TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

CANDIDATE NAME

CIVICS GROUP

H2 BIOLOGY

9744/01

Paper 1 Multiple Choice Questions

23 September 2022
1 hour

Additional material: Multiple Choice Answer Sheet

QUESTION	ANSWER	QUESTION	ANSWER
1	B	16	A
2	D	17	D
3	B	18	D
4	B	19	B
5	B	20	A
6	D	21	D
7	B	22	A
8	D	23	A
9	C	24	C
10	B	25	C
11	A	26	C
12	B	27	C
13	A	28	C
14	D	29	C
15	B	30	D

This document consists of **25** printed pages.

QUESTION 1
Which of the following observations does **not** support the Cell Theory?

A. Glucose molecules that enter a cell are quickly oxidized to pyruvate molecules.

B. Plant cells placed in a hypotonic solution grow rapidly in size.

C. One cancer cell rapidly forms a cluster of cells.

D. The amount of nuclear DNA in a cell doubles during S phase of the cell cycle.

QUESTION 2
Oxygen molecules produced during photosynthesis in a plant cell are often used directly by the same plant cell for cellular respiration.

How many phospholipid **layers** must an oxygen molecule produced during photosynthesis cross in order to reach its functioning destination in cellular respiration?

A. 4 **B.** 5 **C.** 8 **D.** 10

QUESTION 3
The features of the cell membrane are described below.

1. phospholipid molecules move laterally within each phospholipid layer
2. the cell surface membrane can extend around foreign particle and engulf it by phagocytosis
3. integral proteins are scattered within the phospholipid bilayer
4. both saturated and unsaturated phospholipid molecules are present in both phospholipid layers

Which features are described by the fluid mosaic model of cell membranes?

A. 1 and 4 only **B.** 1 and 3 only **C.** 2 and 4 only **D.** 1, 2, 3 and 4

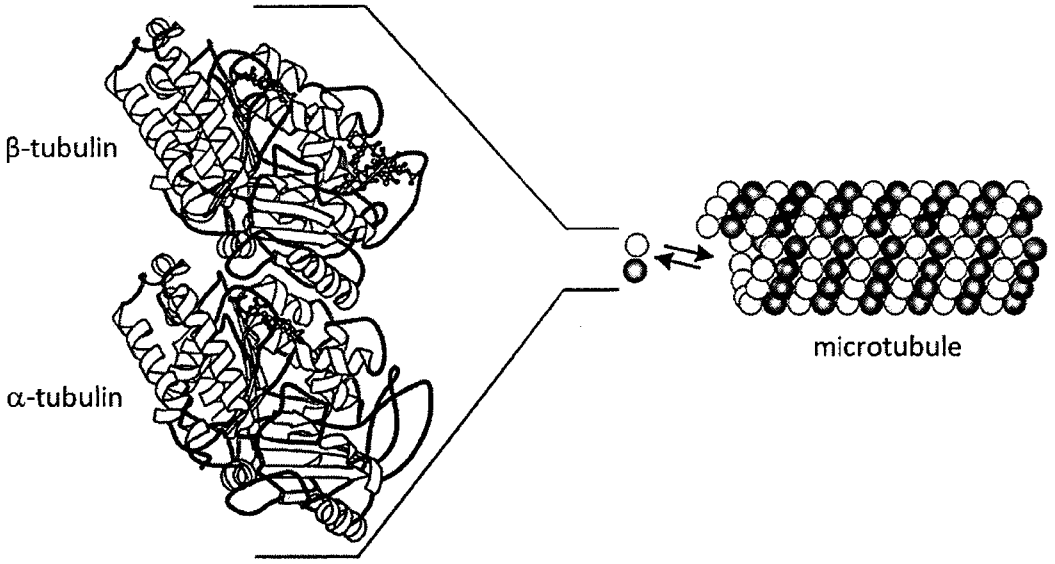
QUESTION 4
A typical human red blood cell contains 2.5×10^8 haemoglobin molecules.

Which of the following is true of a human red blood cell?

	number of α-globin chains present in a human red blood cell	maximum number of oxygen molecules a human red blood cell can carry
A.	5.0×10^8	2.5×10^8
B.	5.0×10^8	1.0×10^9
C.	1.0×10^9	2.5×10^8
D.	1.0×10^9	1.0×10^9

QUESTION 5

Microtubules are assembled from a heterodimeric protein called tubulin, as shown in the diagram below.



Which of the following explains why tubulin is considered as a monomer as well as a polymer?

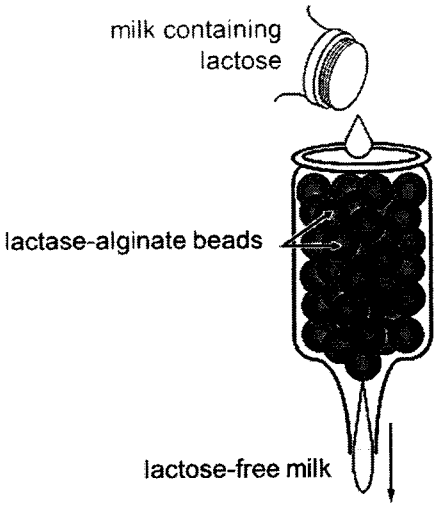
	why tubulin is a monomer	why tubulin is a polymer
A.	It is made up of many amino acids.	It is the building block of microtubule.
B.	It is the building block of microtubule.	It is made up of many amino acids.
C.	It is a quaternary protein.	It is a macromolecule.
D.	It is made up of two different subunits.	It has many α-helices and β-pleated sheets.

QUESTION 6

Enzymes, such as lactase, are often immobilized for use in the production of lactose-free milk.

Lactase is immobilized by encasing it in a gel-like matrix known as alginate beads. The beads vary in size. Small beads are usually selected and placed into a glass column, as shown in the diagram.

As milk that contains lactose passes through the column and comes into contact with the beads, lactose is broken down into its monosaccharides, glucose and galactose.



Which is **not** an advantage of using small beads compared to using large beads?

A. Small beads have larger surface area to volume ratio.

B. Small beads allow more time for lactase to be exposed to milk.

C. Small beads allow more lactase to be exposed to milk at any one time.

D. Small beads accelerate the passage of milk through the column.

QUESTION 7

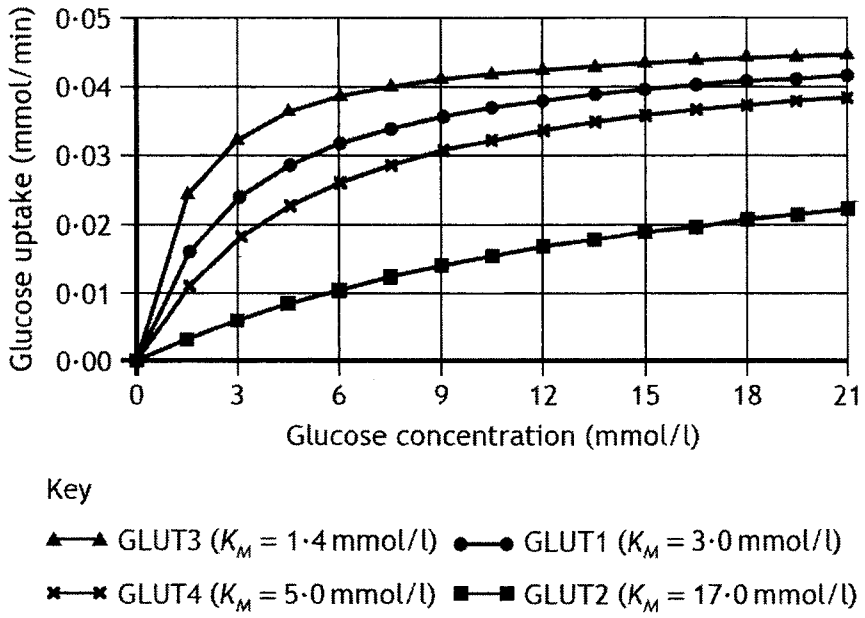
The diffusion of blood glucose across the cell surface membrane of mammalian cells is facilitated by a family of related proteins called glucose transporters (GLUT).

A study measured the changes in rates of glucose uptake by different forms of GLUT as the concentration of glucose is increased. Different forms of GLUT are found in different tissues.

For each type of GLUT, the rate of transport levels off to a maximum value that is termed $\mathbf{V_{max}}$.

The glucose concentration at which the rate of transport is **half $\mathbf{V_{max}}$** is defined as the $\mathbf{K_M}$ of the transporter. $\mathbf{K_M}$ is an indication of the affinity of the GLUT for glucose.

The $\mathbf{K_M}$ for the four forms of GLUT and the effect of increasing glucose concentration of the rate of glucose uptake are shown below.



Which statement can be concluded from the study?

A. GLUT3 has the lowest affinity for glucose.

B. The V_{max} for GLUT2 is 0.04 mmol/min.

C. GLUT1, GLUT3 and GLUT4 transport glucose via facilitated diffusion, while GLUT2 transport glucose via active transport.

D. As glucose concentration is further increased beyond 21 mmol/l, all the four forms of GLUT will eventually reach the same V_{max}.

QUESTION 8

Which of the following describes the fate of the products of the photolysis of water during photosynthesis?

	products of photolysis of water	fate
A.	ATP NADPH oxygen molecule	involved in the reduction stage of Calvin cycle involved in the reduction stage of Calvin cycle serves as the final electron acceptor during respiration
B.	electrons protons hydrogen molecule	replace the electrons lost in photosystem II contribute to the proton gradient in the thylakoid space diffuses out of the plant cell
C.	carbon dioxide hydroxide ions oxygen molecule	combines with RuBP in the Calvin cycle combine with protons to regenerate water serves as the final electron acceptor during respiration
D.	electrons protons oxygen molecule	replace the electrons lost in photosystem II contribute to the proton gradient in the thylakoid space serves as the final electron acceptor during respiration

QUESTION 9
Removal of the source of carbon dioxide from photosynthetic plant cells results in rapid changes in the concentration of ATP, ribulose bisphosphate and glycerate-3-phosphate.

Which of the following shows the correct changes in concentration?

	ATP	ribulose bisphosphate	glycerate-3-phosphate
A.	decreases	decreases	increases
B.	decreases	increases	decreases
C.	increases	increases	decreases
D.	increases	decreases	increases

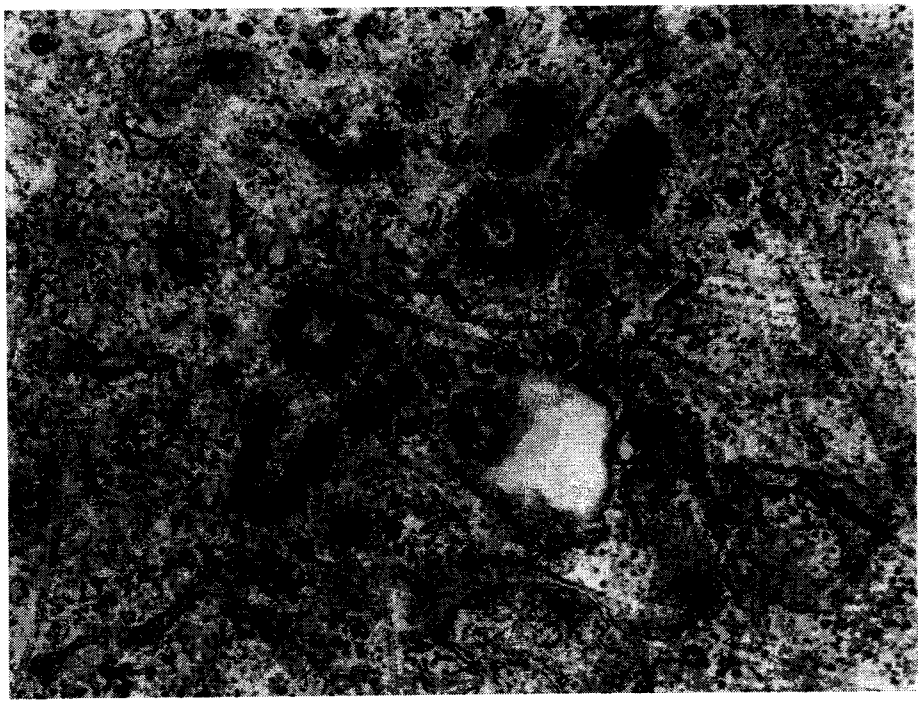
QUESTION 10
Which statements correctly describe cellular respiration?

1. Two turns of the Krebs cycle are required to oxidize one molecule of glucose.
2. Four molecules of carbon dioxide are generated for every molecule of acetyl-coA introduced into the Krebs cycle.
3. During aerobic respiration, glucose produces pyruvate, carbon dioxide and ATP in the cytoplasm of a muscle cell.
4. Aerobic respiration produces about 19 times the amount of ATP produced in anaerobic respiration per glucose molecule.

A. 1 only **B.** 1 and 4 only **C.** 2 and 4 **D.** 1, 3 and 4

QUESTION 11

The electron micrograph shows part of a stem cell that is undergoing mitosis.

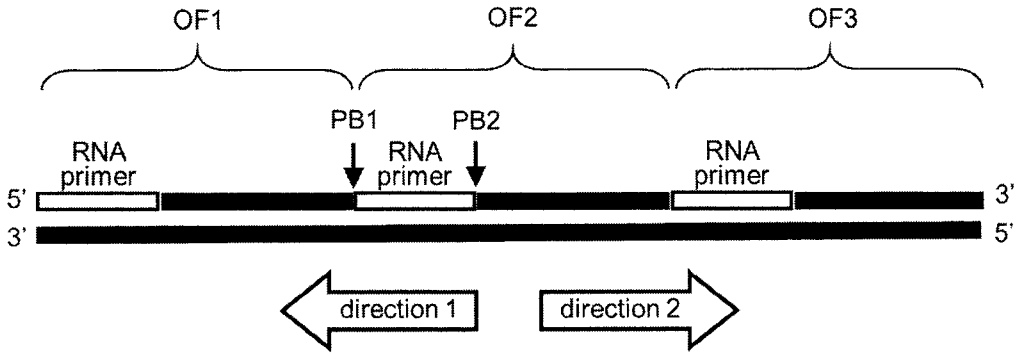


1 μm

Which mitotic phase is the stem cell undergoing?

A. prophase **B.** metaphase **C.** anaphase **D.** telophase

QUESTION 12
The diagram shows a DNA template with the lagging strand prior to the removal of the RNA primers.



Which row correctly shows the events taking place during the synthesis of the lagging strand?

	last Okazaki fragment synthesised	phosphodiester bond formation catalysed by...		polymerization of the lagging strand	polymerization of the RNA primer
		DNA ligase	DNA polymerase		
A.	OF3	PB2	PB1	direction 1	direction 1
B.	OF1	PB2	PB1	direction 2	direction 2
C.	OF3	PB1	PB2	direction 1	direction 2
D.	OF1	PB1	PB2	direction 1	direction 2

QUESTION 13
What do DNA replication, transcription and translation have in common?

1. formation of polymers
2. breaking and forming of hydrogen bonds
3. involvement of only one enzyme
4. reading of the template strand from the 3' to 5' direction

A. 1 and 2 **B.** 1 and 3 **C.** 2 and 3 **D.** 4 only

QUESTION 14
An mRNA contains the following codons. Four of the nucleotides are labelled 1 to 4.

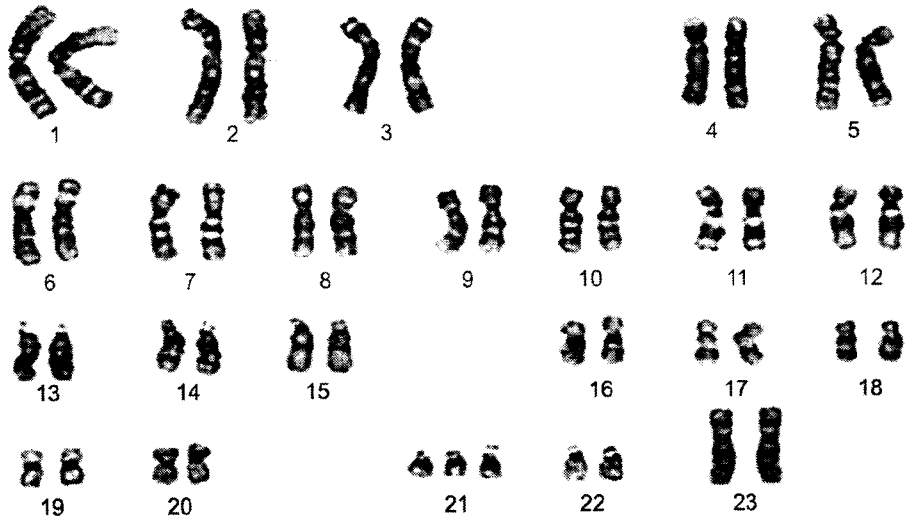
5' AUG CUA AAA UUC CUA GAU UUU CTC AGU UGA 3'
1 2 3 4

Which nucleotides, when deleted, result in a shortened polypeptide chain?

A. 1 and 3 **B.** 2 and 4 **C.** 3 and 4 **D.** 1 and 2

QUESTION 15

The diagram shows a karyotype (an individual's collection of chromosomes) taken from a patient suffering from a disease.



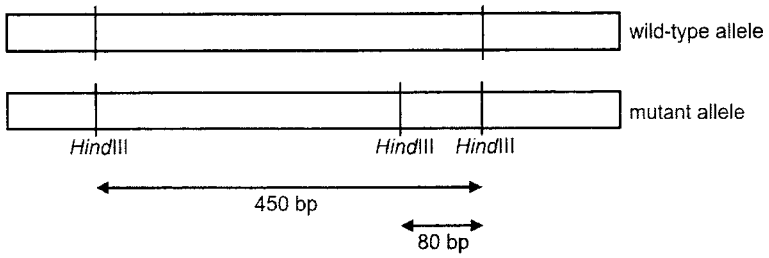
What would be the most accurate description of the cause of the disease and the phenotypes of the patient?

	cause of the disease	phenotypes of the patient
A.	aneuploidy	female, sickle-shaped red blood cells
B.	trisomy	female, mental retardation and up-slanting eyes
C.	polyploidy	male, sickle-shaped red blood cells
D.	chromosomal aberration	male, mental retardation and up-slanting eyes

QUESTION 16

A patient is suspected to be heterozygous for a gene (650bp) associated with mild neurological disorder. The mutated form of the gene arises as a result of a single nucleotide substitution that generates an extra *Hind*III restriction site.

The *Hind*III restriction sites on the wild-type (normal) allele and mutant allele are shown in the diagram.



You collected a blood sample from the patient and extracted the **total genome** from the white blood cells.

Which molecular techniques should be used to ascertain the genotype of this patient?

	polymerase chain reaction	restriction digestion with *Hind*III enzyme	nucleic acid gel electrophoresis	Southern blotting	nucleic acid hybridization
A.	✗	✓	✓	✓	✓
B.	✓	✗	✓	✗	✗
C.	✗	✓	✓	✗	✗
D.	✓	✓	✗	✓	✓

key

✓ = used

✗ = not used

QUESTION 17

A ribonucleoprotein is a complex of ribonucleic acid (RNA) and proteins.

Which are examples of ribonucleoprotein?

1. influenza virus
2. T4 bacteriophage
3. RNA primase
4. spliceosome
5. telomerase
6. ribosome

A. 1, 2 and 3 **B.** 1, 3, and 6 **C.** 3, 5 and 6 **D.** 4, 5 and 6

QUESTION 18

The discovery of introns and splicing in the 1970s led to two theories of their origin that became known as Introns Early and Introns Late.

- The Introns Early theory proposed that introns were present in the common ancestor of prokaryotes and eukaryotes. Introns then suffered different fates in the different lineages: they were progressively lost in prokaryotic lineages but persisted in eukaryotic lineages.

- The Introns Late theory proposed that introns first appeared in eukaryotes and have been inserted into protein-coding genes continuously throughout the evolution of eukaryotes.

Three observations were made regarding introns.

1. In many homologous genes found in animals and plants, introns intervene between exons at the same positions, suggesting that these introns were in place prior to the plant–animal evolutionary split.

2. A small number of prokaryotic genes contain what is known as 'self-splicing introns'. These introns, when transcribed into RNA, are ribozymes that catalyse their own excision.

3. Spliceosome genes are absent in prokaryotes but present in eukaryotes. Spliceosome genes have evolved in eukaryotes as a means to remove introns in mRNA transcribed from nuclear genes.

Which theory is supported by these observations?

	Introns Early	Introns Late
A.	1 and 3	2
B.	2	1 and 3
C.	3	1 and 2
D.	1 and 2	3

QUESTION 19

The worrying reports of antibiotic resistance and limited new antibiotic discoveries have fuelled innovation in other research fields and led to a revitalization of bacteriophage (phage) studies in the Western world.

Phage therapy mainly utilizes lytic phages to kill their respective bacterial hosts, while leaving human cells intact. Phage therapy is rapidly evolving and has saved thousands of lives in clinical trials and emergencies.

What would compel doctors to use phage therapy over antibiotic therapy?

A. Bacteriophage is highly specific; they kill only the bacteria that they can recognize. In contrast, antibiotics are non-discriminatory and kill a broad range of bacterial cells.

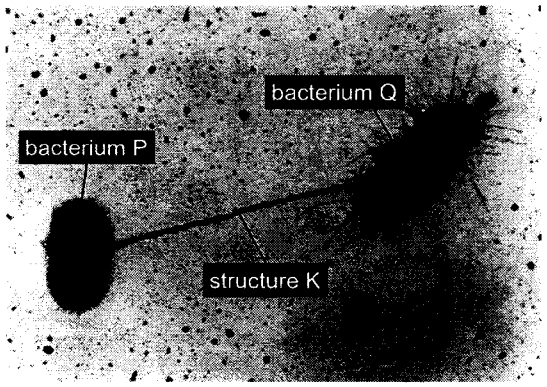
B. Phage therapy is effective in treating bacterial infections that do not respond to antibiotics.

C. Only one dose of bacteriophage is required, since bacteriophage multiply and increase in number by themselves during treatment. In contrast, antibiotic therapy requires multiple doses over a few days.

D. Phages are significantly safer and better tolerated, as they replicate only in bacterial cells but cannot infect mammalian cells. In contrast, antibiotics can result in side effects such as allergic reactions.

QUESTION 20

The micrograph shows a process occurring between two bacterial cells.



Five statements concerning the process are made:

- Structure K is a membrane extension connecting between bacterium P to bacterium Q and it facilitates the transfer of genetic material between the two bacteria.
- A polynucleotide is transferred, 3' end first, from bacterium Q to bacterium P.
- Structure K is made up of protein subunits that are coded for by the genes carried on the chromosomal DNA in bacterium Q.
- At the end of the process, bacterium P will be genetically identical to bacterium Q.
- DNA replication is taking place in bacterium P but not in bacterium Q.

How many statement(s) is/are correct?

A. 0 **B.** 1 **C.** 3 **D.** 5

QUESTION 21
Ampicillin-sensitive *E. coli* cells were subjected to heat-shock transformation to take up plasmid DNA that contain the ampicillin-resistance gene.

Successfully transformed cells were selected and allowed to divide for several generations in a nutrient medium without ampicillin. It was observed that some of the *E. coli* cells were no longer resistant to ampicillin.

What is the most likely explanation for the phenomenon?

A. Error during DNA replication causes a loss-of-function mutation to the ampicillin-resistance gene.

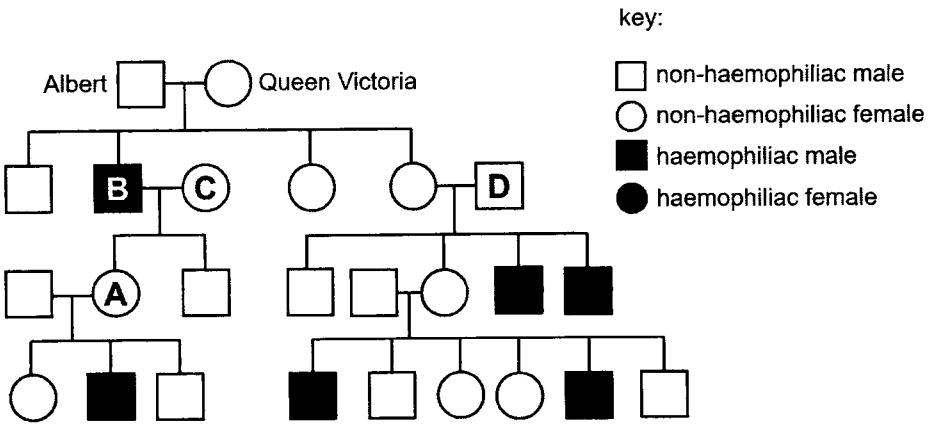
B. Incorporation of the plasmid DNA into the heterochromatin region of the bacterial genome renders the ampicillin-resistance gene inactive.

C. Restriction enzymes present in *E. coli* cells recognize specific sequences on the plasmid DNA and hydrolyse it into fragments.

D. Unequal distribution of plasmid during binary fission results in some daughter cells without plasmids.

QUESTION 22
The pedigree chart shows the inheritance of haemophilia (a sex-linked disease) in some of the descendants of Queen Victoria.

Which letter represents a descendant certain to be heterozygous?



ANSWER: (A)

QUESTION 23

Two genetic crosses in a species of flies were performed. In both crosses, the parents were pure breeding for eye colour and body colour.

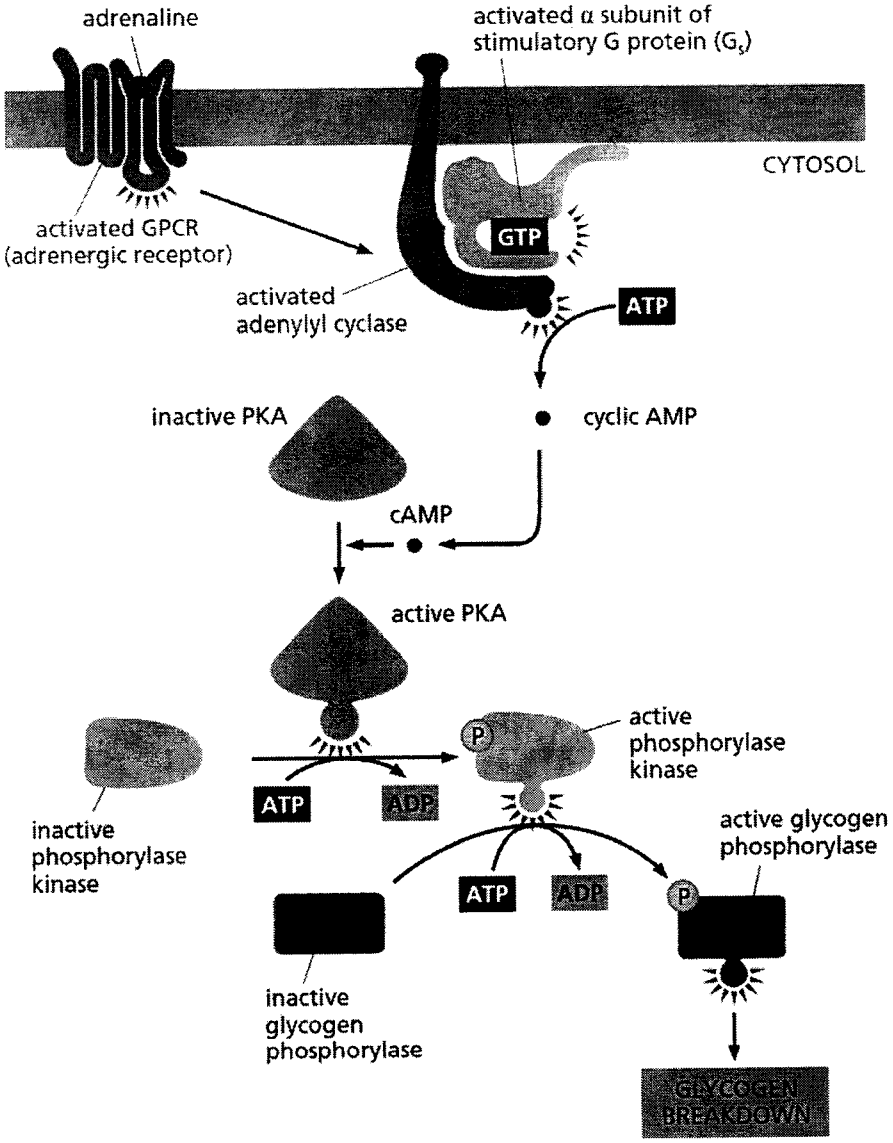
	male	female	offspring
cross 1	red-eyed, black body	white-eyed, grey body	all females are red-eyed, all males are white-eyed, both sexes have black body
cross 2	white-eyed, grey body	red-eyed, black body	both sexes are red-eyed, both sexes have black body

What can be concluded from the results of the two crosses?

	inheritance of eye colour	inheritance of body colour
A.	sex-linked	autosomal
B.	autosomal	sex-linked
C.	sex-linked	sex-linked
D.	autosomal	autosomal

QUESTION 24

The diagram shows the series of molecular events that take place when the hormone adrenaline binds to an adrenergic receptor, a G-protein coupled receptor, on the cell surface membrane of a skeletal muscle cell, leading to glycogen breakdown.



How many amplification steps are there in this transduction pathway?

A. 1 **B.** 2 **C.** 4 **D.** 6

QUESTION 25
In one of the scientific journals that Charles Darwin published in 1839, he wrote:

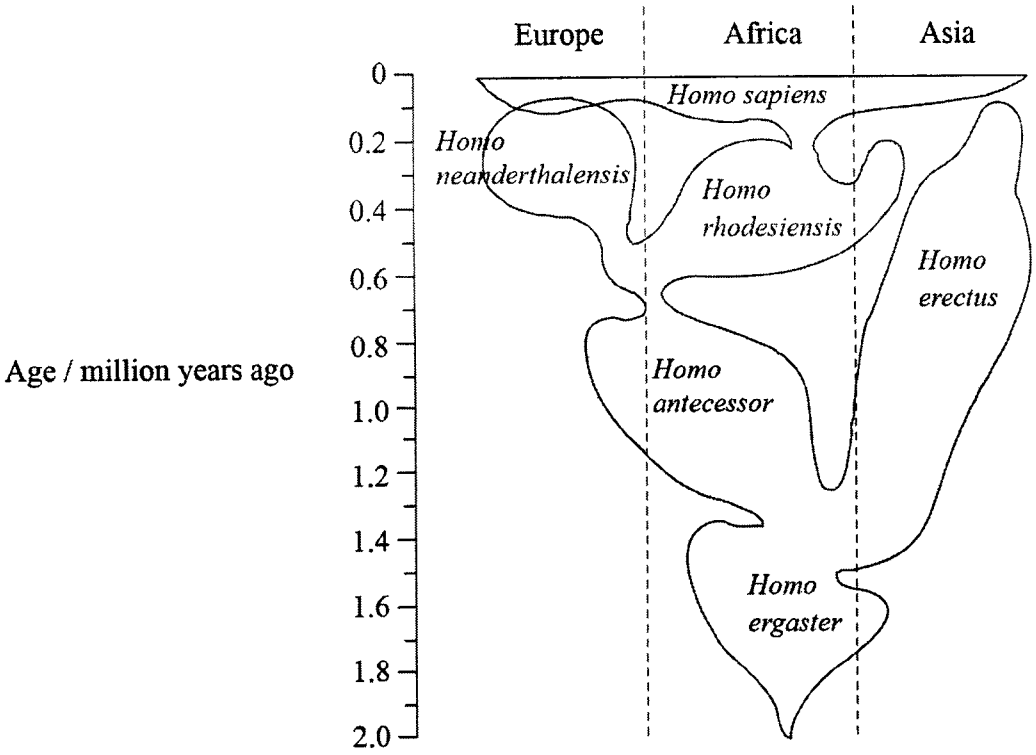
"*I have stated, that in the thirteen species of ground-finches [in the Galápagos Island], a nearly perfect gradation may be traced, from a beak extraordinarily thick, to one so fine, that it may be compared to that of a warbler. I very much suspect that certain members of the series are confined to different islands; therefore, if the collection had been made on any one island, it would not have presented so perfect a gradation. It is clear, that if several islands have each their peculiar species of the same genera, when these are placed together, they will have a wide range of character.*"

What does the above quote illustrate?

	type of speciation	type of variation	type of evolution	type of structure
A.	sympatric	continuous	divergent	analogous
B.	allopatric	discontinuous	convergent	analogous
C.	allopatric	continuous	divergent	homologous
D.	allopatric	discontinuous	convergent	homologous

QUESTION 26

Recently discovered fossilized partial skulls from Ethiopia have raised new questions about early human evolution. This has led to different theories about the origins of *Homo sapiens*. One of these theories is illustrated in the diagram below.



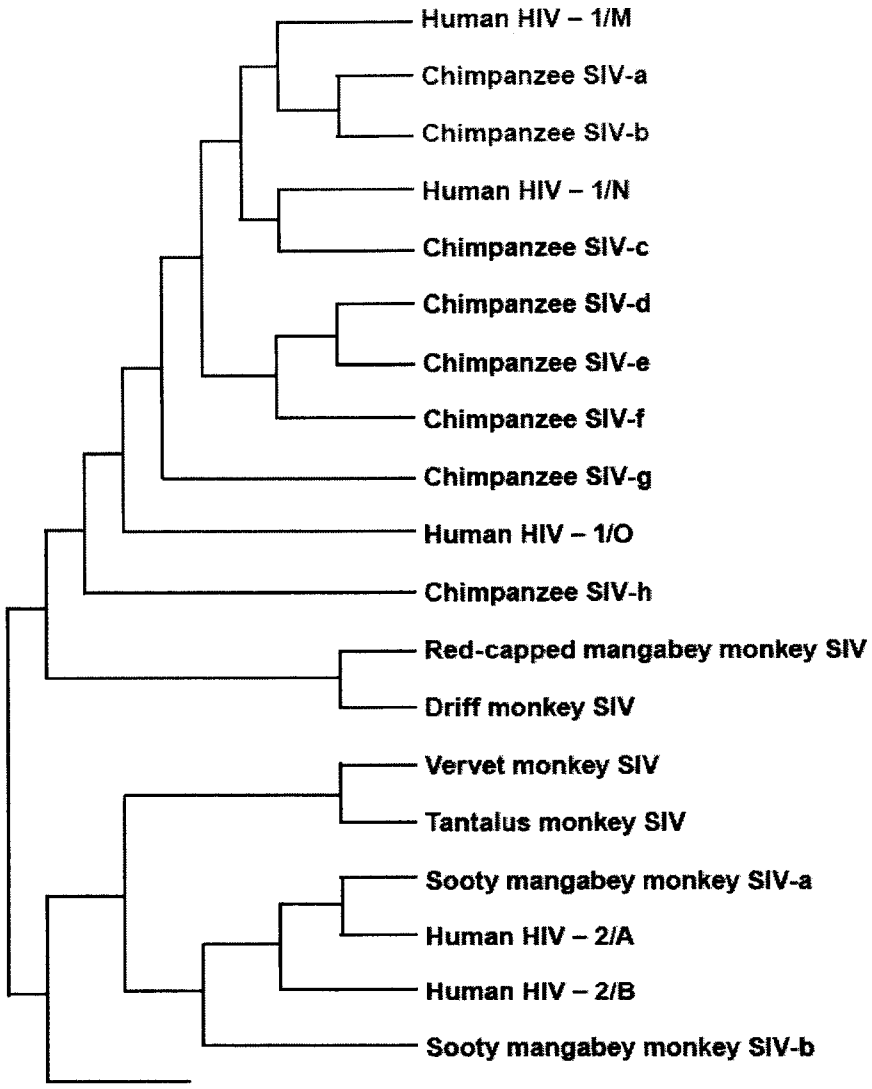
What can be concluded from the diagram?

	species that shows the greatest geographical distribution	species that likely provides the most fossil evidence
A.	*Homo erectus*	*Homo erectus*
B.	*Homo erectus*	*Homo antecessor*
C.	*Homo sapien*	*Homo erectus*
D.	*Homo sapien*	*Homo ergaster*

QUESTION 27

There are two main forms of the Human Immunodeficiency Virus: HIV-1, and the more virulent HIV-2. It is believed that HIV-1 and HIV-2 appeared due to mutations of a virus (SIV) found in monkeys and chimpanzees. These mutations have enabled them to infect humans.

Scientists have analysed the molecular similarities between HIV from infected humans and similar viruses which are found in monkeys and chimpanzees. The phylogenetic tree shows the possible evolutionary history of HIV.



Key: **SIV = Simian Immunodeficiency Virus.**

HIV = Human Immunodeficiency Virus.

What can be concluded regarding the evolution of both forms of human HIV?

A. HIV-2 evolved earlier than HIV-1.

B. HIV-2 and chimp SIV diverged from a common ancestor.

C. HIV-1 evolved thrice and HIV-2 evolved twice.

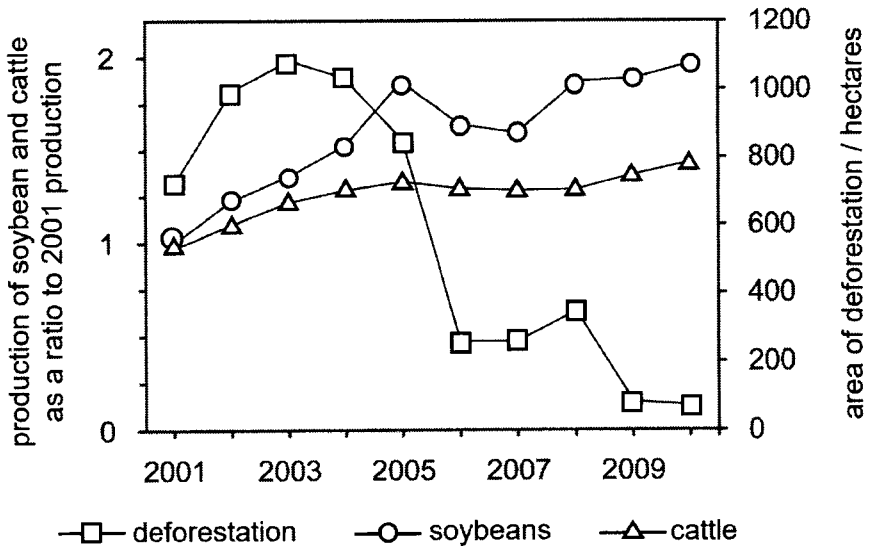
D. HIV-1 and HIV-2 evolved from a common HIV ancestor.

QUESTION 28
Which row correctly shows the mechanism of action of the antibiotic penicillin?

	cellular process interfered	organelle or enzyme inhibited	effect on bacterial cells
A.	protein synthesis (translation)	70S ribosomes	bactericidal
B.	protein synthesis (translation)	80S ribosomes	bacteriostatic
C.	peptidoglycan cell wall synthesis	transpeptidase	bactericidal
D.	peptidoglycan cell wall synthesis	cellulose synthase	bacteriostatic

QUESTION 29
Anthropogenic activities such as deforestation and agricultures are believed to be the major contributors to enhanced greenhouse effect.

The graph shows the annual trends in the area deforested and the production of soybeans and cattle in the state of Mato Grosso in Brazil in the period from 2001 to 2010.



Which of the following statements can be deduced from the information in this graph?

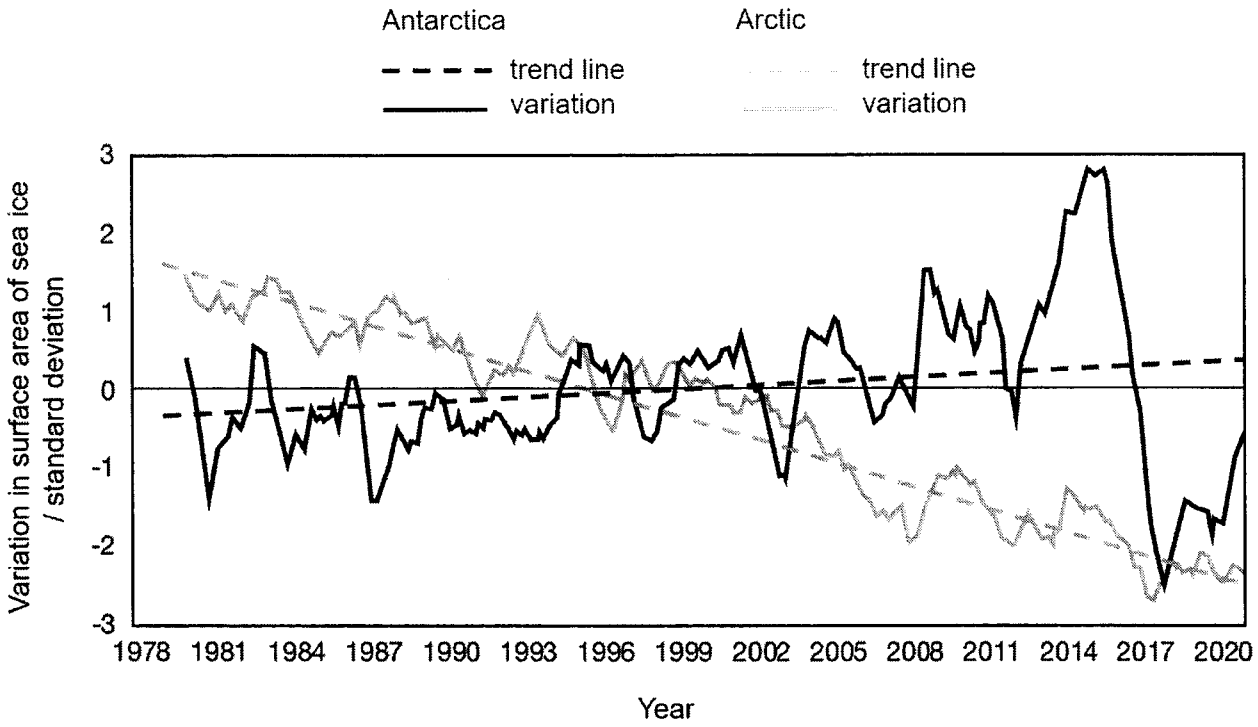
1. Soybean production contributed more to deforestation than cattle production.
2. Many animals lost their habitats in the forest between 2001 and 2002.
3. Carbon sinks declined between 2003 and 2006 and between 2008 and 2009.
4. There has been an increase in consumers' demand for cattle's milk and meat over the period of study.

A. 1 and 2 **B.** 2 and 3 **C.** 2 and 4 **D.** 1 and 4

QUESTION 30

Global warming has changed both the thickness and surface area of sea ice of the Arctic Ocean as well as the Southern Ocean that surrounds Antarctica. Sea ice is highly sensitive to changes in temperature.

Scientists have calculated a long-term mean (from 1981-2010) for the surface area of sea ice in the Arctic and in the Southern Ocean around Antarctica. This mean value is used as a reference for changes in surface area of sea ice. The graph shows the variations (standard deviation) from this mean (zero line) over a period of time.



What can be possibly deduced from the graph?

1. The rate of change in surface area of sea ice is greater for the Arctic than for the Antarctica, but there are greater fluctuations in the surface area of sea ice in the Antarctica than in the Arctic.
2. Melting of sea ice is expected with global warming, but the general increase in variation of surface area of sea ice in the Antarctica Ocean is evident that global warming has complex effects and does not affect all areas in the same way.
3. Penguins in the Antarctica Ocean faced immense hunting by marine predators from 2014 to 2017 due to a drastic loss of dry spots for hiding.
4. Polar bears in the Arctic are in danger of a drastic decrease in population from the retreating sea ice that serves both as their habitat and their hunting ground for seals.

A. 1 only **B.** 2 and 3 only **C.** 3 and 4 only **D.** 1, 2, 3 and 4

☺ End of Paper 1 ☺

TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

H2 BIOLOGY **9744/02**

Paper 2 Structured Questions

14 September 2022

2 hours

SUGGESTED ANSWERS

QUESTION 1

Fig. 1.1 is an electron micrograph of a mammalian liver cell undergoing G1 phase of the mitotic cell cycle. The liver cell contains an abundance of mitochondria and some storage molecules.

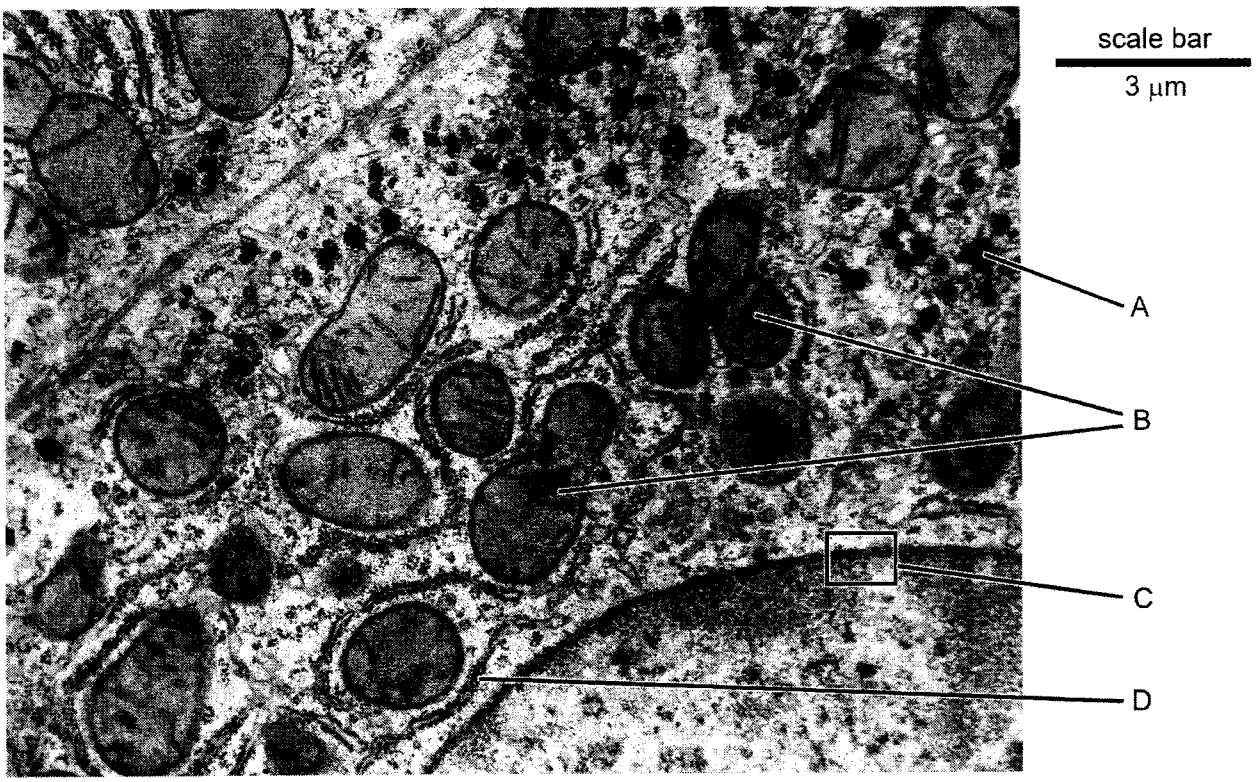


Fig. 1.1

(a) **A** is a storage polysaccharide while **B**, **C** and **D** are organelles or part of an organelle.

Name the storage polysaccharide **A** and organelle **D**. [2]

polysaccharide **A** glycogen

organelle **D** rough endoplasmic reticulum

(b) Explain why a typical light microscope in a Science laboratory could not have produced the image in Fig. 1.1. [1]

- ***Idea that*** resolution of light microscope not powerful enough to see **mitochondria** / **rough ER** / **glycogen granules**

(c) Calculate the magnification of the electron micrograph. Show your working. [2]

1. Measured length of scale bar = 27mm = **27,000μm** **[1]**

2. Magnification = measured length ÷ actual length
   = 27,000μm ÷ 3μm
   = **9,000** **[1, allow e.c.f.]**

Magnification = ×.....

(d) The structures labelled **B** on Fig. 1.1 are two mitochondria that are about to divide. Mitochondria synthesize ATP to power cellular processes.

Explain the importance of the division of mitochondria for the cell shown in Fig. 1.1 **and** for subsequent generations of the mammalian liver cells. [2]

for the cell shown in Fig. 1.1
1. Replace worn out / damaged mitochondria
2. Require more mitochondria (to produce more ATP) as the cells enlarge in size

for subsequent generations of the mammalian liver cells
3. So that daughter cells of the liver tissues receive sufficient mitochondria as cells divide.

(e) Within a cell, substances move between the nucleus and the cytosol. The area labelled **C** in Fig. 1.1 shows an area where this movement occurs.

Fig. 1.2 shows a magnified drawing of area **C**.

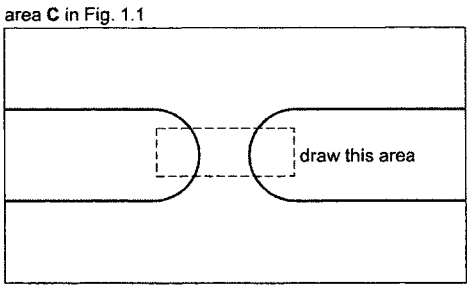
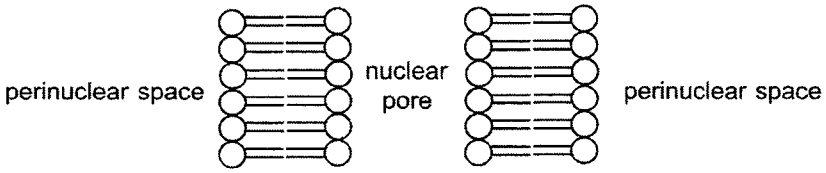


Fig. 1.2

Make a large drawing of the area within the dotted box shown in Fig. 1.2 to show the arrangement of phospholipid molecules. Labeling is **not** required.

You should use the symbol  in your drawing. [2]



[1] Two membranes with a gap (nuclear pore) in between
[1] Show each membrane is a bilayer **and** correct orientation of bilayer

[Total: 9]

QUESTION 2

A collagen polypeptide comprises an abundance of the amino acids glycine, proline and hydroxyproline. The repeating tripeptide sequence of glycine–proline–hydroxyproline is very common in collagen.

Fig. 2.1 shows a section of a collagen polypeptide comprising this tripeptide. The R-groups are indicated in bold.

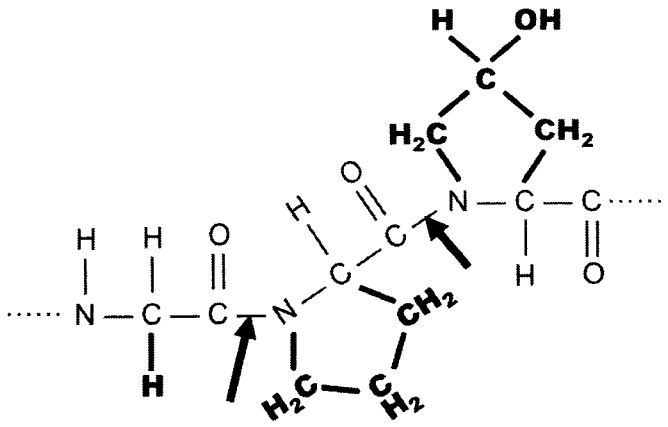


Fig. 2.1

(a) On Fig. 2.1, use arrows to indicate the peptide bonds that join the three amino acids. [1]

(b) Unlike glycine and proline, hydroxyproline is **not** directly added to the collagen polypeptide during translation. After translation is completed, no further amino acid is added.

Explain how a collagen polypeptide eventually contains hydroxyproline. [2]

1. post-translational modification
   OR
   biochemical modification of proteins

2. A **hydroxyl group** is added to / **hydroxylation** of the R-group of (selected) **proline** after the collagen polypeptide is formed

3. Takes place in the **rough endoplasmic reticulum** / **Golgi apparatus**

[Any 2]

(c) Fig. 2.2 shows the structure of a single collagen polypeptide. The R-groups of glycine, proline and hydroxyproline are indicated.

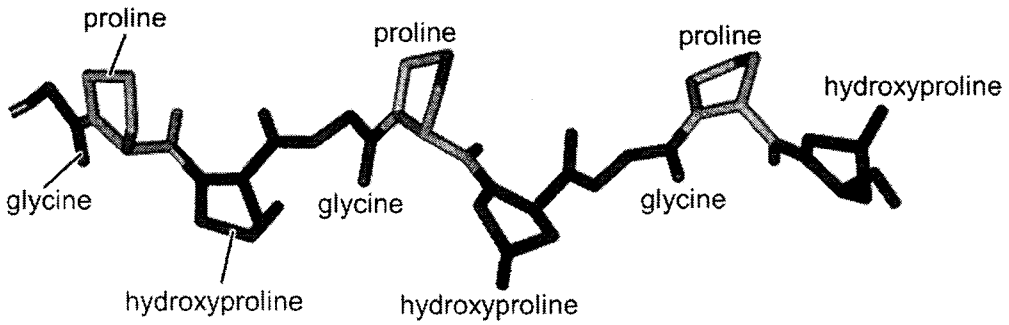


Fig. 2.2

The R-group of glycine is a hydrogen atom. In contrast, proline and hydroxyproline have a rigid and inflexible R-group that tend to cause the polypeptide to bend.

With reference to Fig. 2.2 and the information provided, suggest the role of glycine and that of proline and hydroxyproline in the formation of a tropocollagen molecule. [2]

1. **[glycine]** **small R-group** allows for **tight packing** of the three collagen polypeptides

2. **[proline/hydroxyproline]** (both R-groups are rigid thus) drives the **twisting** of each collagen polypeptide to form a (left-handed) **helix**

(d) The enzyme collagenase breaks down collagen. TIMP-1 is a chemical known to inhibit collagenase.

Fig. 2.3 shows the effect of adding a minute amount of TIMP-1 to collagen. The relative concentration of the products of collagen breakdown was recorded every minute for over seven minutes.

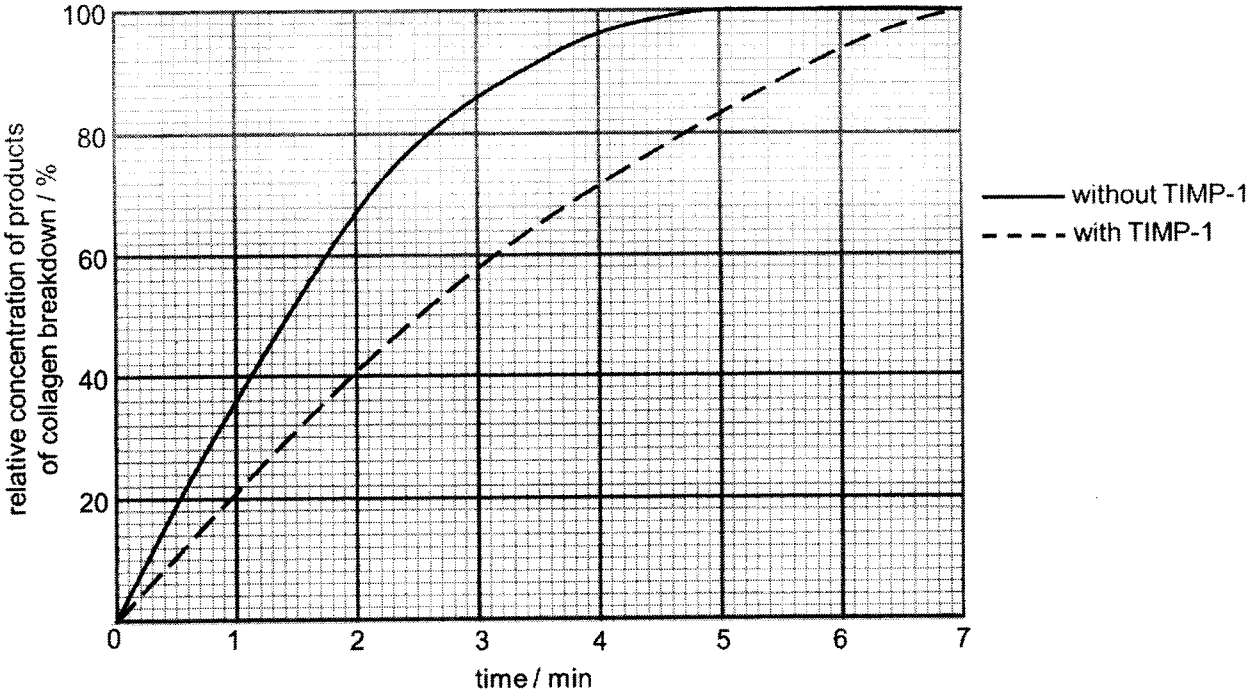


Fig. 2.3

Explain if Fig. 2.3 provides sufficient evidence to conclude if TIMP-1 is a competitive or non-competitive inhibitor of collagenase. [4]

<u>Insufficient</u> + *at least 1 from below*

1. Both types of inhibitors lower the rate of reaction
2. ***Idea that*** given enough time, all collagen will still be broken down, as shown in Fig. 2.3
3. To determine if TIMP-1 CI or NCI, plot **<u>rate of reaction</u>** against **<u>increasing collagen concentration</u>**

[max 2]

4. If CI, V_{max} can be achieved at $[collagen]_{high}$...
5. ...as collagen outcompete TIMP-1 to bind to the active site of collagenase
6. If NCI, V_{max} cannot be achieved at $[collagen]_{high}$....
7. ...since NCI alters collagenase conformation, effectively lowering no. of functional collagenase

[Any 4]

[Total: 9]

QUESTION 3

Fig. 3.1 represents some of the reactions that take place in a leaf cell of a flowering plant.

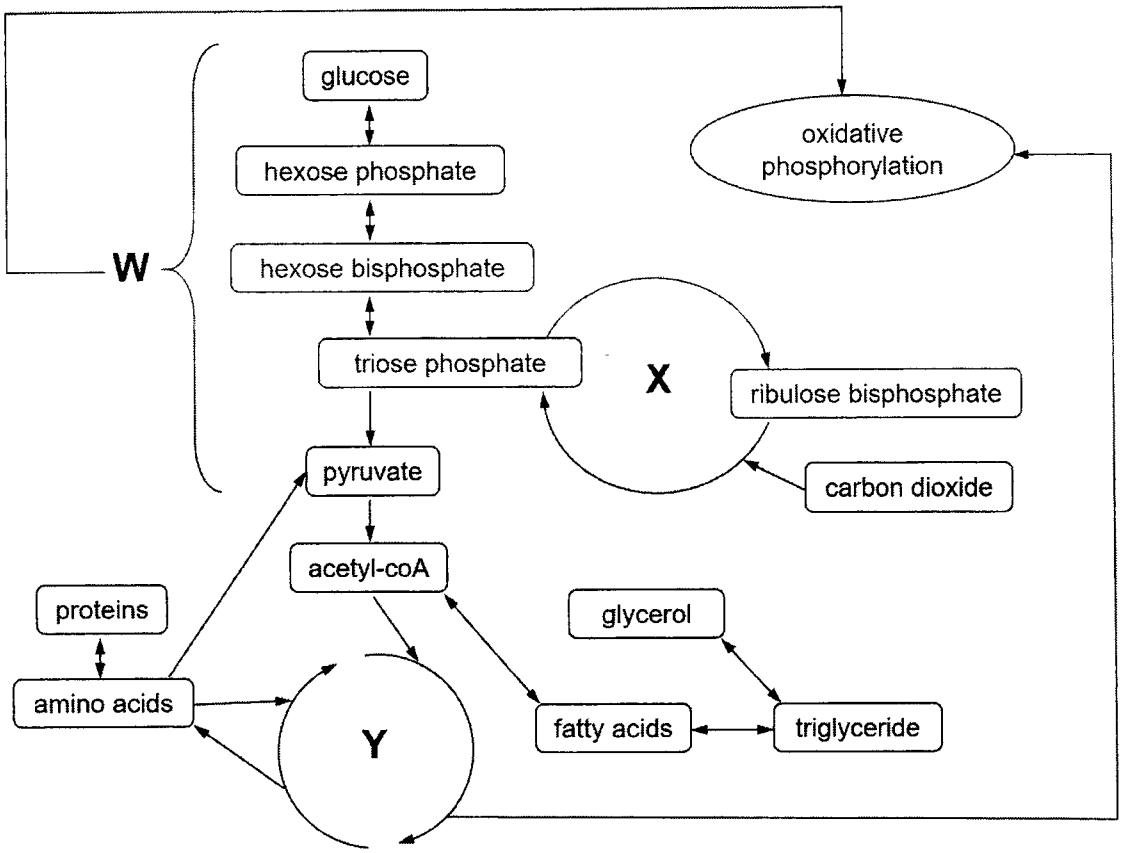


Fig. 3.1

(a) Name the reaction pathways indicated by the letters **W**, **X** and **Y**. [3]

W glycolysis

X Calvin cycle **[Reject: light-independent stage]**

Y Krebs cycle / tricarboxylic acid cycle / citric acid cycle

(b) Explain how the three reaction pathways (**W**, **X** and **Y**) are able to work independently of one another in the same leaf cell. [2]

1. ***Idea of*** compartmentalization / membranous organelles to separate reactions
2. W in **cytosol**, X in **chloroplast**, Y in **mitochondria**
3. ***Ref to*** one advantage of compartmentalization: e.g. localizing enzymes

[Any 2]

(c) With reference to the metabolic reactions outlined in Fig. 3.1, state the distinct role of **three named** coenzymes in this leaf cell. [3]

1. **NAD** / **FAD** – electron and proton acceptor in glycolysis (NAD only) and Krebs cycle
2. **NADP** – final electron acceptor in (non-cyclic) photophosphorylation
3. **NADH** / **$FADH_2$** – donates (high-energy) electrons to the electron transport chain in the inner mitochondrial membrane
4. **NADPH** – reduces 1,3-bisphosphoglycerate to glyceraldehyde-3-phosphate / triose phosphate in Calvin cycle
5. **Coenzyme A** – combines with pyruvate to form acetyl-coA

[Any 3]

(d) The carbons in glucose and the carbons in the fatty acids of triglyceride are used to generate acetyl-coA, a two-carbon molecule.

Using your knowledge on biomolecules and the information in Fig. 3.1, explain why **one molecule** of triglyceride can generate more ATP than **one molecule** of glucose. [4]

1. A triglyceride contains **three fatty acids**
2. Each fatty acid is a **long hydrocarbon** / **contains many carbons**, compared to 6 carbons in glucose
3. **One glucose** generates **two acetyl-coA** (two-carbon), but **one fatty acid/triglyceride** generates **many acetyl-coA** (varies with length of FA)
4. **More turns of Krebs cycle** with each triglyceride
5. More ATP generated by **substrate-level phosphorylation** in Krebs cycle
6. **More NADH / $FADH_2$** generated for **oxidative phosphorylation** to form more ATP

[Any 4]

[Total: 12]

QUESTION 4
A number of different proteins are involved in regulating the cell cycle.

To initiate mitosis, cyclin B and CDK1 (a protein kinase) bind to each other to form a complex called the mitosis-promoting factor (MPF). CDK1, when unbound to cyclin B, is inactive.

MPF phosphorylates proteins that are important for the cell to enter prophase. Examples of these proteins are:

- condensins: the **phosphorylated** form binds to chromatin threads to promote condensation into chromosomes
- lamins: the **unphosphorylated** form binds complementarily to the underside of the nuclear membrane to provide structural support to the nucleus

(a) Explain how phosphorylation of **lamins** by MPF allows the cell to **complete prophase**. [2]

1. Phosphorylation **changes conformation** of lamins
   OR
   Phosphorylated lamins **no longer complementary in shape** to underside of nuclear membrane
2. ***Idea of*** leads to its detachment/dissociation from the underside of nuclear membrane
3. **[COMPULSORY]** ***Idea of*** nuclear envelope disintegrates, which hence completes prophase

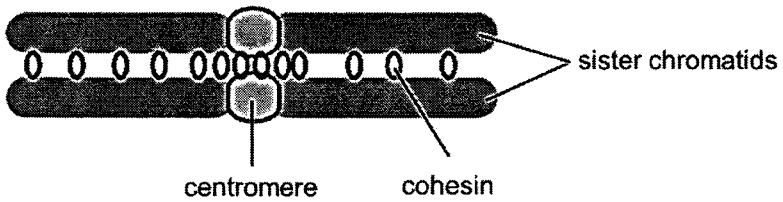
[Any 2]

The condensed chromosomes visible in prophase each consists of sister chromatids, which are held together along their length, including the centromere, by proteins known as cohesin.

Cohesin can be broken down by the enzyme separase.

Separase is initially synthesised in an inactive form by binding to another protein called securin, which physically blocks the active site of separase.

(b) Draw a **labelled** diagram to show how sister chromatids are held together. [3]



two chromatids with centromere [1]
at least 1 cohesin on centromere and both arms [1]
correctly label sister chromatids, centromere and cohesin [1]

(c) Later in mitosis, MPF activates a protein complex called the anaphase-promoting complex (APC).

One role of the activated APC is to catalyse the transfer of ubiquitin molecules to securin and cyclin B. Ubiquitinated proteins are bound for degradation in the proteasome.

Using **all** the information given in this question thus far, explain how

(i) degradation of securin triggers the cell to enter anaphase. [3]

1. **active site** of separase no longer blocked by securin
2. separase binds to and breaks down cohesin
3. sister chromatids pulled apart to opposite poles (anaphase)

(ii) degradation of cyclin B triggers the cell to enter telophase. [3]

1. absence of cyclin B to bind to CDK1
2. CDK1 remains inactive / no MPF

EITHER
3. Condensins become dephosphorylated
4. Chromosome de-condense (telophase)

OR
3. Lamins become dephosphorylated (thus bind underside of nucleus to provide support)
4. nuclear envelope re-forms (telophase)

[Any 3]

(d) Unlike mitosis, meiosis gives rise to genetically different cells.

Outline **two** ways by which meiosis can give rise to genetically different cells. [2]

1. **Crossing over** between **non-sister chromatids** of **homologous chromosomes** during **prophase I**

2. **Independent assortment** and **segregation** of **homologous chromosomes** during **metaphase I** and **anaphase I**

3. **Independent assortment** and **segregation** of **chromatids** during **metaphase II** and **anaphase II**

[Total: 13]

QUESTION 5

DNA methylation usually occurs at the cytosine bases of eukaryotic DNA, catalyzed by DNA methyltransferases (DMT). The methylated cytosine residues are usually immediately adjacent to a guanine nucleotide, resulting in two methylated cytosine residues sitting diagonally to each other on opposing DNA strands.

Different variants of the DMT act in different ways. Fig. 5.1 shows the role of two different variants of DMT (DMT3 and DMT1) at different junctures of DNA methylation.

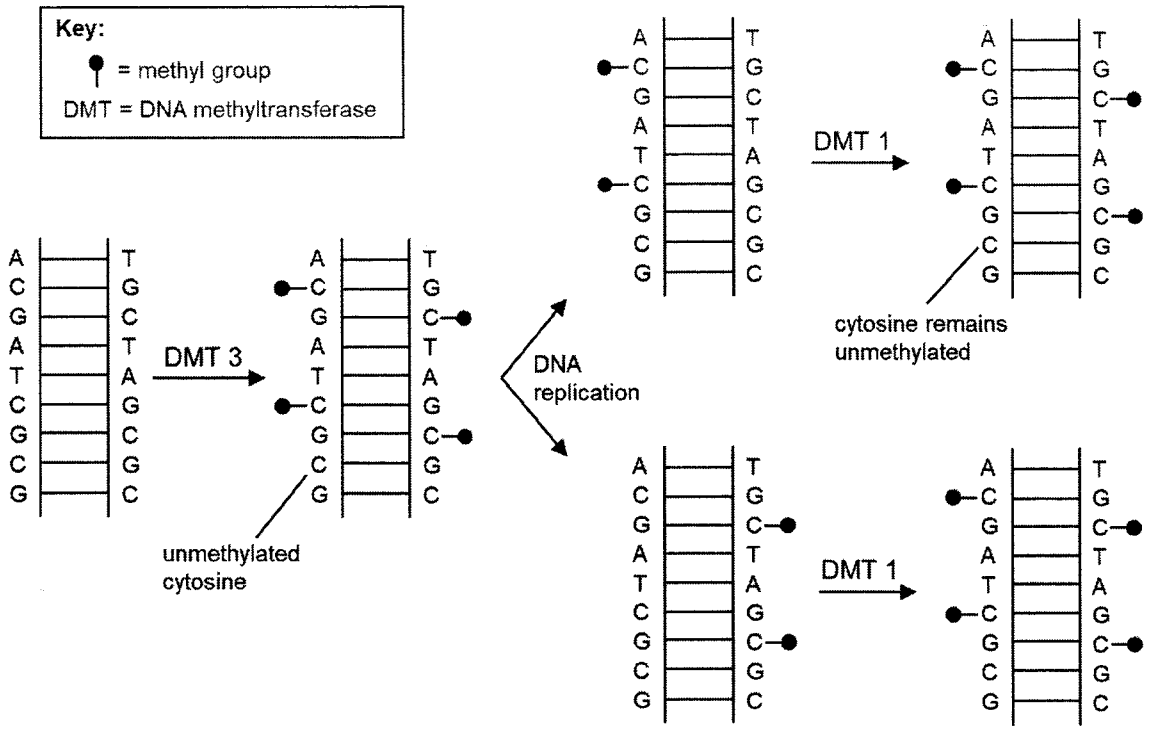


Fig. 5.1

(a) State the name of the enzyme that uses the base sequence of one DNA strand to form the complementary strand. [1]

- DNA polymerase (III)

(b) With reference to Fig. 5.1, state the role of DMT3 and DMT1 in DNA methylation. [2]

1. ***Idea that*** DMT3 adds methyl groups on **certain/some/selected** cytosine on **both strands**

2. ***Idea that*** DMT1 copies the methylation pattern from an existing DNA strand to the complementary strand after replication

[**Reject**: DMT3 methylate both strands, while DMT1 methylate one strand]

The *APC* gene was implicated as a possible cause of colon cancer. Samples taken from colon cancer cells of 10 patients and colon cells of 10 healthy individuals were analyzed for their methylation patterns.

Fig. 5.2 shows the DNA methylation patterns on the promoter of the *APC* gene from the 20 samples. The numbers (32–269) represent the base position on the promoter.

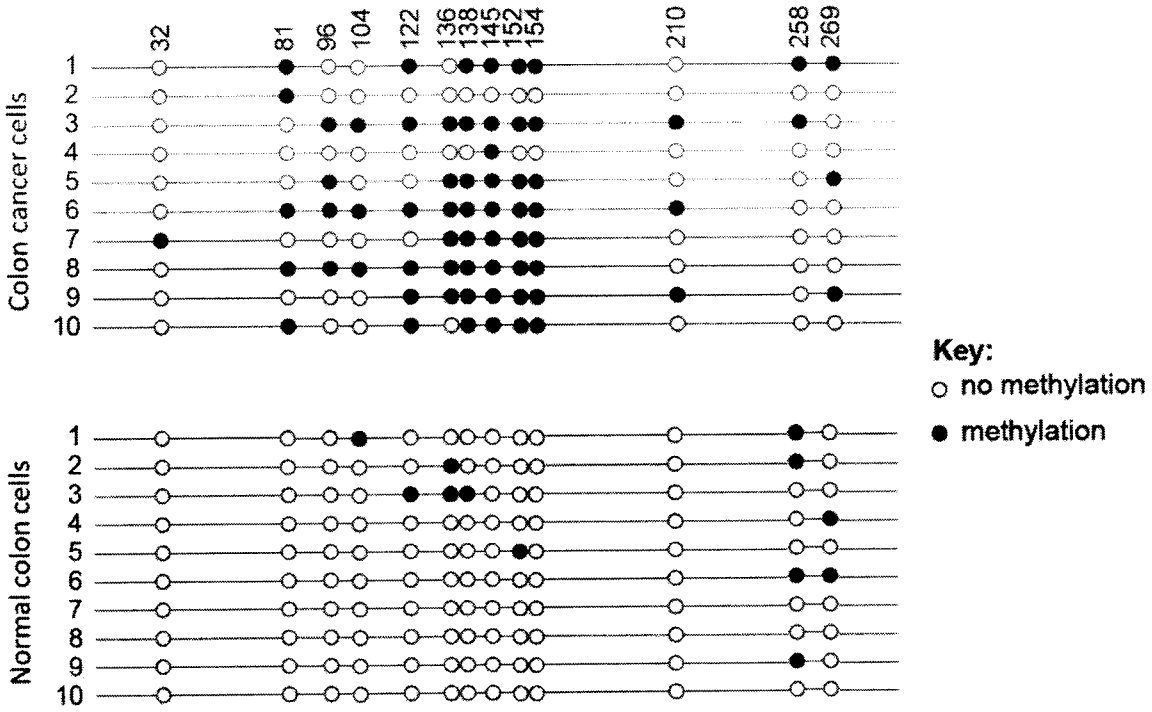


Fig. 5.2

(c) Deduce if the *APC* gene is a proto-oncogene or a tumour-suppressor gene. [1]

- tumour-suppressor gene

(d) Contrast the methylation patterns of cancer and normal samples. [2]

Feature	**Cancer**	**normal**
Overall extent of methylation	Greater extent	Smaller extent
Preferential methylation of specific bases	Base 138 / 145 / 152 / 154 preferentially methylated across the 10 samples	No preferential methylation
Any unmethylated base across the 10 samples?	No unmethylated base across the 10 samples	Some bases / base 32 / 81 / 96 / 145 / 210 are not methylated in all the 10 samples
Any samples not methylated at all?	At least 1 base is methylated	3 samples (7, 8 & 10) are not methylated
AVP		

[Any 2]

(e) Suggest why some healthy individuals did not develop colon cancer, despite the *APC* gene being methylated. [2]

1. Cancer is a result of **accumulation of mutations** in a **single cell**, hence just APC gene alone is not sufficient to result in cancer.

2. **Loss-of-function mutations** need to occur to **other tumor suppressor genes**

3. **Gain-of-function mutations** need to occur to **proto-oncogenes**

4. ***Idea that*** The extent of methylation is too small to result in silencing of APC gene.

[Total: 8]

QUESTION 6

In white clover, *Trifolium repens*, one gene determines the production of a cyanide-forming substrate. Allele **A** produces the cyanide-forming substrate, whilst allele **a** produces no substrate.

A second gene, located on a different chromosome, determines the production of an enzyme that catalyses the release of cyanide from the substrate. Allele **E** produces the enzyme, whilst allele **e** produces no enzyme.

- Clover that has both **A** and **E** alleles releases cyanide rapidly when its leaves are crushed.
- Clover with **A** but not **E** releases cyanide slowly when its leaves are crushed.
- Clover that does not have **A** cannot release cyanide.

In an experiment, a clover that releases cyanide rapidly was self-pollinated. The following numbers of offspring were obtained:

rapid cyanide release	140
slow cyanide release	49
no cyanide release	67

(a) Construct a genetic diagram to explain the above offspring numbers. [4]

Parent phenotype: releases cyanide rapidly x releases cyanide rapidly

Parent genotype: AaEe AaEe [1]

Gametes: (AE) (Ae) (aE) (ae) (AE) (Ae) (aE) (ae) [1]

Offspring genotype & phenotype: [1]

	(AE)	(Ae)	(aE)	(ae)
(AE)	AAEE rapid release	AAEe rapid release	AaEE rapid release	AaEe rapid release
(Ae)	AAEe rapid release	AAee slow release	AaEe rapid release	Aaee slow release
(aE)	AaEE rapid release	AaEe rapid release	aaEE no release	aaEe no release
(ae)	AaEe rapid release	Aaee slow release	aaEe no release	aaee no release

Offspring phenotypic ratio: 9 rapid release : 3 slow release : 4 no release [1]
Which corresponds closely to 140 49 67

(b) A student attempted to perform a chi-squared (χ^2) test on the offspring numbers.

(i) Using the ratio from part **(a)**, complete the table below to show the **expected** number of each phenotype of the offspring. [1]

phenotype	observed number (O)	expected number (E)
rapid release	140	**144**
slow release	49	**48**
no release	67	**64**

(ii) Table 6.1 shows part of the χ^2 table.

Table 6.1

Degrees of freedom	Probability								
	0.9	0.8	0.7	0.5	0.2	0.1	0.05	0.02	0.01
1	0.016	0.064	0.15	0.46	1.64	2.71	3.84	5.41	6.64
2	0.21	0.45	0.71	1.39	3.22	4.60	5.99	7.82	9.21
3	0.58	1.00	1.42	2.37	4.64	6.25	7.82	9.84	11.34
4	1.06	1.65	2.20	3.36	5.99	7.78	9.49	11.67	13.28

The calculated χ^2 value is determined to be 0.273.

Explain what can be concluded from the calculated χ^2 value of 0.273. [3]

1. At df = 2, the calculated χ^2 value of 0.273 is less than the **critical value of 5.99** at **p=0.05**

2. The probability of the difference in observed and expected numbers being due to chance is **between 0.8 and 0.9**, that is, **more than 0.05**.

3. Hence, the difference is **due to chance**, and the observed number of 140:49:67 **conforms to the expected number** of 144:48:64.

[Total: 8]

QUESTION 7

Erythropoietin (EPO) is a glycoprotein hormone produced by the kidney in response to low blood oxygen concentration. EPO binds to its target stem cell to promote the formation of red blood cells.

(a) State the name of the stem cell to which EPO binds **and** describe the unique features of this stem cell. [3]

1. **myeloid** stem cells	**OR**	**blood** / **hematopoietic** stem cells
2. **multipotent**		**pluripotent**
3. able to differentiate into red blood cells **and** (some) white blood cells / named WBC / platelets		able to differentiate into all cell types except the extraembryonic membranes
4. **unspecialized** cells due to the **absence of tissue-specific structures**		
5. indefinite self-renewal / proliferation / cell division		
6. (re)-activated telomerase activity		

[Any 3]

(b) Fig. 7.1 shows the cascade of events that occur upon binding of EPO to the EPO receptor on the target stem cell, leading to the activation of the transcriptional activator, GATA1.

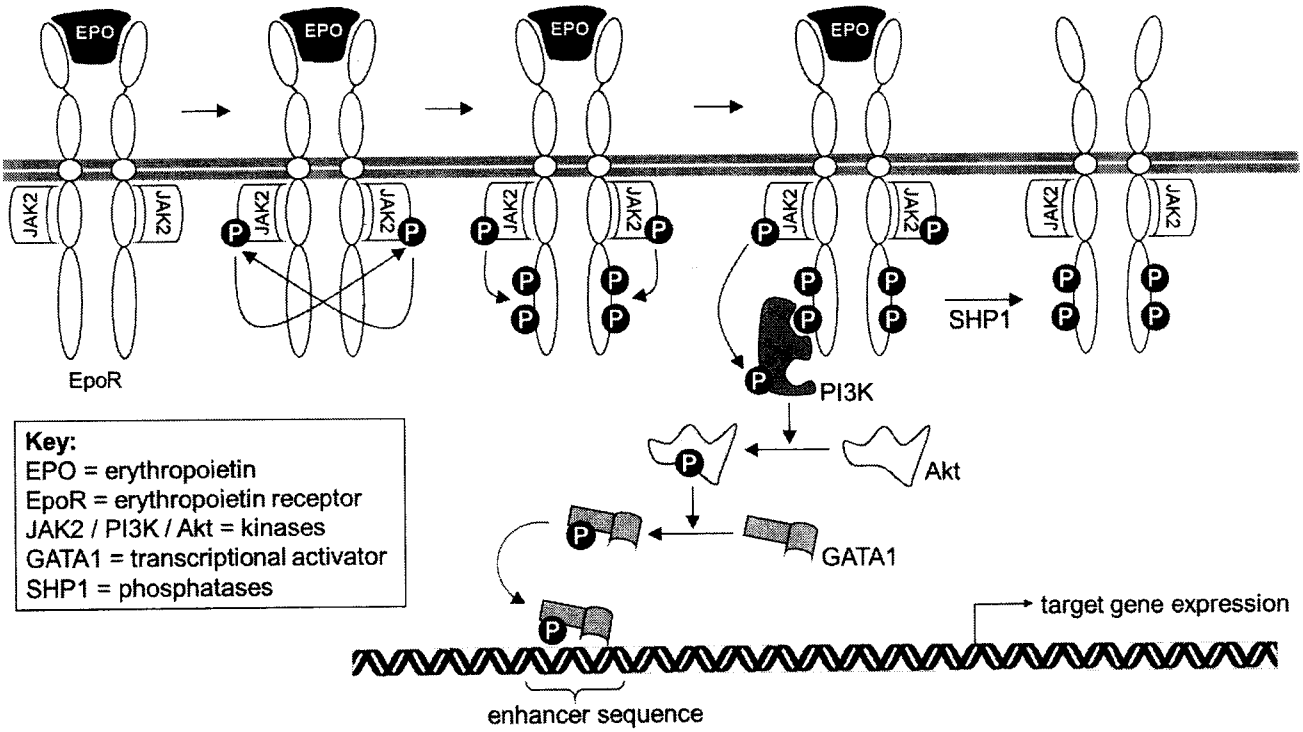


Fig. 7.1

(i) Describe the signal **transduction** events leading to the activation of the transcriptional activator, GATA1. [4]

1. Jak2 kinases **cross-phosphorylate** and activate each other.
2. Activated Jak2 phosphorylate (multiple tyrosine residues) on the **cytoplasmic domain** / **tyrosine tail** of EpoR.
3. PI3K kinase binds to phosphorylated cytoplasmic domain / tyrosine tail of EpoR.
4. Jak2 **phosphorylates** and **activates** PI3K.
5. Activated PI3K phosphorylates and activates Akt.
6. Activated Akt phosphorylates and activates GATA1.

[Any 4]

(ii) Explain how the transcriptional activator GATA1 **upregulates** the expression of target genes. [3]

1. Binds to the **enhancer** sequence
2. ***Ref to role of*** DNA-bending protein
3. Brings GATA1 in close proximity to the promoter sequence
4. Stabilizes the transcription initiation complex / RNA polymerase
5. Ensures RNA polymerase completes transcription without dissociating prematurely.

[Any 3]

(iii) Name one possible target gene that can be upregulated by GATA1. [1]

- (haemo/α/β-) **globin** gene / *any genes involved in mitotic cell cycle* e.g. CDK genes, cyclin genes

(iv) Explain how EPO signaling is terminated. [1]

- SHP1 / phosphatase removes phosphate group from JAK2, inactivating it

(c) As developing red blood cells mature during blood synthesis, membranous organelles such as mitochondria are lost from the cell to make space for haemoglobin molecules. Many organelle-dependent reactions hence do not occur in red blood cells.

(i) Suggest how the loss of mitochondria is a **further** advantage to the proper functioning of red blood cells. [2]

1. Mitochondria use oxygen as the **final electron acceptor** during aerobic respiration

2. ***Idea that*** Having lost mitochondria means that red blood cells do not consume any of the oxygen they are transporting, so they can deliver all the oxygen to respiring tissues

(ii) Explain how red blood cells are still able to synthesize a small amount of ATP throughout their lifespan, despite having lost their mitochondria. [2]

1. ATP can be synthesized via **glycolysis** in the **cytosol**

2. via **substrate level phosphorylation**

3. reduction of **pyruvate to lactate** **regenerates NAD** for glycolysis to continue.

(iii) Despite the lack of genes due to the absence of a nucleus, new protein molecules continue to be synthesised throughout the lifespan of a red blood cell. However, the rate of protein synthesis decreases with the lifespan of the red blood cell and eventually ceases.

Explain why new proteins can still be synthesised by a red blood cell **and** why protein synthesis eventually ceases. [2]

1. **Existing mRNA** in the cytosol can still be translated by (80S) ribosomes

2. **mRNA degradation** / **worn-out of ribosomes** eventually cease protein synthesis

[Total: 18]

QUESTION 8

Science has identified some two million species of plants, animals and micro-organisms on Earth, but scientists estimate that there are thirteen million more left to discover. The most commonly discovered new species are typically insects, a type of animal with a high degree of biodiversity and accounts for more than half of the species identified. New species are typically discovered in remote places that have not been well studied previously, such as islands.

(a) Suggest why it is impossible to identify all living species on earth. [1]

1. ***Ref. to*** inaccessible/remote places (e.g. deep oceans, concealed caves)
2. ***Idea that*** New species are constantly evolving

[Any 1]

(b) Suggest **and** explain why there are so many different species of insects as compared to other animals. [2]

1. **[Suggest]** (Most have) flight ability
2. **[Explain]** Easily dispersed to different environment thus face different selection pressures

3. **[Suggest]** Insects have existed for a long time (before other animals) / evolutionarily older
4. **[Explain]** Hence sufficient time for many rounds of speciation to occur

5. **[Suggest]** Large number of offspring
6. **[Explain]** Affords greater variation, allowing natural selection to act to result in speciation

7. **[Suggest]** Shorter generation time
8. **[Explain]** Within a fixed period of time, more mutations are possible, hence more variation

[Any 1 pair]

(c) Scientists have long been puzzled over how land animals reach remote islands that lie in the midst of vast oceans. Recent studies suggest that animals can travel from one land mass to another by floating on giant rafts of earth and vegetation.

(i) Suggest how climate change may facilitate colonization of remote islands by land animals. [1]

- ***Idea of*** more frequent natural disasters (like massive landslides) that create land masses for land animals to float on.

(ii) Explain why species on remote islands are usually not found anywhere else on earth. [3]

1. **Geographically isolated** from mainland
2. **No/reduced gene flow** from mainland
3. Unique selection pressures
4. Unique set of alleles selected for and against
5. Evolve independently from organisms in the mainland

[Any 3]

(iii) Explain why island populations are much more prone to extinction than mainland populations. [1]

- **Low genetic variation** (due to Founder's effect), hence more prone to extinction when **environment changes**.

(d) Cryptic species are animals that look outwardly similar to another species. Oak Titmouse and Juniper Titmouse, both native to North America, are examples of cryptic species. Until recently, they had been considered as the same species for 151 years.

Fig. 8.1 shows the titmice and their distribution on the North America continent.

Oak Titmouse
(*Baeolophus inornatus*)

Juniper Titmouse
(*Baeolophus ridgwayi*)

Fig. 8.1

(i) State the **lowest** taxonomic rank on the Linnaean system of classification to which the two populations of titmice share. [1]

- Genus **[Reject:** *Baeolophus***]**

(ii) Explain why Oak Titmouse and Juniper Titmouse are now classified as two different species. [2]

1. considerable difference in DNA sequences grouped them into two different branches on the phylogenetic tree (phylogenetic species concept)
2. unable to interbreed to produce viable and fertile offspring (biological species concept)
3. both are adapted to different ecological niche (ecological species concept)
4. genetically incompatible and unable to interbreed to produce viable and fertile offspring (genetic species concept)

[Any 2]

(iii) Suggest **and** explain a **pre-zygotic** isolating mechanism that could prevent successful reproduction between the two populations of titmice in captivity. [2]

Suggest **[1]**	Explain **[1]** ***[Idea that...]***
1. Mechanical	reproductive features do not match
2. Behavioral	different courtship rituals / mating calls
3. Gametic	unsuccessful fertilization / gamete incompatibility
4. Temporal	different breeding seasons / becoming fertile at different times

[Reject: any isolation after zygote formation: e.g. reduced hybrid viability]

[Any 1]

[Total: 13]

QUESTION 9

In mammals, three genes code for the production of antibodies. Fig. 9.1 shows the structural arrangement of the three genes in humans.

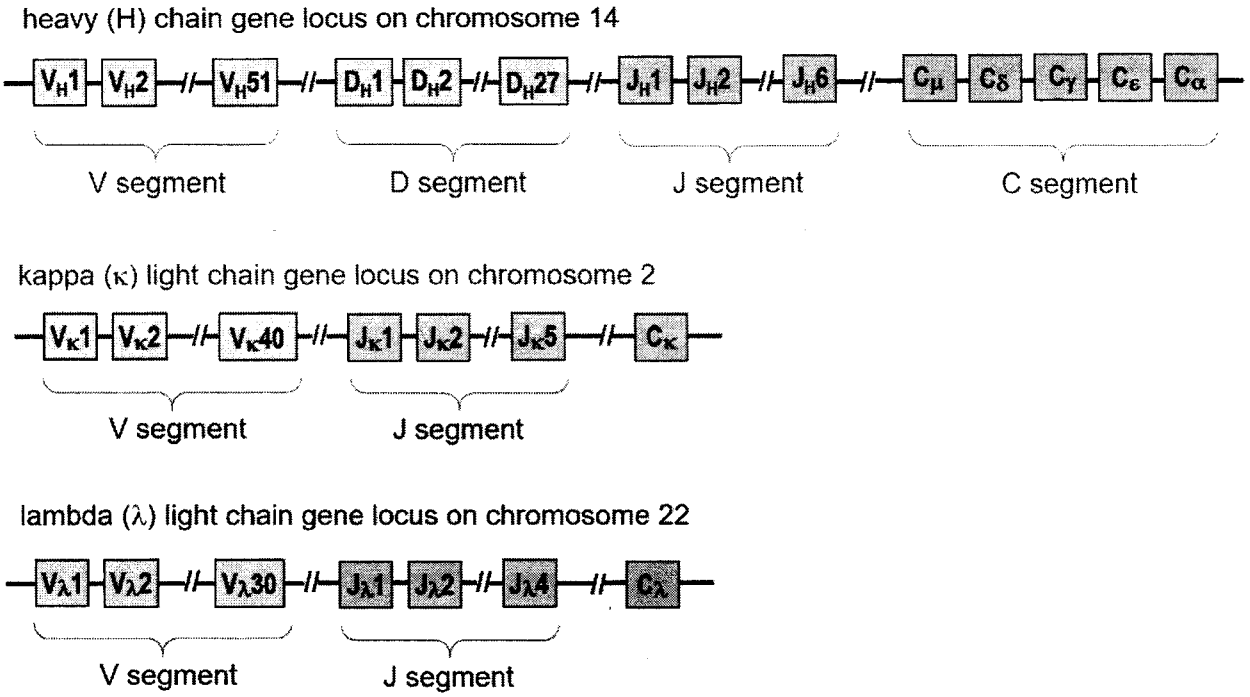


Fig. 9.1

Explain how the structural arrangement of the antibody gene loci creates millions of different antibodies that vary at their antigen-binding site. [5]

1. the genes contain variable/multiple number of V, D (for H chain gene only) and J segments
2. each segment **differs** in their **nucleotide sequence**
3. **somatic recombination**: one random segment from each V(D)J is joined, creating **different combinations of V(D)J**
4. ***cite an example:*** H chain recombination creates V_{10}-D_{24}-J_2 and V_{44}-D_2-J_6 amongst many others / **AVP**
5. remaining segments are removed and degraded
6. expressed / transcribed and translated to form different polypeptides
7. The **VDJ segments of H chain gene** and **VJ segment of L chain gene** together **encode the antigen-binding site**
8. Only **either the lambda or the kappa** light chain gene is **expressed** in any B cell
9. Possible number of different antibodies:
   $[(51\times27\times6) \times (30\times4)] + [(51\times27\times6) \times (40\times5)] =$ **2.64384×10^6** **[Accept:** 2.6×10^6**]**

[Any 5]

[Total: 5]

QUESTION 10

The deer tick (*Ixodes scapularis*) is an arthropod which sucks blood from humans and other mammals. Some deer ticks can be infected by the bacterium *Borrelia burgdorferi*. When a tick bites a human, the bacterium is often introduced, causing Lyme disease. Lyme disease is a public health problem in North America and, if left untreated, can cause neurological impairment.

Fig. 10.1 represents the two-year life cycle of a tick.

The range of hosts at the three key developmental stages of its life cycle are:

- larva – birds and small mammals
- nymph – humans and other small to large mammals
- adult – humans and other large mammals

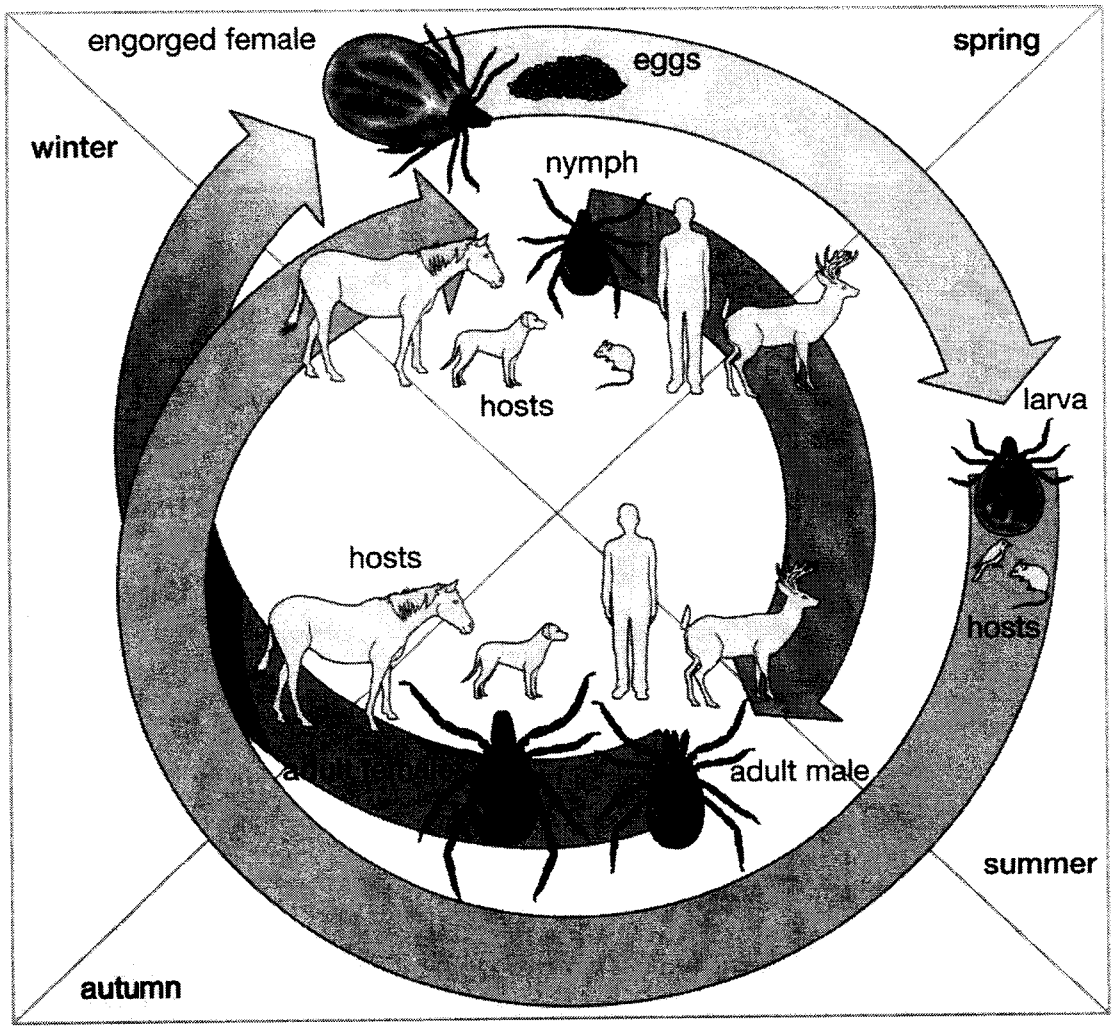


Fig. 10.1

(a) Using the information provided, suggest one possible treatment for Lyme disease. [1]

- **Antibiotics** treatment / ***named antibiotics***

Fig. 10.2 shows the developmental stages of deer ticks throughout the four seasons in a densely human-populated area of Canada for the year 2000 and predicted for the year 2080 based on the rate at which the earth is warming.

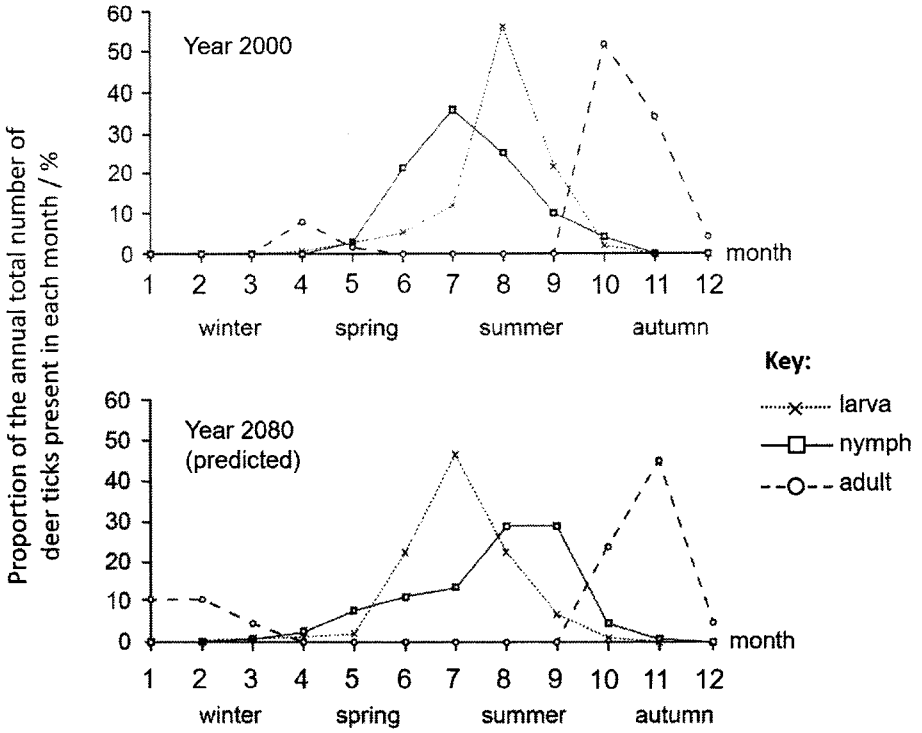


Fig. 10.2

(b) Using Fig. 10.1 and Fig. 10.2, evaluate how global warming will affect the spread of Lyme disease in 2080. [4]

1. **Nymphs** and **adults feed on humans** **[Fig. 10.1]**

2. **[data]** In **Jan, Feb** and **Mar**, **adults present** at **10%**, **10%** and **4%** respectively in 2080 but absent in 2000…
3. **[evaluate]**…hence **more risk of infection** in 2080 in these three months.

4. **[data]** **Adult proportion peaks at 50%** in **Nov in 2080**, vs **43% in Oct in 2000**…
5. **[evaluate]**…hence **peak of Lyme disease** will **shift from Oct to Nov**.

6. **[data]** **Nymphs &/or adults** are **present throughout 2080**, but **no nymphs and adults from Jan to Mar in 2000**…
7. **[evaluate]**…hence Lyme disease will **occur all year round in 2080**.

8. Overall, Lyme disease in 2080 is likely to increase / worsen / **AW**

9. **AVP**

[Any 4]

[Total: 5]

☺ END OF PAPER 2 ☺

TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

H2 BIOLOGY **9744/03**

Paper 3 Long Structured and Free-response Questions

16 September 2022

2 hours

SUGGESTED ANSWERS

Section A
Answer all questions in this section.

QUESTION 1
All life on earth is categorized into three domains – Eukarya, Bacteria and Archaea.

- Eukarya: organisms with cells that contain a nucleus as well as membrane-bound organelles
- Bacteria: unicellular prokaryotic cells that do not contain a nucleus and membrane-bound organelles
- Archaea: a unique class of unicellular prokaryotic cells that present many distinctive features from the domain Bacteria

Archaea were first discovered in 1977 in high-temperature environments, such as hydrothermal vents and terrestrial hot springs. They were later also found to be residing in other extreme conditions, such as highly acidic and anaerobic environments.

(a) One feature unique to Archaea is their cell membranes. Fig. 1.1 shows the molecular structure of the membranes of Eukarya and Bacteria and the membranes of Archaea.

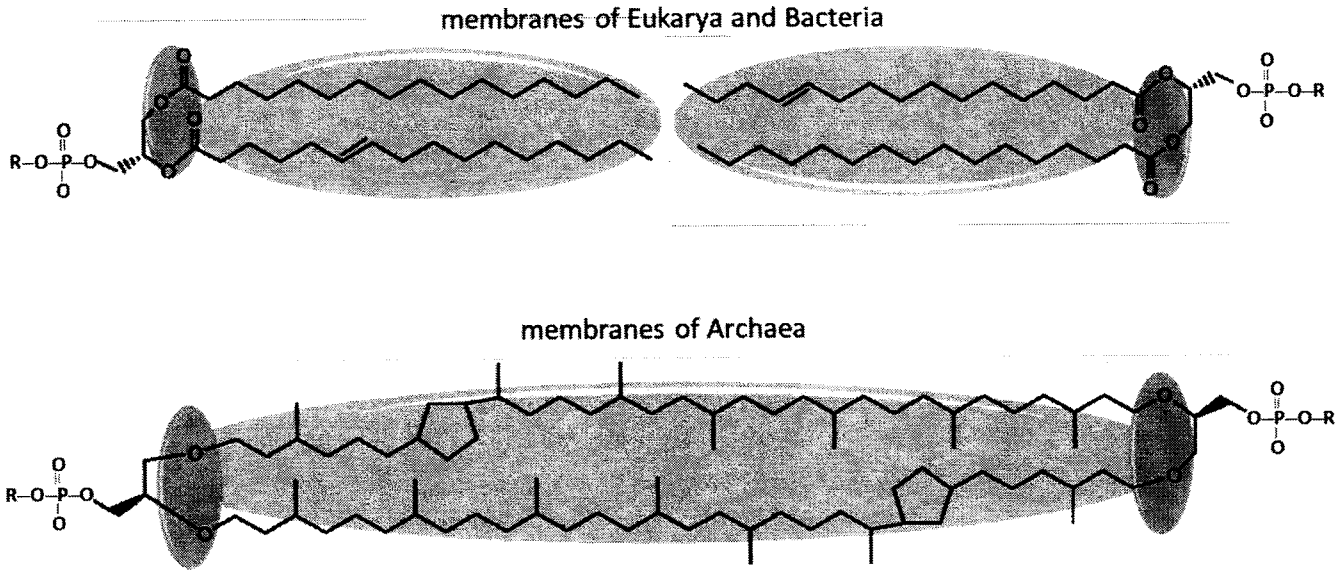


Fig. 1.1

(i) Describe the structural differences between the membranes of Eukarya and Bacteria and the membranes of Archaea. [3]

Eukarya & Bacteria	Archaea
1. a **bi**layer	**mono**layer
2. hydrocarbon chain **unbranched**	hydrocarbon chain **branched**
3. Absence of **ring/cyclic/pentagonal** hydrocarbon	Presence of **ring/cyclic/pentagonal** hydrocarbon
4. Presence of **C=C double bonds** **OR** **unsaturated** hydrocarbons	Only **C–C single bonds** **OR** **saturated** hydrocarbons
5. **Less carbons** (due to no branching)	**More carbons** (due to branching)
6. **Shorter** hydrocarbon chain	**Longer** hydrocarbon chain
7. **Ester** bond between glycerol and hydrocarbon chains	**Ether** bonds between glycerol and hydrocarbon chains

[Any 3]

(ii) Suggest how **one** of the structural differences you have described in **(a)(i)** enables Archaea to survive in high-temperature environments. [2]

- **Monolayer/cyclic**: allows the membrane to be **less fluid** / **more rigid** / **AW**

OR Branched/more carbons: increases hydrophobic interactions
OR Lacks C=C double bonds, hence no kinks, hence less fluid

- At high temperatures, allow membranes to **remain intact / not rupture** / **AW**

(b) Some archaeal cells synthesize ATP via photophosphorylation, using ATP synthase and a protein called bacteriorhodopsin. Permanently associated with bacteriorhodopsin is a light-harvesting prosthetic group called retinal, which changes conformation upon light absorption. On top of its light-harvesting property, bacteriorhodopsin is also a proton pump.

Fig. 1.2 shows the structure of bacteriorhodopsin and ATP synthase embedded in the archaeal cell surface membrane.

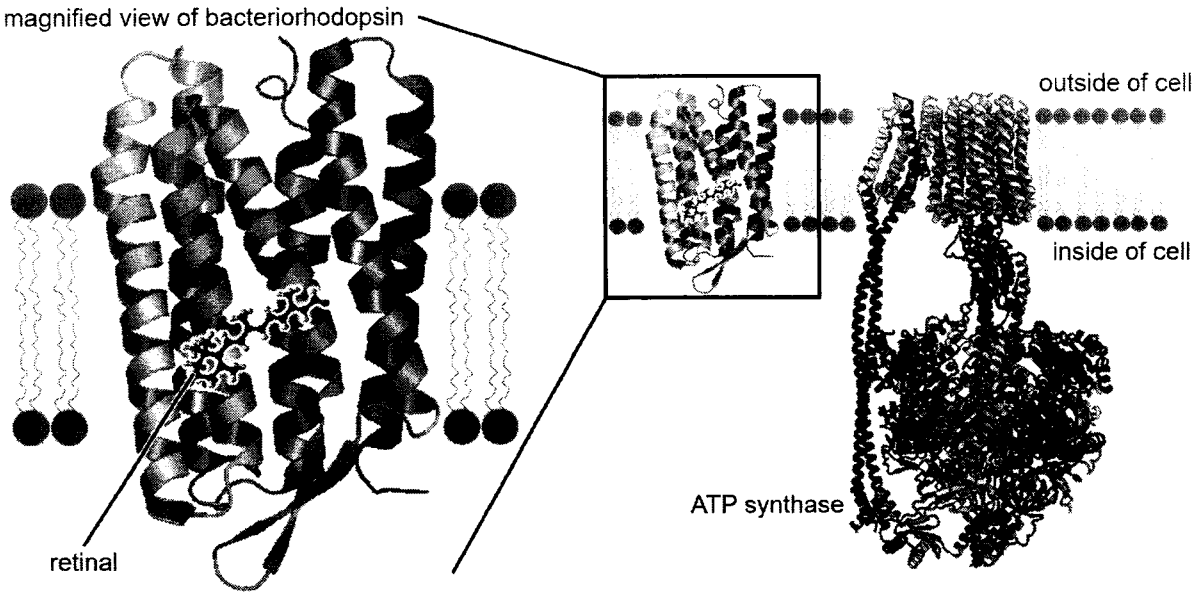


Fig. 1.2

(i) Outline the structural arrangement of bacteriorhodopsin in the archaeal membrane. [2]

1. **Seven α-helices**...
2. ...that **span the membrane** / a **transmembrane** protein
3. **β-pleated sheet** faces the **inside of cell**
4. Retinal molecule within the membrane

[Any 2]

(ii) With reference to Fig. 1.2, suggest how photophosphorylation occurs in the Archaea. [4]

1. **Retinal absorbs light energy** and **changes conformation**
2. Induces **conformational change in bacteriorhodopsin**, activating it.
3. Bacteriorhodopsin **pumps protons** from **inside** of archaea **to outside**, establishes **proton gradient** (across archaea membrane)
4. **Facilitated diffusion** of protons through **ATP synthase** (embedded in archaeal surface membrane) **into the cell**
5. **Proton-motive force** used to drive **ATP** synthesis from **ADP** and **inorganic phosphate**

[Any 4]

(c) Before their discovery in 1977, archaeal cells had been wrongly classified as bacterial cells, receiving the name Archaebacteria, for many years.

Fig. 1.3 shows two possible evolutionary relationships among the three domains of life.

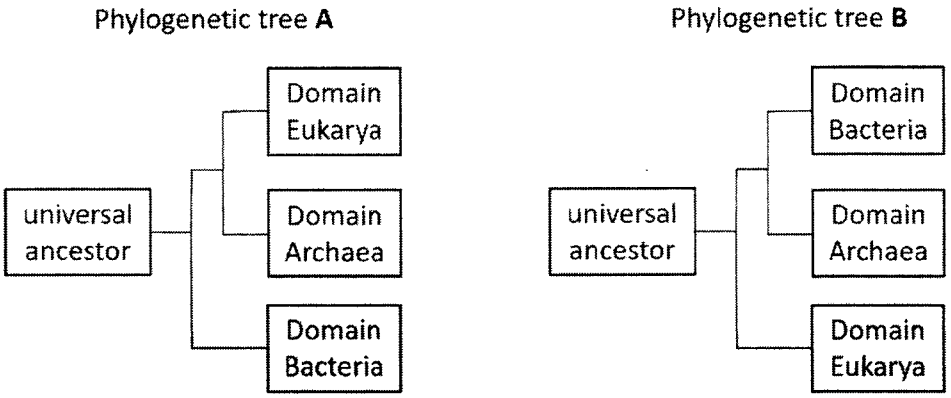


Fig. 1.3

Fig. 1.4 shows the general structure of an archaeal cell.

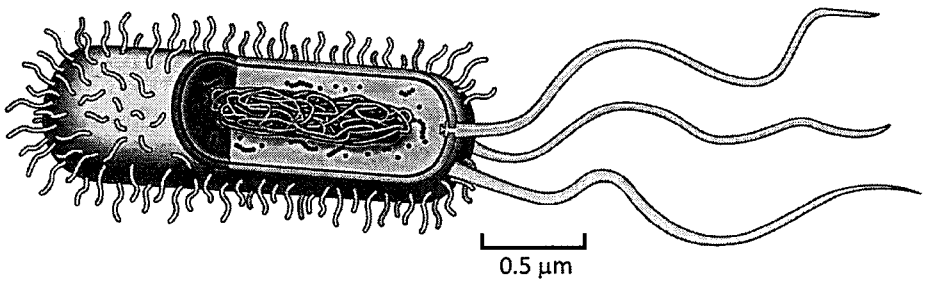


Fig. 1.4

(i) With reference to Fig. 1.3 and Fig. 1.4, explain why Phylogenetic Tree **A** could appear to be unexpected. [3]

1. ***Idea that*** Archaea is morphologically very similar to Bacteria

2. ***Ref to*** any **one** structural feature shared with Bacteria, e.g. size, no nucleus, multiple flagella, cell wall, pili, **AVP**

3. Hence Bacteria and Archaea are expected to be more closely related (Tree **B**)
   OR
   Tree **A** shows that Eukarya is more closely related to Archaea, hence unexpected.

(ii) Although the domains Bacteria, Archaea, and Eukarya were founded based on genetic criteria, biochemical properties have also provided strong evidence that Archaea form an independent prokaryotic group and that they share features with both Bacteria and Eukarya. Major examples of these features are shown in Table 1.1.

Table 1.1

Features	Bacteria	Archaea	Eukarya
organization	unicellular	unicellular	unicellular and multicellular
nuclear envelope	absent	absent	present
DNA form	single, circular	single, circular	multiple, linear
histones associated with DNA	absent	present	present
nature of promoter	Pribnow box	TATA box	TATA box
presence of introns	no	in some genes	yes
types of RNA polymerase	Bacterial in nature	Eukarya-like	Eukaryal in nature
transcription factors	absent	present	present
operon	present	present	absent
initiator amino acid during translation	formyl-methionine	methionine	methionine
ribosomes	70S	Eukarya-like	80S
peptidoglycan in cell wall	present	absent	absent
response to the antibiotics streptomycin and chloramphenicol	inhibited	not inhibited	not inhibited

Explain which Phylogenetic Tree (**A** or **B**) is supported by the data in Table 1.1. [3]

1. Tree A
2. Archaea shares **more similarities** (9 out of 13) with Eukarya than with Bacteria
3. ***Idea that*** Archaea and Eukarya shares more **molecular homologies**, which is the **basis for phylogeny**
4. ***One example:*** promoter sequences, genes for transcription factors / histones / RNA polymerases / rRNA / ribosomal proteins

[Point 1 + Any 2]

(iii) One of the structural similarities shared between Archaea and Eukarya is the use of histone proteins in DNA packaging. Fig. 1.5 shows how DNA is packaged in eukaryotic and archaeal cells.

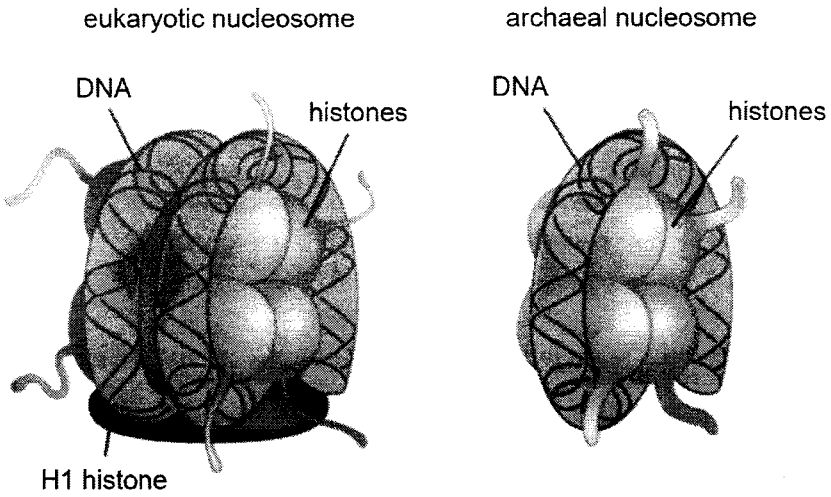


Fig. 1.5

State the differences in DNA packaging between eukaryotic and archaeal cells. [2]

eukaryotic	archaeal
1. presence of **H1 histone**	absence of H1 histone
2. **eight histones** in **each nucleosome**	**four histones** in **each nucleosome**
3. **two turns** of DNA per nucleosome	**one turn** of DNA per nucleosome

[Any 2]

(d) In eukaryotic cells, proteins destined for secretion are first synthesized by ribosomes bound to the rough endoplasmic reticulum (ER) membrane. The synthesized polypeptides then enter the ER lumen, where they are packaged into transport vesicles that undergo exocytosis. Exocytosis is not possible in archaeal and bacterial cells due to the lack of internal membranes.

Using the above information, suggest how archaeal and bacterial cells secrete proteins. [3]

1. **Ribosomes bind** directly (to channel proteins) on the **cell surface membrane**
2. ***Idea that*** Emerging polypeptide then traverse through the cell surface membrane...
3. ...via **protein channel** embedded on the cell surface membrane
4. **Folds** into **globular shape** only when **outside** the cell

[Any 3]

(e) Although some Archaea inhabit the human body and possess some characteristics of human pathogens, surprisingly, no pathogenic archaeal species has been identified to date.

Characteristics possessed by human pathogens that are shared by Archaea include:

- They are highly diverse and are present in large numbers in the environment that would afford them the opportunity to cause disease.
- They are recognized by antigen-presenting cells, B cells and phagocytes.
- Some possess genes that code for toxin proteins needed for pathogenicity.

(i) Some scientists have partly attributed the lack of pathogenic archaeal cells to the observation that there are far less viruses that infect Archaea than viruses that infect Bacteria.

Suggest why scientists have made this attribution. [2]

1. Viruses serve as a vehicle for gene transfer via **transduction**

2. **Virulent/toxin genes** can be transferred from one species of archaea to another

OR

Viruses can contain **virulent/toxin genes** that can be directly transferred to bacteria

3. ***Idea that*** Lack of archaeal viruses hence limits genetic diversity of pathogenic archaea

[Any 2]

(ii) Using Table 1.1 on page 7, suggest why the emergence of pathogenic archaeal cells could threaten the entire human population. [1]

- Existing **antibiotics** (e.g. streptomycin and chloramphenicol, ***from Table 1.1***) are **not effective** against archaeal cells

(f) The recent discovery of giant viruses shatters the textbook definition of viruses as "filterable" infectious agents because these giant viruses do not pass through bacterial filters. This destroys all boundaries between viruses and cellular life forms in terms of size.

Not only are giant viruses larger than numerous bacterial and archaeal cells, but the genomes of Pandoraviruses, the current record holder at approximately 2500 kilobases, are also larger and more diverse in gene content than many bacterial and archaeal genomes. Several scientists hence have proposed the need to classify viruses into a fourth domain of life, but such proposal was met with many disagreements from other scientists.

Fig. 1.6 shows the relationship between virus particle size and genome size from all the different virus families. The size of the circles represents of the relative average viral particle size from each virus family.

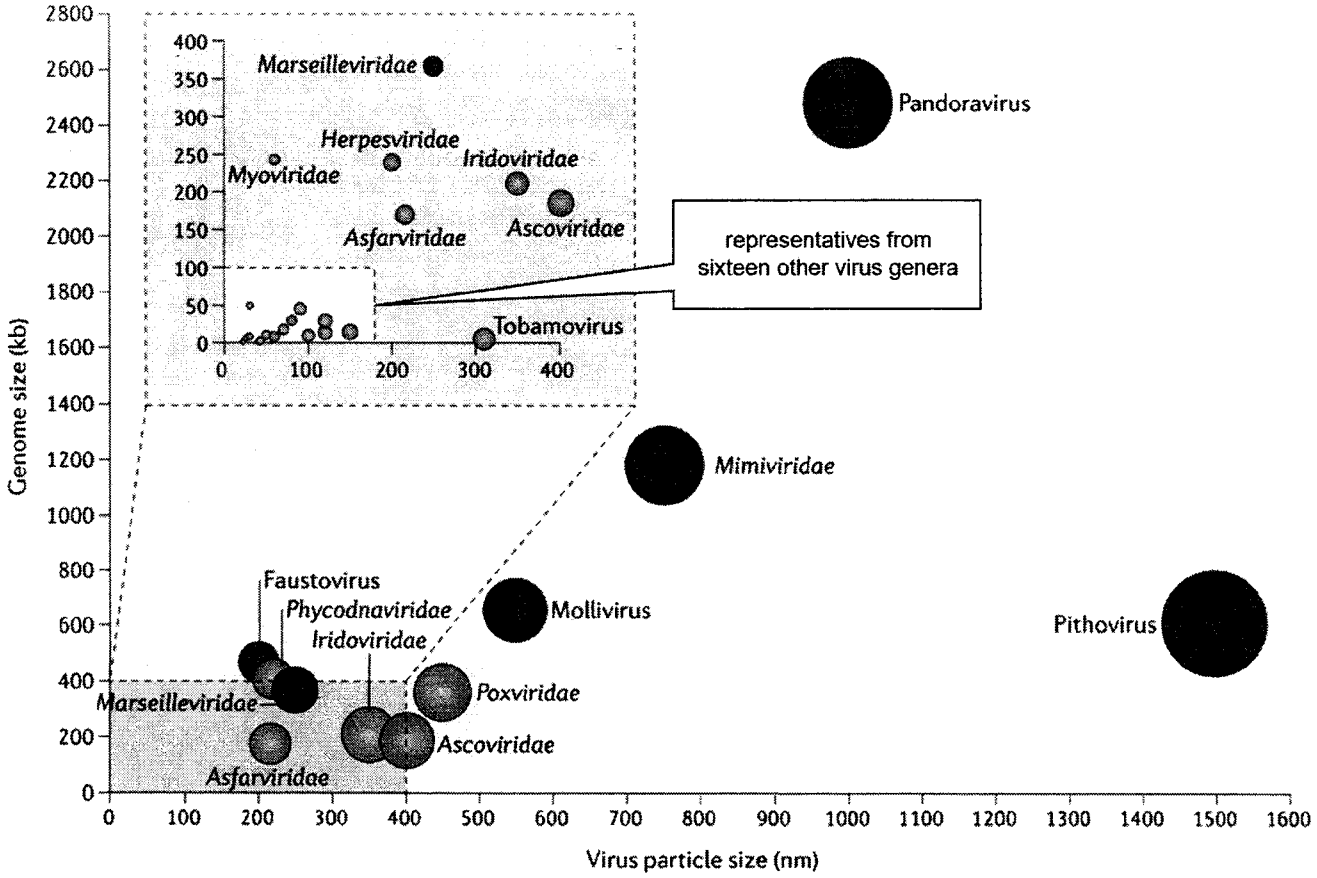


Fig. 1.6

(i) Comment on the trend data in Fig. 1.6. [3]

1. **[Compulsory]** In general, as particle size increases, genome size increases
2. ***Valid data for the increasing trend***
3. Anomaly: Tobamovirus, 310nm but genome size is only 5kb.
4. Anomaly: Pithovirus, 1500nm but genome size is only 600kb.
5. Anomaly: Myoviridae, 50mn but genome size is 245kb.
6. Most virus falls within particle size 400nm and within genome size 400kb
7. **AVP**

[Any 3]

(ii) Suggest why the proposal to classify viruses into a fourth domain of life has been a subject of controversy. [3]

1. **[COMPULSORY]** Viruses are considered **non-living**, hence does not fit into the domain of *life*
2. Cannot reproduce/replicate independently on their own
3. Need to exploit the metabolic machinery of host cells for reproduction
4. Lacks cellular **enzymes** / ***named example*** (e.g. glycolytic enzymes) for **metabolic reactions** / ***named example*** (e.g. respiration) to produce ATP
5. Lacks **organelles** / ***named example*** (e.g. ribosomes) for **cellular processes** / ***named example*** (e.g. translation)
6. Cannot respond to stimuli / Cannot move on their own
7. **AVP**

[Any 3]

[Total: 31]

QUESTION 2

Proteins must fold into defined three-dimensional structures to gain functional activity. In the cellular environment, newly synthesized polypeptides are at great risk of misfolding and aggregation. Cells hence engage proteins called chaperones to assist in protein folding.

These chaperones have two roles:

1. They bind to proteins to promote folding.
2. They direct misfolded polypeptides for degradation in the cytosol.

However, polypeptides that are in the midst of folding may be mistaken by chaperones as misfolded proteins and hence are directed for degradation. Therefore, protein folding needs to be completed quickly to prevent premature degradation.

A recently discovered endoplasmic reticulum (ER) protein complex called S-E complex was found to delay premature degrading of polypeptides that are in the midst of folding. In its absence, approximately 30% of newly synthesized proteins that could otherwise fold correctly are degraded.

Fig. 2.1 illustrates these processes.

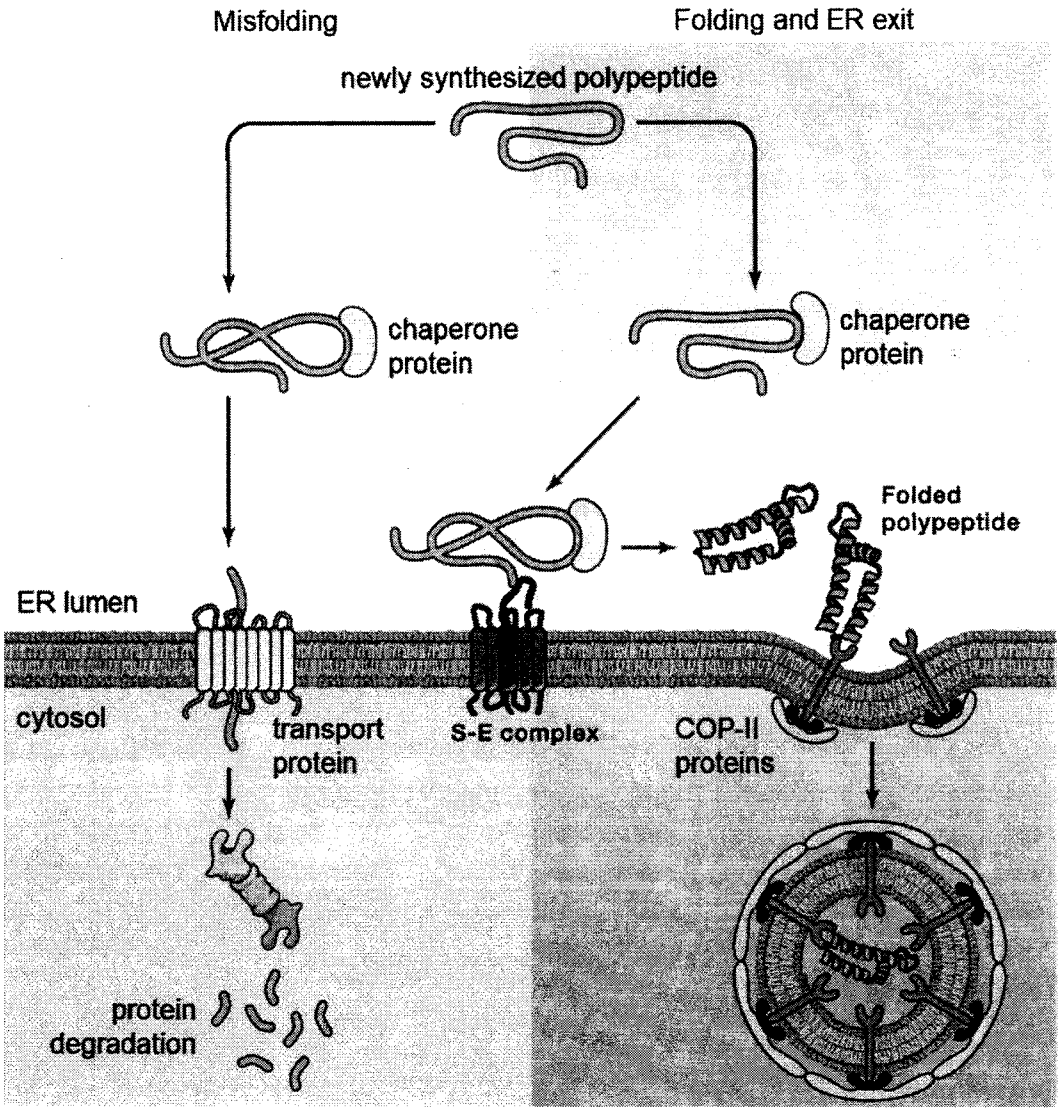


Fig. 2.1

(a) Protein folding is driven mainly by the primary structure of the protein. In the midst of folding, the R-groups of polypeptides are exposed to their surrounding environment that contains many other different molecules.

Using the information above, suggest why it is important to have chaperone proteins to assist in protein folding. [1]

- ***Idea of*** shielding the exposed R-group to prevent them from forming bonds with other molecules

(b) With reference to Fig. 2.1, suggest how the S-E complex allows polypeptides to complete their folding. [2]

1. S-E complex (is a membrane-anchored protein that) **binds** to chaperone-polypeptide
2. ***Idea of*** Prevents polypeptide from being prematurely transported out of the ER for degradation
   OR
   Allows polypeptide to stay longer in the ER to complete folding

(c) ER vesicle formation is not a random event but is carefully orchestrated.

With reference to Fig. 2.1, describe how ER vesicle formation is triggered. [2]

1. **Folded protein binds** to the domain of **COP-II protein** facing the ER lumen
2. Such binding triggers ER membrane to undergo **budding** / **pinching off**
3. ***Idea that*** fusion of the two approaching ends of phospholipid bilayer forms a vesicle

[Any 2]

(d) With reference to Fig. 2.1 and your knowledge on protein degradation, explain how unfolded polypeptides in the ER are degraded. [3]

1. Polypeptide transported through a **transport protein** embedded in the RER membrane
2. Attached to **ubiquitin** proteins (when in cytosol)
3. Targeted to the **proteasome**
4. For **hydrolysis** into **individual amino acids** / **shorter peptides**

[Any 3]

(e) Misfolded proteins in the ER tend to spontaneously associate with one another to form an aggregate, causing cellular toxicity. It is hence important that any misfolded protein is immediately degraded and not remain in the ER for too long.

(i) Explain why misfolded proteins in the ER tend to spontaneously associate with one another to form an aggregate. [2]

1. Misfolded proteins have their **hydrophobic** amino acid **R groups/side chains** exposed
2. ***Idea of*** The need to shield themselves away from the aqueous ER lumen
3. Hence, hydrophobic R groups from different misfolded protein associate with one another via **hydrophobic interaction**

[Any 2]

(ii) Suggest why accumulation of protein aggregates in the ER is toxic to the cell. [1]

1. ***Idea that*** Such aggregate may interact with enzymes / membrane proteins to interfere with their function
2. ***Idea that*** constrains the ER lumen space available to metabolic enzymes / other proteins
3. **AVP**

[Any 1]

(f) Protein aggregates are usually due to genetic diseases. One classic example is Huntington's disease, a neurodegenerative disorder with a wide variation in the age of onset. A mutation in the *HTT* gene causes Huntington's disease. The *HTT* gene codes for a protein called huntingtin.

The *HTT* mutation that causes Huntington's disease involves a DNA segment in the *HTT* gene known as a CAG trinucleotide repeat. This segment is made up of a series of CAG that appears multiple times in a row.

An increase in the number of CAG repeats leads to the production of an abnormally long version of the huntingtin protein. The elongated protein is cut into smaller, toxic fragments that aggregate together and accumulate in neurons, disrupting the normal functions of these cells.

Fig. 2.2 shows how the number of CAG repeats varies in 1200 people with different ages of onset. Each data point represents an individual person.

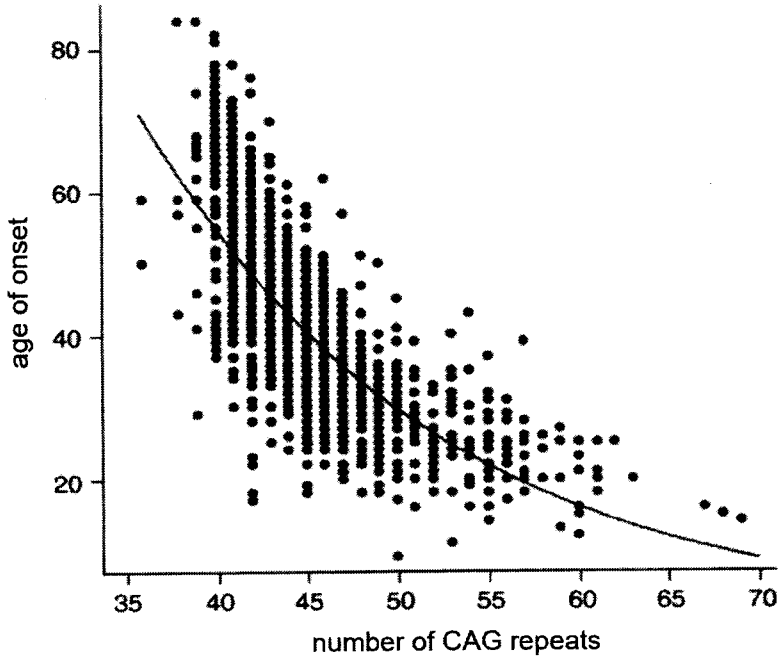


Fig. 2.2

(i) Deduce if Huntington's disease is a dominant or recessive genetic disorder. [1]

- Dominant

(ii) With reference to Fig. 2.2, evaluate the extent to which the number of CAG repeats can predict the age of onset of Huntington's disease. [3]

1. **[Cite general data]** Generally accurate, since as CAG repeats increases from **36 [accept 35]** to **70**, age at onset decreases from **70 to 11 [accept 12]**.
2. **[Evaluate extent]** Not very accurate, since two persons with widely different age at onset can have the same number of repeats
3. **[Cite data]** e.g. 42 repeats, 18 and 75 years old / ***other valid data***
4. **[Evaluate extent]** If no. of CAG repeats is 35 **[accept 36]** or less, definitely no Huntington disease, hence accurate.

[Any 3]

(iii) Explain how molecular techniques can be used to estimate the number of CAG repeats in total DNA isolated from a person with Huntington's disease. [4]

1. Design **two different primers** **[accept:** forward and reverse primers**]** **flanking the CAG repeats**
2. Perform **polymerase chain reaction** to **amplify the CAG repeats**
3. **More repeats** result in a **longer fragment** amplified.
4. **Gel electrophoresis**: **separates amplified DNA fragment(s)** based on their **length**
5. **Estimate length of amplified product** using the **DNA ladder** (of known fragment lengths)
6. **[Compulsory] Divide the length by 3** to give the number of CAG repeats

Note: Deduct 1m for wrong sequence of procedure

[Any 4]

[Total: 19]

Section B
Answer **ONE** question.

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.

QUESTION 3
(a) Discuss the biological importance of water to living organisms. [15]

[Role in photosynthesis and respiration]
1. Undergoes **photolysis** during (light-dependent stage of) **photosynthesis**

2. Source of **electrons** to replace electrons lost in **photosystem II**

3. Source of **protons** contributing to the **high proton concentration in thylakoid space**

4. Source of atmospheric **oxygen** as **final electron acceptor** in **aerobic respiration**

5. Forms when oxygen accepts electron and protons at end of the electron transport chain

[Role in reactions]
6. **Hydrolysis** reaction to break covalent bond
   a. So that translation can be terminated by hydrolysis of acyl bond between polypeptide and tRNA / so that glucose released can be used as respiratory substrate, etc.

7. Restores the two polar groups (e.g. –OH and –OH/–NH_2)

8. **Condensation** reaction to form covalent bond
   a. So that polysaccharides such as starch / glycogen can be used as energy storage molecules, etc.

9. ***Valid example:*** glycosidic bond / peptide bond / phosphodiester bond / ester bond

[Role as a solvent]
10. **Solvent** for **hydrophilic** molecules by forming **hydrogen bonds** / ***named molecules*** e.g. glucose, insulin, glucagon hormones, ions)

11. **Solvent** to **dissolve gases** / ***named gases*** e.g. oxygen, carbon dioxide

12. hence serves as a **transport medium**

[Role in driving formation of phospholipid bilayer]
13. Aqueous environment drives the **phospholipids** to adopt a **bilayer** structure

14. To **shield** the **hydrophobic hydrocarbon chains** away from water

15. **Phosphate head** interacts with **water** via **hydrogen bond**

[Role in driving protein folding]
16. **Hydrophobic R-groups** project into the protein **core**, interacting via **hydrophobic interaction**

17. **Hydrophilic R-groups** projects **outwards**, interacting with water via **hydrogen bond**

18. Allows **globular proteins** to be **soluble** in water
   a. as water drives protein folding into its tertiary / 3D structure

19. ***Named example***: haemoglobin / **AVP [max 1]**

20. Allows **fibrous proteins** to precipitate, because it is **insoluble** in water, fulfilling structural support role

21. ***Named example***: collagen / keratin / spindle fiber / microtubule / **AVP**

[AVP]

22. Role in maintaining turgidity of plant / bacterial cells through osmotic pressure

23. Role in cooling in human by removal of latent heat via evaporation

24. Reactant in Krebs cycle e.g. converting fumarate to malate

25. Medium for removal of waste products in body via production of urine

26. Lubricant around joints

27. **AVP**

[Any 15]

(b) Tryptophan synthesis and lactose catabolism are regulated in a similar manner in bacterial cells.

Describe how tryptophan synthesis in bacterial cells is regulated **and** explain the advantages of such a regulation system in the context of lactose catabolism. [10]

[How tryptophan synthesis is regulated] – at least 1

[*Trp operon*]
1. Repressible ***Trp* operon** system

2. Five structural genes / *Trp A–E* genes under control of one promoter

3. These genes **code for enzymes** that **synthesize tryptophan**

[*TrpR* regulatory gene]
4. ***TrpR* gene** codes for an inactive repressor protein

5. Inactive repressor not complementary in shape to and hence cannot bind to operator sequence

[When tryptophan is present]
6. Tryptophan is a **co-repressor**

7. Binds to and activates the repressor protein

8. Activated repressor proteins binds to the operator sequence

9. Blocks the RNA polymerase from binding to promoter

10. *Trp A–E* genes not transcribed

[When tryptophan is absent]
11. Unbound repressor dissociates from operator

12. RNA polymerase binds to promoter and transcribes *Trp A–E* genes

[Advantages of operon in the context of lactose catabolism] – at least 1

13. Allows genes that are involved in lactose catabolism to be regulated together

14. Allow cells to respond quickly to changes in environmental lactose concentration

15. Ensure cells do not synthesize these enzymes unnecessarily when lactose is absent

[Any 10]

QUESTION 4

(a) Explain why cancer development is a multi-step process **and** discuss the factors that increase of chances of cancer. [10]

[Why cancer development is a multi-step process] – at least 1

1. **Gain-of-function mutation** in **proto-oncogenes** that become **oncogene**
2. **Loss-of-function mutation** in **tumor suppressor genes**
3. One such mutation does not cause cancer immediately
4. A **single cell** needs to **accumulate mutations** in both tumor suppressor genes and proto-oncogenes to become cancerous
5. ***Idea that*** Accumulation of such mutations takes time
6. ***Ref to*** **angiogenesis** – tumour directs the growth of blood vessels to itself
7. ***Ref to*** **metastasis** – spread of some cancer cells from the primary tumour via the blood circulation to other body parts

AVP: Re-activation of telomerase gene needs to occur in order for cancer cells to divide indefinitely.

[Factors that increases of chances of cancer] – at least 1

8. Exposure to chemical carcinogens / ***named carcinogen*** e.g. ethidium bromide
9. Exposure to excessive ionizing radiation / ***named ionizing radiation*** e.g. X-rays
10. Exposure to ultraviolet radiation
11. Agents that cause inflammation, which generates DNA-damaging oxidizing agents in the cell
12. ***Points 8-11:*** cause DNA damage, resulting in replication error thus mutation
13. Infection by certain viruses / ***named virus*** e.g. human papillomavirus, HIV
14. Virus can introduce an oncogene
15. Virus can disrupt a tumor-suppressor gene during integration as provirus
16. Infection by certain bacteria / ***named bacteria*** e.g. *Helicobacter pylori*
17. ***Ref to*** Age
18. ***Ref to*** Genetic predisposition: inheriting an oncogene / mutated TSG from parent
19. ***Ref to*** Loss in immunity: cytotoxic T cells unable to destroy cancer cells

[Any 10]

(b) The SARS-CoV-2 is an enveloped RNA virus that infects the respiratory airways, causing Covid-19 disease. Some Covid-19 vaccines contain mRNA that codes for a glycoprotein on the viral envelope.

Explain how intramuscular injection with the mRNA vaccine leads to the protection against SARS-CoV-2 **and** discuss the factors that affect the extent of transmission of the disease. [15]

[How vaccination with the mRNA vaccine leads to the protection] – max 9

uptake of mRNA and translation

1. mRNA **taken into muscle / body cells**
2. ribosomes **translate** the mRNA into the **glycoprotein**

presentation of antigen on surface of muscle cells via class I MHC to activate cytotoxic T cell

3. glycoprotein degraded into antigenic peptides and presented on **class I MHC** on the cell surface membrane of muscle cells
4. **cytotoxic T cell** with receptor complementary to the MHCI-peptide binds to the muscle cells and is activated (by cytokines secreted by helper T cells)
5. cytotoxic T cell secretes **perforin** and **granzymes** to kill muscle cells presenting MHCI-peptide

presentation of antigen on surface of APC via class II MHC activate helper T cell

6. glycoprotein **secreted out** of body/muscle cells
7. **antigen presenting cells** engulf the glycoprotein and digest it into smaller peptides
8. peptides are loaded onto **class II MHC** and presented on the cell surface membrane of APC
9. **helper T cell** with receptor complementary to the MHCII-peptide binds to the APC
10. APC secretes **cytokines** to activate the helper T cell, which then proliferates

activation of helper B cell

11. **B cells** with receptor specific for (the epitopes on) the glycoprotein binds, engulfs and present the peptide on MHCII
12. activated helper T cell binds to and activate B cells presenting the same peptide on MHCII
13. the B cells **differentiate** into **plasma cells** and **memory B cells**
14. plasma cells **secrete antibodies** against the glycoprotein

protection against SARS-CoV-2

15. **memory B cells** remain quiescent but will **differentiate into plasma cells** upon real infection with the virus
16. the antibodies secreted by plasma cells bind to the glycoprotein to **prevent attachment** of virus to the host cell surface receptor, preventing infection.

[Factors affecting spread] – max 6

17. ***Ref to*** evolution of the virus **[1m for each sub-point]**

    a. How fast the virus evolves into **different variants/strains**...

    b. ...that can be **more infectious** / binds with higher affinity to host surface receptor

    c. ...that can result in a **higher viral load** / produce more viral progeny

    d. ...that can **render the current vaccine ineffective**

18. ***Ref to*** vaccine **[1m for each sub-point]**

    a. How fast the vaccine can be produced

    b. How fast the population is vaccinated to achieve **individual protection**

    c. How fast the population is vaccinated to achieve **herd immunity**

    d. **Efficacy** of the vaccine / % of vaccinated individuals who developed immunity

19. ***Ref to*** social responsibility **[1m for each sub-point]**

    a. Wearing of **face masks**

    b. Frequent **washing of hands** / use of hand sanitizers

    c. Keeping a **safe distance**

    d. **Visiting doctor** when having **respiratory symptoms**

20. ***Ref to*** population density – **denser population** leads to **faster spread**

21. ***Ref to*** actively **testing people** with **respiratory symptoms**

22. ***Ref to*** **quarantining** infected people

23. ***Ref to*** closing of country borders / restricting international travels

24. ***Ref to*** restricting movement/activity within a country

25. **AVP**

[Any 15]

END OF PAPER 3