Anglo-Chinese Junior College

JC2 Biology Preliminary Examination
Higher 2

CANDIDATE NAME		FORM CLASS	
TUTORIAL CLASS		INDEX NUMBER	

BIOLOGY **9744/03**

Paper 3 Long Structured and Free-response Questions 28 August 2024
2 hours

Additional Materials: Free-response Question Answer Booklet

READ THESE INSTRUCTIONS FIRST

Write your Name, Class and Index number 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 spaces provided on the separate Free-response Question 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 Examiners' use only	
1	/ 30
2	/ 10
3	/ 10
4 / 5	/ 25
Total	/ 75

Section A

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

1 Lactose is the main carbohydrate found in mammalian milk and is important for meeting the nutritional needs of an infant. Lactose is a disaccharide of glucose and galactose, and has been considered healthier than other disaccharides such as sucrose and maltose.

Table 1.1 shows the glycaemic index of lactose, sucrose, maltose and glucose. The glycaemic index measures the rise in blood glucose levels two hours after ingestion of the measured substance.

Table 1.1

carbohydrate	glycaemic index
lactose	46
sucrose	65
maltose	105
glucose	100

(a) Suggest explanations for the following two observations:

(i) the glycaemic index of lactose is lower than glucose

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(ii) the glycaemic index of lactose is lower than sucrose.

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Lactose intolerance is a condition which occurs due to the lack of the enzyme lactase in the small intestines. In humans, lactase is encoded by the *LCT* gene on chromosome 2.

In most of the human population, lactose intolerance occurs as the expression of the *LCT* gene declines past the infant stage due to a reduced reliance on milk. Adults with lactose intolerance will present with gastrointestinal symptoms when milk is consumed, and the condition worsens with age.

It is hypothesised that methylation of the promoter of the *LCT* gene is involved in the age-related decrease in gene expression.

(b) Explain how methylation of the promoter may lead to a decrease in *LCT* gene expression.

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The extent of methylation of the *LCT* gene was analysed in 48 individuals between the ages of 8 to 23 and of a largely European descent. Fig. 1.1 records the percentage methylation of the *LCT* gene and the lactase activity measured in each individual.

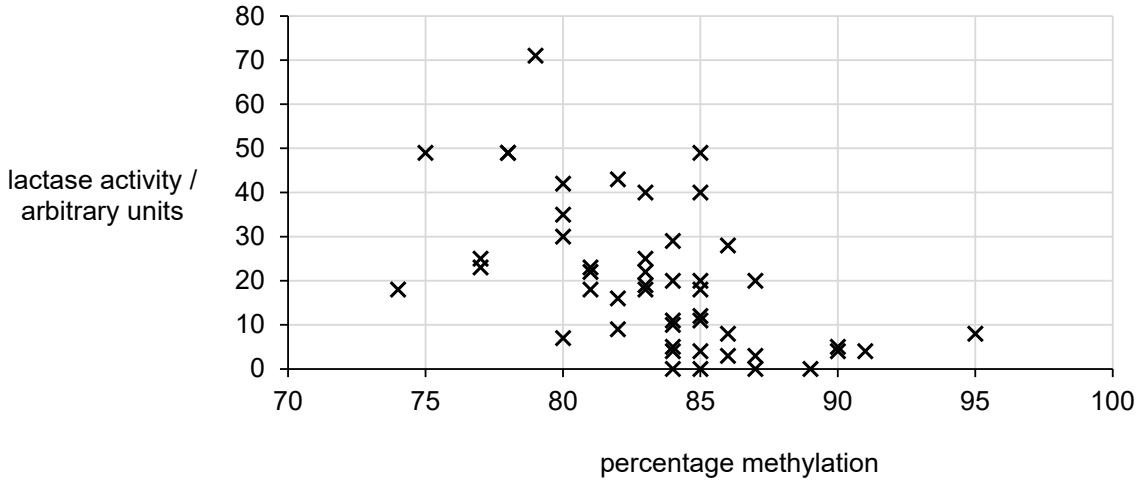

Fig. 1.1

(c) **(i)** Draw a line of best fit on Fig. 1.1. [1]

(ii) Discuss whether the results in Fig. 1.1 support the hypothesis that methylation is involved in the age-related decline in *LCT* gene expression.

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In some individuals, *LCT* gene expression continues throughout adulthood, allowing the digestion of lactose in milk. These adult individuals are said to be lactase persistent and can tolerate the consumption of milk.

Genomic studies have identified the *MCM6* gene to be involved in the regulation of the expression of the *LCT* gene. Scientists made these observations of the two genes, represented in Fig. 1.2:

- *MCM6* gene is located upstream of the *LCT* gene on the same chromosome
- *MCM6* gene contains 15 introns
- mutations in specific DNA sequences within two of the introns have been found in individuals who are lactase persistent
- regulatory proteins can bind to these specific DNA sequences that have undergone mutations
- these regulatory proteins control the transcription of the *LCT* gene.

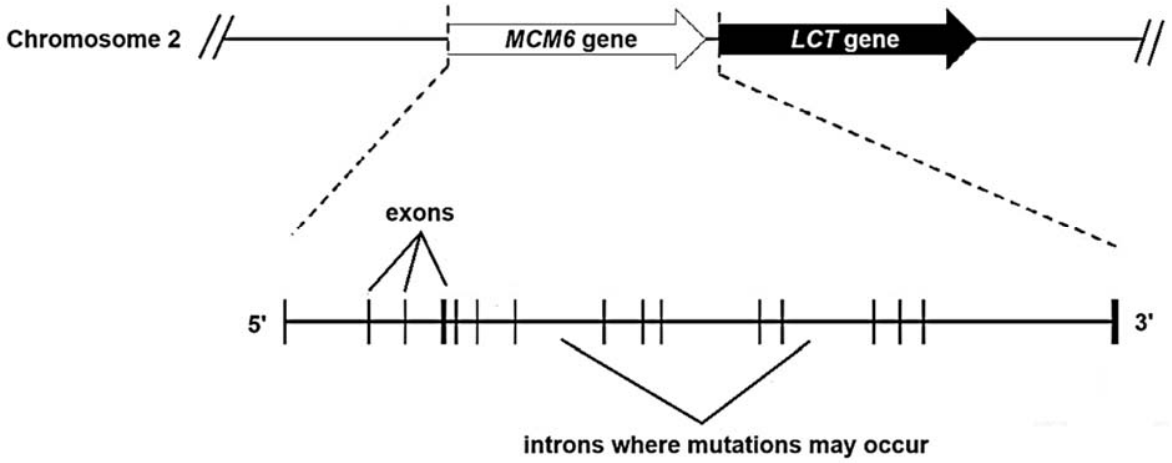

Fig. 1.2

(d) (i) Suggest how mutations to specific DNA sequences in the introns of the *MCM6* gene may result in the lactase persistent condition.

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[Turn over

(ii) Describe one other mechanism by which introns may play a role in the regulation of gene expression.

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Lactose in milk cannot be directly absorbed at the small intestines. It needs to be hydrolysed by intestinal enzymes before the resulting monosaccharides can be taken up.

When a person with lactose intolerance consumes milk, the unhydrolysed lactose passes into the large intestines, where it is metabolised by bacteria in the large intestines using a mechanism similar to that in yeast under low oxygen conditions. Gas produced through bacteria metabolism of lactose results in bloating and abdominal discomfort. Other metabolic products and any unabsorbed sugars in the lumen of the large intestines also stimulate a watery diarrhoea.

A summary of these effects is shown in Fig. 1.3.

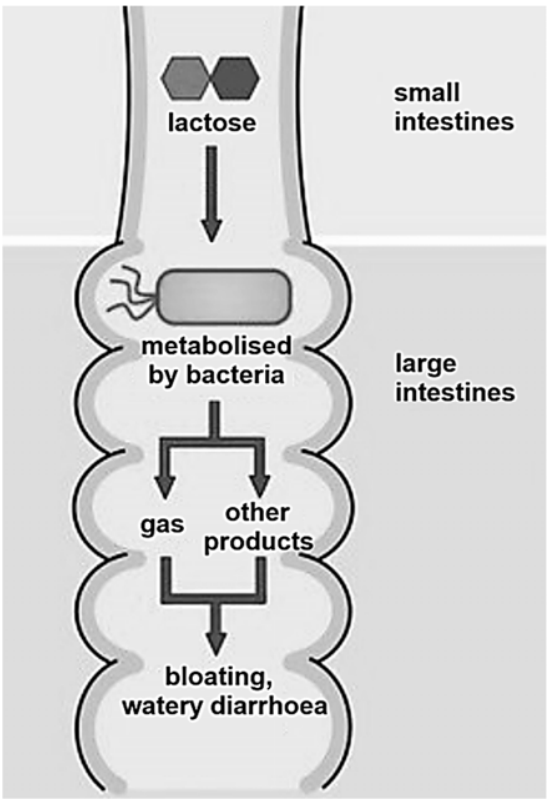

Fig. 1.3

(e) **(i)** Suggest how unhydrolysed lactose may be metabolised by bacteria in the large intestines to produce gas.

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(ii) Explain how the presence of metabolic products and unabsorbed sugars in the lumen of the large intestines may lead to water diarrhoea.

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Glucose taken up by cells will undergo glycolysis in the first phase of respiration. Glycolysis is a multi-step process which converts glucose into pyruvate.

Aldolase is one of the enzymes involved in glycolysis which catalyses the splitting of respiratory substrates into three-carbon molecules. It is encoded by the *ALDOA* gene on chromosome 16. A loss-of-function mutation in both copies of this gene results in a condition characterised by haemolytic anaemia, or the lysis of red blood cells.

Pyruvate kinase is another enzyme in glycolysis which catalyses the transfer of phosphate from a triose phosphate to ADP, forming pyruvate and ATP. The *PKM* gene on chromosome 1 codes for this enzyme, and a loss-of-function mutation in both copies of this gene similarly results in haemolytic anaemia.

(f) **(i)** Suggest why the lack of membrane-bound organelles in mature red blood cells make them more susceptible to the effects of either mutation.

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(ii) A man who is a carrier for the mutant alleles of both the *ALDOA* and *PKM* genes is married to a woman who is also a carrier for the mutant alleles of both genes. Both individuals do not suffer from haemolytic anaemia.

Using a genetic diagram, show the probability that their offspring will suffer from haemolytic anaemia.

[5]

[Total: 30]

[Turn over

2 *Mycobacterium tuberculosis* is the organism which causes tuberculosis, a lung infection that is difficult to treat.

Fig. 2.1 shows the structure of a tubercle, a mass of cells found in an infected lung, from which the name of the disease is derived. Each tubercle is surrounded by fibroblasts, which are cells responsible for forming connective tissue that makes up the boundary of the tubercle.

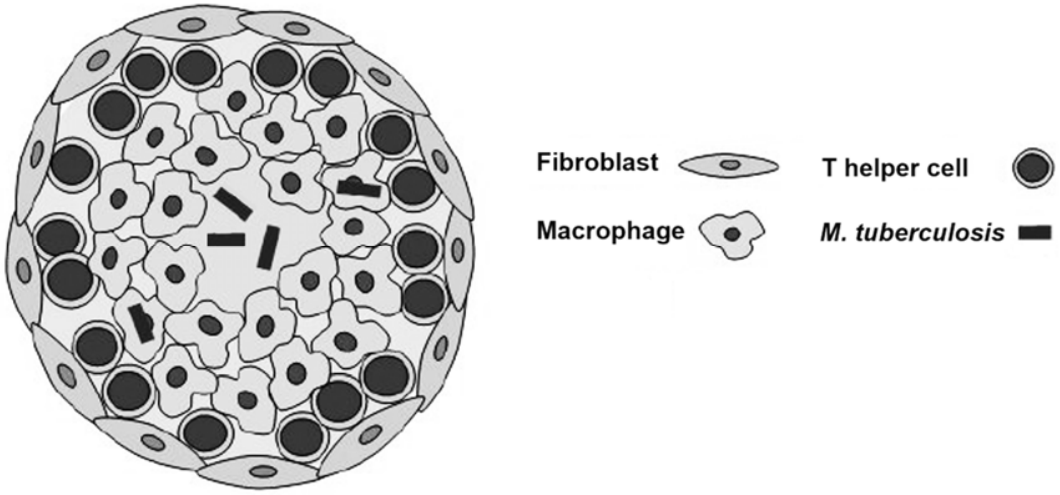

Fig. 2.1

(a) With reference to Fig 2.1, explain how a tubercle is formed during the infection.

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Vaccines can be used to protect a population against a disease, such as tuberculosis, that has the potential of spreading widely.

The effectiveness of a vaccine containing live attenuated bacteria was compared with another vaccine containing inactivated bacteria. Individuals injected with each type of vaccine are monitored for one year after vaccination. The number of individuals who contracted the disease within one year is shown in Table 2.1.

Table 2.1

type of vaccine	live attenuated vaccine	inactivated vaccine
number of individuals monitored	3916	3936
number of individuals contracting the disease within one year	53	93
percentage of individuals contracting the disease within one year		

(b) (i) Complete Table 2.1 by calculating the percentage of individuals contracting the disease within one year of receiving each type of vaccine. [1]

(ii) Using the results in Table 2.1, calculate how much more likely individuals who received the inactivated vaccine will contract the disease within one year compared to individuals who received the live attenuated vaccine.

Provide your answer as a percentage. Show your workings.

Individuals who received the inactivated vaccine are …… more likely to contract the disease compared to individuals who received the live attenuated vaccine. [1]

(iii) Suggest why the live attenuated vaccine has a higher effectiveness compared to the inactivated vaccine in protecting against disease.

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[Turn over

(iv) Describe the advantages of inactivated vaccines over live attenuated vaccines.

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[Total: 10]

3 Viral dengue disease, also known as dengue fever, is caused by an infection by the dengue virus.

(a) Table 3.1 compares some features of the dengue virus with that of the influenza virus, another enveloped virus which infects humans.

Complete Table 3.1 with the features of the influenza virus.

Table 3.1

feature compared	dengue virus	influenza virus
type of genetic material	single-stranded RNA	
sense of genome	positive-sense	
envelope proteins	E and M proteins	
mechanism of viral entry into host cells	receptor-mediated endocytosis	
mechanism of viral release from host cells	exocytosis	

[3]

In most individuals, symptoms of dengue fever are mild and recovery takes two to seven days. In a small proportion of cases, the disease develops into a more severe form known as dengue haemorrhagic fever. Dengue haemorrhagic fever can be fatal.

Two indicators are measured from the blood tests of patients with milder dengue fever (DF) and dengue haemorrhagic fever (DHF):

- Haematocrit is a percentage of the volume occupied by red blood cells in whole blood. A change in the volume of blood plasma (the cell-free component of blood), but without a change in the volume of red blood cells, will change the haematocrit.
- Platelet count measures the concentration of platelets in whole blood.

The two blood indicators, represented as the mean ± standard deviation, are shown in Table 3.2.

Table 3.2

indicator	patients with DF (number of patients = 11)	patients with DHF (number of patients = 8)
haematocrit / %	37.0 ± 0.1	39.7 ± 2.0
platelet count / x 10^4 mm^{-3}	10.9 ± 0.7	2.6 ± 0.3

[Turn over

(b) (i) A *t*-test can be used to determine whether there is any significant difference in each of the two blood indicators between patients with DF and patients with DHF.

Calculate the value of *t* for each blood indicator and the number of degrees of freedom, using these formulae:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} \qquad \nu = n_1 + n_2 - 2$$

key to symbols

s = standard deviation
$\bar{x}$ = mean
n = sample size (number of observations)
ν = degrees of freedom

Show your working.

[3]

(ii) Table 3.3 shows the critical values for t at several different probabilities and degrees of freedom.

Table 3.3

degrees of freedom	probability, p			
	0.5	0.1	0.05	0.01
1	1.00	6.31	12.71	63.66
2	0.82	2.92	4.30	9.92
3	0.76	2.35	3.18	5.84
4	0.74	2.13	2.78	4.60
5	0.73	2.02	2.57	4.03
6	0.72	1.94	2.45	3.71
7	0.71	1.89	2.36	3.50
8	0.71	1.86	2.31	3.36
9	0.70	1.83	2.26	3.25
10	0.70	1.81	2.23	3.17
11	0.70	1.80	2.20	3.11
12	0.70	1.78	2.18	3.05
13	0.69	1.77	2.16	3.01
14	0.69	1.76	2.14	2.98
15	0.69	1.75	2.13	2.95
16	0.69	1.75	2.12	2.92
17	0.69	1.74	2.11	2.90
18	0.69	1.73	2.10	2.88
19	0.69	1.73	2.09	2.86
20	0.69	1.72	2.09	2.85

Use Table 3.3 and your answers to **(b)(i)** to decide whether there is any significant difference in each of the two blood indicators between patients with DF and patients with DHF.

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[Turn over

(iii) Explain what the results indicate about the symptoms of dengue haemorrhagic fever (DHF).

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[Total: 10]

Section B

Answer **one** question in this section.

Write your answers in the spaces provided on the separate Free-response Question Answer Booklet.

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 the mode of action of insulin in the regulation of blood glucose concentration. [15]

(b) "The future of medical therapy in the treatment of diseases solely depends on finding enzyme inhibitors that targets pathways involved in cell signalling."

Discuss the validity of this statement. [10]

[Total: 25]

5 **(a)** With named examples, outline how environmental factors can cause cancer and explain why it is often challenging to cure cancer. [15]

(b) Discuss whether cancer could act as a selection pressure in the evolution of humans by natural selection. [10]

[Total: 25]

—————— End of Paper ——————