Candidate Name: _____

Class	Adm No

H

millennia institute

2023 End-of-Year Examination

Pre-University 3

H2 Biology **9744/03**

Paper 3 Long Structured and Free-response Questions **20 September 2023**

2 hours

READ THESE INSTRUCTIONS FIRST

Do not open this booklet until you are told to do so.

Write your Admission number and name on all the work you hand in.
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.

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.

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	**Question**	**Marks**
A	**1**	**/30**
	2	**/10**
	3	**/10**
B	**4/5**	**/25**
Total Marks		**/75**

This question paper consists of 21 printed pages, including 1 blank page.

[Turn over]

Section A

Answer **all** questions in this section.

1 The tomato plant (*Solanum lycopersicum*) is a crop harvested in many regions of the world for its edible fruit. Its red skin is primarily due to the presence of the organic compound lycopene, a pigment also found in many other fruits such as carrots and watermelon. Lycopene is only made up of carbon and hydrogen, as shown in Fig. 1.1.

Lycopene is also a precursor to many carotenoids, which absorb light from a certain wavelength during photosynthesis. In addition to carotenoids, other essential pigments are chlorophylls *a* and *b*.

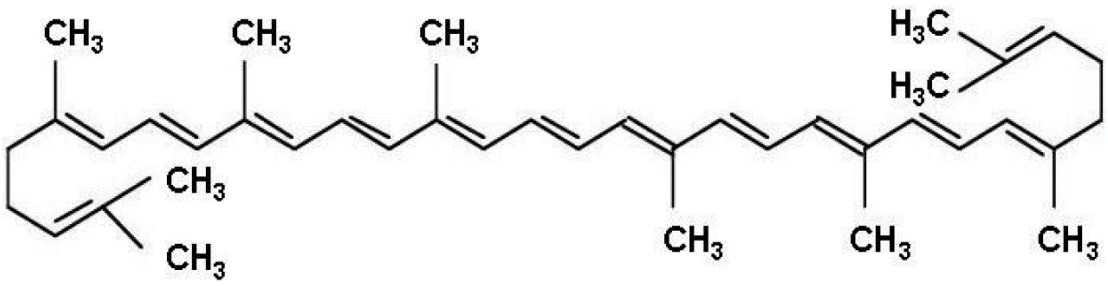

Fig. 1.1

(a) (i) Suggest a cellular structure in which lycopene can be found in a tomato cell. Explain your answer.

.....

.....

.....

..... [2]

1. Cell surface membrane/mitochondrial membrane/membrane of endoplasmic reticulum/membrane of Golgi apparatus;
2. Carbon and hydrogen in lycopene allow favourable hydrophobic interaction with hydrophobic fatty acid tail /hydrophobic core of lipoproteins

Fig. 1.2 shows the absorption spectrum of lycopene and the action spectrum of the tomato plant.

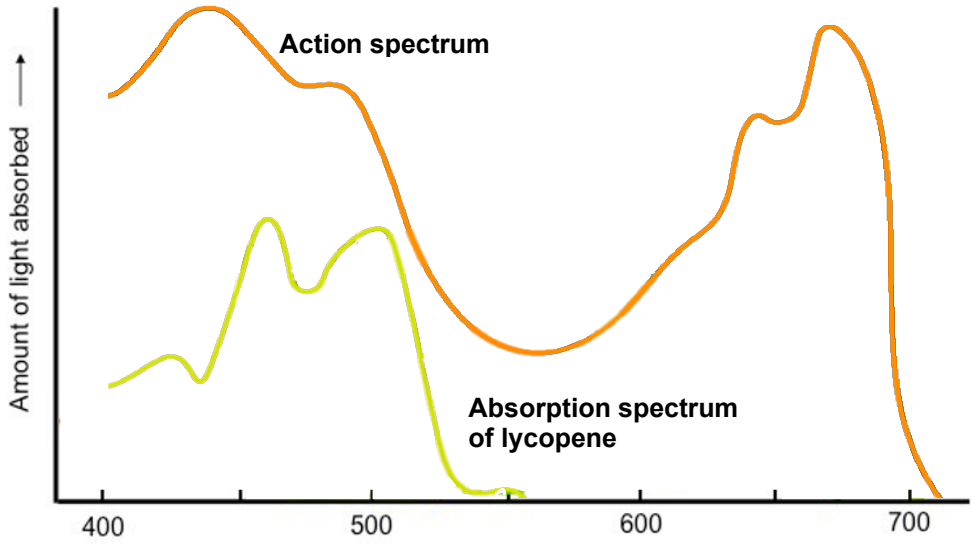

Fig. 1.2

(ii) With reference to Fig. 1.2, state the wavelength(s) of peak absorption by lycopene.

500 nm, 460nm [1]

(iii) Explain how the data in Fig. 1.2 shows that lycopene is not the only photosynthesis pigment in the tomato plant.

1. Lycopene does not absorb light above 550/560nm;
2. But photosynthesis still takes place above 550/560nm according to the action spectrum; [2]

(b) Different conditions and variables can greatly affect the rate of photosynthesis that occurs in tomato plants. To investigate this, the net photosynthetic rate (P_N) was measured against photosynthetically active radiation (PAR). PAR measures the amount of photons that the plant is exposed to per unit area per unit time.

The plants were also subjected to four different levels of relative soil water content (RSMC), labelled T1 to T4. (RSMC) measures the amount of water in the soil.

Fig. 1.3 shows the results.

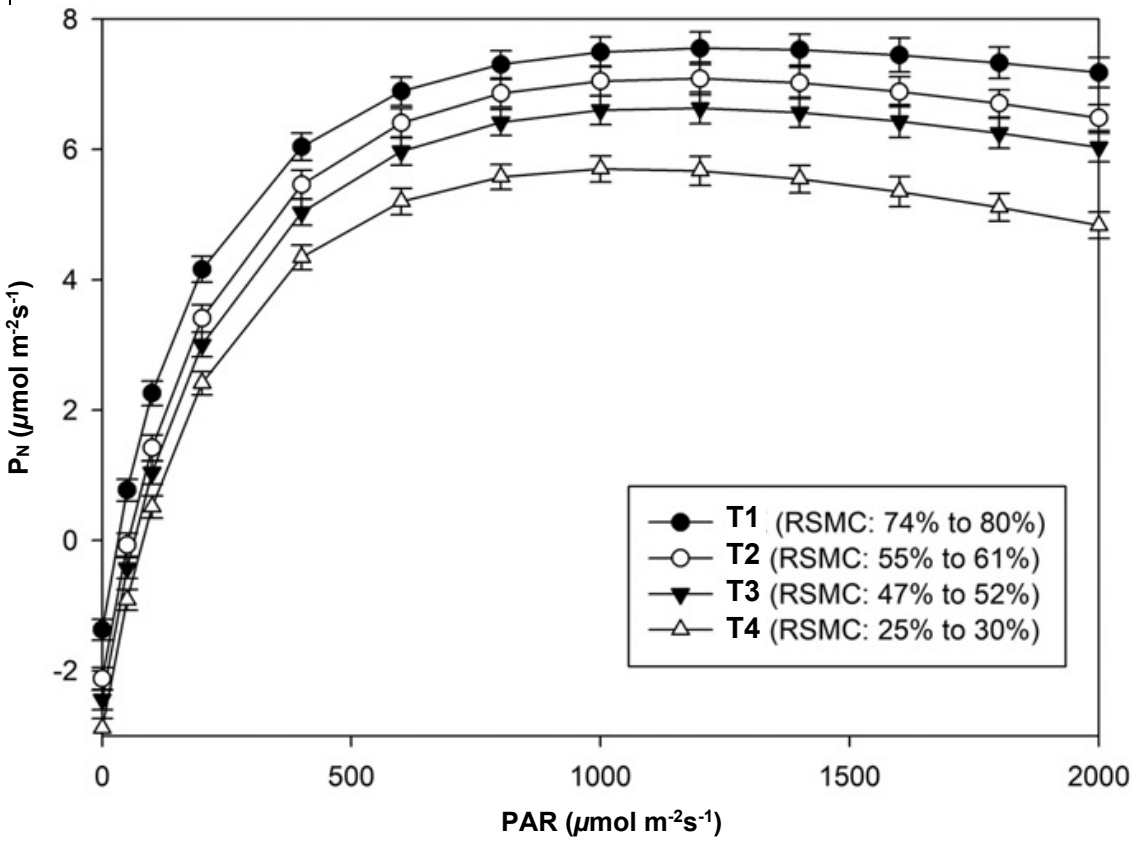

Fig. 1.3

(i) Explain the overall relationship between P_N and RSMC from 0 to 1000 μmol $m^{-2}s^{-1}$.

1. As RSMC increases from T4, to T1, the highest P_N value increases from 5.8 µmol $m^{-2}s^{-1}$ to 7.8 µmol $m^{-2}s^{-1}$;
2. Higher RSMC means there is a higher water content, which also means there is a higher rate of photolysis of water;
3. Allows for more electrons to be passed down the electron transport chain during light dependent reaction, increasing production of ATP and NADPH;
4. ATP and NADPH used for Calvin Cycle to form G3P, thus increasing the rate of photosynthesis;

(ii) Suggest and explain the overall trend observed from 1500 to 2000 μmol $m^{-2}s^{-1}$.

1. The P_N of all curves gradually decreases from 1500 to 2000 µmol $m^{-2}s^{-1}$;
2. PAR/light intensity is no longer a limiting factor;
3. Rate of photosynthesis decrease due to heat stress;

. [2]

(iii) Using Fig. 1.3, estimate the P_N when the PAR is 750 μmol $m^{-2}s^{-1}$ and the RSMC is between 55% to 61%.

6.5-6.8 µmol $m^{-2}s^{-1}$

... [1]

(c) The products of the light-dependent reaction are important for the formation of carbohydrates in plants.

Outline how carbohydrate can be continually formed using these products.

1. Carbon dioxide reacts with RuBP, cataysed by Rubisco to eventually form PGA;
2. ATP and NADPH reduce PGA to form G3P;
3. For every 3 molecules of CO2, there are 6 molecules of G3P;
4. One molecule of G3P exits the cycle to be used as carbohydrate;
5. the other 5 molecules form RuBP using ATP/RuBP is regenerated and can continue to fix carbon dioxide;

Any 4 points for 4 marks;

[4]

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[Turn over]

Stressful conditions can lead to the damaging of plant DNA. This leads to the activation of multiple cell signalling pathways to repair the DNA, which involves halting the cell cycle at its checkpoints.

Fig. 1.4 shows one such simplified pathway, known as the DNA damage response (DDR) signalling pathway. DDR activation depends on two protein kinases, ATM and ATR. ATM responds to double-stranded breaks (DSBs), where a double-stranded DNA breaks off at both strands, and ATR is activated by the presence of single-stranded DNA and any defects in replication fork progression. The result of the pathway is the inhibition of cell cycle progression.

In response to the activation of ATM and/or ATR, the following pathways occur:

- Phosphorylation of the histone protein H2AX to form *γ*-H2AX (gamma-H2AX).
- The activation of SOG1, a transcription factor, activating proteins NAC44 and NAC85, which in turn will lead to the regulation of the M checkpoint.
- The expression of RBR1 and E2FA proteins, which are tumour suppressor proteins and WEE1, which is a G2 Checkpoint Kinase.

Through the activation of DDR, the DNA is subsequently repaired.

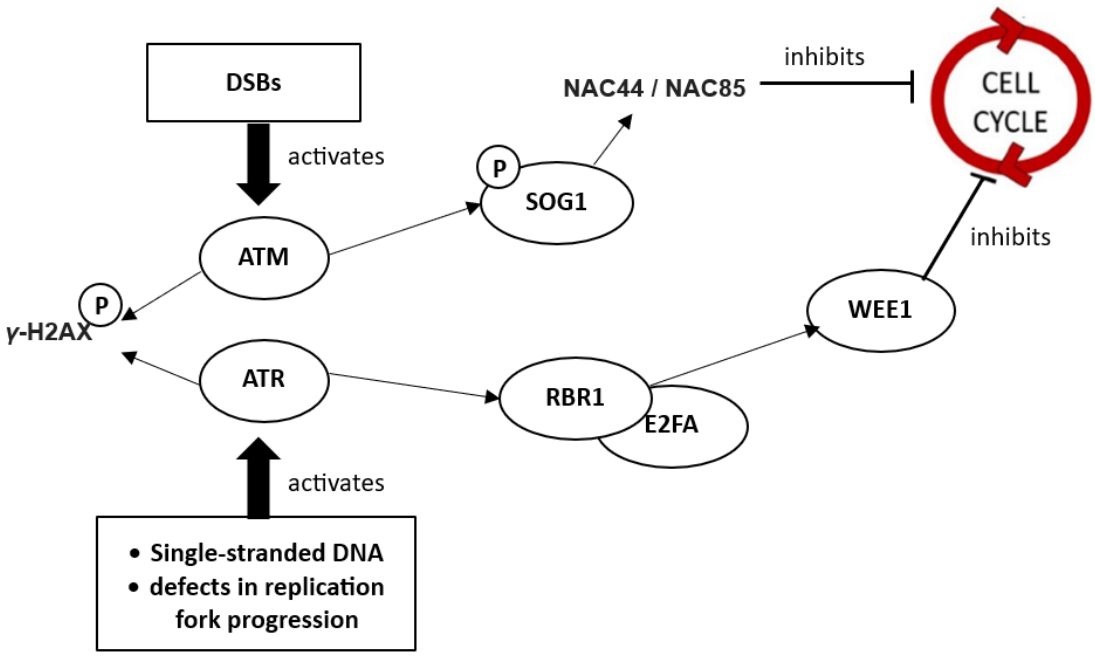

Fig. 1.4

Table 1.1 lists down three processes that will result from the activation of the DDR pathway.

Table 1.1

Which protein kinase ATM and/or ATR will be activated?	Protein(s) involved	Processes due to activation of ATM / ATR
		formation of heterochromatin
		cell size stops increasing
		spindle fibres not attached to centromere

ATM and ATR	H2AX
ATR	RBR1, E2FA, WEE1
ATM	SOG1, NAC44, NAC85

1 mark for each row

(d) (i) Complete Table 1.1 by filling in the following:

- If protein kinase ATM, ATR or both activated the pathway.
- The protein(s) that fit the description: H2AX, SOG1, NAC44, NAC85, RBR1, E2FA and WEE1. You are to fill in all the protein names in the table, and you only need to fill in each protein once.

[3]

(ii) Explain the importance of inhibiting cell cycle progression in the presence of DSBs and single-stranded DNA.

1. To prevent accumulation of DSBs and ssDNA which may lead to the development of cancer;
2. If this occurs, this may lead to gain of function mutation of proto-oncogenes to oncogenes and loss of function mutation of tumour suppressor genes;
3. To also prevent passing of mutations to daughter cells;
4. Provide time for cell machinery to be repaired should there be any damage;

…. [3]

(iii) Suggest why it is possible for tomato plants to have tumours but not cancer.

1. uncontrolled cell division leading to formation of tumours;
2. but (idea of) Cells are not mobile thus are not able to metastasise to other locations;

..
2]

(e) The gradual decline in tomato plant production over the years can also be attributed to diseases caused by plant viruses. One such virus is the tomato spotted wilt virus (TSWV), which was first described in Australia in 1919. Most TSWV variants are enveloped viruses, and their genetic material is distributed across three segments. They have been found to bear resemblance to a few animal-infecting viruses. One such example is the animal influenza virus, in which there is similarity in the type of genetic material and reproduction cycle.

TSWV is also the only plant virus transmitted to other types of crops, such as potatoes and cucumbers, via thrips, a type of insect that sucks the sap of plants.

Fig. 1.5 shows the structure of TSWV. Fig. 1.6 shows the thrip insect.

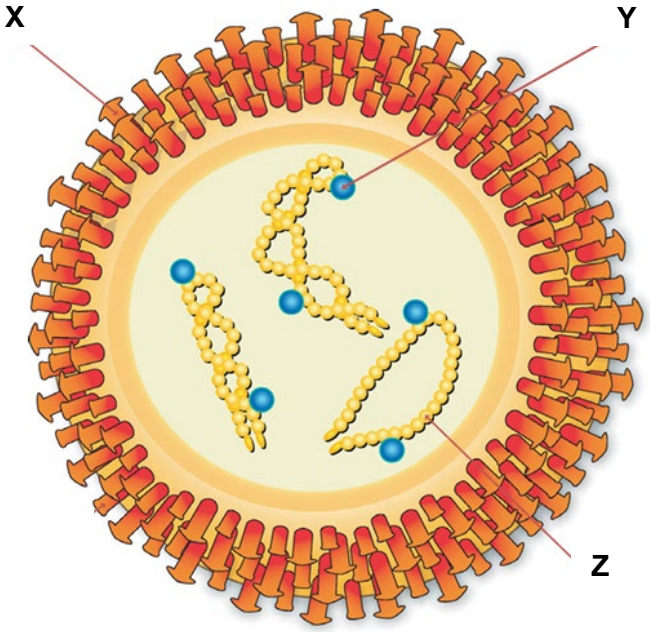

Fig. 1.5

Fig. 1.6

Using the information provided and your own knowledge of the influenza virus,

(i) Identify the structures **X, Y** and **Z**.

X: ……..

Y: ……..

Z: ……..

X: glycoproteins
Y: RNA dependent RNA polymerase /nucleoprotein
Z: negative sense single-stranded RNA

[3]

(ii) Describe how the genetic material is replicated and used in the TSWV reproduction cycle.

1. RNA-dependent RNA polymerase/Y copies/replicates the negative sense RNA template/Z into complementary positive sense RNA;
2. Positive sense RNA used as template to synthesise negative sense RNA
3. Positive sense RNA used as mRNA to be translated by host protein-synthesising machinery OR Free ribosomes in the cytosol to synthesise capsid proteins and viral enzymes and bound ribosomes to synthesise viral glycoproteins;

…… [3]

(iii) Identify how the thrip is able to transmit the virus from one plant to another.

……

……

Acts as a vector/can carry the virus without being infected /allow virus to undergo extrinsic incubation period before transmitting to another plant

…… [1]

[Total: 30 marks]

2 Diseases can be characterised by defects that occur in many protein structures. For example, there are several diseases related to defects in the haemoglobin structure, which can lead conditions such as anaemia.

(a) State the effect on the haemoglobin's structure for the following defects and how it affects the function of the haemoglobin.

(i) No iron found in haem group

Effect: oxygen unable to reversibly bind to haem group

Affected function: prevent uptake and release of oxygen/affect cooperativity binding of oxygen

..... [2]

(ii) Hydrophilic amino acid residues in the interior of structure.

Effect: no deep hydrophobic cleft;
Affected function: no hydrophobic environment for binding of haem group
OR
Effect: hydrophobic amino acid residues on the exterior of haemoglobin;
Affected function: haemoglobin is no longer soluble in aqueous environment;
OR
Effect: loss of specific 3D conformation of haemoglobin;
Affected function: haemoglobin no longer able to bind to oxygen;

..... [2]

The ... such dis... order where B cells are unable to mature and the individual's immunity is compromised.

(b) **(i)** Describe three structural features of immunoglobin which allow it to perform its function.

.....

1. Each immunoglobulin has two identical antigen binding sites that are complementary to the epitope determines antigen binding specificity;
2. Has two identical antigen binding sites to bind to two antigens at the same time;
3. Constant region determines its class/effector function/isotype of the antibody;
4. The hinge region which is made up of disulfide linkages provides the antibody with greater flexibility to better bind to the antigens/move independently;

..... [3]

(ii) Explain why an individual's immunity is compromised when B cells are unable to mature.

1. B cell cannot differentiate into a plasma cell and secrete antibodies/ immunoglobulins;
2. There will be no antibodies that can (any one):
   a. Neutralise foreign antigens and prevent them from entering host cell;
   b. Bind to foreign antigens for opsonisation and allow phagocytosis;
   c. Activate complement system for enhanced phagocytosis/opsonisation;
   d. Coat tumour cells for natural killer cells to recognise and allow antibody-dependent cellular toxicity;
3. Cannot form memory B cells for stronger secondary immune response;

..... [2]

(iii) Researchers have found a way to genetically engineer plants to produce antibodies, known as plantibodies. Plantibodies can be extracted and injected into humans to fight diseases.

Suggest how using plantibodies could be advantageous over the natural methods of producing antibodies in humans.

1. No need for immune cell activation/antigen presentation;
2. No latency period when using plantibodies;

..... [1]

[Total: 10 marks]

3 *Acropora* is a genus of coral known for their size and hardness. They are also known to be the main contributors to the building of reefs. They contain numerous species and their phylogeny is well studied.

The number of single nucleotide polymorphisms (SNPs) shared between species can help to illustrate the relationship between these corals. SNPs are variations at a single position in a DNA sequence among individuals. A total of 1000 SNPs per species was investigated between three species, *A. hyacinthus, A. robusta* and *A. pichoni.* Table 3.1 shows the number of SNPs unique to each species when compared with one another.

Table 3.1

Comparison between species		Number of unique SNPs
A. hyacinthus	*A. robusta*	44
A. robusta	*A. pichoni*	724
A. pichoni	*A. hyacinthus*	487

(a) Using the information provided,

(i) calculate the number of shared SNPs between each species in the space below.

Between *A. hyacinthus* and *A. robusta*: 956
Between *A. robusta* and *A. pichoni*: 276
Between *A. pichoni* and *A. hyacinthus*: 513

Between *A. hyacinthus* and *A. robusta*: .....
Between *A. robusta* and *A. pichoni*: .....
Between *A. pichoni* and *A. hyacinthus*: ..... [3]

(ii) determine which two species have the most recent common ancestor. Explain your answer.

1. Between *A. hyacinthus* and *A. robusta* ; (ecf)
2. The highest number of shared SNPs indicates that there is a high number of sequence similarity/high molecular homology, showing they are the most closely related;

..... [2]

(b) Explain why it is impossible for evolution to occur at the individual level.

1. A population is a group of interbreeding individuals belonging to the same species that live in the same geographical area.
2. Evolution is the measure of change in allele frequency in a population's gene pool over many generations.
3. There must be variation in a population before selection can take place, where individuals are selected for or against by natural selection.
4. Alleles coding for advantageous traits are passed down to next generation, and these traits become more common.

[3]

Fig. 3.1 shows a group of unicellular photosynthetic algae, zooxanthellae, that reside in the cells of these corals. The relationship between the zooxanthellae and the corals is known to be symbiotic.

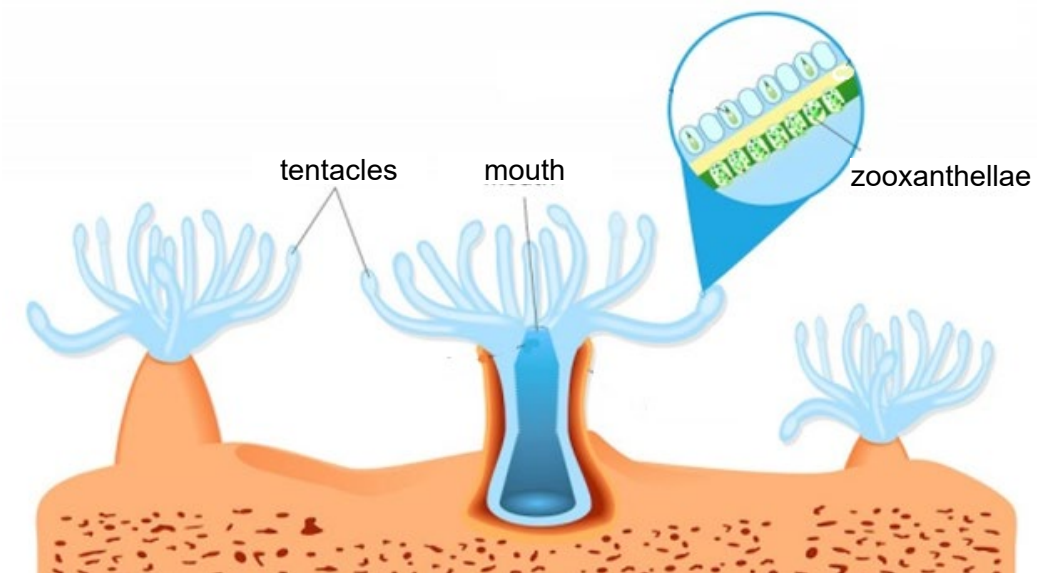

Fig. 3.1

(c) Describe how the relationship is symbiotic.

1. Beneficial to zooxanthellae as corals provide nutrients and protection for zooxanthellae;
2. Beneficial to coral as zooxanthellae undergo photosynthesis to provide corals with food;

... [2]

[Total: 10 marks]

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 pose, where appropriate.

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

4	**(a)**	Prokaryotic and eukaryotic genomes are organised differently. Explain how these differences affect the regulation of gene expression in prokaryotes and eukaryotes. **[10]**	
	(b)	With reference to the life cycle of *Aedes aegypti*, describe the impact of temperature on the mosquito vector and dengue transmission. **[15]**	
			[Total: 25]
5	**(a)**	The cell theory is characterised by concepts that define a cell. Explain how these concepts can be accounted for by both mitosis and the different types of stem cells. **[10]**	
	(b)	With reference to examples, explain how phenotype is linked to genotype and the environment. **[15]**	
			[Total: 25]

END OF PAPER

4(a) Prokaryotic and eukaryotic genomes are organised differently. Explain how these differences affect the regulation of gene expression in prokaryotes and eukaryotes. [10]

Note: question is about how the differences affect the regulation, and not what the differences are. It should also be clear which genome has which structure even if not explicitly stated per point.

Chromatin level

1. Prokaryotic genome is not associated with histones, and thus histone modification is not possible at the chromatin level;
2. Eukaryotic genome has DNA wound around histone proteins, which allows for histone acetylation and methylation;
3. This also controls access of transcription machinery to DNA;
4. Prokaryotic genome is smaller than eukaryotic genome, thus more genes coding for more proteins in eukaryotic genome;

Operon

5. Prokaryotic genome organised into operons/has polycistronic mRNA where many structural genes are under the control of one promoter;
6. Allows for more efficient/coordinated control of gene expression for prokaryotes since genes responsible for same function are clustered and expressed together;
7. Eukaryotic genome has monocistronic mRNA where only one gene is under the control of one promoter;
8. Allows for individual control in eukaryotes but not in prokaryotes;

Transcriptional/Translational level

9. Eukaryotic genome has different combinations of enhancers and silencers that allow for combinatorial and coordinate control of genes;
10. Prokaryotic genome is mainly regulated by operator which switches the operon on and off;
11. Prokaryotic genome is found in nucleoid region but eukaryotic genome is enclosed in membraned bound nucleus;
12. transcription and translation can occur simultaneously in prokaryotes, which is not possible in eukaryotes;

Presence of introns

13. Prokaryotic genome has no introns which allows simultaneous transcription and translation to occur;
14. Eukaryotic genome has introns and thus has to undergo post transcriptional modification to remove introns to form a continuous mRNA;
15. Alternative splicing is also possible in eukaryotes which allows different proteins to be formed from the same mRNA;

4(b) With reference to the life cycle of *Aedes aegypti*, describe the impact of temperature on the mosquito vector and dengue transmission. [15]

Relationship between Life Cycle of aedes and temperature

1. *Aedes aegypti* is the primary vector of dengue virus;
2. Mosquitoes are cold blooded animals/ ectotherm where their body temperature is affected by the environment;
3. The egg of the mosquito develops into larvae, then pupae, and finally adult mosquito;

4. Embryonic development is usually completed in 48 hours in a warm and humid environment, but may take weeks in cooler environment;
5. Increased temperature leads to shorter hatching time of egg into larvae;
6. Larval development occurs in four stages and is dependent on temperature, availability and density;

Effect of Temperature on mosquito vector

7. Temperature greatly influences its behaviour, development, reproduction and survival (at least 2);
8. Increased temperature increases the rate of enzymae catalysed reactions which lead to higher metabolic rates;
9. As metabolic rates increase, the development rates/life cycle of egg, larva and pupa shortens/hasten;

10. At higher temperature, insects will mature, mate and reproduce in a shorter span of time than normal and consequently there is a greater capacity to produce more offspring/eggs during the transmission period;
11. At higher temperature, adult female mosquitoes digest blood faster and feed more frequently,
12. thus increasing transmission intensity as more humans are bitten;

13. Increased temperature leads to increase water temperature, larvae take shorter time to mature and consequently there is greater capacity to produce more offspring;

14. Shorten developmental time of mosquito increases its survival rate as egg, larvae and pupae are less susceptible to predators, diseases and parasitism (any 1);
15. At temperature higher than 30^{o}C, the survival rate of larvae and pupae drop/OWTTE;

Effect of Temperature on dengue transmission

16. Global warming leads to temperatures in the sub-tropical regions becoming more optimal for both mosquitoes and dengue virus;
17. Global warming can lead to higher humidity (in the sub-tropics), more stagnant water breeding sites of water available for mosquitoes to lay eggs; OR
18. Increase temperature may also lead to less stagnant water, reducing stagnant water breeding sites for adult mosquitoes to lay eggs;

19. Increased temperature leading to increased precipitation/rainfall increases the number and quality of breeding sites for mosquitoes;

20. Global warming will result in the spread of this disease beyond the tropics;
21. to higher altitudes and higher latitudes where it is cooler;
22. The tropics could become too hot for the mosquito to survive, as such, they might be a decrease in incidence of dengue in the tropics;
23. Increased temperature may lead to warmer and shorter winters, allowing more mosquitoes to survive during and through winter as they can be active for a longer period of time.
24. In warmer climate, dengue virus complete extrinsic incubation within the female adult mosquito faster, thereby increasing the proportion of infectious vector;

QWC 1 mark: Answer in structured and clear paragraph, with **coherent link between temperature, life cycle of mosquito and dengue transmission;**

5(a) The cell theory is characterised by concepts that define a cell. Explain how these concepts can be accounted for by both mitosis and the different types of stem cells. [10]

Cell theory (3 marks)

1. States that the cell is the basic unit of structure and organisation in organisms;
2. All organisms are made up of one or more cells;
3. All cells come from pre-existing cells;

How mitosis supports cell theory (2 marks)

4. In humans, genetically identical daughter nuclei are formed from parental nuclei via mitosis;
5. Multicellular organisms are made up of more than one cell via mitosis;

How stem cells support cell theory (max 5 marks)

6. Stem cells are unspecialised and undifferentiated cells;
7. Stem cells can undergo extensive proliferation through mitosis to form a population;
8. And differentiation to give rise to specialised cell types;
9. In multicellular organisms, there are different types of stem cells: totipotent, pluripotent, multipotent and unipotent;
10. Totipotent stem cells can differentiate into all types of cells;
11. Pluripotent stem cells can differentiate into cells from all three germ layers of embryo;
12. Multipotent stem cells can differentiate into cells within a closely related family;
13. Unipotent stem cells are differentiated cells with the ability to self-renew indefinitely;

5(b) With reference to examples, explain how phenotype is linked to genotype and the environment. [15]

How phenotype is linked to genotype (max 4 marks)

1. The genotype of an organism is its genetic make-up, which is the combination of alleles on the same gene on homologous chromosomes;
2. Phenotype is the physical or physiological traits of an individual which are observable/measurable;
3. As a result of gene expression and environmental factor;
4. Genes are transcribed into mRNA which is further translated into proteins;
5. Protein folds into specific 3D conformation, which determines the phenotypes;

Specific examples of genotype to phenotype (max 4 marks)

6. In a heterozygote, allele that shows itself in phenotype is dominant allele, and recessive allele is not expressed/dominant allele masks recessive allele;
7. In incomplete dominance, heterozygote exhibits phenotype that is an intermediate between the two homozygous forms;
8. In codominance, both alleles have an equal effect on the phenotype of the offspring/equally expressed in phenotype of heterozygote;
9. In sex-linkage, genes are found on the sex chromosomes and males with only one X chromosome will express the phenotype of the single allele present;
10. In epistasis, the presence of one allele of a particular gene affects the expression of other genes due to gene interaction;
11. In continuous variation, polygenic inheritance occurs where multiple genes are involved and there is an additive effect of each gene;

How phenotype is linked to environment

12. The phenotype of a characteristics is determined by the gene(s) controlling that particular characteristic but the degree of expression of these genes may be influenced by the environment;
13. Environmental effect exerts an effect on phenotype determine by polygenes/presence of two or more genes;

Temperature: Himalayan Rabbits

14. Temperature affects the coat colour of Himalayan rabbits;
15. Black fur is due to the pigment synthesised by an enzyme;
16. At low temperature, the gene coding for the enzyme that produces the pigment is expressed, giving rise to black fur;
17. At high temperature, the gene coding for the enzyme that produces the pigment is not expressed, giving rise to white fur;

Diet: Queen and Worker bees

18. Queen and workers have the same amount of genetic material but they are phenotypically different;
19. These phenotypic differences are due to the diet of the larvae;

20. After hatching, all the larvae are fed with royal jelly;
21. Larvae destined to be workers are switched to a diet consisting of honey and pollen, whereas those destined to be queen continue with royal jelly;
22. The high protein content of royal jelly stimulates the formation and maturation of the female reproductive system in the queen bees;
23. Mutagens in the environment result in gene mutations resulting in changes in phenotype;

QWC Answer in structured and clear paragraph, with at least 2 points from all three paragraphs.