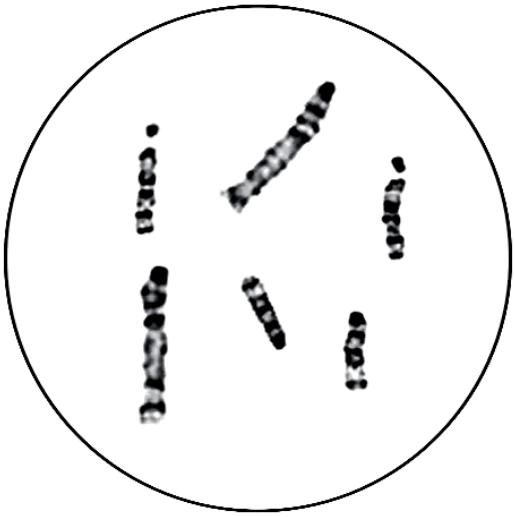

Fig. 3.1

Identify **one** pair of homologous chromosomes on Fig. 3.1 by drawing circles around two chromosomes. [1]

(b) Fig. 3.2 shows the banding pattern of chromosome pair 11 of *M. musculus*. The banding pattern is obtained by staining.

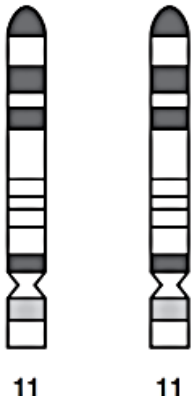

Fig. 3.2

(i) Explain why chromosomes, such as those in Fig. 3.2, are described as a homologous pair.

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[3]

(ii) State the number of chromosomes that are present in *M. musculus* spermatozoa.

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[1]

(c) *M. musculus* produces gametes by meiosis. These gametes are genetically different.

There is random fusion of gametes at fertilisation.

(i) Explain why meiosis is important in the life cycle of *M. musculus*, **apart from** producing genetically different gametes.

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[2]

(ii) Explain how the random fusion of gametes leads to the expression of rare, recessive alleles.

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[2]
[Total: 9]

4 (a) Cats with black fur or white fur are common in Europe whereas cats with brown fur are less common.

A gene, coding for an enzyme involved in pigment production, has two alleles.

- The dominant allele, **B**, results in black fur.
- The recessive allele, **b**, results in brown fur.

A second gene can affect fur colour.

- The dominant allele, **A**, prevents pigment production, resulting in a cat with white fur.
- The recessive allele, **a**, has no effect on fur colour.

The two genes are on different pairs of autosomes.

(i) Use a genetic diagram to show how a cross between two cats, heterozygous at both loci, can produce offspring with three different colours: white, black and brown.

State the expected ratio of the different coloured offspring.

[4]

(ii) Suggest how the presence of allele **A** prevents pigment production.

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[3]

(b) Apart from having different fur colour, a variety of domestic cat does not have a tail. This condition is controlled by a single gene with two alleles. These alleles are

- 'with tail'
- 'without tail'

Table 4.1 shows the results of four crosses between cats with tails and cats without tails. Each male was crossed with several females.

Table 4.1

parental phenotype			offspring phenotype			
			male		female	
cross	**male**	**females**	**with tail**	**without tail**	**with tail**	**without tail**
1	without tail	without tail	21	32	19	40
2	with tail	with tail	65	0	70	0
3	with tail	without tail	40	25	25	36
4	without tail	with tail	35	27	38	36

(i) Explain how the results of **crosses 1 and 2** show that the allele 'without tail' is dominant.

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(ii) Explain how the results of **crosses 3 and 4** show that the gene for this condition is not sex linked.

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[3]

[Total: 10]

5 Different signalling pathways generate calcium (Ca^{2+}) signals which regulate many cellular functions such as smooth muscle contraction.

Fig. 5.1 shows the inositol trisphosphate/calcium (IP_3/Ca^{2+}) signalling pathway.

Phosphatidyl inositol-bisphosphate (PIP_2) is hydrolysed into IP_3 and diacylglycerol (DAG) by phospholipase C.

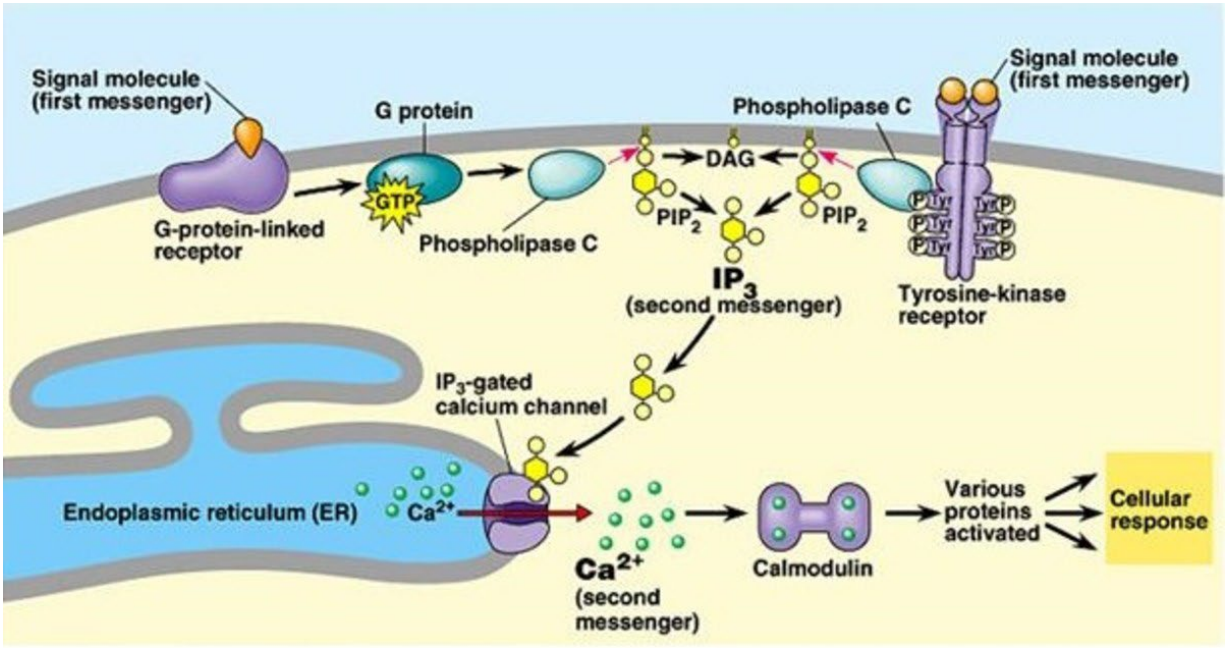

Fig 5.1

(a) With reference to Fig. 5.1,

(i) describe the structural differences of the two receptors.

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[2]

(ii) define second messengers and explain their role in signal transduction.

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(iii) outline two stages where signal amplification may occur.

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[2]

(iv) Dysregulation of the IP_3/Ca^{2+} signalling pathway can lead to many different possible human diseases. Hypertension is caused by increased smooth muscle contraction due to enhanced IP_3/Ca^{2+} signalling.

Suggest the type of mutation in phospholipase C that could lead to hypertension.

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[2]

(b) Calcium binding by calmodulin exhibits considerable cooperativity, making calmodulin an unusual example of a monomeric (single-chain) cooperative-binding protein with four calcium-binding sites.

Fig. 5.2 shows calmodulin without calcium (left), and calmodulin with calcium (right). Sites that bind target proteins are indicated by the stars (*).

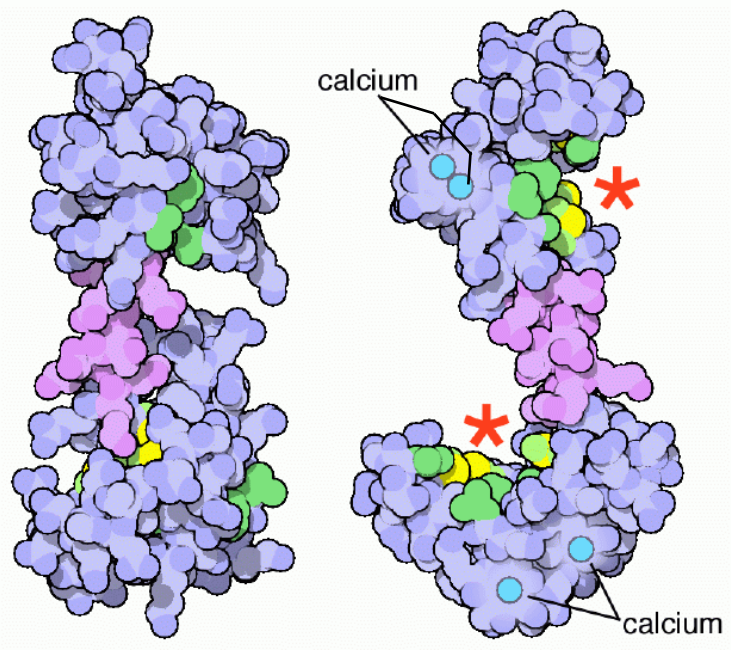

Fig. 5.2

With reference to Fig. 5.2, suggest how cooperative binding of Ca^{2+} ions to calmodulin is necessary for calmodulin activity.

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[2]

[Total: 10]

6 The diagram below shows the structure of Human Immunodeficiency Virus (HIV).

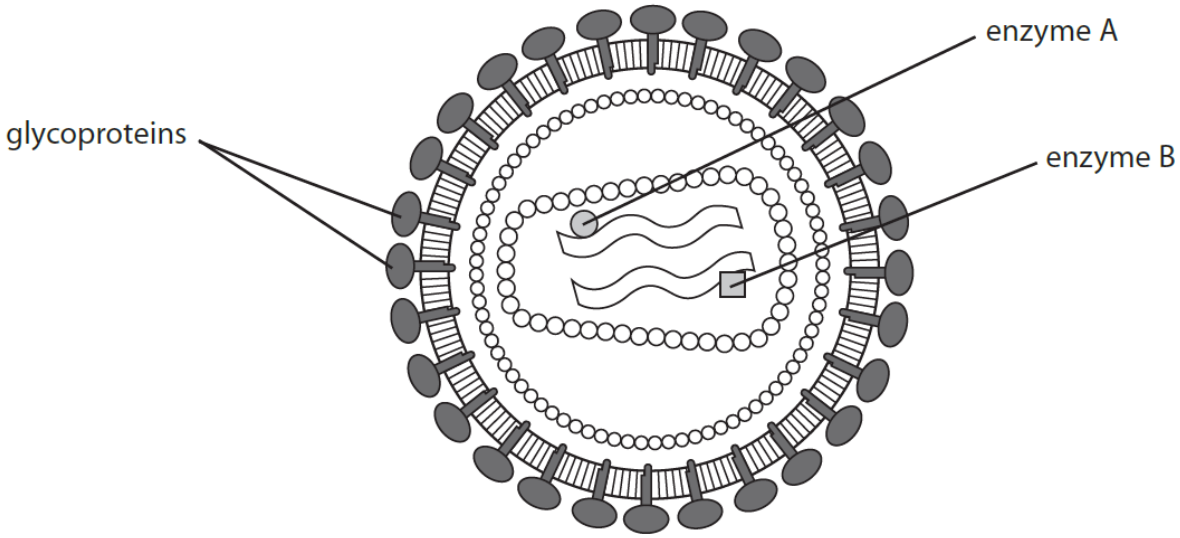

Fig. 6.1

(a) State how the genetic material in HIV differs from the genetic material in the bacterium *Mycobacterium tuberculosis* that causes TB.

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(b) Some anti-viral drugs prevent HIV entering the host cells.

Suggest how these anti-viral drugs could prevent HIV from entering the host cells.

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(c) Describe how the enzymes shown in the diagram are involved in HIV infection.

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[Total: 10]

7 (a) The results of investigations carried out on mitochondria show how the structure of a mitochondrion is related to its role in aerobic respiration.

- Intact mitochondria (not damaged) were removed from cells.
- A technique was used to remove the outer mitochondrial membrane, leaving the inner membrane intact.
- The inner mitochondrial membrane was separated from the contents of the matrix so that both could be analysed.

(i) The removal of the outer membranes of mitochondria involves placing the organelles in pure water. This results in the rupture (bursting) of the outer membrane. The inner mitochondrial membrane does not rupture and remains intact.

Suggest **and** explain why the inner membrane of a mitochondrion remains intact when the organelle is placed in pure water.

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(ii) Name **three** molecules, other than coenzymes, that are found in the mitochondrial matrix **and** explain their role in aerobic respiration.

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(iii) The inner membrane contains a very high proportion of the molecule cardiolipin. Cardiolipin makes the membrane impermeable to some ions.

Suggest why the inner membrane contains a very high proportion of cardiolipin.

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[1]

(b) In further experiments it was found that, in an intact mitochondrion:

- there is a membrane potential across the inner mitochondrial membrane, with the matrix having a negative charge
- the transport of ATP, ADP and inorganic phosphate (P_i) is driven by the membrane potential across the inner membrane.

Fig. 7.1 shows the location of some inner membrane carrier proteins.

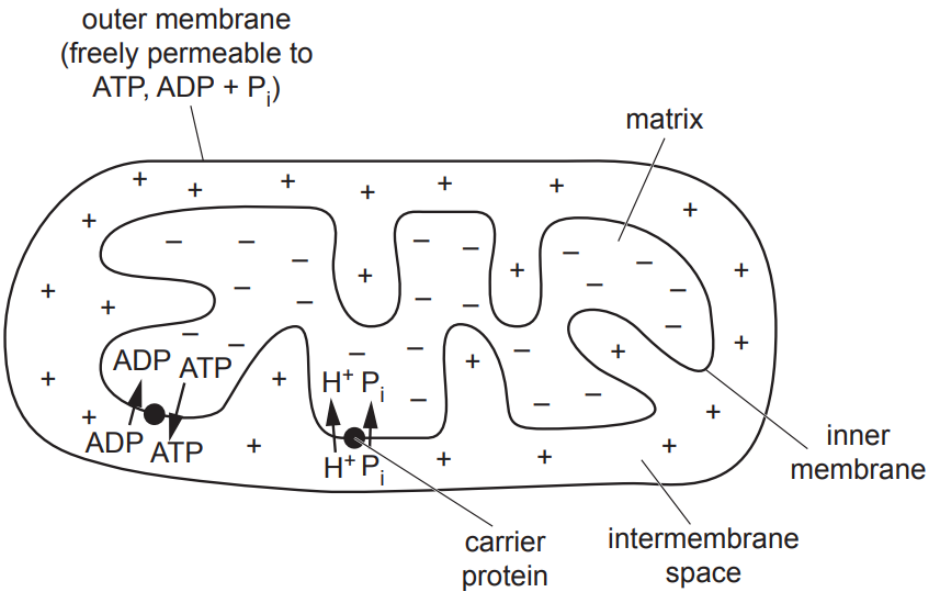

Fig. 7.1

(i) Suggest **and** explain how P_i is transported across the inner membrane of the mitochondrion into the matrix.

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(ii) Suggest the advantages of linking ATP transport to ADP transport across the inner membrane of the mitochondrion.

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[Total: 10]

8 Arabinose is a monosaccharide containing five carbon atoms. The arabinose operon, also known as the *araBAD* operon, is an operon required for the breakdown of arabinose in the bacteria, *Escherichia coli*.

The *araBAD* operon contains three structural genes: *araB*, *araA*, *araD*, which code for three different enzymes that are required for the breakdown of arabinose. Other than the promoter of the structural genes, there are other regulatory regions of the operon including the CAP binding site and the operator, as shown in Fig. 8.1.

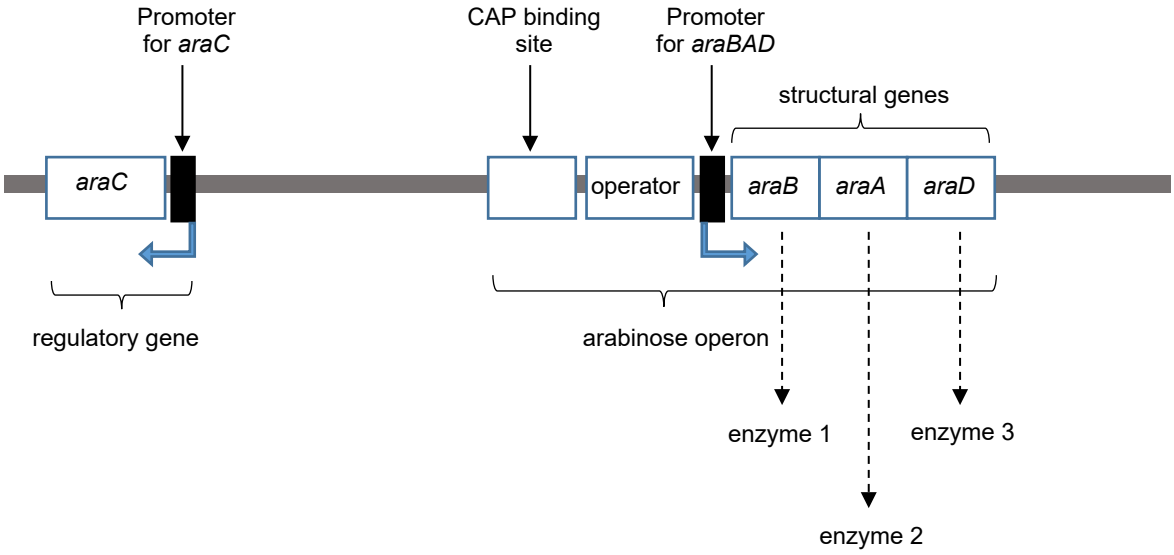

Fig. 8.1

When the cell is starved of glucose, the CAP-cAMP complex binds to the CAP binding site resulting in positive regulation of the *araBAD* operon.

The regulatory protein, araC protein, is coded for by the regulatory gene, *araC*. In the presence of arabinose, arabinose will bind to the araC protein forming the arabinose-araC protein complex. The arabinose-araC protein complex will then bind to the operator of *araBAD* operon, recruiting RNA polymerase to the *araBAD* promoter. When there is no arabinose, araC protein binds to the operator of *araBAD* operon in a manner that prevents RNA polymerase from binding to the *araBAD* promoter.

(a) With reference to Fig. 8.1,

(i) explain the term 'operon'.

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[2]

(ii) explain if the operon is an inducible or a repressible operon.

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(iii) describe the positive regulation of gene expression in the *araBAD* operon.

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[3]

(b) Fig. 8.2 shows the changes in the activity of enzymes in normal *E. coli* cells that synthesise tryptophan and break down arabinose after the addition of tryptophan and arabinose.

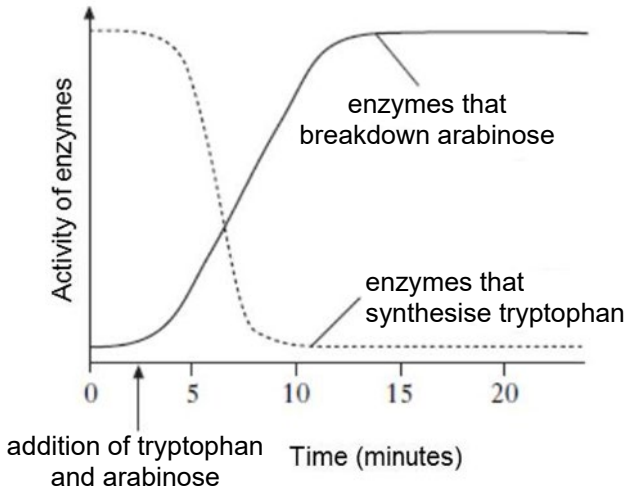

Fig. 8.2

In a scientific investigation, the *trp* operator sequence in the *E. coli* was altered such that it was no longer complementary to the DNA-binding site on the trp repressor proteins. The *araC* coding sequence was also altered such that the araC protein was no longer complementary to arabinose.

Describe and explain the effects of the mutations on the activity of enzymes that breakdown arabinose and enzymes that synthesise tryptophan in the altered *E. coli* upon the addition of

(i) arabinose,

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(ii) tryptophan.

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[2]

[Total: 11]

9 The evolutionary origin of the four-legged amphibians (such as frogs and toads) from fish has been the subject of much debate for many years.

Among living fish, the rarely-caught coelacanth and the lungfish are thought to be most closely related to these amphibians.

Samples of blood were taken from two coelacanths that were captured recently near Comoros.

The amino acid sequences of the α and β chains of coelacanth and lungfish haemoglobin were compared with the known sequences of amphibian adults and their aquatic larvae (tadpoles). Organisms with more matches in the amino acid sequence of a polypeptide chain share a more recent common ancestor than those with fewer matches.

The comparisons with three species of amphibians, *Xenopus laevis* (Xl), *X. tropicana* (Xt) and *Rana catesbeiana* (Rc) are shown in Table 9.1.

Table 9.1

		percentage of matches of amino acid sequence					
		species of amphibian adults			**species of amphibian larvae (tadpoles)**		
	fish species	*Xl*	*Xt*	*Rc*	*Xl*	*Xt*	*Rc*
α chains	coelacanth	42.0	47.5	no data	45.4	42.6	48.2
	lungfish	40.4	42.1	no data	40.7	39.0	37.9
β chains	coelacanth	42.1	43.2	40.7	52.1	52.1	58.2
	lungfish	44.1	45.9	41.4	47.3	45.9	48.6

(a) (i) Explain whether or not the information in Table 9.1 supports the suggestion that coelacanths and amphibians share a more recent common ancestor than do lungfish and amphibians.

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(ii) Suggest why adults and tadpoles of the same species of amphibian have different amino acid sequences in their haemoglobin.

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[2]

(b) Coelacanth haemoglobin has a very high affinity for oxygen, suggesting that coelacanths, which have been captured at depths of between 200 m and 400 m, live in water that has a low concentration of oxygen.

Explain how an environmental factor, such as the low concentration of oxygen in deep water, can act:

(i) as a stabilising force in natural selection.

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[2]

(ii) as an evolutionary force in natural selection.

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[2]

[Total: 10]

10 Table 10.1 shows different stages in the life cycle of a female *Aedes aegypti* mosquito, which is responsible for the spread of dengue.

Table 10.1

Stage	Aquatic	Terrestrial	Able to transmit dengue virus
Eggs			
Larva			
Pupa			
Adult			

(a) (i) Place a tick (✓) in appropriate boxes that applies to each stage. [2]

(ii) Despite the protection offered by the antibodies in the primary infection, the recurrent exposure to DENV, particularly of a different serotype, can result in the manifestation of severe dengue fever.

Explain why the infection by a different serotype can result in severe dengue fever.

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[3]

(b) Insects are the most dominant group of organisms on the planet in terms of species richness, abundance, and biomass. Global warming has a marked influence on the physiology of insects, including *A. aegypti*.

(i) Outline how increases in temperature as a result of global warming can impact insects such as *A. aegypti*.

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[3]

(ii) The male *A. aegypti* mosquitoes feed on nectar instead of blood and is considered an insect pollinator.
Using this information and your answers in **(b)(i)**, explain how global warming may affect global food security.

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[2]
[Total: 10]