YISHUN INNOVA JUNIOR COLLEGE
JC2 PRELIMINARY EXAM
Higher 2

NAME **ANSWERS**

INDEX NO | CG

BIOLOGY

9744/03

Paper 3 Long Structured and Free-Response Questions

15 Sep 2023

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, highlighters, glue or correction fluid/tape.

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 Question Paper.
Indicate the question you have attempted at the top of page **18**.

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 **25** printed pages and **1** blank page.

Section A

Answer **all** questions in this section.

1 (a) Table 1.1 shows the incidence rates per 100 000 women for tuberculosis and breast cancer in Sweden from 2010 to 2020.

Table 1.1

year	incidence rate per 100 000 women per year	
	breast cancer	tuberculosis
2010	149	7.2
2012	157	6.6
2014	175	5.8
2016	179	5.1
2018	184	4.9
2020	188	3.5

Medical treatment, preventative measures, diet and lifestyle have changed over this time period and may account for the trends shown in Table 1.1.

(i) With reference to Table 1.1 and the information provided, suggest and explain a hypothesis that may account for the trends of each of the diseases shown in Table 1.1.

breast cancer

1 incidence rate increased from 149 to 188 per 100 000 women from 2010 to 2020

2a due to increased awareness of need for early screening resulting in early detection/ reporting;

2b due to increase in proportion of fatty food in diet, thus increasing cancer risk;

2c due to decrease in physical activity/ exercise among women, thus increasing cancer risk;

2d due to increase in cigarette smoking among women, thus increasing exposure to chemical carcinogens that promote cancer development;

tuberculosis

3 incidence rate decreased from 7.2 to 3.5 per 100 000 women from 2010 to 2020

4a due to progressive use of antibiotics against Mycobacterium tuberculosis, thus reducing number of infected people in population;

4b due to effective vaccination programme against tuberculosis, thus maintaining herd immunity in population;

4c ***due to advancement in methods for faster detection and isolation of infected people, thus minimizing spread of disease;***

AVP; [4]

(ii) Explain why tuberculosis is considered an infectious disease while breast cancer is not.

1 ***tuberculosis is caused by a bacteria/pathogen/ Mycobacterium tuberculosis***

while breast cancer is a genetic disease resulting from (accumulation of) mutations to cancer-related genes/ not caused by a pathogen;

2 ***tuberculosis can be transmitted from one individual to another via airborne/aerosol droplets***

while breast cancer cannot be transmitted from one individual to another; [2]

(b) Epidemiological studies suggest that incidence of cancer is associated with type 2 diabetes. Type 2 diabetes is a form of diabetes that is characterised by high blood sugar levels and insulin resistance, whereby cells do not respond properly to insulin. Type 2 diabetes is thought to be attributed to lifestyle factors.

One study in Sweden investigates the incidence rates of various types of cancer in people with and without type 2 diabetes from 1998 to 2013.

Fig. 1.1 shows some of the results of the study.

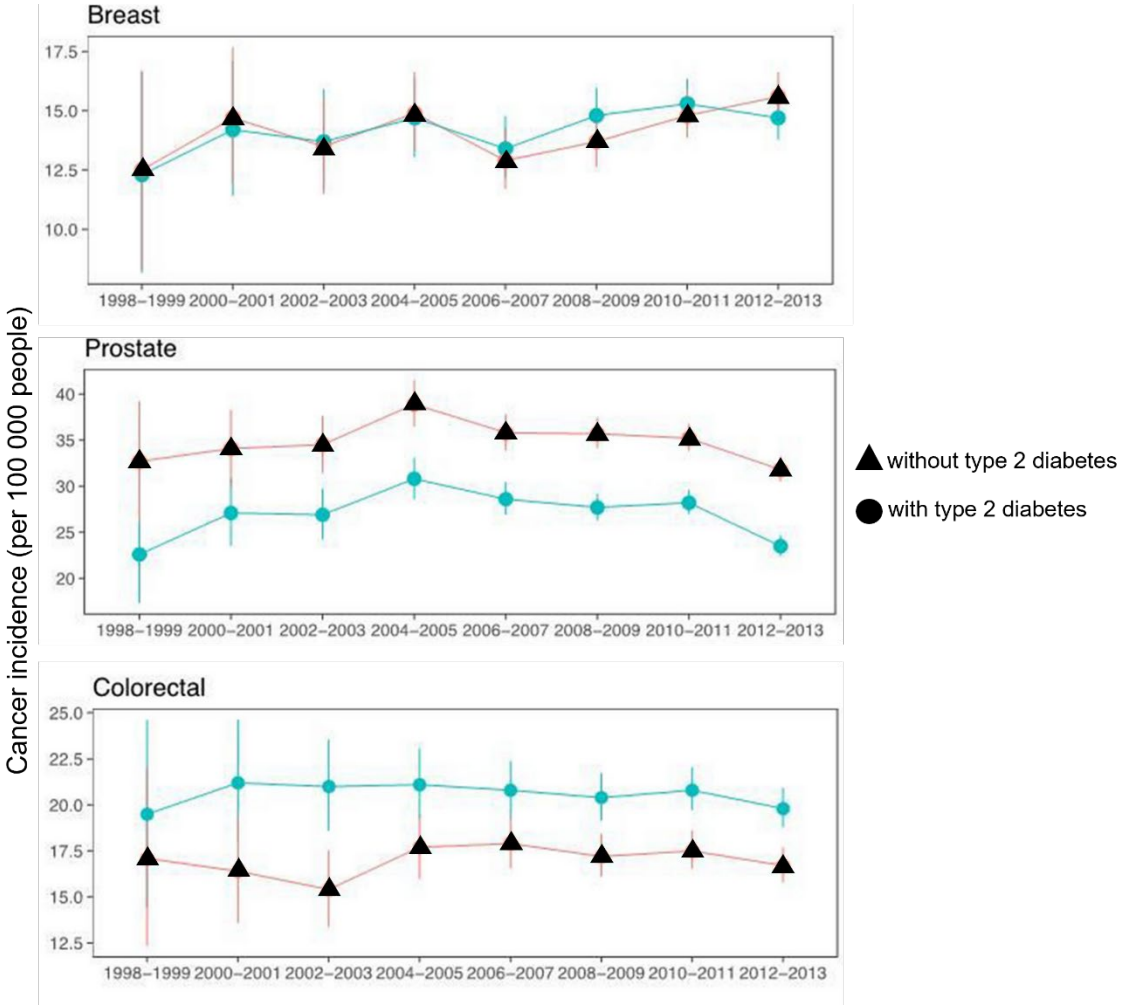

Fig. 1.1

"People with type 2 diabetes are at higher risk of cancer."

Using Fig. 1.1, discuss if the above statement is valid.

1 statement is valid for colorectal cancer;

2 whereby people with type 2 diabetes have a higher cancer incidence

quote relevant data to illustrate cancer incidence is consistently higher across the years for people with type 2 diabetes than those without (A: quote range);

3 statement is not valid for prostate cancer;

4 whereby people with type 2 diabetes have a lower cancer incidence than those without

25 per 100 000 people vs 35 per 100 000 people (A: quote range);

5 statement cannot be concluded for breast cancer;

6 no clear distinction between cancer incidence rates of people with and without diabetes

quote same average incidence/ similar range; [6]

(c) Age has been identified as a risk factor common to both cancer and type 2 diabetes. In economically developed countries, 78% of all newly diagnosed cancer cases are among individuals aged 55 years and older.

In the US, it is reported that the prevalence of type 2 diabetes among those 60 years or older is almost ten-fold the prevalence of type 2 diabetes among those between 20 to 39 years of age.

(i) Explain why the risk of cancer increases with age.

1 cancer results from accumulation of mutations to cancer-related genes

e.g. tumour suppressor genes and proto-oncogenes;

2 as person ages, increased exposure to mutagens (e.g. chemical carcinogens/ ionising radiation)

increases mutations to such genes to result in uncontrolled cell division; [2]

(ii) Suggest one reason why the risk of type 2 diabetes increases with age.

as person ages, effects of unhealthy diet/ lack of exercise accumulates to result in diabetes; [1]

(d) Apart from age, diet has also been identified as a risk factor for type 2 diabetes. Many research studies have attempted to investigate the relationships between:

- the percentage of energy intake in the diet that comes from saturated fatty acids and the risk of developing type 2 diabetes
- the concentration of low-density lipoprotein (LDL) in the blood and the risk of developing type 2 diabetes

Fig. 1.2 shows three proposed causal links between diet and type 2 diabetes as arrows **P**, **Q** and **R**. For example, the causal link represented by arrow **P** is the idea that an increase in saturated fatty acids in the diet **causes** an increase in the concentration of LDL in the blood.

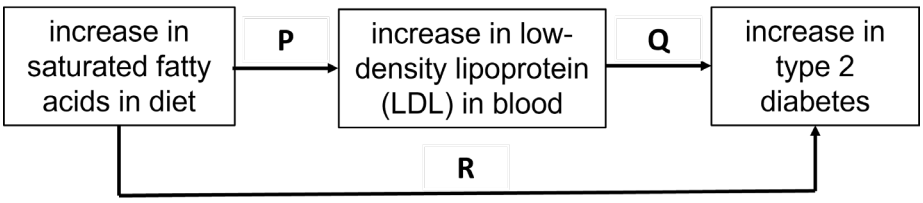

Fig. 1.2

The findings from some of these research studies are shown in Fig. 1.3, Fig. 1.4, Fig. 1.5 and Fig. 1.6.

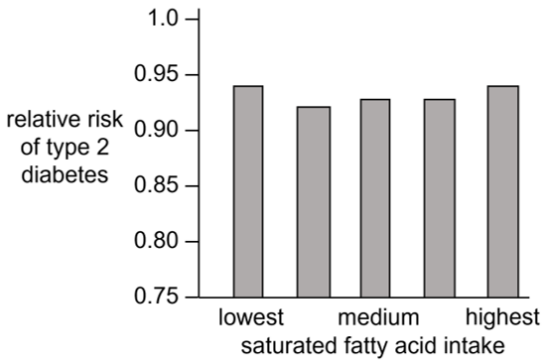

Fig. 1.3

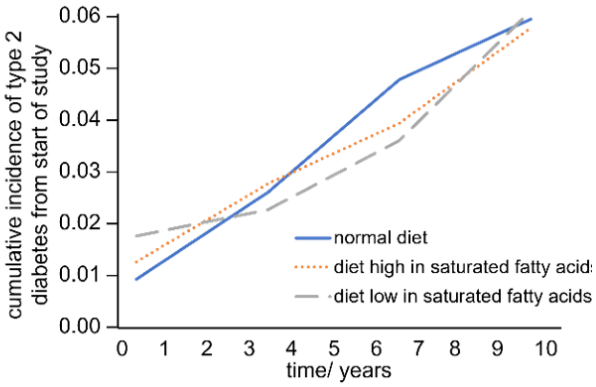

Fig. 1.4

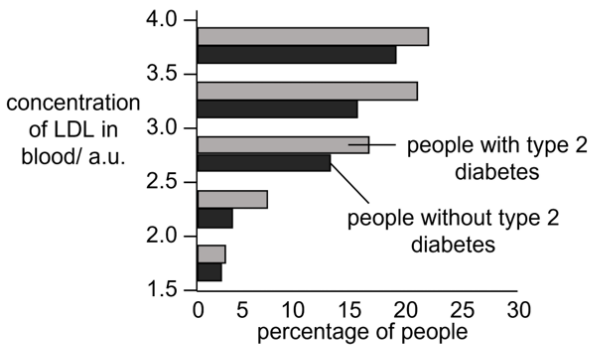

Fig. 1.5

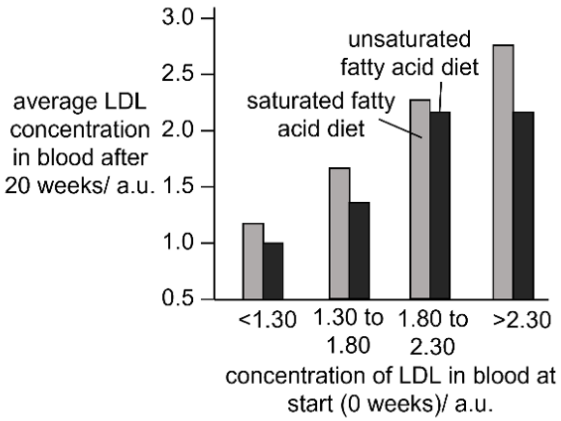

Fig. 1.6

(i) Complete Table 1.2 to show for each set of results:

- which of the causal links of the proposed in Fig. 1.2 were investigated (write **P**, **Q** or **R**)
- whether the results support the casual link shown by this arrow (writes yes or no).

Table 1.2

results	casual link investigated	do the results support the causal link?
Fig. 1.3	***R***	***no***
Fig. 1.4	***R***	***no***
Fig. 1.5	***Q***	***yes***
Fig. 1.6	***P***	***yes***

[4]

(ii) Distinguish between the structures of a triglyceride and a fatty acid.

1 ***triglyceride contains 1 glycerol***

and 3 fatty acid chains/ tails;

2 ***fatty acid contains hydrocarbon chain***

with carboxyl/ carboxylic acid group; [2]

(ii) Low-density lipoprotein (LDL) is commonly known as "bad cholesterol", while high-density lipoprotein (HDL) is commonly known as "good cholesterol".

State **two** roles of cholesterol in cells.

1 ***cholesterol regulates memb fluidity***

by increasing memb fluidity at low temp/ decreasing memb fluidity at high temp;

2 ***cholesterol is used (as a precursor/ starting material)***

to synthesise steroid compounds/ hormones; [2]

(e) In considering the possible biologic links between diabetes and cancer risk, the role of insulin receptors in mediating cellular responses to elevated blood glucose levels (hyperglycemia) is of interest.

Most cancer cells exhibit increased expression of insulin-like growth factor (IGF) receptors.

Fig. 1.7 shows one signal transduction pathway triggered by insulin binding to an IGF receptor on the cell surface membrane. PI3K, Akt and mTOR are protein kinases while NF-κβ is a transcription factor.

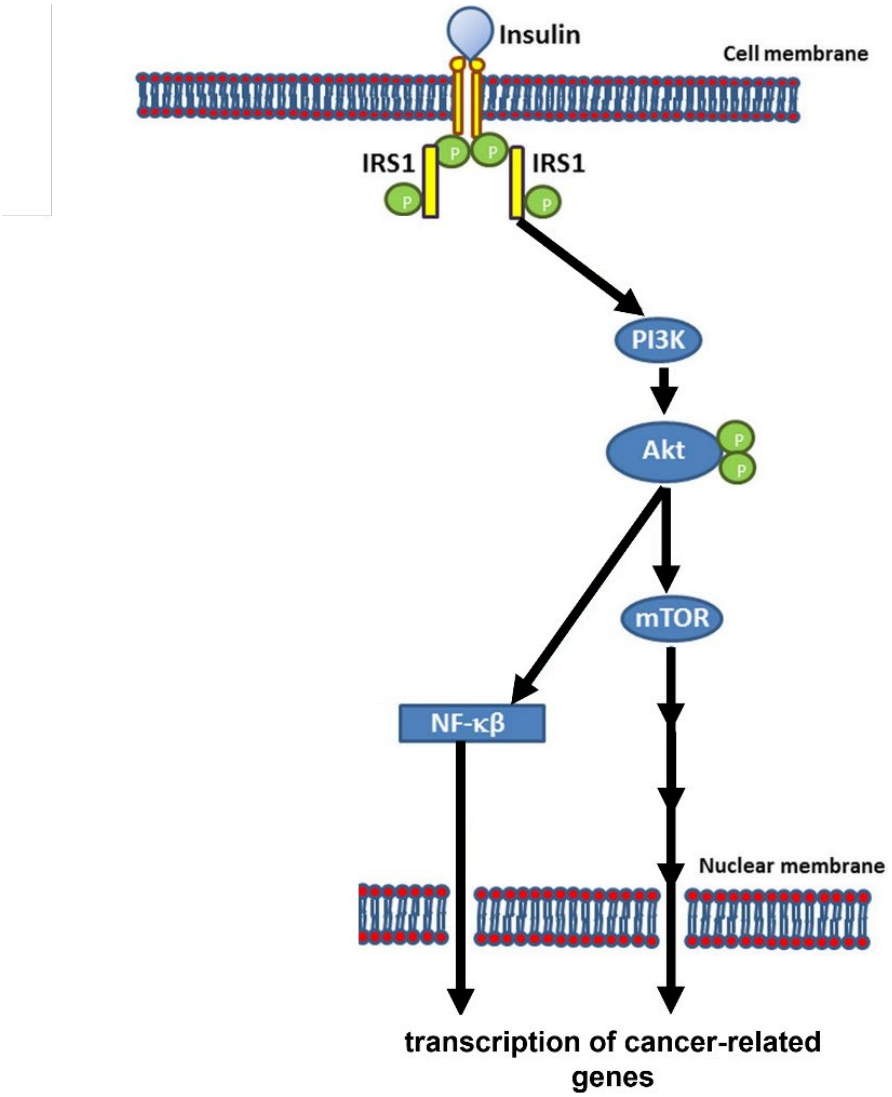

Fig. 1.7

(i) Explain why insulin needs to bind to a cell surface receptor in order to trigger downstream cellular responses.

1 *insulin is a large molecule/ protein*

which is polar/ hydrophilic;

2 *insulin is repelled by/ unable to pass through hydrophobic core of phospholipid bilayer*

hence, needs to bind to receptor at extracellular domain/ ligand-binding site to trigger intracellular response; [2]

(ii) With reference to Fig. 1.7 and your knowledge of insulin receptors, describe how hyperglycemia may lead to the synthesis of proteins involved in tissue invasion and metastasis.

1 increased blood glucose conc stimulates insulin secretion

from (β-cells of islets of Langerhans in) pancreas;

2 insulin binds to IGF receptor (at extracellular domain)

causing it to change in (3D) conformation;

3 tyrosine kinase of each subunit phosphorylates tyrosine residues of the other subunit

in cross-phosphorylation/ autophosphorylation;

4 binding and activation of insulin receptor substrate (IRS) 1

which activates PI3K which in turns phosphorylates Akt;

5 Akt activates mTOR and NF-κβ

which translocate into nucleus to activate transcription of genes involved in tissue invasion and metastasis (mRNA get translated in nucleus to produce proteins); [5]

[Total: 30]

2 In detecting sickle-cell anaemia, part of the β-globin gene is first amplified using Polymerase Chain Reaction (PCR), with the help of *Taq* polymerase and specially designed primers.

Fig. 2.1 shows the specific location of target sequence within the DNA.

Fig. 2.1

(a) **(i)** With reference to Fig. 2.1, state the pair of 15-nucleotide long primers which could be used in the amplification of the target sequence.

5' – ATTCTCGATCGGAAG – 3'
5' – CTATCGATATGATCG – 3' [2]

(ii) Explain one advantage and one limitation of using *Taq* polymerase instead of the DNA polymerase from *Escherichia coli* originally used in PCR.

1 ***Advantage:***
Unlike normal DNA polymerase, Taq polymerase is thermostable/resistant to heat/does not denature at high temperatures

allowing it to be reused for multiple cycles of PCR/automated PCR process;

2 ***Limitation:***
Unlike normal DNA polymerase, Taq polymerase lacks (3' to 5') proofreading ability

which result in more errors in replication;

[2]

(b) **(i)** Explain how a single base substitution resulted in the removal of one restriction site in the HbS allele.

1 ***single base substitution resulted in a change in DNA nucleotide sequence (from CTC to CAC (or GAG to GTG)/ thymine to adenine)***

results in loss of a restriction site in HbA allele;

2 ***change in conformation of DNA***

no longer complementary in shape (and charge) to active site of restriction enzyme MstII;

[2]

(ii) In some laboratories, another method is employed where whole genomic DNA instead of PCR fragments is used in the restriction digest. This results in smears instead of distinct bands on the gel after gel electrophoresis has been run.

Outline the steps on how the resultant gel could still be used in detecting disease alleles.

1 *double-stranded DNA is denatured/become single strands by an alkaline solution/ buffer*

transferred to a nitrocellulose/ nylon membrane;

2 *Nitrocellulose/ nylon membrane is incubated with a radioactive probe,*

which will hybridise with complementary target allele;

3 *after hybridization, (membrane is washed to remove any unhybridised probes)*

subjected to/ perform autoradiography/X-ray film over the membrane;

4 *black/ dark spot/ bands observed*

which correspond to exact location where specific band(s) is found on gel;

[4]

[Total: 10]

3 The *araBAD* operon, which is found in *Escherichia coli*, contains three structural genes: *araB*, *araA*, *araD* (collectively known as *araBAD*) that code for three metabolic enzymes required for the metabolism of the carbohydrate arabinose.

AraC is a regulatory protein which can act as a repressor or activator of the *araBAD* operon, depending on whether arabinose is bound to it.

Fig 3.1 shows the regulation of the *araBAD* operon.

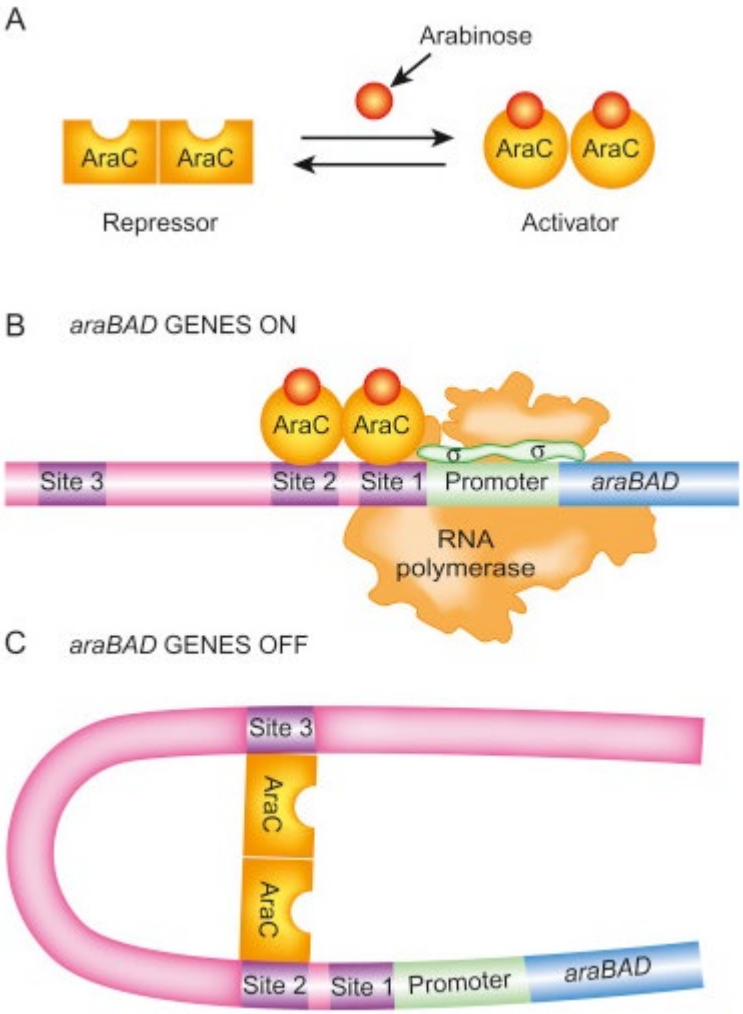

Fig. 3.1

(a) Using the information provided and your own knowledge on operons, explain whether *araBAD* operon is an inducible or a repressible operon.

1. Inducible operon;

2. default state of operon is OFF since AraC acts as repressor in the absence of arabinose

by binding to site 2 and site 3;

3. In the presence of arabinose, arabinose binds to AraC, converting it to an activator that binds to site 1 and site 2

to allow RNA polymerase (to bind to the promoter) to transcribe the structural genes; [3]

(b) Explain how a single mRNA produced from transcription of *araBAD* structural genes can be translated into three separate proteins.

1. Transcription of araBAD structural genes (as a single transcriptional unit)

leads to formation of a polycistronic mRNA;

2. This polycistronic mRNA has 3 start codons

and 3 stop codons;

3. Three separate (70S) ribosomes can bind to the 3 start codons independently

and translate the (polycistronic) mRNA from 5' → 3';

4. Each ribosome will stop translation once the stop codon is reached

hence three separate proteins are produced; [4]

(c) *AraC* gene has a gene mutation which changes the conformation of arabinose binding site.

Explain how this gene mutation affects the bacterial cell's ability to utilise arabinose.

1. Arabinose is no longer complementary to the arabinose binding site on the AraC (protein)

and cannot bind to AraC (protein);

2. AraC (protein) remains as repressor and binds to site 2 and site 3

which prevents the expression of araBAD structural genes;

3. Hence no araBAD structural proteins are produced

and the bacterial cell cannot metabolise arabinose (as an alternative sugar source); [3]

[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, were appropriate.
Your answers must be in continuous prose, where appropriate.
You answers must be set out in parts **(a)**, **(b)**, etc., as indicated in the question.

4 (a) Nucleic acid is an important class of biomolecules found in all cells. [15]

Outline the roles of nucleic acids in the synthesis of proteins in eukaryotic cells.

DNA ;
1. *Each DNA molecule carries genetic code/information/instructions / contains genes for the synthesis of RNA or protein ;*
2. *each gene is a specific sequence of nucleotides which codes for a polypeptide or RNA ;*
3. *DNA as template for (replication and) transcription/synthesis of mRNA ;*

mRNA ;
4. *Acts as template for translation / polypeptide synthesis ;*
5. *Mature mRNA are exported out of nucleus via nuclear pores and enter the cytoplasm to bind to ribosomes ;*
6. *one codon codes for one specific amino acid ;*
7. *mRNA strand codes for the amino acid sequence of specific polypeptide ;*
8. *Complementary base pairing between codon and anticodons ;*

(award once in either mRNA or tRNA discussion pt 8 or 15)

9. *allow for excising of introns at splice sites for alternative RNA splicing ;*
10. *enables a single gene to code for more than one polypeptide, depending on which exons are spliced together to form a continuous coding sequence ;*
11. *Start and terminate translation via start (AUG) codon and stop (UAA, UGA, UAG) codons ;*

tRNA ;
12. *To act as an intermediate molecule between the codon of mRNA and the amino acid sequence of the polypeptide chain ;*
13. *To carry the correct amino acid from the cytoplasm to the polypeptide chain being synthesised at the ribosome ;*

OR

14. *The 3' end with CCA stem serves as site for amino acid attachment to transfer/carry amino acids to the ribosomes during translation ; (award 15 or 16)*
15. *Anticodon on tRNA complementary base pairs with a particular codon on the mRNA via hydrogen bonding ; (award once 10 or 17)*
16. *Ribosome recognition site – make specific base pairing with rRNA in the ribosomes;*
17. *Has shape complementary to aminoacyl tRNA synthetase for activation of amino acid / has activating enzyme site for aminoacyl tRNA synthetase to catalyse the attachment of tRNA with its specific amino acid ;*

rRNA ;

18. *rRNA combines with proteins (in the nucleolus) to form small and large ribosomal subunits which will combine to form ribosomes (as site of protein synthesis) ;*
19. *rRNA in the small ribosomal subunit complementary base pair to the mRNA during translation ;*
20. *rRNA in the large ribosomal subunit complementary base pair to tRNA in the P site and A site ;*
21. *A ribozyme, peptidyl transferase, in the large ribosomal subunit catalyses the formation of peptide bonds between adjacent amino acids ;*

QWC [1]
Includes at least two nucleic acids, and at least two roles in the synthesis of proteins, in separate paragraphs ;

(b) The prokaryotic genome is preserved from parent to daughter cell through vertical gene transfer and is varied from cell to cell through the processes of horizontal gene transfer.

[10]

Describe the processes by which the prokaryotic genome is preserved yet varied and justify why they are critical in giving rise to an abundance of prokaryotic cells on Earth.

Preserved
- *Ref to mechanism of proper separation*
- *Ref. to semi-conservative DNA replication*
- *Ref to two genetically identical daughter cells*

Varied
Transformation
- *Ref to competent recipient cell takes up DNA fragment*
- *Ref. to homologous recombination*
- *Donor cell's DNA is incorporated into the recipient cell's bacterial chromosome*

Transduction
- *Ref to bacteriophage infection either causing generalised or specialised transduction*
- *Ref. to homologous recombination*
- *Donor cell's DNA is incorporated into the recipient cell's bacterial chromosome*

Conjugation
- *F^+ cell attaches to F^- cell via sex pilus*
- *via cytoplasmic mating bridge*
- *Ref to passing on of plasmid to recipient bacteria*

Justify
Binary fission
- *Ref to binary fission faster*
- *Ref. ability to double in number every 20 minutes or so*
- *Ref to more bacteria being able to populate the environment*

Horizontal Gene Transfer
- *Ref to advantageous / beneficial genes to be spread throughout the population*
- *Ref to being selective advantages*

QWC: Description of processes communicated clearly without ambiguity to include discussion of both:

[Total: 25]

5 (a) Outline how different substances are taken up by cells. [15]

Simple diffusion

1. ***Small hydrophobic/non-polar molecules/CO_2/O_2 (A: any valid example) can move into cells via simple diffusion across the cell surface membrane ;***
2. ***Diffusion is the net movement of molecules from a region of higher concentration (of that molecule) to a region of lower concentration (of the same molecule) / down a concentration gradient ;***
3. ***Diffusion is a passive process / does not require energy and continues until a dynamic equilibrium is reached ;***

Osmosis

4. ***Water molecules enter cells by passing through the transient pores (between the phospholipid molecule) in the cell surface membrane ;***
5. ***Osmosis is the net movement of water molecules from a region of higher water potential to a region of lower water potential, across a selectively permeable membrane ;***
6. ***Osmosis is a passive process / does not require energy ;***

Facilitated diffusion

7. ***Polar molecules/charged ions/glucose/Na^+ (A: any valid example) (R: glucose is charged) can move into cells via facilitated diffusion ;***
8. ***From a region of higher concentration (of that molecule/ion) to a region of lower concentration (of the same molecule/ion) / down a concentration gradient, with the aid of specific transport proteins (A: channel proteins and carrier proteins) ;***
9. ***Facilitated diffusion is a passive process/does not require energy ;***
10. ***Polar molecules or charged ions pass through the hydrophilic channels of the transport proteins (A: channel proteins and carrier proteins) ;***

Active transport

11. ***Polar molecules/charged ions (A: any valid example) can move into cells via active transport ;***

    OR

    Mineral ions can move into plant cells via active transport ;
12. ***Active transport is the movement of polar molecules or charged ions from a region of lower concentration (of that molecule/ion) to a region of higher concentration (of the same molecule/ion) against a concentration gradient, across a selectively permeable membrane via the aid of specific carrier proteins ;***

13. ***Energy in the form of ATP** is used ;*

Endocytosis / Phagocytosis / Pinocytosis (max. 3)

14. *Macromolecules too large or hydrophilic to enter the cell via diffusion can enter via **endocytosis**, which is **bulk transport** ;*
15. *Solid particles (e.g. food or bacteria) enter the cell via **phagocytosis**, involving larger vesicles ;*
16. *Fluid droplets enter the cell via **pinocytosis**, involving smaller vesicles ;*
17. *Endocytosis / Phagocytosis / Pinocytosis is an active process which requires **energy in the form of ATP** ;*
18. *The cell surface membrane **invaginates** to form a flask-shaped depression which envelops/engulfs the materials from the exterior of the cell ;*
19. *The invagination becomes sealed off, enclosing the extracellular material to form an endocytic **vesicle** which moves into the cell ;*

Receptor-mediated endocytosis

20. *Viruses enter the cell via **receptor-mediated endocytosis** ;*
21. *Viral glycoproteins (such as haemagglutinin of influenza virus) **recognise and bind** to **specific receptors** on cell surface membrane of host cell and cell surface membrane of host cell invaginates and pinches off ;*

AVP

22. *Phagocytosis only occurs in a few specialised cells known as phagocytes (e.g. macrophages) ;*
23. *Transformation (uptake of naked foreign DNA from extracellular env by competent bacterial cells);*

Max. 14 marks

For the examples in points 1, 7 and 11, award max 2 for two examples.

QWC (1 mark) ;
Explains at least 3 different processes in separate paragraphs.

(b) Discuss the view that all life forms depend on phosphate. [10]

[Nucleic acids] [4]

1. *Phosphate is a component of nucleotide*
2. *Needed to form phosphodiester bonds in a polynucleotide*

Any one function of nucleic acid

3. *DNA: contains genetic information needed to synthesize proteins for cells to function*
4. *mRNA: conveys genetic information from nucleus to the cytoplasm*
5. *tRNA: carries amino acids to the ribosome for synthesis of polypeptide*
6. *rRNA: forms part of ribosome, the translation machinery*
7. *telomerase RNA: forms part of telomerase, where it is a template for extension of telomere*
8. *snRNA: part of spliceosome, needed for RNA splicing to produce mature mRNA*

9. *- charged and binds to +histones for packing*

[Phospholipids in biological membranes] [4]

10. *Forms phospholipids, of biological membranes*
11. *Due to its hydrophilicity/polar, membrane forms a bilayer, where the phosphate group faces the aqueous external environment and aqueous cytosol*

Any one

12. *Regulate substances to be transported in and out of cell*
13. *Phosphate of phospholipids also interact with proteins to allow their embedment*
14. *Phosphate of phospholipids also interact with cholesterol to regulate membrane fluidity*

[ATP] [2]

15. *Energy molecule that releases energy upon hydrolysis of phosphate bond*

Any one function of ATP

16. *For phosphorylation of glucose and fructose during glycolysis*
17. *To convert glycerate-3-phosphate to 1,3-bisphosphoglycerate in Calvin cycle*
18. *For active transport of substances against concentration gradient*
19. *Named example: e.g. pump protons from cytosol into lysosomes to maintain acidic pH*
20. *For movement of vesicles within the cell*
21. *As a substrate for adenyl cyclase to produce the second messenger cyclic AMP (cAMP)*

[Cell Signalling] [1]

22. *Needed for auto/cross-phosphorylation of tyrosine residues by tyrosine kinase of each subunit of RTK;*
23. *Needed by kinases to phosphorylate and hence activate proteins e.g. during phosphorylation cascade/signal transduction*

Role of NADPH (for reduction for GP to G3P) [1]

Phosphate/ phosphorus as a important mineral/ component of fertilisers for plants to grow healthily [1]
QWC – draws a conclusion with reference to marking points from 2 sections.

[Total: 25]

Question _____

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