Civics Group	Index Number	Name (use BLOCK LETTERS)	H2

ST. ANDREW'S JUNIOR COLLEGE
2022 JC2 PRELIMINARY EXAMINATIONS

H2 BIOLOGY **9744/01**

Paper 1: Multiple Choice

Friday 16th September 2022 1 hour

Additional Materials: Multiple Choice Answer Sheet

READ THESE INSTRUCTIONS FIRST

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

Write your name, civics group and index number on the multiple choice answer sheet in the spaces provided.

There are **30** questions in this paper. Answer all questions. For each question, there are four possible answers, A, B, C and D.

Choose the one you consider correct and record your choice in soft pencil on the separate multiple choice Optical answer sheet.

INFORMATION TO CANDIDATES

Each correct answer will score one mark. A mark will not be deducted for wrong answer. Any rough working should be done in this booklet.

At the end of the examination, submit both question paper and multiple choice answer sheet.

This document consists of 30 printed pages

[Turn over

1 Which group of eukaryotic cell structures all contain nucleic acids?

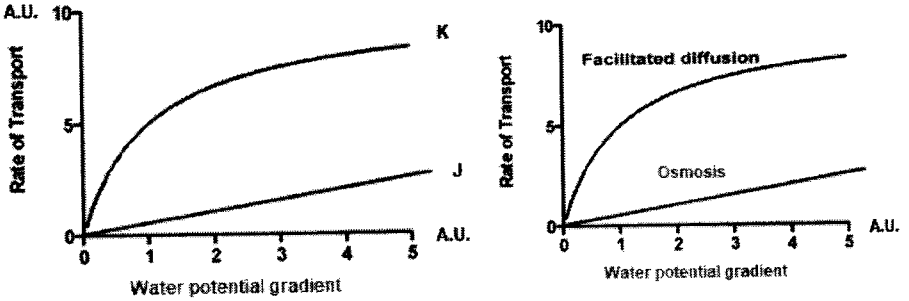
A	cytoplasm, Golgi bodies, mitochondria, nuclei
B	centrioles, chloroplasts, mitochondria, ribosomes
C	centrioles, mitochondria, nuclei, ribosomes
D	chloroplasts, mitochondria, cytoplasm, ribosomes

2 Which properties of phospholipids explain why single layers of phospholipids added to water immediately form bilayers?

1 The hydrophobic fatty acid chains repel water molecules so the tails pack together.
2 The non-polar fatty acid chains are attracted to each other by hydrophobic interactions.
3 Charged phosphate groups form hydrogen bond with water.
4 Phospholipids are insoluble in water

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

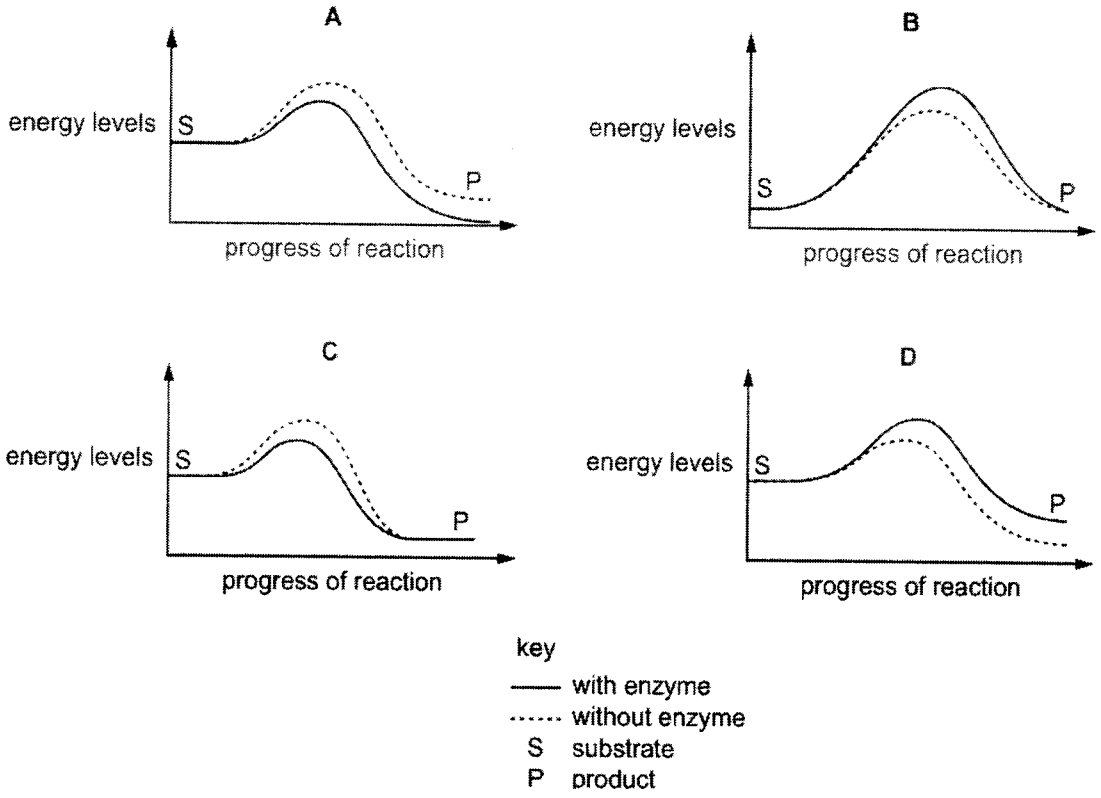
3 The graph shows rates of osmosis and facilitated diffusion of water molecules (through aquaporins) across the cell surface membrane.



Which row is correct?

	graph K	Explanation
A	facilitated diffusion	limited by the number of aquaporins in the cell surface membrane
B	Osmosis	allows the concentrations of water molecules inside and outside the cell to be equal in a shorter time
C	facilitated diffusion	rate of transport approaches plateau at high water potential gradient due to dynamic equilibrium being achieved
D	Osmosis	limited by the number of transient gaps in the cell surface membrane

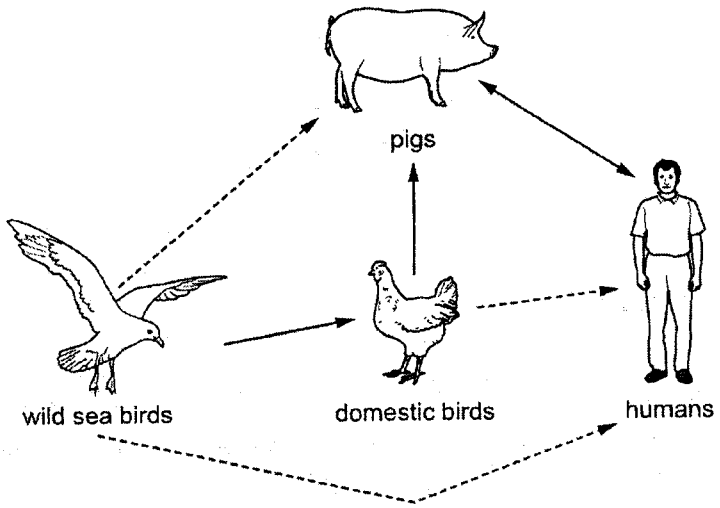
4 Which graph correctly shows possible changes in energy levels as a chemical reaction progresses with or without an enzyme? **Answer C**



5	In 2016, the United Kingdom government allowed scientists to genetically modify cells obtained from very early human embryos(immediately after fertilization till 8 cells stage). Which statement correctly describes an ethical concern about this research?	
	A	Genetically modified iPSCs could give rise to genetically modified individuals.
	B	Genetically modified multipotent stem cells could give rise to genetically modified individuals.
	C	Genetically modified pluripotent stem cells could give rise to genetically modified individuals.
	D	Genetically modified totipotent stem cells could give rise to genetically modified individuals.
6	The sub-types of the influenza A virus that infect birds, humans and pigs in one area of the world in recent times are shown in the table.	

	influenza A virus sub-types present		
time period	birds	humans	pigs
1918–1957	show any one of the H1–H16 antigens combined with any one of the N1–N9 antigens	H1N1	H1N1
1958–1970		H2N2	
1971 to present day		H3N2 H1N1	H3N2 H2N3

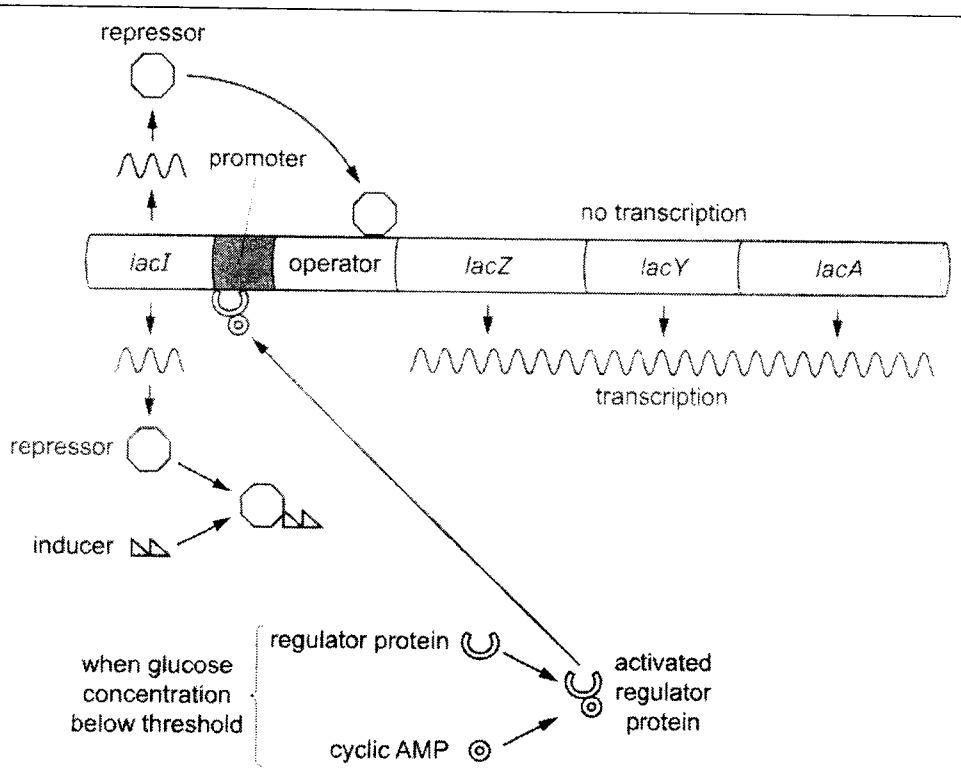
High risk of transmission of influenza A virus between species is shown by solid arrows in this diagram. A dotted arrow shows a low risk of transmission.



Which statement correctly describes a danger to human health in this area of the world?

	A	Antigenic drift of human viruses such as H3N2, leading to vaccines being less effective
	B	Antigenic drift within pigs, leading to emergence of H2N2 virus able to infect humans
	C	Antigenic shift of bird viruses, leading to emergence of new viruses such as H7N10
	D	Antigenic shift within humans, combining H2N2 from older people with H1N1 or H3N2

7	The diagram shows some of the factors affecting the expression of the lac operon.

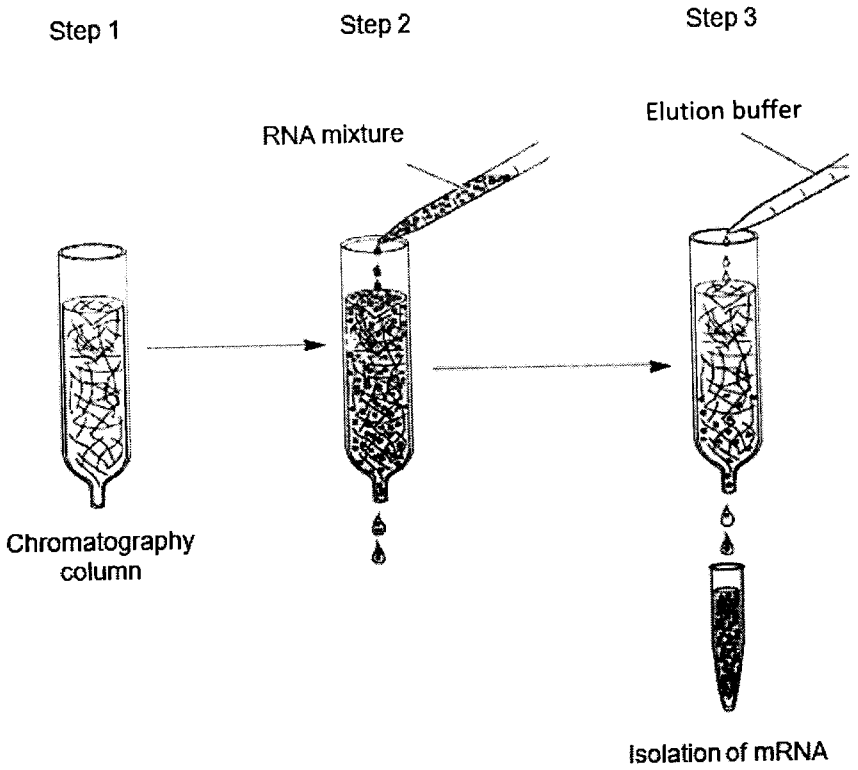


Only when the concentration of glucose is below a critical threshold can the lac operon be fully induced by the presence of lactose. As the concentration of glucose decreases, the concentration of cyclic AMP increases.

Which statement describes the role of cyclic AMP in the expression of the lac operon?

	A	It prevents the regulator protein from binding to the promoter when the glucose concentration is high.
	B	It activates the inducer to bind to the lac operator.
	C	It prevents the expression of the lac operon when the glucose concentration is high.
	D	It activates a regulator protein that helps RNA polymerase bind more effectively to the promoter.

8	The isolation of mature mRNA can be done by passing an RNA mixture obtained from homogenised tissue through a chromatography column. The procedure of the mRNA isolation is as follows:



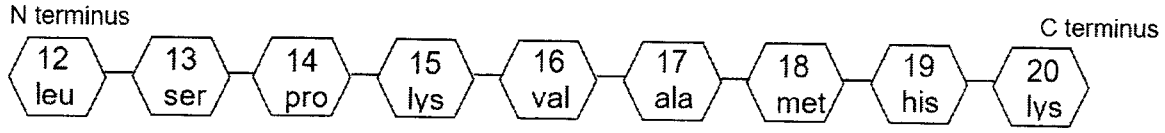
Step 1	Set up a chromatography column which contains short lengths of uracil nucleotides attached to a solid support medium.
Step 2	Add RNA mixture to the chromatography column. RNA that do not hybridise with the uracil nucleotides will pass through and leave the column.
Step 3	Add water to the chromatography column to remove and isolate the hybridised mRNA.

Which of the following statements is **not** true?

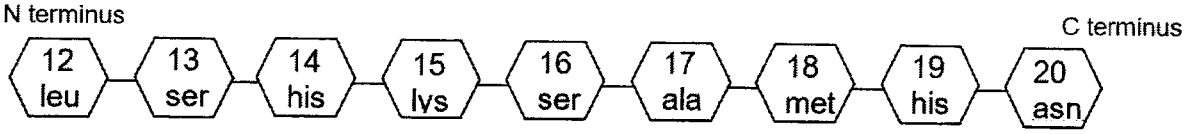
A	rRNA and tRNA molecules could pass through and leave the column in Step 2.
B	Complementary base pairing is responsible for the attachment of RNA to the solid support medium.
C	The isolated mRNA in Step 3 do not contain introns.
D	The RNA that attached to the chromatography column lack poly-(A) tails.

9 When a mutation occurs at the gene coding for protein A1, a structurally similar mutant protein, protein A2, is synthesised instead. The two proteins differ by only three amino acids, at positions 14, 16 and 20.

amino acid sequence of normal protein A1



amino acid sequence of mutant protein A2



The table shows the mRNA codons for the amino acids in these positions for proteins A1 and A2.

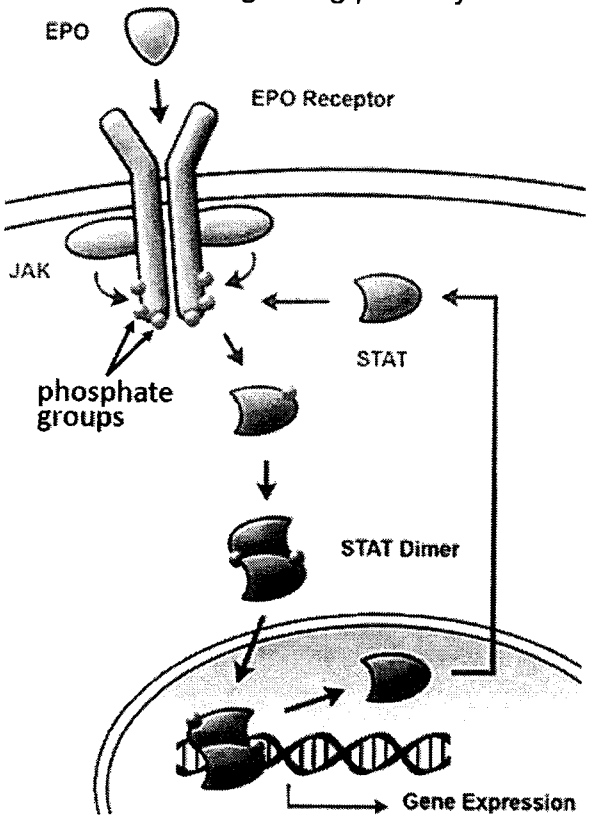
amino acid	mRNA codons
ala	GCU
ser	AGU UCA
pro	CCA
leu	CUU UUA
lys	AAA
ala	GCU
met	AUG
his	CAU CAC
asn	AAU
val	GUC

Which combination of mutations occurred in order to account for the amino acid sequence of the mutant protein A2?

1 Frameshift mutation resulting from an addition of a single nucleotide in the codon that codes for amino acid at position 14.

	2 Substitution of a single nucleotide in the codon that codes for amino acid at position 14. 3 Frameshift mutation resulting from a deletion of two nucleotides in the codon that codes for amino acid at position 16. 4 Deletion of a single nucleotide in the codon that codes for amino acid at position 16.	
	A	1 and 3
	B	1 and 4
	C	2 and 3
	D	3 and 4

10 The diagram shows the JAK-STAT cell signalling pathway.



Which of the following statements are correct?

1 EPO is a large and non-polar lipid hormone and hence it needs a cell surface receptor to cross the membrane.

2 Phosphorylation of STAT causes them to dimerize.

3 Gene expression is terminated when phosphatases remove phosphate groups from STAT dimers.

4 Signal amplification occurs as JAK phosphorylates different tyrosine residues on the EPO receptor.

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

11	Which of the following modification(s) would allow *E. coli* cells to start synthesising a eukaryotic protein? **1** Insertion of the cDNA which was reverse transcribed using the mature mRNA coding for the eukaryotic protein. **2** Presence of activators and histone acetylases. **3** Insertion of a eukaryotic promoter next to the eukaryotic gene in a bacterial plasmid	
	A	**1** only
	B	**1** and **3** only
	C	**2** and **3** only
	D	All of the above.
12	Which of the following is **true** of gene regulation in prokaryotes and eukaryotes?	
	A	Gene regulation in both eukaryotes and prokaryotes can involve proteins binding to DNA.
	B	In eukaryotes, increase in efficiency of translation requires regulatory proteins binding to the mRNA while in prokaryotes, increase in efficiency of translation requires regulatory proteins binding to the ribosomes.
	C	In eukaryotes, RNA polymerase binds to the TATA box while in prokaryotes, RNA polymerase binds to the operator.
	D	Repressors and activators regulate expression in eukaryotes while prokaryotes are regulated by repressors only.
13	Seahorses and spider monkeys both possess a prehensile tail, allowing them to grasp and hold onto structures.  How many of the following statements is/are valid? **1** The prehensile tail is a homologous structure derived from a recent common ancestor shared by the seahorse and spider monkey.	

	2 The seahorse and spider monkey evolved the prehensile tail independently due to similar selection pressures in their environment. 3 The prehensile tail is an example of convergent evolution due to both species sharing the same ecological niche. 4 The prehensile tail is an example of descent with modification, as the tail shows modifications in the two species over time.	
	A	1
	B	2
	C	3
	D	All of the above.

14 Relationships between different primates can be found by comparing their proteins and DNA.

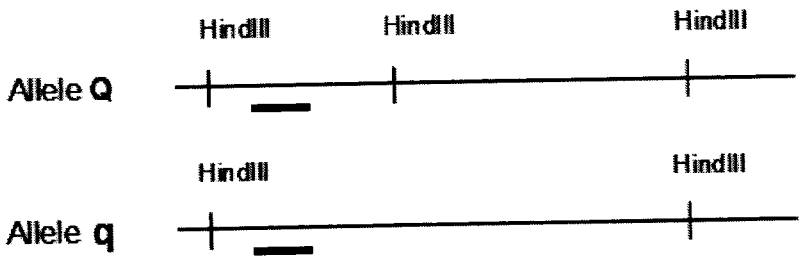
The protein albumin obtained from a human was injected into a rabbit. The rabbit produced antibodies against the human albumin.

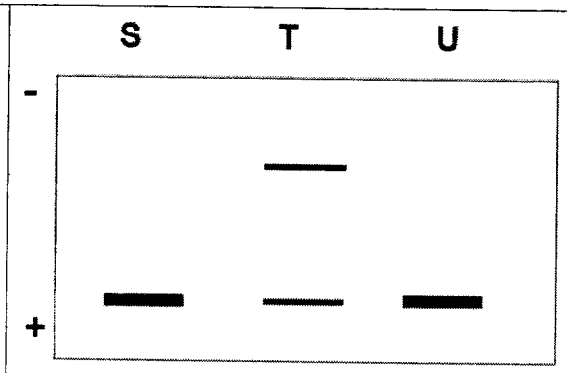
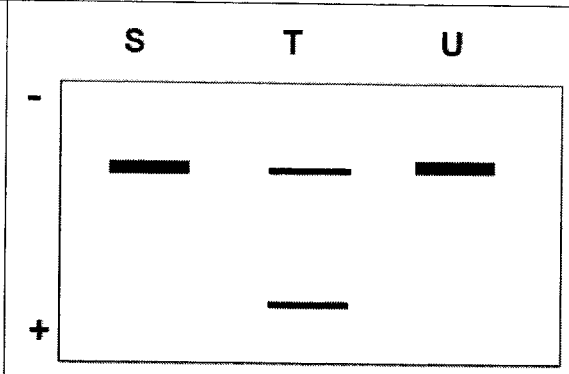
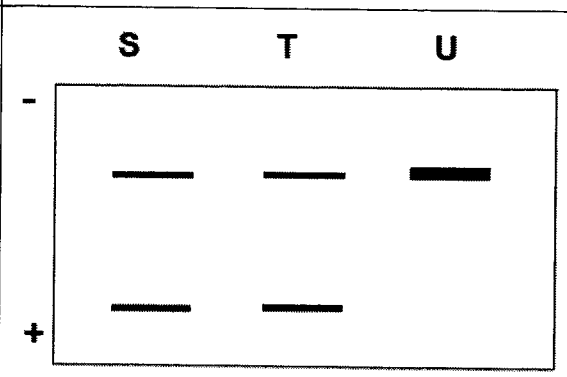
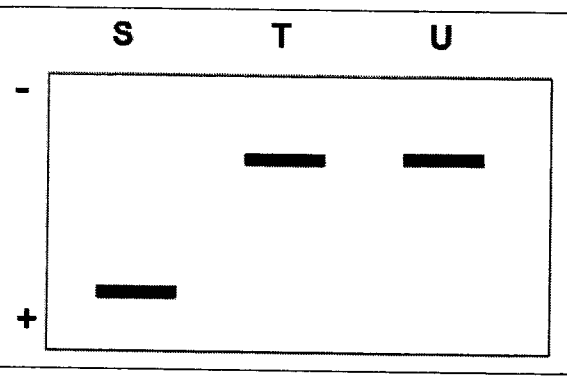
These antibodies were extracted from the rabbit and then added to samples of albumin obtained from four different animal species. Precipitation occurs when antibodies bind to albumin. The amount of precipitate produced in each sample was then measured and shown in the table below.

Species from which albumin was obtained	Amount of precipitate / arbitrary units
Rat	80
Chimpanzee	96
Marmoset	85
Trout	45

Which of the following statements is true of the results obtained above?

	A	Rabbit is most closely related to chimpanzee, and least closely related to trout.
	B	The constant region of the rabbit antibodies allows the antibodies to bind to albumin samples from the four animals tested.

	C	Rat and marmoset are more closely related to each other than they are to humans.
	D	Human shares a more recent common ancestor with chimpanzee, followed by marmoset, rat and then trout.
15	Two alleles from a gene located on a particular chromosome is shown below.  *Hind*III indicates the restriction sites for this enzyme, and the black bar indicates the position of the DNA probe used for analysis. DNA fragments from three different individuals, **S**, **T** and **U**, were subjected to restriction digestion by *Hind*III and separated by gel electrophoresis. Given that **S** and **T** are the parents of **U**, which of the following diagrams is NOT a valid result for **U**?	

	A	
	B	
	C	
	D	

16 An analysis of the number of chromosomes in gametes obtained after the meiosis of 2 human germ cells are shown in the table below.

Human germ cell X undergoes meiosis to produce gametes 1-4, while human germ cell Y undergoes meiosis to produce gametes 5-8.

Human germ cell X		Human germ cell Y	
Gamete	**Number of chromosomes**	**Gamete**	**Number of chromosomes**
1	22	5	23
2	24	6	23
3	24	7	22
4	22	8	24

Which of the following descriptions is consistent with the data shown in the table above?

	A	Homologous chromosomes could not pair up to form bivalents in germ cell X.
	B	Non-disjunction of a pair of chromatids during anaphase II in germ cell X.
	C	Centromere of a pair of chromatids failed to divide during anaphase II in germ cell Y.
	D	Fusion of Gametes 2, 3, and 8 with a normal gamete will always result in offspring with Down Syndrome.

17 Certain types of cancer are associated with chromosomal rearrangements.

Which of the following is a possible consequence when a tumour suppressor gene is translocated within the centromeric sequence of another chromosome?

1 Gene is transcriptionally active.
2 Gene codes for a non-functional tumour suppressor protein.
3 The centrometric sequence is transcribed together with the gene.
4 Cell is unable to carry out DNA repair.

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

18 In cats, coat colour is determined by the X-linked, codominant alleles: black and orange. A calico (black, orange and white fur) female, which is the homogametic sex, is bred many times with a black male. Which of the following is a possible outcome of their offspring?

1 All black offspring are female cats.
2 If any orange offspring are obtained, they are male cats.
3 Probability of a female offspring being calico is 0.25.
4 Cross of a black female offspring with an orange male cat will give 1 calico female : 1 black male in the next generation.

A	1 and 3
B	2 and 3
C	2 and 4
D	1, 2 and 4

19 In garden peas, the allele **T** codes for terminal position of flowers and is dominant over the allele **t**, which codes for axil position.

In an experiment, two garden pea plants, both heterozygous for terminal flowers, produced 77 offspring with flowers at the terminal position and 43 offspring with flowers at the axil position. A χ^2 test was done to determine whether the results of the experiment follow the expected pattern of inheritance.

Given that the χ^2 critical value at 1 degree of freedom and a probability of 0.05 is 3.84, which of the following conclusions can be drawn from the experiment and the χ^2 test?

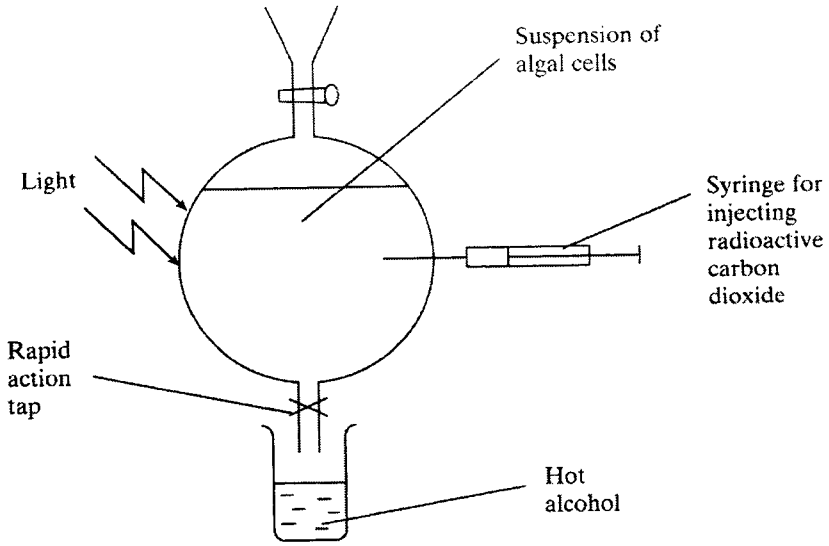
$$Note: \chi^2 = \Sigma \frac{(Observed - Expected)^2}{Expected} = \Sigma \frac{(O-E)^2}{E}$$

A	Since the χ^2 value obtained from the experiment is less than 3.84, flower position in garden peas involves a single pair of segregating alleles at the **T** locus.
B	Since the χ^2 value obtained from the experiment is less than 3.84, flower position in garden peas does not involve a single pair of segregating alleles at the **T** locus.
C	Since the χ^2 value obtained from the experiment is greater than 3.84, flower position in garden peas involves a single pair of segregating alleles at the **T** locus.
D	Since the χ^2 value obtained from the experiment is greater than 3.84, flower position in garden peas does not involve a single pair of segregating alleles at the **T** locus.

20 An investigation was carried out to find out the sequence of biochemical changes that occur during photosynthesis.

Radioactive carbon dioxide was added to a suspension of algal cells, which was placed under light conditions. At intervals, samples of the suspension were removed and dispensed into hot alcohol. These samples were analysed for different radioactively labelled compounds.

The experimental setup is shown below.



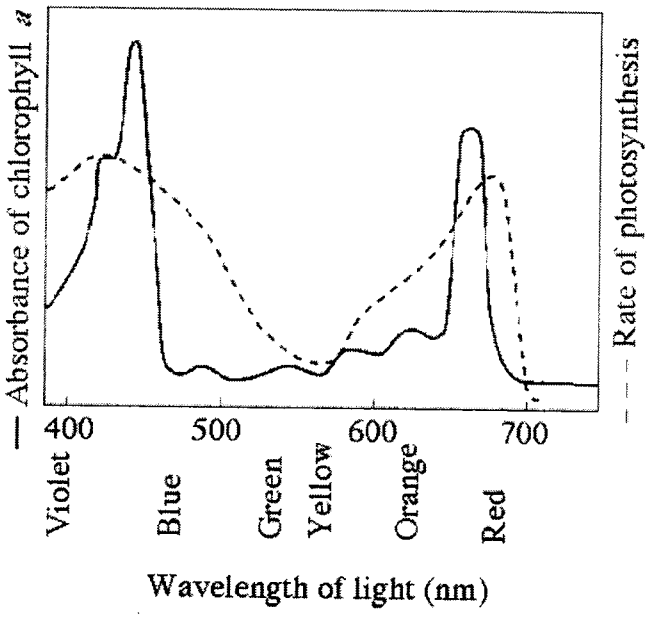
Samples were removed from the suspension at four different times, between 5 seconds and 600 seconds after the start of the experiment. In each sample, the amount of radioactivity present in three different organic compounds, **P**, **Q**, and **R** was measured, and shown in the table below.

organic compound	amount of radioactivity present / arbitrary units			
	5 s	60 s	180 s	600 s
P	0.01	0.08	0.17	0.67
Q	1.00	3.10	3.15	3.15
R	0.05	0.16	1.00	1.00

What are the most likely identities of the three organic compounds?

	P	Q	R
A	Rubisco	Glycerate 3-phosphate (GP)	NADP
B	Triose phosphate (TP)	RuBp	Glycerate 3-phosphate (GP)
C	5-carbon compound	Glycerate 3-phosphate (GP)	Triose phosphate (TP)
D	Triose phosphate (TP)	5-carbon compound	6-carbon compound

21 The graph shows the absorption spectrum for chlorophyll *a* and the action spectrum of a plant.



What is the reason for the difference in the absorption spectrum and the action spectrum?

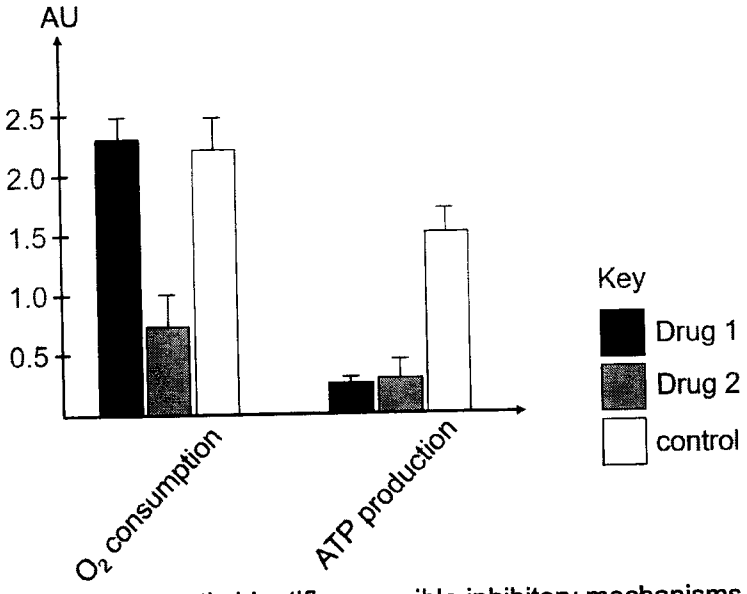
	A	Wavelengths of 480-630nm provide the least energy for photosynthesis.
	B	Chlorophyll *a* is the main pigment responsible for photosynthesis in the plant.
	C	There are other pigments responsible for photosynthesis in the plant.
	D	There are other limiting factors affecting the rate of photosynthesis in the plant.

22 Which of the following processes occur during glycolysis:

1 Two 3-carbon compounds combine to form 6-carbon compound
2 Dehydrogenation of substrate
3 Oxidative decarboxylation
4 Substrate-level phosphorylation

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

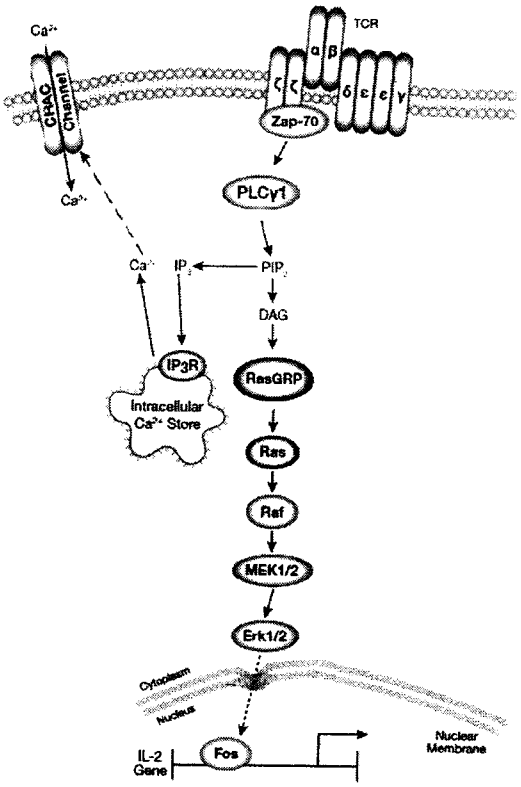
23 Two drugs, Drug 1 and Drug 2, inhibit different proteins found in mitochondria. Their effects on oxygen consumption and ATP production are recorded in the figure below.



Which of the following correctly identifies possible inhibitory mechanisms of Drugs 1 and 2?

	Drug 1	Drug 2
A	Inhibits ATP synthase	Inhibits a dehydrogenase involved in glycolysis
B	Inhibits cytochrome oxidase	Inhibits an electron carrier
C	Inhibits an enzyme in Krebs cycle	Inhibits ATP synthase
D	Provides an alternative pathway for H^+ to pass through the inner mitochondrial membrane	Inhibits cytochrome oxidase

24 T Cell Receptor (TCR) activation promotes several signalling cascades that ultimately determine cell fate. The diagram below shows part of the cell signalling pathway.



Which of the following can be inferred from the diagram?

1 Zap-70 activates phospholipase C (PLCγ1), which hydrolyses PIP_2 to produce the second messengers diacylglycerol (DAG) and inositol trisphosphate (IP_3).
2 IP_3 triggers the release of Ca^{2+} from the intracellular store, which promotes entry of extracellular Ca^{2+} into cells through CRAC channels.
3 Signal is amplified along the phosphorylation cascade involving kinases such as MEK1/2 and ErK1/2.
4 ErK1/2 activates Fos, which increases the transcription of IL-2 gene, leading to leading to production of antibodies.

	A	1 only
	B	2 and 3 only
	C	1, 2 and 3 only
	D	All of the above

25 *Greto oto* is a species of clearwing butterfly that has a proportion of its wings having no coloured scales, making them partially transparent.

Different populations of *Greto oto* have varying degree of transparency (i.e. area of wing with no coloured scales), depending on their habitat heterogeneity. Habitat heterogeneity is measured by considering the number and evenness of discreet structural elements in a habitat; the higher the number, the more complex it is.

A researcher glued 30 butterflies (all had wing transparency of 75%) at four different locations and measured the predation rate after 24 hours (defined as the percentage of glued butterflies removed by predators). He also captured 30 live butterflies from the same four locations and recorded their degree of wing transparency.

The table below shows the relationship between habitat heterogeneity, predation rate and degree of wing transparency.

Population	Habitat heterogeneity	Predation rate / %	Degree of wing transparency / %
1	8.2	67.2	72.4
2	6.9	75.4	80.6
3	4.5	83.0	85.3
4	2.1	89.6	90.7

Which of the following can be deduced?

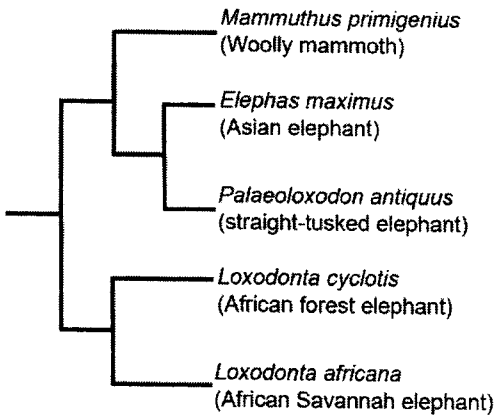
1 Predators have less success in habitats that are more complex.
2 Butterflies with higher degree of wing transparency face higher predation rates.
3 Predation acts as a selection pressure that favors wings that are more transparent.
4 Female butterflies preferred to mate with colourful males (i.e. more coloured scales on wings).

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

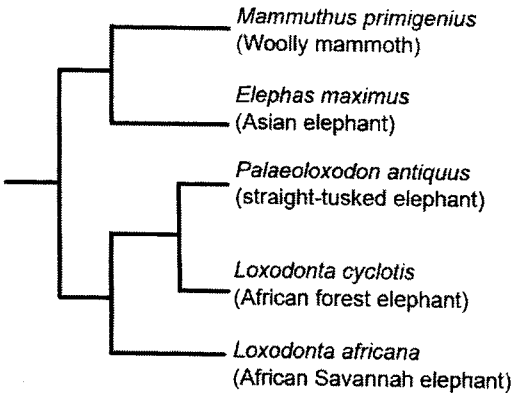
26 The straight-tusked elephants, *Palaeoloxodon antiquus,* were widespread across Eurasia during the Pleistocene. Phylogenetic reconstructions using morphological traits have grouped them with Asian elephants (*Elephas maximus*). The recovery and analyses of mitochondrial genomes and nuclear genomes from two *Palaeoloxodon antiquus* fossils suggest that *Palaeoloxodon antiquus* was a close relative of extant African forest elephants (*Loxodonta cyclotis*) instead.

The phylogenetic trees below show the evolutionary relationships between the elephants, using morphological and molecular data respectively.

Constructed using morphological data



Constructed using molecular data

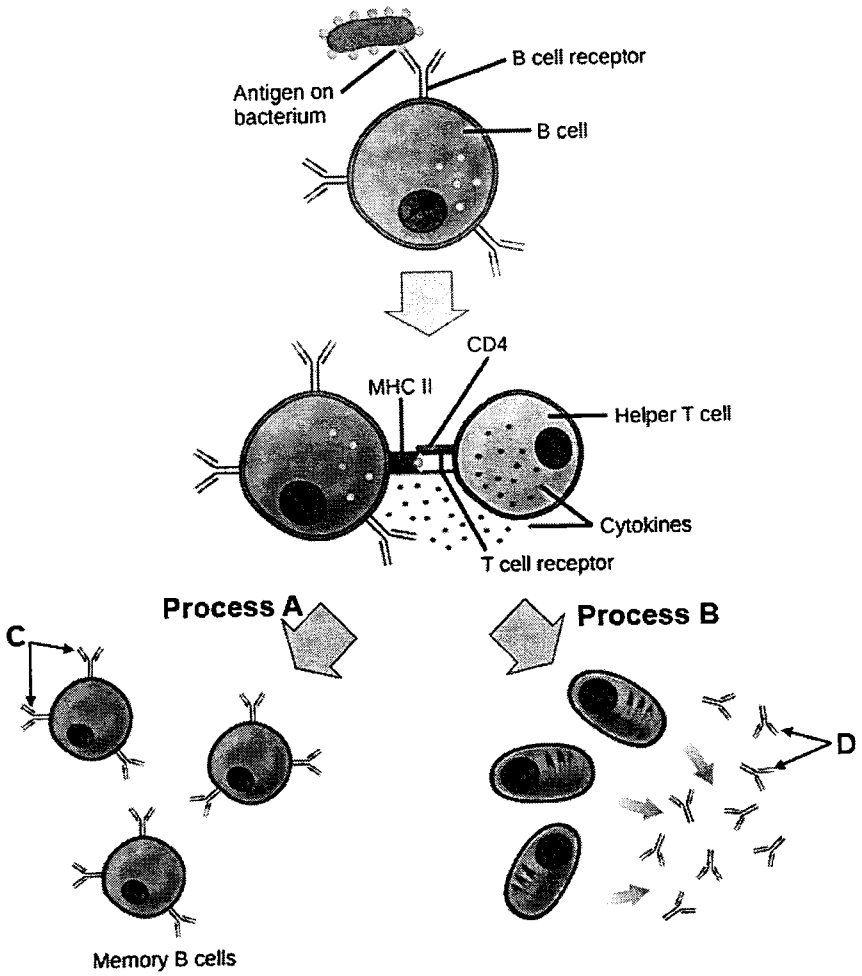


Which of the following statements can be deduced?

1 *Palaeoloxodon antiquus* and *Elephas maximus* share more morphological similarities with each other than they did with *Loxodonta cyclotis.*
2 *Palaeoloxodon antiquus* share more morphological similarities with *Mammuthus primigenius* than it did with *Loxodonta cyclotis.*
3 *Loxodonta cyclotis is more closely related to Loxodonta africana than it is to Palaeoloxodon antiquus because they are the same genus.*
4 *Palaeoloxodon antiquus* is more closely related to *Loxodonta africana* than it is with *Elephas maximus.*

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

27 The diagram below shows some processes of the adaptive immune system.



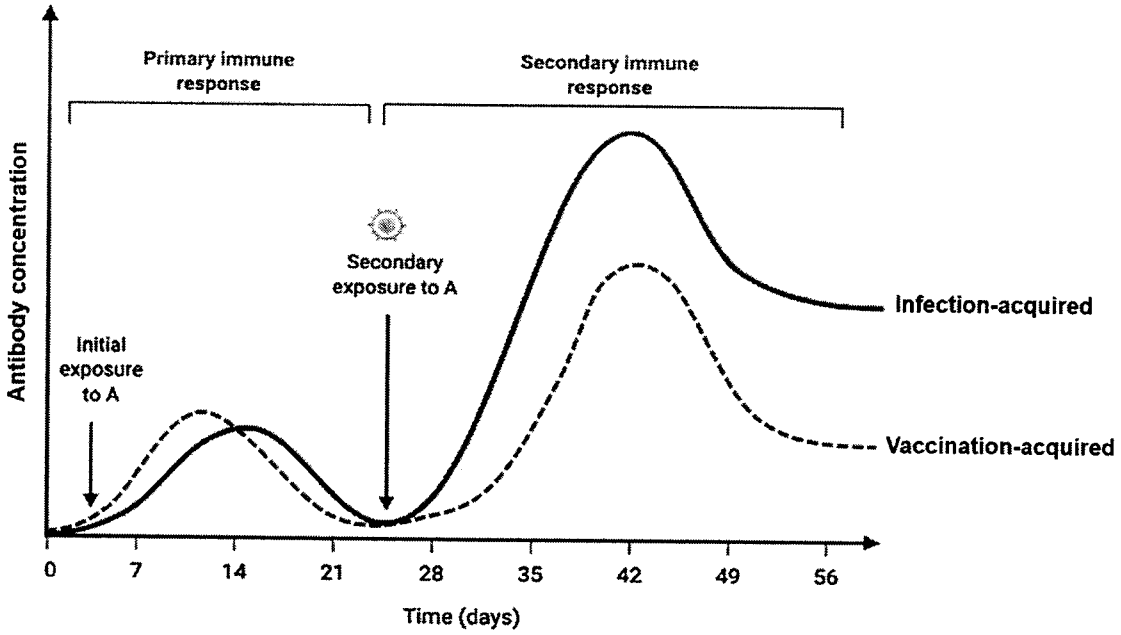
Which of the following are true?

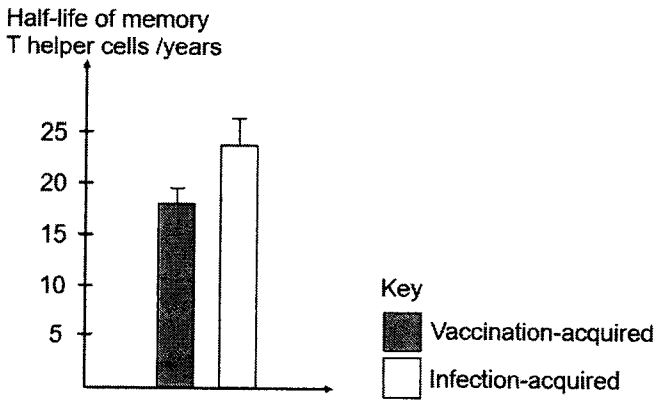
1 Processes **A** produces cells that are involved in the primary response.
2 Process **B** includes somatic recombination and somatic hypermutation.
3 Activated B cells secrete cytokines during Process **B.**
4 Structures **C** and **D** differ in the constant region of the molecule.

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

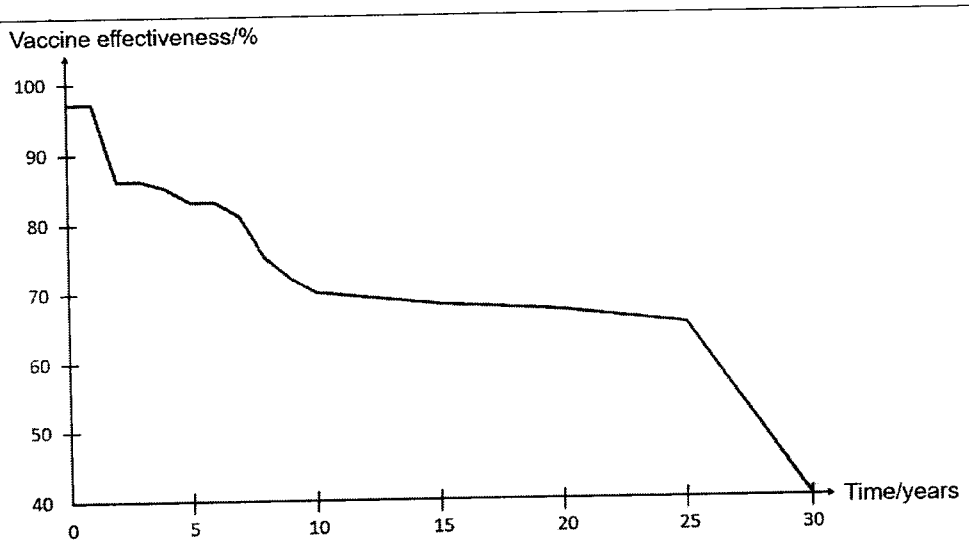
28 A study was conducted to investigate the difference between adaptive immunity acquired via normal infection vs vaccinations. The researchers obtained two comparative groups of people: one group was hospitalized from being infected with pathogen A and one group was vaccinated against pathogen A. The vaccine contained a mixture of purified viral envelope proteins.

They measured the antibody concentration during primary and secondary response, the half-life of the memory T helper cells produced against pathogen A and the effectiveness of the vaccine over a 30-year period. The diagrams below show the results of the study.





*Half-life is defined as time required for number of T helper cells to decrease by half.



Which of the following can be deduced from the results of this study?

1 A vaccinated person produces less antibodies when exposed to the actual pathogen A compared to a recovered patient who is exposed to pathogen A again.
2 If a patient was infected by pathogen A when he was 10 years old, he would have no more memory T cells specific to pathogen A when he turns 60.
3 The infection-acquired immunity will be better than vaccination-acquired immunity to protect against re-infection should pathogen A mutate.
4 The vaccine will no longer be able to protect individuals 30 years after it was given.

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

29 The table below records data collected from four countries.

Country/Region	Latitude, North/°	Summer temperature range/°C	Life cycle of *Aedes. aegypti* /days	Dengue fever cases per 100,000 people	Projected dengue fever cases per 100,000 people in 2050
Singapore	1.35	26.0 – 32.0	8	577.0	360
Heilongjiang, China	35.9	18.0 – 25.0	21	3.46	50
India	20.6	25.0 – 42.0	10	229.1	120
London, UK	37.1	15.0 – 23.0	No data	0	30

The projected dengue fever cases were calculated based on a 2°C increase in global temperatures predicted by current climate studies.

Which of the following statements are possible explanations of the trends shown in the data?

1 Temperatures are higher at lower latitudes (nearer to the equator) mainly due to increased deforestation, releasing more greenhouse gases. ✗

2 *Aedes aegypti* does not live in regions colder than 23°C.
3 In 2050, regions in higher latitudes are predicted to become more hospitable to *Aedes aegypti* but regions in lower latitudes become less hospitable.
4 *Aedes aegypti* population decreases as duration of life cycle decreases, causing the number of projected dengue fever cases in 2050 to drop. *

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

30 Which of the following correctly matches the example of human activity to its direct impact?

	Human activity	Impact
1	Increased beef consumption	Increased CO_2 and methane sequestered in their sinks
2	Increased burning of fossil fuel	Increased food insecurity, especially in temperate countries
3	Increased livestock farming	Intensifies water cycle
4	Increased oil palm plantations	Decreased potential for biomedicine discovery

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

End of Paper

Civics Group	Index Number	Name (use BLOCK LETTERS)	**H2**

ST. ANDREW'S JUNIOR COLLEGE
2022 JC2 PRELIMINARY EXAMINATIONS

H2 BIOLOGY **9744/2**

Paper 2

Monday 29th August 2022 Total 2 hours

Materials: Question Papers

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagram, graph or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions.
Write your answers in the spaces provided on the question paper.

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

Conceptual error (C)	Data Quoting (D)	Expression (E)	Misreading the question (Q)

For Examiners' Use	
1	/10
2	/10
3	/8
4	/12
5	/10
6	/10
7	/10
8	/11
9	/8
10	/6
11	/5
Total	**/100**

This document consists of **29** printed pages **1** Blank page.

[Turn over]

QUESTION 1

(a) Fig. 1.1 shows an electron micrograph of a plant cell.

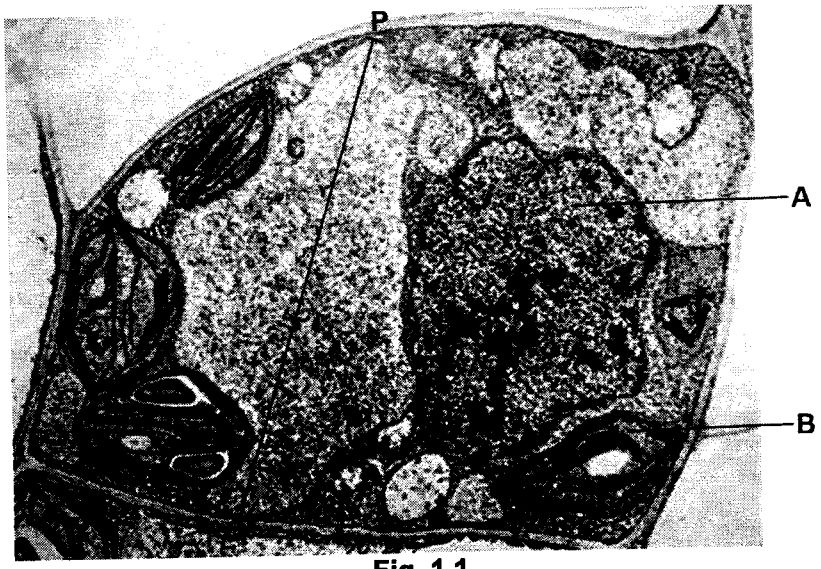


Fig. 1.1

(i) The magnification of the photomicrograph is x560. Calculate the actual length of organelle C in µm, along the line P-Q. Show your working.

..... [2]

Length of PQ = 6.8cm

$$\text{Actual length of organelle C} = \frac{\text{length of image}}{\text{magnification}} = \frac{6.8 \times 10\,000\ \mu m}{560}$$

= 121.4µm (1 d.p.) or 121.43 (up to 2 d.p.)

1 Use of correct formula and accurate measurement of length PQ
2 Correct number of decimal places and use of unit.

(ii) Identify organelles **A** and **B** and compare their structural features.

..... [4]

1 Organelle A: nucleus Organelle B: chloroplast [1 mark]

Similarities [max 1]:
2 Both of them are bound by <u>double</u> membrane.
3 Both of them contain DNA (and RNA).

Differences [max 2]:
4 Nucleus has linear DNA while chloroplast has circular DNA.
5 Nucleus does not have a third membrane system inside it/thylakoids while chloroplast has thylakoid membranes inside.
6 Nucleus is larger/more dense than chloroplast.
7 Nucleus does not contain ribosomes but chloroplast contain 70S ribosomes.
8 Presence of chlorophyll pigments in chloroplasts etc vs absent in nucleus

AVP: A is continuous with RER, but not B. A has pores but not B. B has electron carriers but not A. B has starch granules but not A.

(b) Cyclins are a group of proteins that regulate the cell cycle. There are four basic types of cyclins found in humans and most other eukaryotes: G1 cyclins, G1/S cyclins, S cyclins, and M cyclins.

Each cyclin is associated with a particular phase, or set of phases, in the cell cycle and helps drive the events of that phase or period. For instance, M cyclin promotes the events of M phase.

The levels of the different cyclins vary considerably across the cell cycle, as shown in Fig. 1.2.

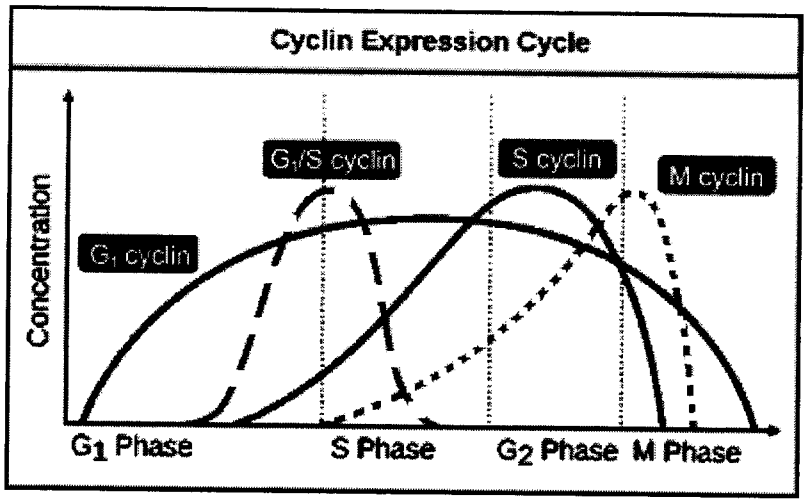


Fig. 1.2

A typical cyclin is present at low levels for most of the cycle but increases rapidly at the stage where it is needed. In order to drive the cell cycle forward, a cyclin must activate enzymes called the cyclin-dependent kinases (Cdks). In general, Cdk levels remain relatively constant across the cell cycle, but Cdk activity changes as levels of the various cyclins rise and fall.

Fig. 1.3 shows the cell cycle checkpoints and the activation periods of various Cdks. Percentage times (%T) in each phase are approximations of total cell cycle time. For instance, cells spend approximately 5% of their total cell cycle time in M phase.

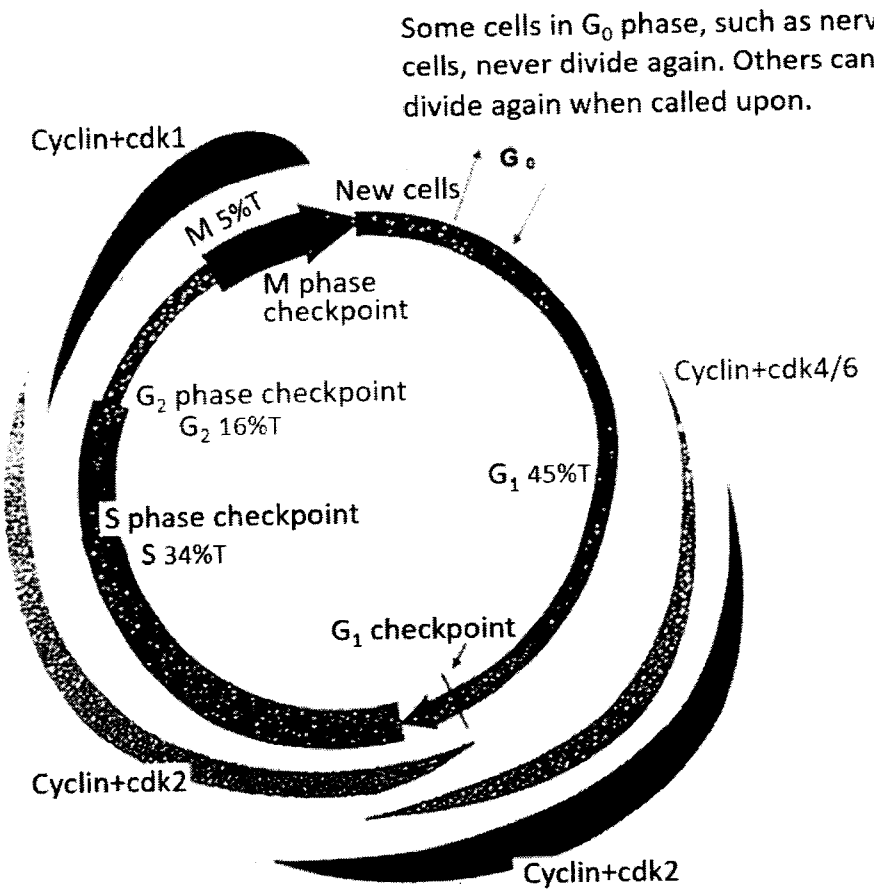


Fig. 1.3

(i) With reference to post-translational control of gene expression, suggest how cells reduce the concentration of cyclins when they are not needed in the cell cycle.

..... [1]

1 **Ubiquitinate** the cyclins to target them to <u>proteasomes</u> for degradation.

(ii) With reference to Fig. 1.2 and 1.3, identify the molecules that are at abnormally low concentrations for cells to be arrested at S phase.

..... [1]

1 M cyclin and cdk 1

Explanation: Fig. 1.2 shows that M cyclins need to increase for cells to enter G2, Fig. 1.3 shows cdk1 starts to increase during G2 phase, implying that without it, cells cannot proceed to G2.

(iii) It was found that cancerous cells show only 2%T at G2 phase. Explain the implications of this.

..... [2]

1 Cancer cells spend **lower** percentage time at G2 phase than normal cells which implies that cancerous cells **bypass** the G2 checkpoint
2 Cells with <u>DNA</u> **damage/abnormalities/replication errors** are allowed to proceed to M phase / divide.
3 allowing them to **accumulate mutations** which can lead to cancer development.

[Total: 10]

QUESTION 2

(a) Explain how the molecular structure of haemoglobin is related to its functions.

.....[3]

1 Amino acids with **charged/polar R-groups** are found on the **exterior** of haemoglobin (structure); enabling the globular protein to be soluble (Property) in aqueous medium **/cytoplasm of Red blood cell** (RBC)→ **can transport oxygen** to organs when RBC move through the blood stream (function)

2 **One Haem group** is present in each subunit (S)→ **4 oxygen molecules** are able to be carried by each haemoglobin (P) → **increase efficient of oxygen molecules** to be carried by the haemoglobin protein (F).

3 **Fe^{2+} present in each Haem grp** (S)→ allows **reversible binding of oxygen** (P) → can **release oxygen to tissues** where **oxygen level is low** (F)

4 The four subunits in haemoglobin associate together **via non-covalent interactions**→ slight changes in oxygen concentration causes **a conformational change in one subunit** which is relayed to the other subunits, enabling **cooperative binding of oxygen/ easier uptake of oxygen**

(b) Blood arriving in the lungs from the heart is oxygenated as it passes through the pulmonary capillaries. Sickle-shaped red blood cells are present in a person with sickle cell anaemia. These red blood cells have a very high quantity of abnormal haemoglobin and take up and transport less oxygen than red blood cells containing normal haemoglobin.

The cause of the differences between abnormal haemoglobin and normal haemoglobin is a mutation in the gene that codes for one of the two types of polypeptide found in a haemoglobin molecule. This mutation leads to a change in the mRNA produced during transcription, causing a change in the primary structure of the polypeptide formed.

Fig. 2.1 shows some of the changes that occur as a result of this gene mutation.

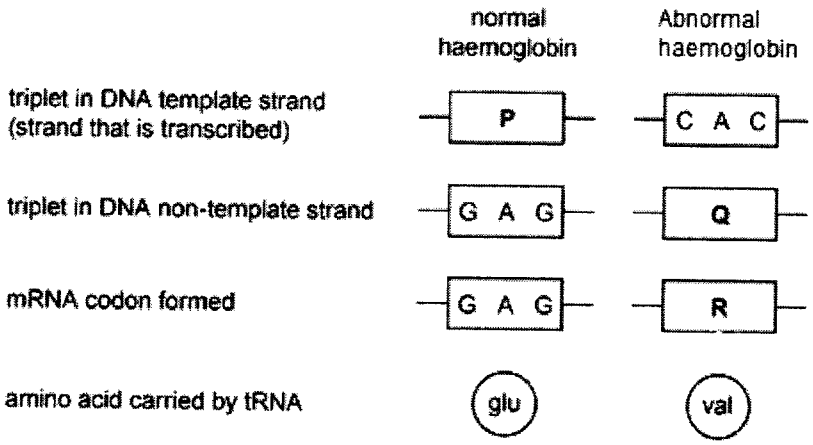


Fig. 2.1

(i) With reference to Fig. 2.1, state:
- the base sequence of DNA triplet P

.....

P - C T C ;

• the base sequence of DNA triplet Q

.....

Q - G T G ;

• the base sequence of mRNA codon R

.....[3]

R - G U G ;

(ii) Name the polypeptide that is altered in the abnormal haemoglobin molecule.

.....[1]

β-globin chain / beta globin;

(c) Fig. 2.2 shows the oxygen dissociation curve for adult haemoglobin in a person who does not have sickle cell anaemia.

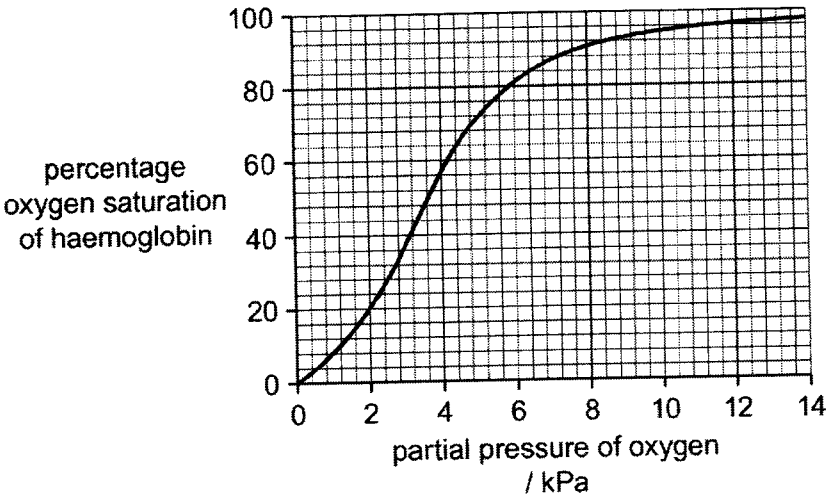


Fig. 2.2

Compared to Fig. 2.2, the oxygen dissociation curve for adult haemoglobin in a person with sickle cell anaemia is shifted to the right. The uptake of oxygen by haemoglobin in the lungs and the release of oxygen by haemoglobin in respiring tissues is different in a person with sickle cell anaemia compared with a person who does not have the disease.

With reference to Fig. 2.2, state **and** explain these differences.

uptake of oxygen .....

.....

release of oxygen .....

.....

Explanation for these differences .....

.....[3]

any three from:

in terms of sickle cell:

uptake:

1 lower uptake of oxygen / lower saturation of haemoglobin at same partial pressures/e.g. requires higher partial pressure of oxygen to reach same level of saturation

Release:

2 oxygen is more easily released (at same partial pressures);/ Oxygen release at higher partial pressure of oxygen

3 Explanation : lower affinity for oxygen / lower carrying ability of haemoglobin S for oxygen / more difficult for oxygen to bind to haemoglobin S / AW + due to any of the following

- **ref. to structure of abnormal haemoglobin, e.g. form fibres at low oxygen concentration**
- **reduced allosteric effect of haemoglobin molecule for uptake**
- **ref. to allosteric release of oxygen in respiring tissues**

[Total: 10]

QUESTION 3

HER2-positive breast cancer is a breast cancer that tests positive for a protein called human epidermal growth factor receptor 2. A member of the HER family of tyrosine kinase receptors (HER1–4), HER2 is an essential breast cancer oncogene.

Fig. 3.1 shows the Southern blot (DNA analysis) and Western blot (protein analysis) results of HER2 gene expression for a healthy individual and a breast cancer patient, and Fig. 3.2 shows the HER2 signaling pathway.

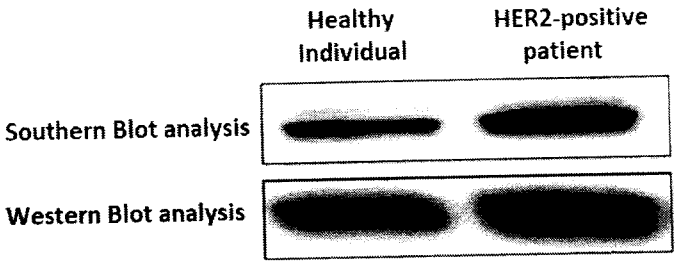


Fig. 3.1

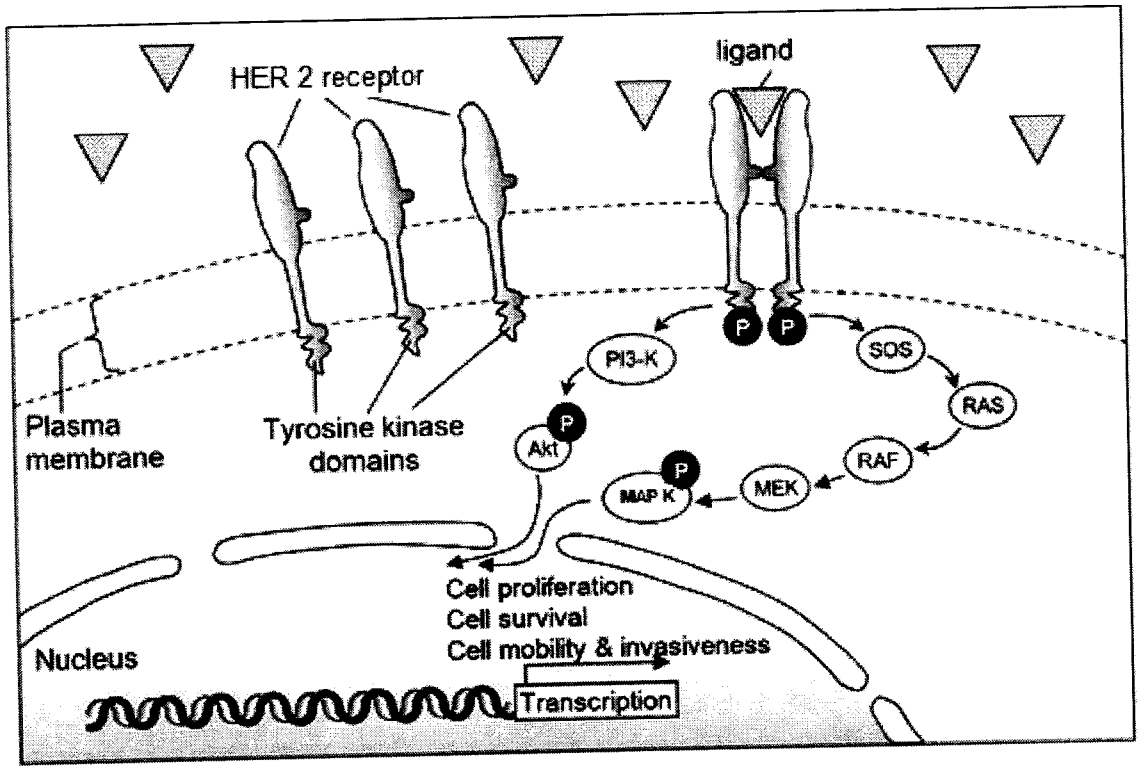


Fig. 3.2

(a) Research shows that 1 in 5 cancer patients shows an over-expression of HER2 gene. With reference to Fig. 3.1, suggest how the HER2 gene is converted to an oncogene in cancer patients.

.....[1]

(Thicker band seen for the Southern Blot analysis)

1 ref. Amplification of / Increase in number of copies of HER2 gene;

R! All other scenarios

(b) Distinguish between how the HER2 receptor and a G-protein linked receptor function as transmembrane receptors upon binding of their respective ligands.

.....[2]

1 Binding of ligand leads to dimerization of HER2 receptors, but no dimerization for GPLR;
2 Activation of HER2 receptors results in auto-cross phosphorylation of the tyrosine kinases domains, but activation of GPLR results in activation of G-protein.

(c) Patients with HER2-positive breast cancer have responded well to treatment when the drug Herceptin is used in combination with other chemotherapy drugs. Herceptin binds to the extracellular domain of the receptor.

With reference to Fig. 3.2, suggest and explain how Herceptin may act to prevent further progression of breast cancer.

.....[3]

1 ref. prevents ligand-receptor interaction via
- Drug is complementary in shape to / binds at / competes with ligand for binding at ligand-binding site of HER2 receptor
/ Drug binds at a site other than the ligand-binding site, and changes 3D conformation of ligand binding site;

2 ref. preventing downstream signal transduction such as activation of SOS, RAS, RAF, MEK, MAP K etc, and cellular response
3 ref. at least one of cellular response - cancer cells die / stop dividing / no loss of anchorage dependence / unable to undergo metastasis;

(d) Even with the effective treatment of Herceptin and chemotherapy, a proportion of cancer patients who were in remission, still experienced recurrence of cancer some years later.

Suggest how the cancer cells in these cases overcome the effects of Herceptin.

.....[2]

1 ref. gene (substitution) mutation of HER2 gene resulting in changes of 3D conformation of ligand-binding site / allosteric site;
2 Unable to bind to Herceptin;

OR

1 Gain-in-function mutation of downstream relay proteins to become constitutively active / no longer dependent on activation of HER2 receptor;
2 constitutive signal transduction → expression of genes resulting in increased cell proliferation, independent of ligand binding.

OR

1 **Gene amplification** / over-expression of genes coding for ;
2 enzyme/protein that degrades/hydrolyses Herceptin (prevents it from binding to HER2 receptor;

AVP

1 Gene amplification of the HER2 gene / chromosomal translocation of gene near enhancer/more active promoter → increase expression of HER2 gene,
2 Increase in HER2 receptors embedded in membrane => overcome inhibitory effect of Herceptin (present in lower concentrations)

[Total: 8]

QUESTION 4

(a) Fig. 4.1 shows the small ribosomal subunit rRNA loops containing double-stranded sections, H27, H30, H31 and H34, from bacteria and the mitochondria of mammals and plants. Grey shading highlights the locations of H31 and H34.

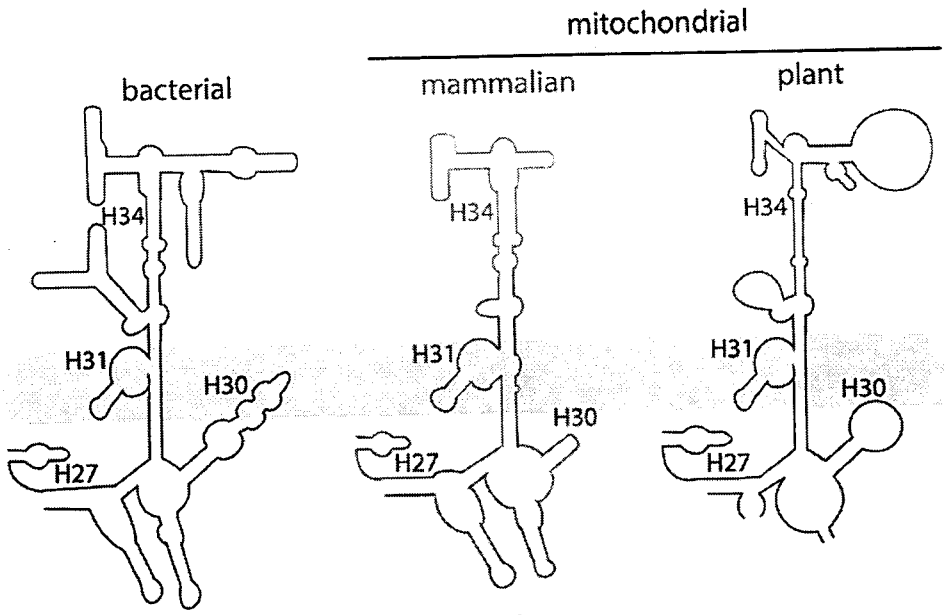


Fig. 4.1

(i) With reference to Fig. 4.1, compare the structures of the bacterial and mammalian mitochondrial small ribosomal subunit rRNA. [2]

Similarities
1 Both are single-stranded rRNA.
2 Both have similar loop structures at H27, H31 and H34 (need at least 2)
AVP: Both contain H27, H30, H31 and H34 double-stranded helices.

Differences
3 The H30/H34 in bacterial mitochondrial rRNA has a longer/more extensive loop that is absent from the H30/H34 in mammalian rRNA.
4 The bacterial rRNA is longer than the mammalian mitochondrial rRNA.

(ii) Describe the roles of rRNA in the process of protein synthesis. [2]

1 rRNA is **assembled with proteins** to form ribosomal subunits, which assemble to form ribosomes.
2 hold tRNA and mRNA in close proximity, to position new amino acid to growing polypeptide chain
3 it has peptidyl transferase activity, to catalyse formation of peptide bond during translation

(iii) Mammals and plants belong to the domain Eukarya while bacteria are grouped into their own domain, Bacteria. With reference to Fig. 4.1, comment on the suitability of using the small ribosomal rRNA structure to study the phylogenetic relationships between bacteria, mammals and plants.

..... [3]

1 Not suitable.
2 Mammals and plants share a more recent common ancestor than they do with bacteria / mammals and plants are more closely related to each other than either one is to bacteria.
3 However, the **loop structures** of the small ribosomal rRNA of mammals are more similar to those of bacteria than to plants.

AVP: determining the extent of similarity/differences in the loop structures can be subjective

AVP: as the rRNA from mammalian and plant cells were taken from their mitochondria, which are **prokaryotic** in origin, it is not suitable to compare their structure with bacteria rRNA to study phylogenetic relationship between Bacteria and Eukarya. Instead, eukaryotic rRNA from mammalian and plant cell cytoplasm should be used.

(b) Fig. 4.2A shows an electron micrograph of DNA replication occurring in organism X. Fig. 4.2B shows a representative diagram of the same process. The dotted line represents the daughter strands. Ori R represents the origin of replication.

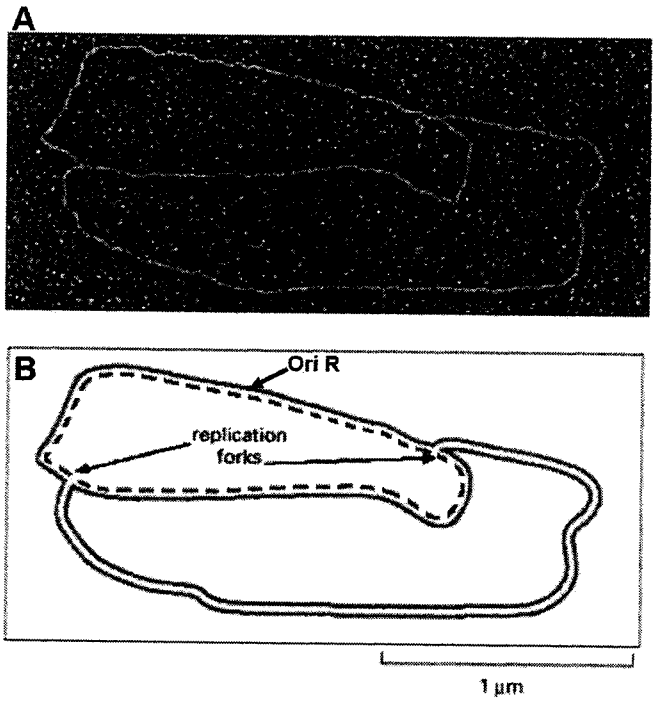


Fig. 4.2

(i) State whether organism X is a prokaryote or a eukaryote. Explain your answer.

..... [2]

1 Prokaryote
2 It has circular DNA.

AVP one origin of replication

Fig. 4.3 shows a diagrammatic representation of the DNA replication process. The arrow in the diagram on the left shows the direction of the synthesis of one of the daughter strands.

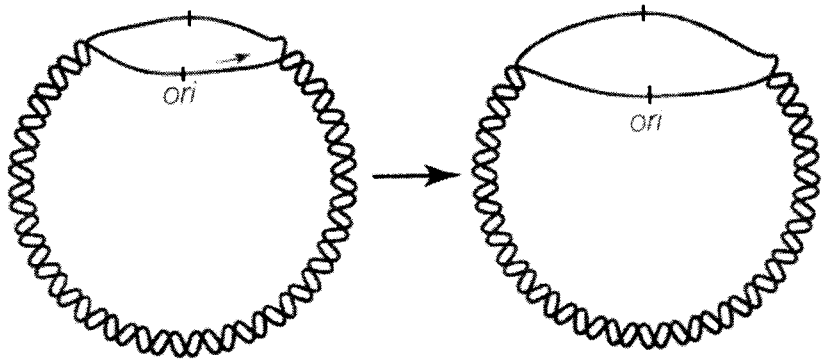
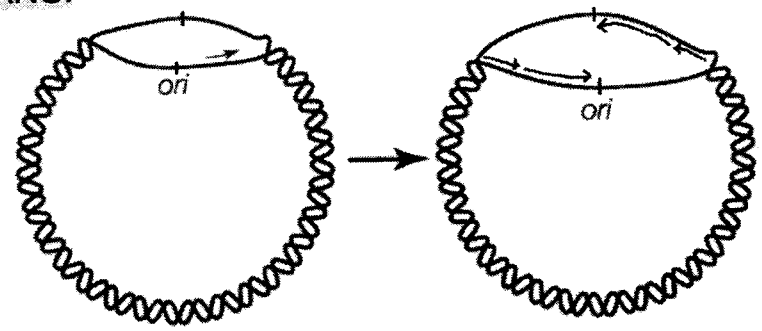


Fig. 4.3

(ii) Draw arrows in Fig. 4.3, on the DNA to the right, to indicate how the Okazaki fragments are synthesised. [1]

ANS:



(iii) Describe how the process of DNA replication differs between prokaryotes and eukaryotes.

..... [2]

Feature	Prokaryotes	Eukaryotes
Number of origins of replication	DNA replication begins at a **single origin of replication**.	DNA replication begins at **multiple origins of replication.**
Location	Occurs in the **nucleoid** region.	Occurs in the **nucleus**.
Replication complete or incomplete	The whole chromosome is replicated completely.	The 3' ends of parental strands are not copied onto the 5' end of daughter strands.
Speed	Relatively fast (due to smaller DNA)	Relatively slower (due to larger DNA molecules)

[Total: 12]

QUESTION 5

Gibberellins (GA) are plant hormones that regulate developmental processes such as stem elongation and flowering. Fig. 5.1 shows the effect of different levels of GA on stem elongation. Plant 1 lacks GA and has an internode length of "0" ("dwarf" plant). Plant 2 has a moderate amount of GA and an average internode length ("normal" plant). Plant 3 has a large amount of GA and so has a much longer internode length ("giant" plant).

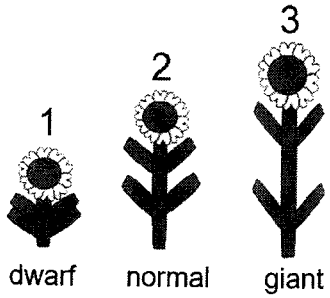


Fig. 5.1

Gene **K** encodes an enzyme responsible for one of the first steps of GA biosynthesis in *Arabidopsis* plants. The recessive allele of this gene results in GA-deficient *Arabidopsis* dwarfs. The dominant allele of Gene **T** codes for an activator which triggers the over-expression of Gene **K**, resulting in *Arabidopsis* giants.

When pure-breeding normal plants are crossed with pure-breeding dwarf plants, they produced F_1 which are all giants. Selfing of the F_1 generation produced the following F_2 generation:

443 giants
159 normal
197 dwarfs

(a) Draw a genetic diagram to show the results of the F_2 generation from the selfing of the F1 generation.

..... [3]

F_1 phenotype: *Arabidopsis* Giant x *Arabidopsis* Giant
F_1 genotype: KkTt x KkTt
Gametes: (KT) (Kt) (kT) (kt) x (KT) (Kt) (kT) (kt)

F_2 Punnett square

	(KT)	(Kt)	(kT)	(kt)
(KT)	KKTT giant	KKTt giant	KkTT giant	KkTt giant
(Kt)	KKTt giant	KKtt normal	KkTt giant	Kktt normal
(kT)	KkTT giant	KkTt giant	kkTT dwarf	kkTt dwarf
(kt)	KkTt giant	Kktt normal	kkTt dwarf	kktt dwarf

F_2 phenotypic ratio: 9 giants : 3 normal : 4 dwarfs

Mark Scheme
1 F_1 genotype match with phenotype
2 Gametes (circled)
3 F_2 genotypes match with phenotypes + correct ratio

(b) (i) The expected phenotypic ratio of the F_2 generation is 9 giants : 3 normal : 4 dwarfs.

Calculate the value of χ^2 applicable to these data.

$$\chi^2 = \Sigma \frac{(O-E)^2}{E} \qquad v = c - 1$$

where Σ = 'sum of...' O = observed 'value'
v = degrees of freedom E = expected 'value'
c = number of classes

..... [2]

1 Calculation of expected numbers:

Classes	*Observed number (O)*	*Expected ratio*	*Expected number (E)*
Giant	444	9	449
Normal	159	3	150
Dwarf	197	4	200

2 Calculation of χ^2 value:

$$\chi^2 = \frac{(443-449)^2}{449} + \frac{(159-150)^2}{150} + \frac{(197-200)^2}{200}$$

= 0.67 (2 d.p.)
[Accept: 0.70 for students who gave expected numbers to 1 d.p.]

(ii) Use the calculated value of χ^2 and the table of probabilities provided to find the **probability** of the observed results differing by chance from the expected numbers.

degrees of freedom	probability, p				
	0.10	*0.05*	*0.02*	*0.01*	*0.001*
1	2.71	3.84	5.41	6.64	10.83
2	4.61	5.99	7.82	9.21	13.82
3	6.25	7.82	9.84	11.35	16.27
4	7.78	9.49	11.67	13.28	18.47

..... [2]

1 Degrees of freedom = 3-1 = 2
2 $p > 0.10$

(iii) State the conclusions that may be drawn from the probability found in **(ii)**.

..... [3]

1 p value is larger than 0.05, there is no significant difference between observed and expected results. Any difference is due to chance.
2 There is independent assortment of Genes **K** and **T**.
3 **kk** is epistatic over the **T/t** locus, resulting in dwarf plants due to the lack of the enzyme involved in GA synthesis.
4 In the presence of a dominant **K** allele, the dominant **T** allele results in over-expression of the **K** allele, resulting in giant plants.

[Total: 10]

QUESTION 6

Bacteria can undergo genetic recombination, a process by which genetic information from one bacterium is transferred to, and then recombined with that of another bacterium.

Experiments have shown that two strains of bacteria can undergo conjugation when grown in a common medium. However, when they are separated by a filter in the Davis U-tube, as shown in Fig. 6.1, conjugation cannot occur.

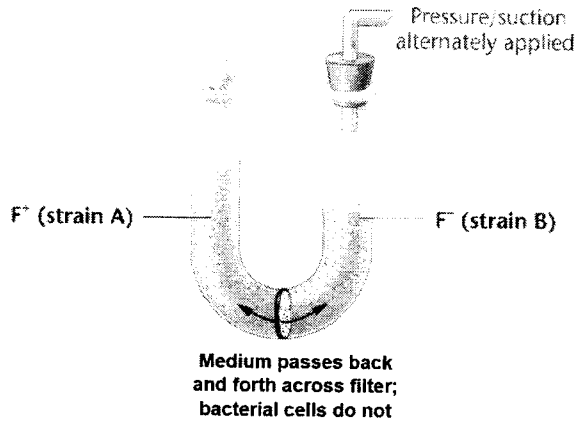


Fig. 6.1

(a) With reference to Fig. 6.1, explain why conjugation cannot occur when the two strains of bacteria are placed in the Davis U-tube.

..... [2]

1 Ref to presence of filter therefore **no cell to cell contact** between strain A and strain B;
2 **No attachment via sex pilius / no formation of conjugation / mating bridge** therefore no transfer of plasmid from F+ donor cell to F- recipient cell;

In another experiment investigating possible recombination in the bacterium *Salmonella typhimurium*, when researchers mixed *Salmonella* strains X and Y in a common medium, they recovered recombinants.

In a separate experiment using the Davis U-tube, the strains X and Y were separated by a filter, thus preventing cell contact but allowing growth to occur in a common medium. Surprisingly, when samples were removed from both sides of the filter, recombinants were recovered only from the side of the tube containing strain X bacteria. Researchers postulated that a filterable agent was released by the strain Y cells and responsible for transferring the new genetic information.

Three subsequent observations were useful in identifying the filterable agent:

1. The filterable agent was released by the strain Y cells only when they were grown in association with strain X cells.
2. The addition of DNase, which enzymatically digests naked DNA, did not render the filterable agent ineffective.
3. The filterable agent could not pass across the filter of the Davis U-tube when the pore size was reduced below the size of 20nm.

(b) (i) Suggest the source of the new genetic information which strain X cells received.

.....[1]

- **Strain Y; [Reject: virus]**

(ii) State the process of genetic recombination that has occurred.

..... [1]

- **Transduction;**

(iii) Describe how the filterable agent could have transferred the new genetic information to strain X.

..... [3]

1 **(Generalised transduction) Phage enzymes degrade bacterial host DNA and parts of bacterial DNA repackaged into new phages ;**

OR

2 **(Specialised transduction) Phage DNA integrate to form prophage, but later excise part of bacteria DNA out before repackaging into new phages;**

3 **Progeny phages released from the host carrying Strain Y DNA cross filter attaches to Strain X bacterial cell wall (receptor) / to infect other recipient strain X bacteria;**

4 **Ref. to homologous recombination/site specific integration**
NO ECF

Fig. 6.2 represents the reproductive cycle that a T4 phage can carry out.

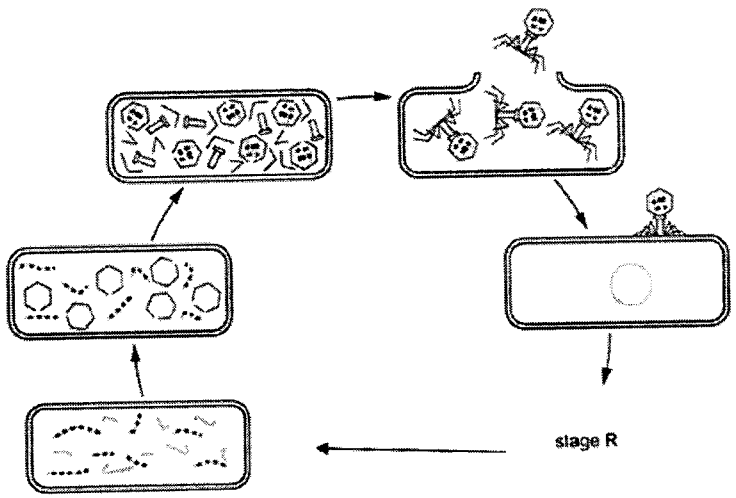


Fig. 6.2

(c) Describe what happens in stage R of the reproductive cycle shown in Fig. 6.2.

.....[3]

1. Tail sheath contracts and injects the phage DNA genome through the cell wall and plasma membrane
2. Ref. host DNA/chromosome broken down to provide nucleotides
3. ref. to synthesis of viral protein e.g. capsid protein using host ribosomes
4. Ref. viral genome using host DNA polymerase;

[Total: 10]

QUESTION 7

Corals grow in shallow sea water. Corals consist of colonies of small animals called polyps. These polyps have photosynthetic protoctists called algae within their cells, which is advantageous both to the coral polyps and to the algae.

The algae that live within the cells of coral polyps can also live independently as free-living algae.

(a) The rate of photosynthesis of algae that live within the cells of coral polyps is higher than that of free-living algae.

Suggest and explain why the rate of photosynthesis in algae that live within the cells of coral polyps is higher than that of free-living algae.

.....[2]

1 The carbon dioxide concentration is higher / increased within the cells of the coral due to **respiration** from coral / polyp ;
2 hence there is increased CO_2 for Calvin cycle / light independent reactions in algae ;
AVP further detail of effect of CO_2 concentration on binding of CO_2 to rubisco ;

The algae that live within the cells of coral polyps have five different chloroplast pigments.

Table 7.1 shows the light wavelengths at which each algal chloroplast pigment shows its two largest peaks of light absorption.

Table 7.1

chloroplast pigment	peak 1 wavelength / nm	peak 2 wavelength / nm
chlorophyll *a*	430	662
peridinin	456	485
chlorophyll c_2	450	396
dinoxanthin	442	471
β-carotene	454	480

Corals can be kept in glass tanks that are usually lit by lamps radiating mainly violet and blue light, with wavelengths in the range of 400 nm to 490 nm.
With reference to Table 7.1, suggest why lamps radiating mainly violet and blue light are expected to increase the growth of coral polyps more than lamps radiating light of all wavelengths.

..... [3]

1 pigments absorb violet-blue light with wavelength 400–490 nm well / best / most / at 8 (out of 10) peaks ;
2 rate of photosynthesis of algae increases with more light absorbed ;
3 ref. to transfer of, organic nutrients, to polyps from algae and hence more coral growth (increases) with more photosynthesis ;

(c) ATP is used or produced at different stages in the oxidation of glucose in aerobic conditions. Complete Table 7.2 to show whether ATP is used or produced at each stage of respiration. Write either YES or NO in each box. [2]

Table 7.2

stage of respiration	ATP used	ATP produced
glycolysis		
link reaction		
Krebs cycle		
oxidative phosphorylation		

stage of respiration	ATP used	ATP produced
glycolysis	yes	yes
link reaction	no	no
Krebs cycle	no	yes
oxidative phosphorylation	no	yes

;;

4 correct = 2 marks, 2 or 3 rows correct = 1 mark
If ticks and crosses used need all 4 correct for maximum 1 mark

(d) An experiment was carried out to investigate the effect of epicatechin on mitochondrial respiration in mice. Epicatechin is a naturally occurring compound in cocoa beans and so is present in chocolate. Two groups of mice, group A and group B, were used in this experiment.

- Group A was given water containing epicatechin, twice a day for 15 days.
- Group B was given water without epicatechin, twice a day for 15 days.

After 15 days, the structure of mitochondria from striated muscle cells in both groups of mice was examined. The surface area of the inner membrane of the mitochondria was divided by the surface area of the outer membrane to obtain a ratio for each mouse. Table 7.3 shows the mean ratios for the two groups of mice.

Table 7.3

group	mean ratio
A	2.0 : 1
B	1.7 : 1

The mice in group A were observed to be able to exercise longer than to exercise longer than the mice in group B.

With reference to Table 7.3, explain why the mice in group A were able to exercise for longer than the mice in group B.

.....[3]

1 Group A has **higher** mean ratio of inner membrane to outer membrane 2.0 : 1 as compared to group B with 1.7 :1 ;
2 This suggest that inner membrane / cristae is more highly folded than B, therefore more, ETCs / cytochromes / ATP synthetase are embedded.
3 resulting in higher rate of oxidative phosphorylation / chemiosmosis, and more ATP produced per unit time, hence muscles can contract for, longer / more time / without getting tired;

[Total: 10]

QUESTION 8

(a) A geneticist studied the following pedigree diagram in Fig. 8.1 of a family with several members diagnosed with a genetic condition which originated from a mutation in a particular gene.

Given that the disease is autosomal dominant, Southern Blotting was also performed using genomic DNA isolated from each family member. The DNA samples were first subjected to restriction digestion by *EcoRI*, before hybridising to probes derived from the said gene.

The results for all family members, except those for the foetus, are shown below in Fig. 8.1. The sizes of the DNA fragments obtained after *EcoRI* digest are as indicated.

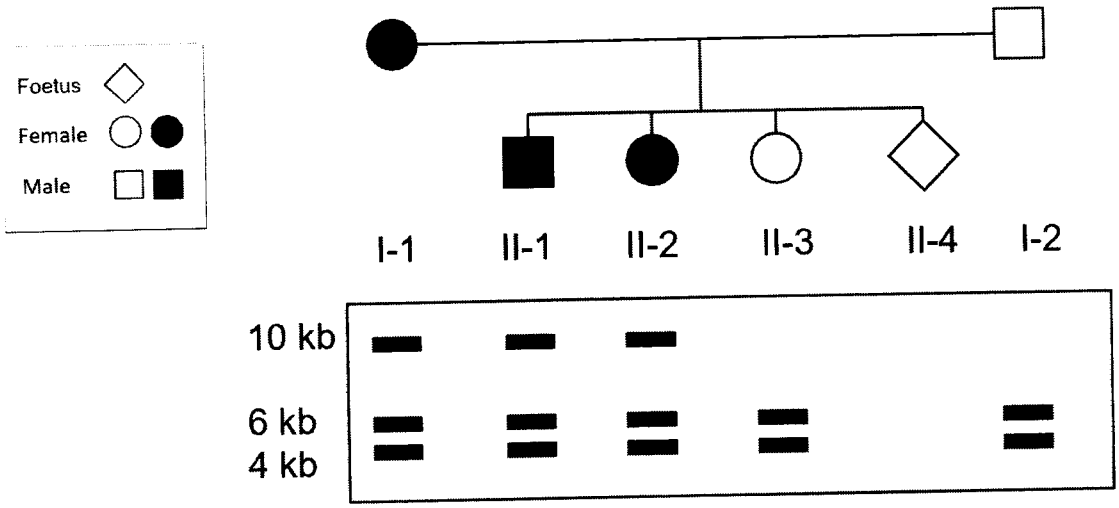


Fig. 8.1

(i) With reference to the Southern Blot results of individual **I-1** in Fig. 8.1, use arrows to indicate the relative positions of the *EcoRI* restriction sites on the region of the genomic DNA recognised by the probe.

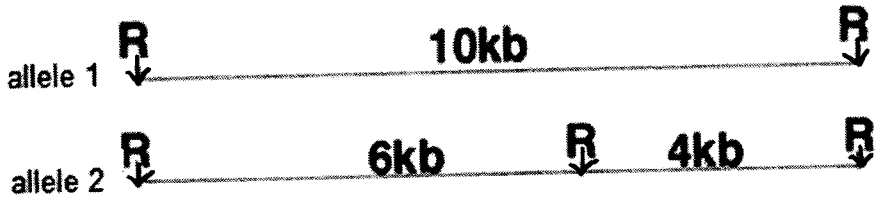
Label ALL the restriction sites as "**R**" and indicate the length of bases in kb.

.....[2]

allele 1 _____

allele 2 _____

Answer: Award mark for showing restriction sites at both ends of the alleles. 1 mark each for allele 1 and 2



(ii) Calculate the probability of the foetus being a boy and inheriting the disease. Explain your answer.

.....[2]

1 ref. mother is heterozygous and father is homozygous recessive;
2 Probability of foetus receiving dominant allele is ½ and probability of getting a son is also ½;
3 ½ X ½ = ¼ or 25%;

Accept: Punnett Square with defined alleles as explanation for 1 & 2;

(b) Fig 8.2 shows the possible restriction sites of a gene and the results of four individuals after subjecting their genomic DNA to Polymerase Chain Reaction (PCR) and restriction enzyme digest. The number below each band indicates the molecular sizes of the individual fragments.

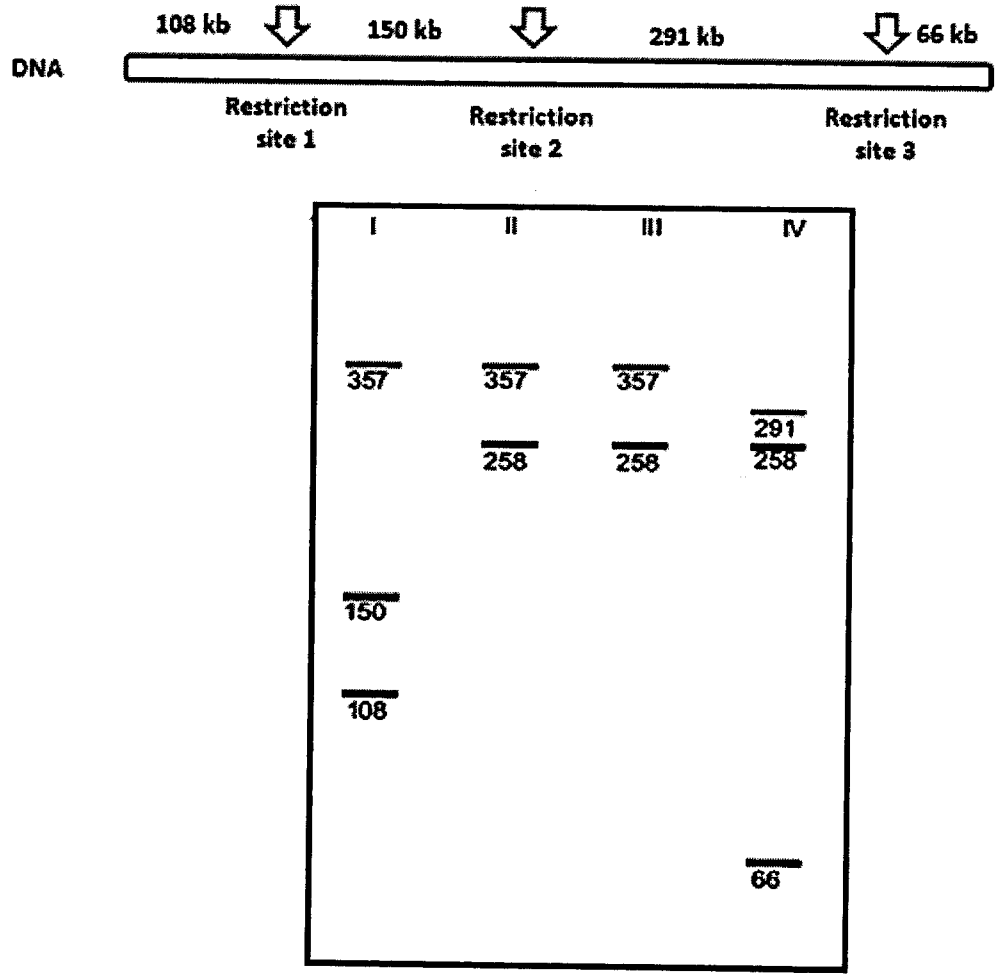


Fig 8.2

(i) Suggest the significance of carrying out PCR for the genomic DNA samples before subjecting the samples to restriction enzyme digest.

.....[1]

1 To **avoid getting a smear/multiple bands** of DNA fragments of different molecular sizes **by amplifying/isolating only the desired/target gene** for analysis;

(ii) With reference to Fig. 8.2, identify the total number of alleles presented by this gene in the four individuals tested. Explain your answer.

.....[4]

1 3 different alleles;
2 Allele 1: Restriction sites 1 and 2 resulting in 357 kb, 150 kb and 108 kb fragments in individual I;
3 Allele 2: Only restriction site 2 resulting in 357 kb and 259 kb fragments shown in individual II and III;
4 Allele 3: Restriction sites 2 and 3 resulting in 357 kb, 150 kb and 108 kb fragments in individuals IV;

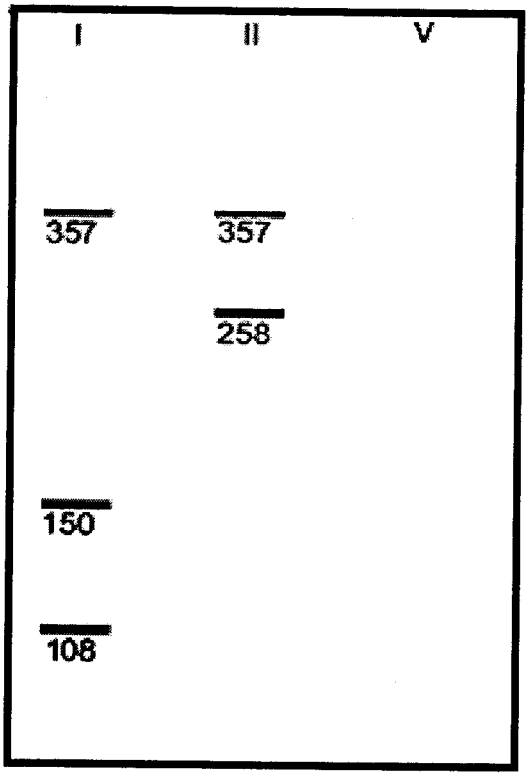
(iii) Suggest how a mutation can result in the different alleles for this gene.

.....[1]

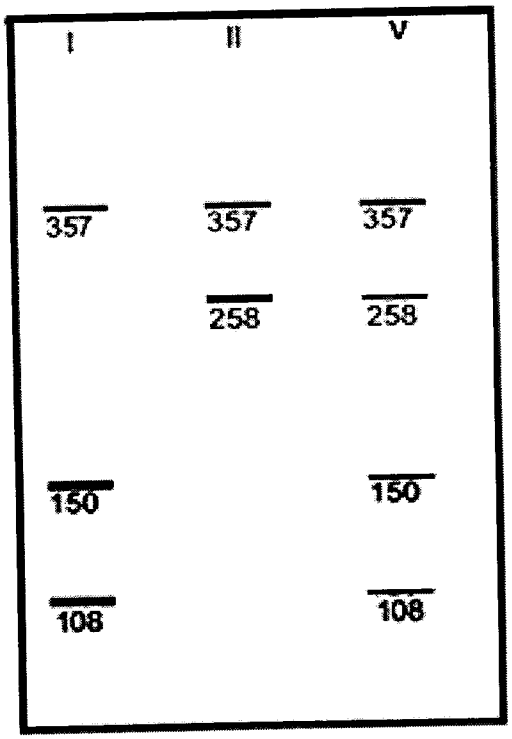
1 **Single base substitution** that results in the loss of a restriction site;
Reject: ref. missense or nonsense mutations.
Reject: All other types of gene mutation as insertion or deletion of a single base, will change the length of the restriction fragment obtained.

(iv) Individuals I and II had a child V. Draw his banding pattern in the diagram below after subjecting his genomic DNA to the same PCR and restriction digest treatment.

[1]



Ans:



Award mark only if band for 258kb, 150kb and 108 kb are thinner compared to the homozygous parents.

[Total: 11]

QUESTION 9

The genus *Heliconius* contains more than 40 species of brightly patterned butterflies. Researchers have investigated in the laboratory how one species, *Heliconius heurippa*, could have developed as a separate species. The phenotype of *H. heurippa* is intermediate between that of two other species, *H. cydno* and *H. melpomene*.

Laboratory breeding experiments showed that:

- matings between *H. cydno* and *H. melpomene* (parent species) produce fertile hybrid offspring
- controlled matings of the hybrids produce individuals identical in appearance to *H. heurippa* within three generations
- hybrid butterflies prefer to mate with each other, rather than with individuals of either of the parent species.

(a) The researchers concluded that the *H. heurippa* species could contain DNA from the two parent species as a result of hybridisation.

(i) Suggest, with reasons, one prediction that can be made about the chromosome numbers of *H. cydno* and *H. melpomene*.

..... [2]

1 [Compulsory point]: Chromosome numbers are the same.
2 Hybrids are fertile.
3 Homologous chromosomes can pair up / bivalents can form (in meiosis) to produce viable gametes.

(ii) The researchers thought that, because the hybrid butterflies preferred to mate with each other, this could make speciation more likely to occur.

Give reasons why the researchers thought that this made speciation more likely.

..... [4]

1 There is <u>behavioral isolation</u> (between hybrids and parent species.)
AVP: Sexual selection
2 This **reduces the gene flow** between hybrids and parent species.
3 Genetic differences can accumulate via mutation, genetic drift and natural selection [any two]
4 Over time, <u>sympatric speciation</u> can occur.

(b) *Heliconius* butterflies taste unpleasant to predators such as birds. The bright colours on the wings act as warnings so that birds avoid eating them.

Individual birds learn which patterns to avoid. If one *Heliconius* species is abundant, or if it has a pattern shared with another similar species, predators learn to avoid this pattern faster. Therefore, this pattern provides a selective advantage.

Fig. 9.1 shows the distribution of several *Heliconius* species in South America.

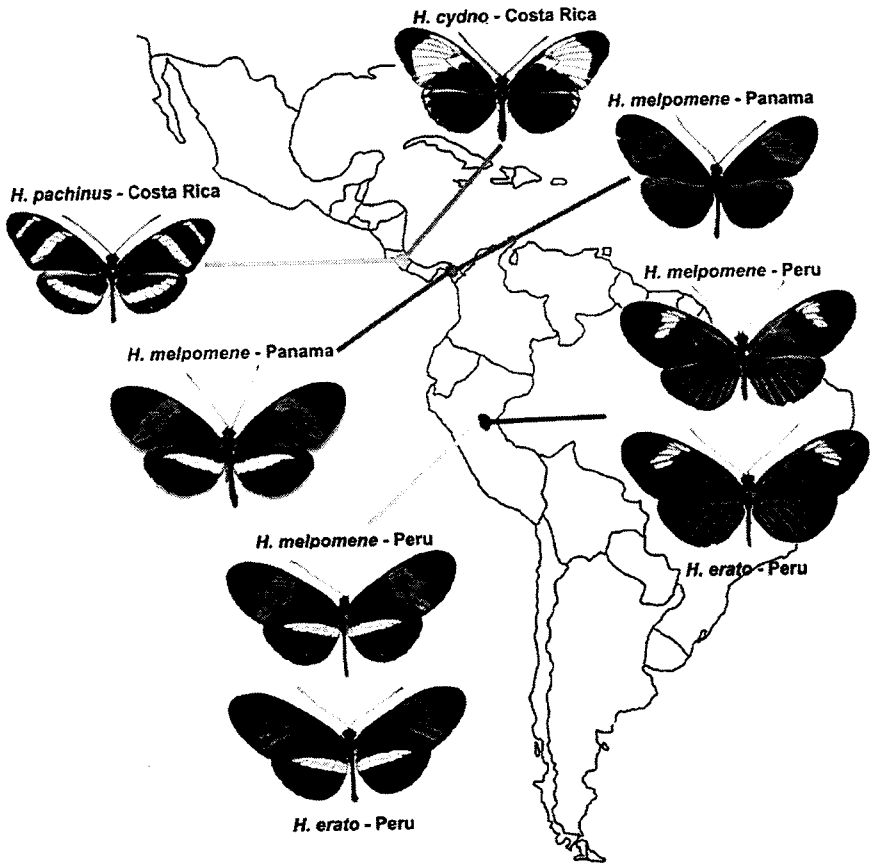


Fig. 9.1

With reference to Fig. 9.1 and your knowledge of anatomical homology and biogeography, comment on the evolutionary relationships between *H. Melpomene*, *H. cydno*, *H. pachinus* and *H. erato*. [2]

1 *H. melpomene* is very closely related to *H. erato* as they have very similar wing patterns and are found in the same locations in Panama and Peru. Accept same ecological niche / face same selection pressures;

2 *H. cydno* and *H. pachinus* are more closely related to each other than they are to *H. Melpomene* as they are found in the same location in Costa Rica, but are further away from *H. Melpomene*

OR

H. pachinus is more closely related to *H. melpomene* than it is to *H. cydno* as its wing pattern more resembles that of *H. Melpomene*.

[Total: 8]

QUESTION 10

Fig. 10.1 shows some of the general changes in the immune system during a viral infection.

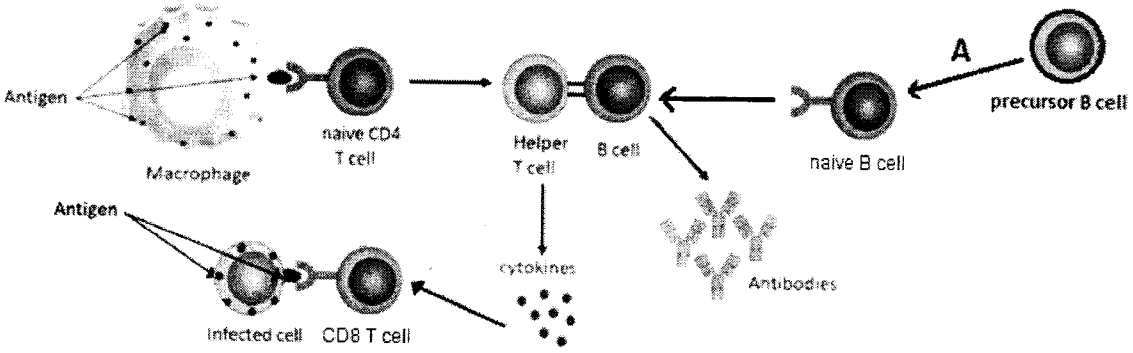


Fig. 10.1

(a) Outline the genetic mechanism that occurs in stage **A** and explain its significance in the adaptive immune response.

.....[4]

1 ref. **somatic recombination** of **V, D and J gene segments** of the variable region of the immunoglobulin genes / of V, D and J gene segments at heavy chain locus and V and J segments at a light chain locus

2 giving rise to different light and heavy chain variable regions, which generates a **wide diversity of** B cells such as B1-B3; **R**: antibodies

3 Each B cell has a **distinct/ specific B cell receptor** which recognises a single **specific**/complementary antigen/epitope from **different pathogens**;

4 Ref. production of **specific** antibodies to neutralise/opsonise the pathogen.

(b) A HIV-infected person infected saw his CD4 T cell count decrease within the first few weeks of his infection and then start to increase again.

With reference to Fig 10.1 and your own knowledge on adaptive immunity, suggest an explanation for the changes in his CD4 T cell count.

.....[2]

1 [decrease in CD4 T cells] ref. infected CD4 T cells present antigens on their cell surface (via MHC Class I) and
are removed/destroyed by cytotoxic T cells
/ bound by antibodies and destroyed by macrophages/NK cells;

2 [increase in CD4 T cells] ref. HIV in latent phase,
healthy CD4 T cells are being regenerated (from haematopoietic stem cells)
/ antigen not displayed on cell surface of infected T cells, thus T cells not lysed or killed;

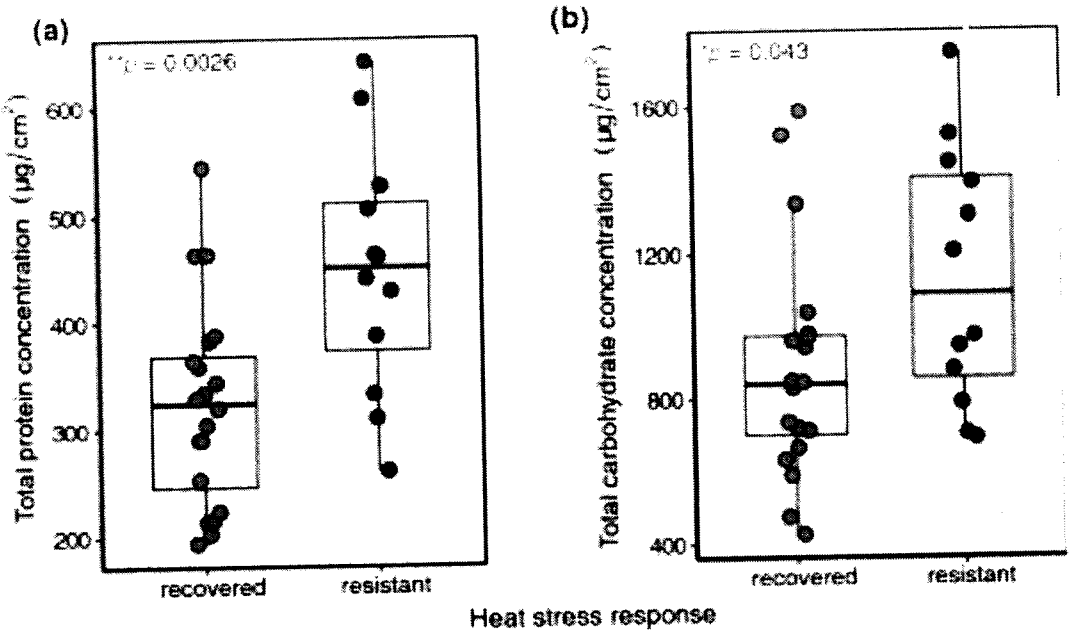
[Total: 6]

QUESTION 11

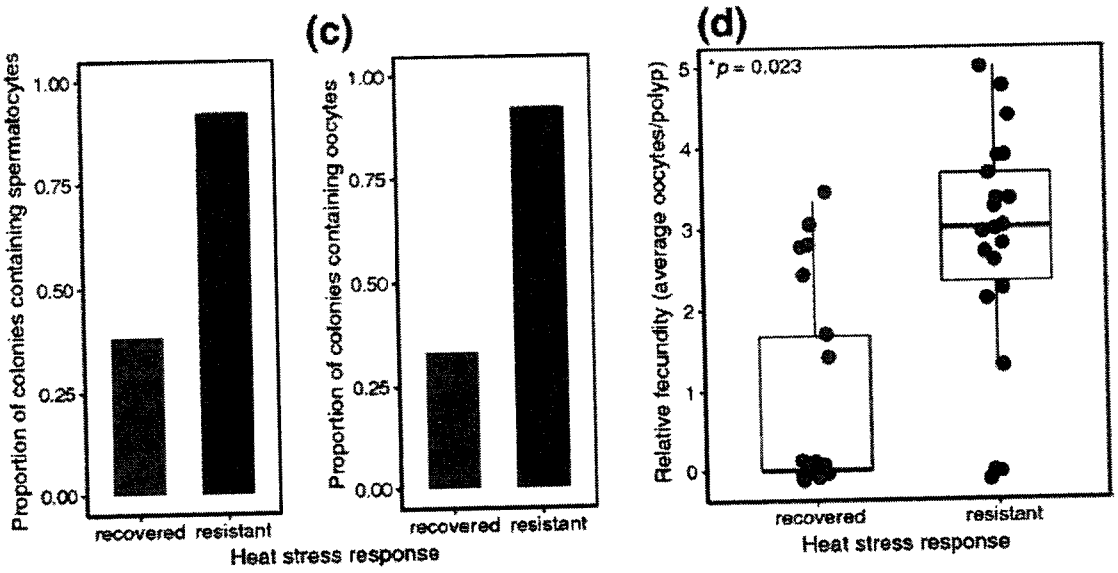
Rising seawater temperatures are contributing to coral bleaching, with mass coral bleaching events projected to increase in both frequency and severity.

Fig 11.1 shows the impact of thermal bleaching stress on stored protein and carbohydrate reserves and reproductive output of two categories of corals five months after the bleaching event – corals that were resistant to bleaching events and corals that were bleached but later recovered.

For both types of corals, zooxanthellae was able to recolonise them and both types of corals also looked visually healthy.



Energetic condition of recovered and resistant coral colonies five months after mass bleaching event. **(a)** Total protein content normalised to host tissue surface area. **(b)** Total carbohydrate content normalised to host tissue surface area. The data point represents a single colony.



(c) Proportion of recovered and resistant colonies containing spermatocytes and oocytes. **(d)** Relative fecundity (fertility) in recovered and resistant colonies. Each data point represents one colony.

Fig 11.1

(a) Suggest which type of corals would demonstrate better promote reef recovery after disturbance. Justify your choice with evidence from Fig 11.1.

.....[3]

1 Resistant corals; [1]

2 ref. **higher energy reserves** which can be allocated for **coral reproduction / production of gametes**, to **repopulate coral reef**;

3 *[Quote data for any one]* i.e. higher total protein content (range of 250 – 650 ug/cm^3) compared to recovered corals (200 – 550 ug/cm^3)
/ higher carbohydrate content (range of 700 – 1700ug/cm^3) compared to recovered corals (400 – 1600ug/cm^3); **Accept** ave/mean protein or carbohydrate content
OR

4 *[Quote data for any one]* i.e. higher proportion of corals containing spermatocytes and oocytes (0.95) compared to recovered corals (0.35 and 0.30 respectively)
/ higher relative fecundity (3 ave oocytes per polyp) compared to recovered corals (0 ave oocytes per polyp);

Accept: Quoting of mean as comparison between resistant and recovered corals;

Synthetic biology offers the potential to isolate and cultivate the resistant strains of coral that can naturally withstand higher sea surface temperatures associated with climate change.

Fig. 11.2 shows the process of using synthetic biology in promoting community reef recovery.

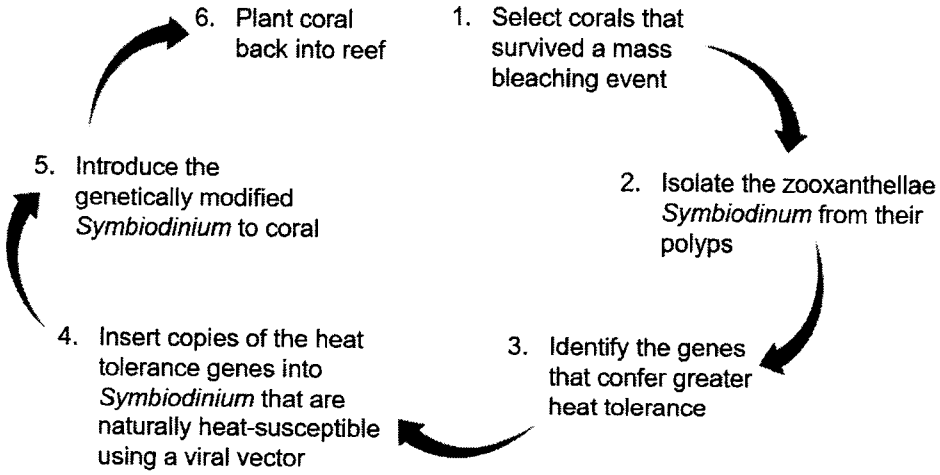


Fig. 11.2

A national survey was conducted with 1,148 Australians, measuring psychological predictors of support for a synthetic biology conservation solution to coral loss.

Participants were moderately strongly supportive of technology development and were most keen to implement genetically engineered coral with between 50 and 70% of reef remaining intact.

The findings suggest that the general public are not averse to the development of a synthetic biology solution for restoring the reef, and they may be especially influenced by whether the synthetic biology solution is shown to be effective, particularly in comparison to other conservation solutions (such as rubble stabilization, manual removal of coral predators like crown-of-thorns starfish).

However, support for a synthetic biology intervention is conditional and many participants expressed concerns about possible long-term impacts on humans, animals, and the environment as a result of deploying engineered coral.

(b) Discuss the ethical considerations that support and oppose the use of genetically engineered coral for reef restoration.

..... [2]

Support:

1 Restoration of reefs will restore the ecosystem services of the coral reef, such as coastal protection and nursery for marine species **despite a rising sea temperature**.

2 The synthetic biology solution will complement the existing conservation solutions to **hasten** the process of reef restoration. (Idea that rubble stabilization and manual removal of crown-of-thorn starfish will only reduce the death of existing coral, but it will take them time to recover in number, as opposed to deploying the genetically engineered coral to rebuild the reef; especially in the face of warming oceans).

Oppose:

3 Idea that there might be unforeseen adverse effect on the species that feed on the genetically engineered coral, and hence affects the whole food chain/web.

4 Idea that the genetically modified corals might out-compete the native corals and drive them to extinction. Leads to lower genetic diversity.

5 Idea that the selective breeding of heat-resistant coral can achieve the same result and is less risky.

6 The deployment of genetically modified coral might not be effective in restoring the reef's ecosystem services (idea that the reef might be rebuilt, but the marine species do not return to the reef)

[At least one point for each side of the argument]

Reject: Generalised statements like playing God, GE corals are unnatural, resulting in negative impacts on marine life etc. Suitable elaboration or explanations are needed.

[Total: 5]

End of Paper

Civics Group	A Level Index Number	Name (use BLOCK LETTERS)	H2

ST. ANDREW'S JUNIOR COLLEGE
2022 JC2 PRELIMINARY EXAMINATIONS

H2 BIOLOGY **9744/03**

Paper 3

Thursday 15th September 2022 2 hours

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagram, graph or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions.
Write your answers in the spaces provided on the question paper.

All working for numerical answers must be shown.

Conceptual error (C)	Data Quoting (D)	Expression (E)	Misreading the question (Q)

For Examiners' Use	
1	/30
2	/9
3	/11
4 or 5	/25
Total	**/75**

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

[Turn over]

Answer **all** *questions.*

QUESTION 1

(a) SWI/SNF (SWItch/Sucrose Non-Fermentable) is a subfamily of ATP-dependent chromatin remodelling complexes found in eukaryotes. Products of SWI and SNF genes can destabilise histone-DNA interactions, resulting in sliding or ejection of nucleosomes, as shown in Fig. 1.1.

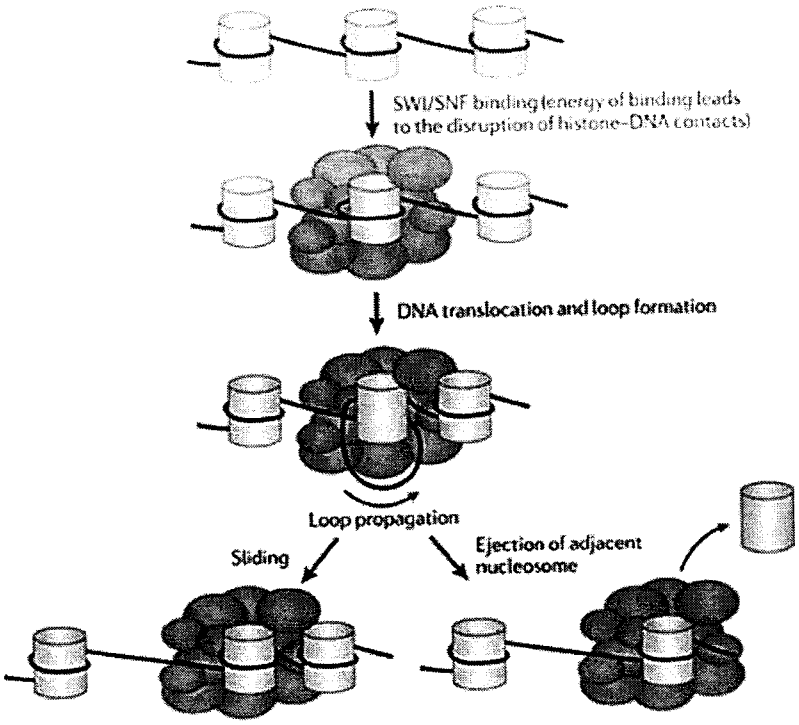


Fig. 1.1

In contrast, Polycomb Repressive Complex (PRC), with the histone methyltransferase EZH2 as its catalytic subunit, is associated with chromatin compaction.

(i) With reference to Fig. 1.1, describe how the activity of SWI/SNF complexes can lead to the active transcription of genes.

..... [2]

1 The binding of SWI/SNF complex to DNA results in **DNA translocation and loop formation** which results in sliding or ejection of nucleosomes
2 making the linker DNA accessible to transcription factors and RNA polymerase to bind and trigger transcription.

(ii) Describe two mechanisms that can produce the same chromatin remodelling effect as PRC/EZH2 complex.

.....[3]

1 **DNA methylation** by DNA methyltransferases
2 Recruits histone deacetylases which **removes acetyl groups** from lysine residues in the histone tails
3 Restores ionic interaction between positively charged histone tails and negatively charged DNA, DNA becomes more compact.

(iii) Describe how the nucleosomes will eventually pack into chromosomes during prophase of mitosis.

..... [5]

1 Interactions between the linker DNA and the histone tails of the nucleosomes on either side of the linker DNA.
2 Nucleosomes and linker DNA result in the formation of a 10nm **chromatin fibre** / **"beads-on-a-string"** structure.
3 Coils/folds the chromatin into a solenoid/30 nm chromatin fibre
4 6 nucleosomes in **one turn of the helix** of the solenoid
5 Attachment of the 30-nm chromatin fibre to a central protein scaffold at multiple locations, forming a series of radial loops (looped domains), this forms a 300-nm chromatin fibre.
6 Further packing of the radial loops form the metaphase chromosome.

(b) Over 20% of human cancers carry a mutation in SWI/SNF complex subunit genes. Fig. 1.2 shows that the inactivation of SWI/SNF causes a failure to inhibit PRC at promoters and typical enhancers (TE) of genes involved in differentiation. The residual functional SWI/SNF complexes are preferentially localized to super-enhancers (SE) of genes maintaining cell renewal. The resulting imbalance between differentiation vs. self-renewal promotes tumorigenesis (tumour formation) .

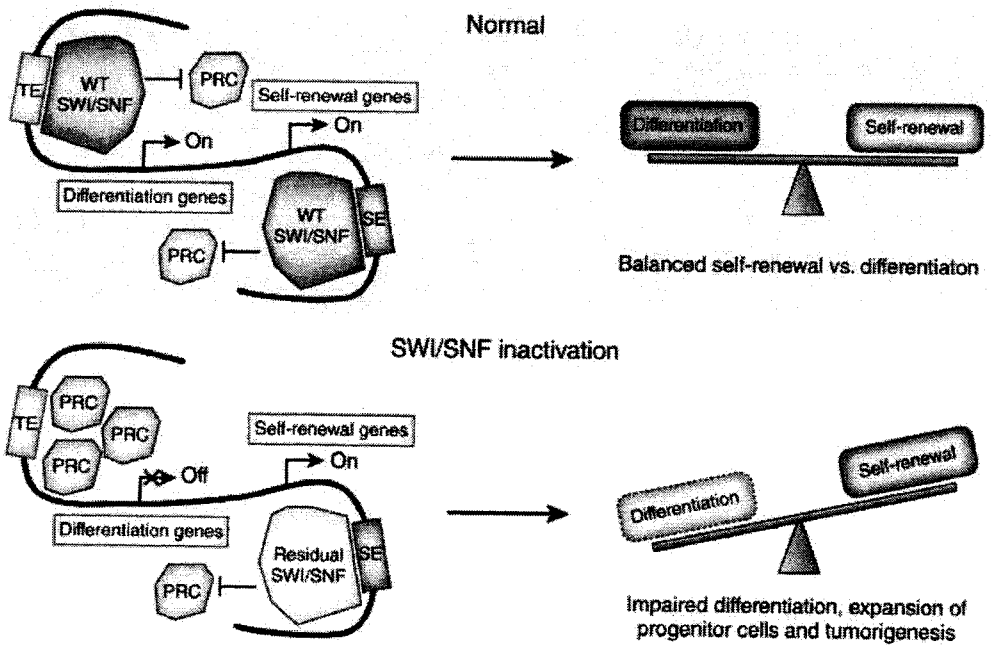


Fig. 1.2

(i) Describe the role of enhancers in the control of gene expression.

..... [3]

1 Enhancers serve as attachment site for activator proteins.
2 Increase rate of transcription of genes involved in cell differentiation.
3 Involved in time and tissue specific expression

(ii) With reference to information from **1(a)** as well as Fig. 1.2, describe the downstream effect of failing to inhibit PRC due to inactivation of SWI/SNF.

..... [3]

1 PRC leads to the **compaction of chromatin**,
2 hence general transcription factors are unable to bind to the promoter
3 and **activators are unable to bind to the typical enhancers** of genes involved differentiation.
4 Cannot stimulate/increase transcription of the genes, hence **no differentiation of the cells**.

(iii) Explain how the "imbalance between differentiation vs. self-renewal promotes tumorigenesis".

.....[2]

1 The imbalance occurs when cells continue to divide **indefinitely/excessively**
2 [compulsory point]: forming a mass of **undifferentiated /unspecialized** cells called a tumour.

(c) Different mutations in the proto-oncogene coding for Epidermal Growth Factor Receptor (EGFR) are associated with several cancers such as lung cancer. Lung tissue samples were taken from two lung cancer patients and cultured on Petri dishes for 24 hours. The average cytoplasmic mRNA levels (Fig. 1.5A) as well as 6-hourly protein levels (Fig. 1.5B) of EGFR and β-actin were investigated. β-actin is a house-keeping gene that is expressed in almost all cell types and is used as a positive control.

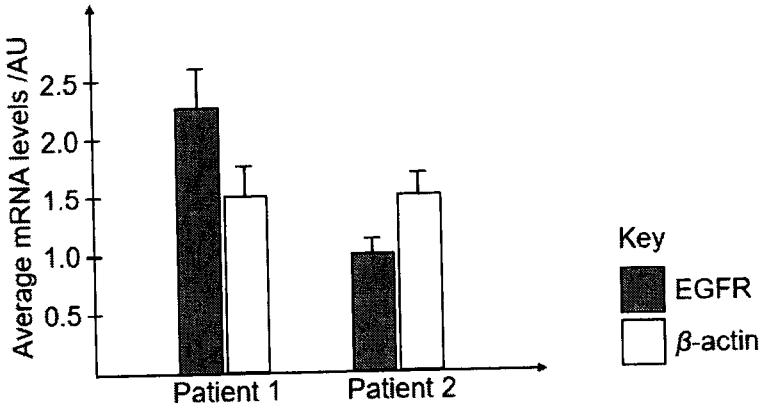


Fig. 1.5A

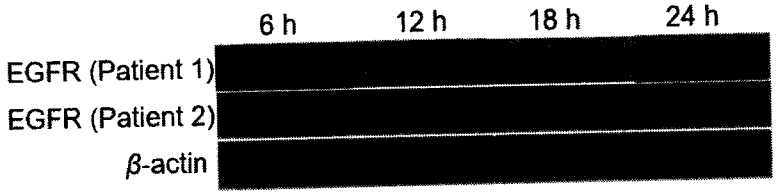


Fig. 1.5B

(i) Describe the rationale of using β-actin as a positive control.

..... [2]

1 As it is a house-keeping gene, its mRNA and protein levels are expected to **remain relatively constant** at all times;
2 It is to show that any changes in mRNA levels or protein levels in the other gene/EGFR is due to **differential gene expression and not due to any other factors**, e.g. improper lab techniques.

(ii) Describe the difference in average mRNA and protein level of EGFR between the two patients.

.....[2]

1 Patient 1 has a **higher** average mRNA level of 2.25 AU compared to 1.0 AU of patient 2.
2 Protein level in patient 1 **increased from 6h to 18h** and **decreased from 18h to 24h** while protein level in patient 2 **remained relatively constant throughout the 24h**.

(iii) Suggest and explain possible mutations in the EGFR gene of patients 1 and 2 that could result in the differences described in **c(ii)**.

.....[4]

Possible mutations in patient 1:

1 *[Suggest]* **Gene amplification** of EGFR resulted in **more copies of DNA templates**,
2 *[Explain]* resulting in increased transcription and higher mRNA levels.
OR
3 *[Suggest]* Mutation in the promoter of EGFR gene
4 *[Explain]* leading to higher affinity with RNA polymerase, hence increasing the rate of transcription
OR
5 *[Suggest]* **Longer poly(A) tail** is added to the mRNA of patient 1,
6 *[Explain]* resulting in **longer half-life**, and hence higher cytoplasmic mRNA levels.

Possible mutation in patient 2:

7 *[Suggest]* **Substitution** mutation in the **coding sequence**
8 *[Explain]* resulted in oncoprotein that is **resistant to degradation** as seen from no decrease in protein levels
OR
9 *[Suggest]* **Substitution** mutation in **coding sequence**
10 *[Explain]* resulted in (normal expression level of the receptor but the) **hyperactive** receptor which can trigger cell signaling **despite absence of ligand**

(iv) Contrast between the function of a proto-oncogene such as EGFR and a tumour suppressor gene such as p53.

.....[2]

1 EGFR codes for a receptor involved in **cell signalling**, stimulating **normal cell division**
2 while p53 codes for a transcription factor that **triggers the expression of other genes** whose **products arrest cell cycle, repairs DNA and triggers apoptosis**.

(v) The tissue samples taken from the two lung cancer patients showed mutations in several other genes besides proto-oncogenes and tumour suppressor genes.

Explain how these mutations contributed to the development of lung cancer.

.....[2]

Some mutations cause

1 activation of telomerase gene, which codes for telomerase enzyme which restores the telomeres, allowing cancer cells to divide indefinitely
2 the loss of ability to differentiate
3 loss of anchorage-dependent inhibition / loss of cell adhesion
4 loss of contact-dependent / density-dependent inhibition
5 angiogenesis, the recruited blood vessels provide cancer cells with oxygen and nutrients for growth and to remove any waste products.
6 metastasis / cancer cells detach from the parent mass, invade surrounding tissues and spread via the circulatory system to other tissues to form secondary tumors

Reject mutations in telomerase gene

[Any 2]

[Total: 30]

QUESTION 2

Measles is an infectious disease for which vaccines have been developed. The commonly used vaccine consists of an attenuated (weakened) form of the virus. The measles vaccine is normally given to children when they are about one year old, followed by a booster dose when they are about four years old.

Fig. 2.1 shows the number of reported cases of measles and the percentage of the population vaccinated worldwide between 1980 and 2002.

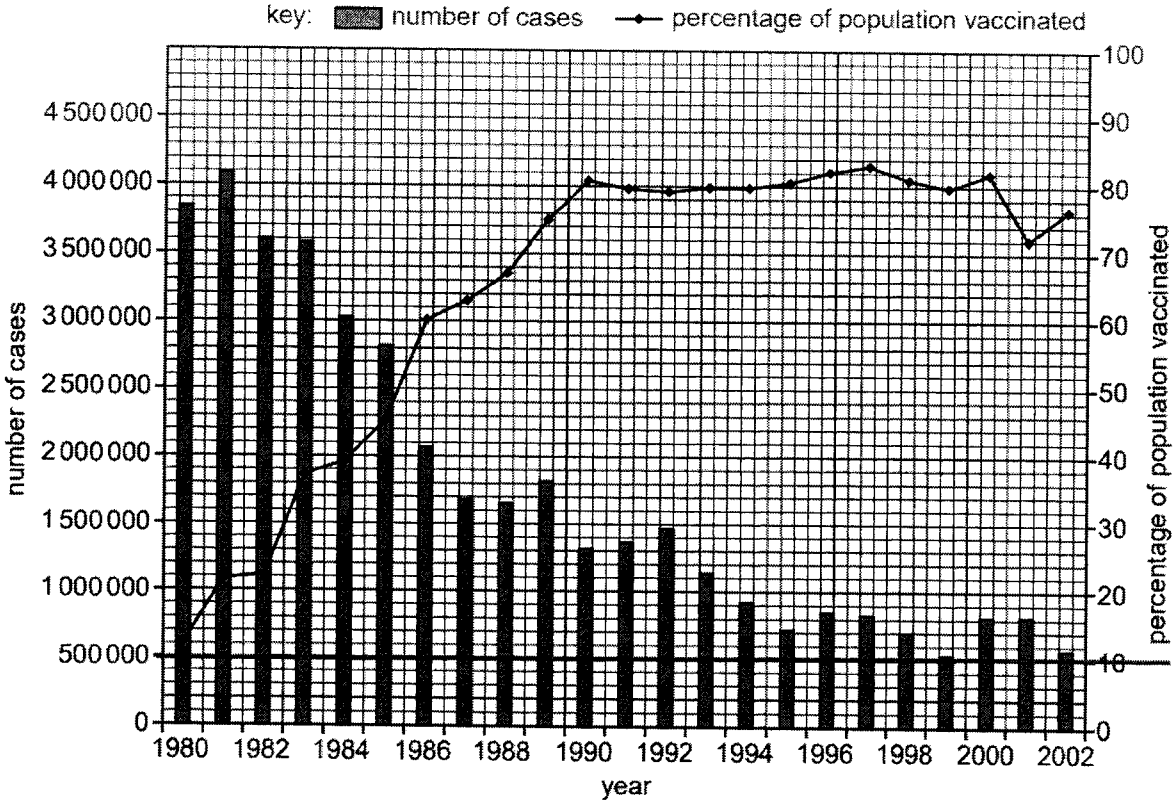


Fig. 2.1

(a) Describe the trends shown in Fig. 2.1:

between 1980 and 1990

.....

between 1990 and 2002.

.....[4]

1980 – 1990

- percentage of population vaccinated increased from 12% to 81% ;
- number of cases decreased (steeply) from 3850000 to Accept :130000-1320000 ;

1990 – 2002

- percentage vaccinated, levels off/remains relatively constant between 79-81% from 1990-2000 and decreasing to 72% in 2001 before increasing to 76% in 2002 /relatively constant;

- number of cases decreases (less steeply than earlier) to 700,000 in 1994 and fluctuates between 500,000 to 800,000 from 1995 to 2002 ;

(b) The vaccination of a high enough percentage of the population can break the disease transmission cycle, giving 'herd immunity'.

The measles virus spreads easily by droplet transmission. One estimate of its reproduction number, R_o, is 15, meaning that each person infected with measles is expected to infect 15 other people.

If the percentage of people who are immune to a disease exceeds the herd immunity threshold, the disease can no longer persist in the population. Assuming 100% efficacy of the vaccine, the herd immunity threshold is calculated as:

$$100 \times (1 - 1/R_o)$$

(i) Calculate the herd immunity threshold for measles, if $R_o = 15$.

Herd immunity threshold = ...% [1]

ANS:
Herd immunity threshold = 93.3%

(ii) Use Fig. 2.1 and your answer to **(b)(i)** to explain why the number of measles cases remain above 500,000.

.....[2]

1 According to Fig 2.1, **the highest percentage of the population vaccinated was in 1997 where 83 % of the population was vaccinated**. The percentage of vaccination also fell to 72% in 2001.
2 This was **lower than the herd immunity threshold of 93.3%** and therefore the measles virus is still able to spread in the population causing the number of measles cases to remain above 500,000

(c) The measles virus has a unique protein on its surface called MV-H which can bind to a protein called CD-46 on the surface of human cells. This allows the measles virus to infect these cells.

Suggest how the two proteins, MV-H and CD-46, can bind to each other.

.....[2]

1 CD–46 is a receptor on the cell surface which has binding site which is **complementary in shape/conformation** of MV-H;

2 ref. to interaction of **R-groups** /amino acid side chains in the binding site with the R-groups of MV-H ;

3 ref. formation of hydrogen bonds / ionic bonds to bind MV-H and CD-46 together.

REJECT disulfide/ peptide

[Total: 9]

QUESTION 3

Fig. 3.1 shows the percentage cover of live corals and the density of herbivorous fish (plant-feeding) on a coral reef over a number of years. Due to unusually warm water, many of the corals living on the reef died in 1998.

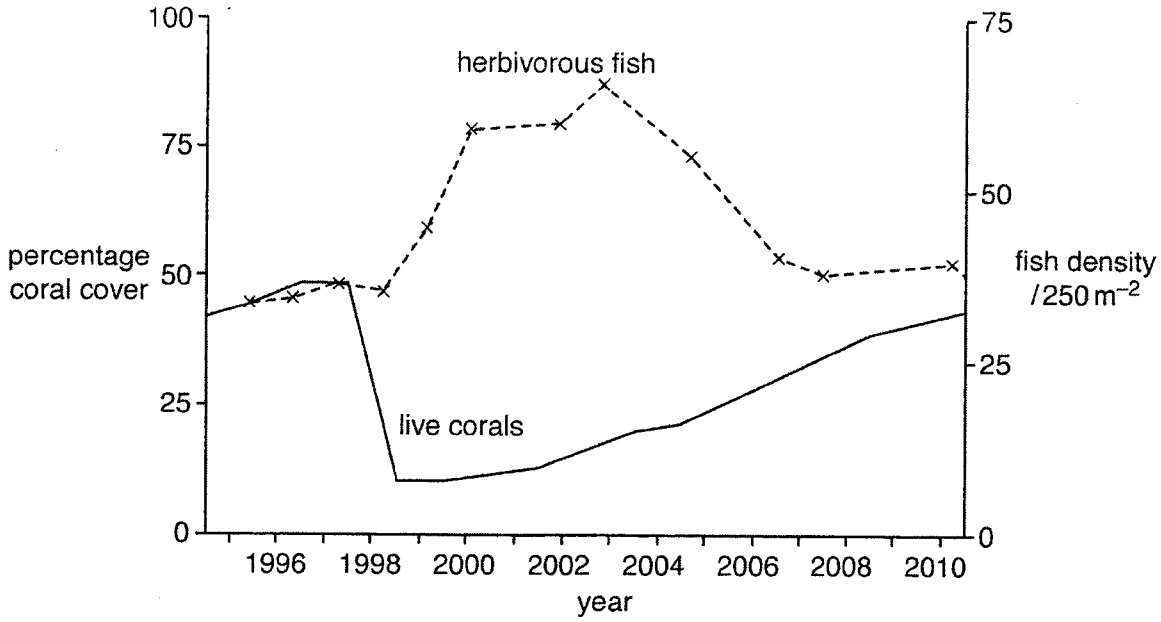


Fig. 3.1

(a) Describe the change in percentage cover of live corals shown in Fig. 3.1.

.....[3]

1 Slight **increase** in percentage coral cover from around **40% to 50%** observed from **mid 1994 till mid 1997**,
2 Followed by a sharp **decrease/dip** in percentage coral cover (from 50%) **to 10% till mid 1998,**
3 Percentage coral cover start to **increase** steadily (from 10%) **to around 40% after mid 1998** to year 2010;

(b) Suggest possible impacts due to the change in percentage cover of the live corals.

.....[3]

1 Possible shift in food sources to other plant sources (i.e. sea grass and kelps) resulting in higher competition with other species feeding on these food sources.
2 Population size of species dependent on corals as habitats will decrease as they may die / migrate to other coral reefs /OWTTE;
3 Loss of biodiversity;
4 Direct correlation in change of coastal protection in tropics region;

5 Change in global food supply distribution of fishes that depends on corals;
6 Shift in ecotourism / tourism;

(c) State a possible reason why the density of herbivorous fish increases after the death of many of the corals in 1998.

.....[1]

1 ref. death of corals due to the unusually warm water leading to expulsion of more zooxanthellae/algae for herbivorous fish to feed on
2 possible change increase in growth of sea grass and kelps due to increase in temperature

The impact of climate change is a major threat not only for corals but also for life on earth a whole. Fig. 3.2a shows the loss of ice mass between 1992 and 2018. Fig. 3.2b shows the median extent of sea ice concentration in 1992 as compared to 2018. Fig. 3.3 the number of polar bears living in this biome.

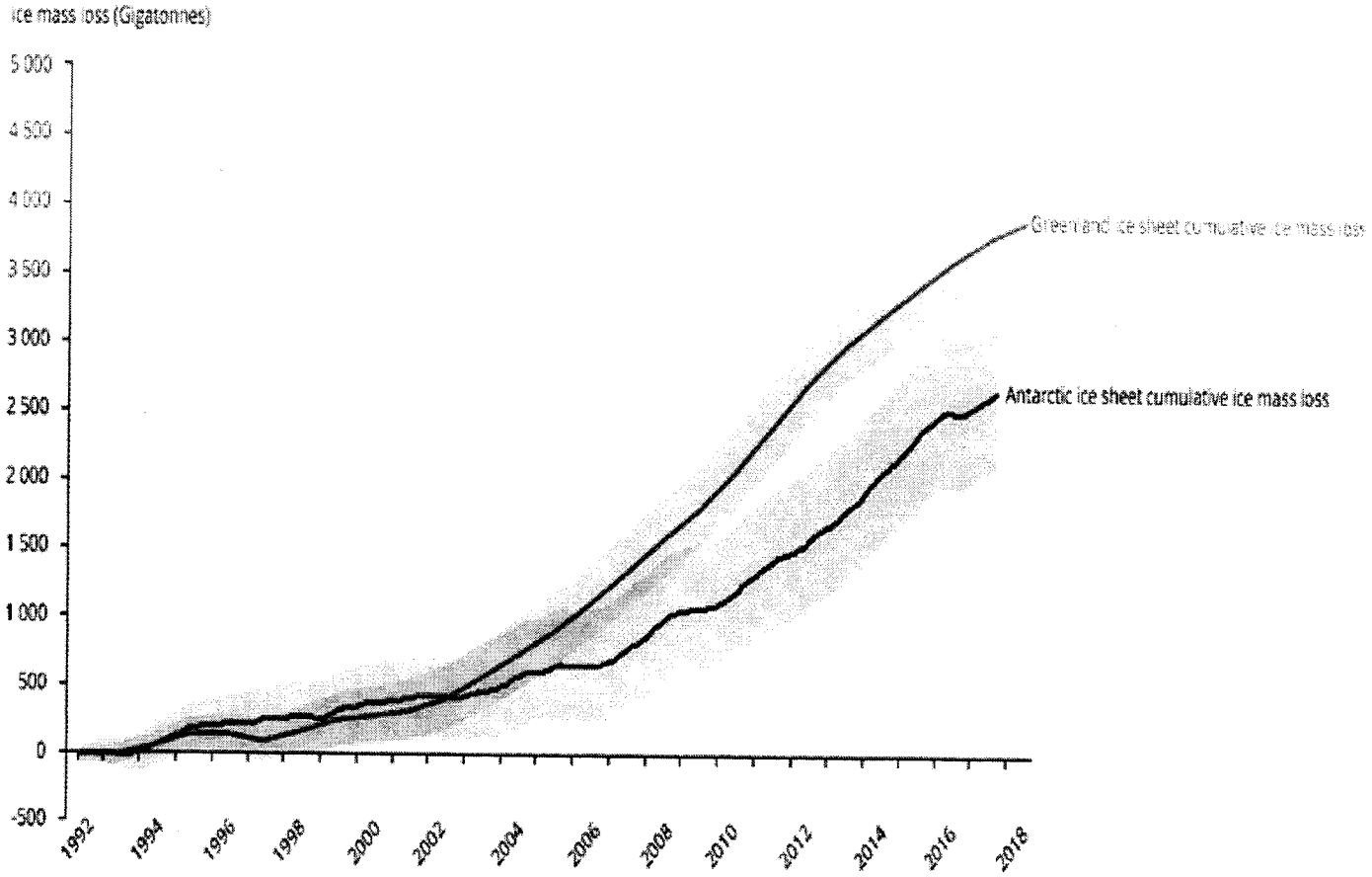
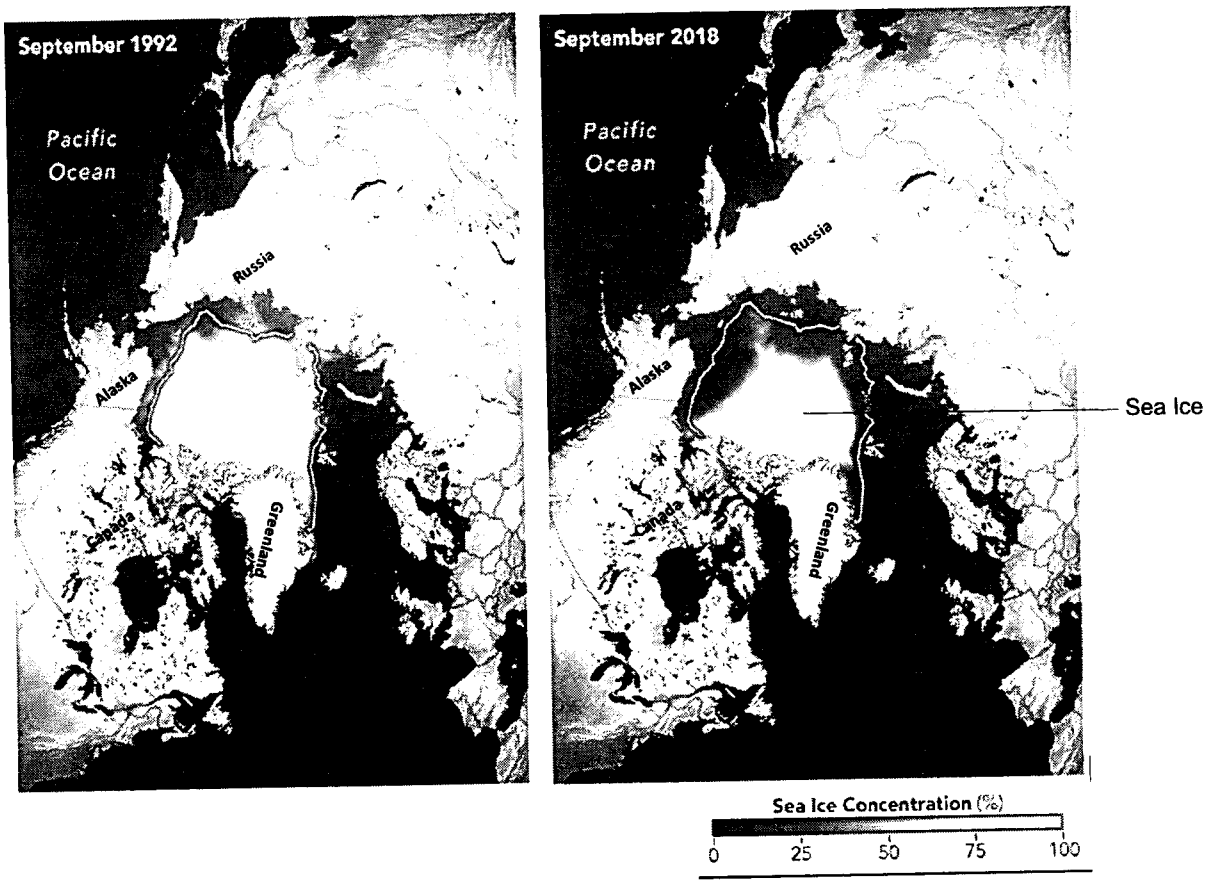


Fig. 3.2a



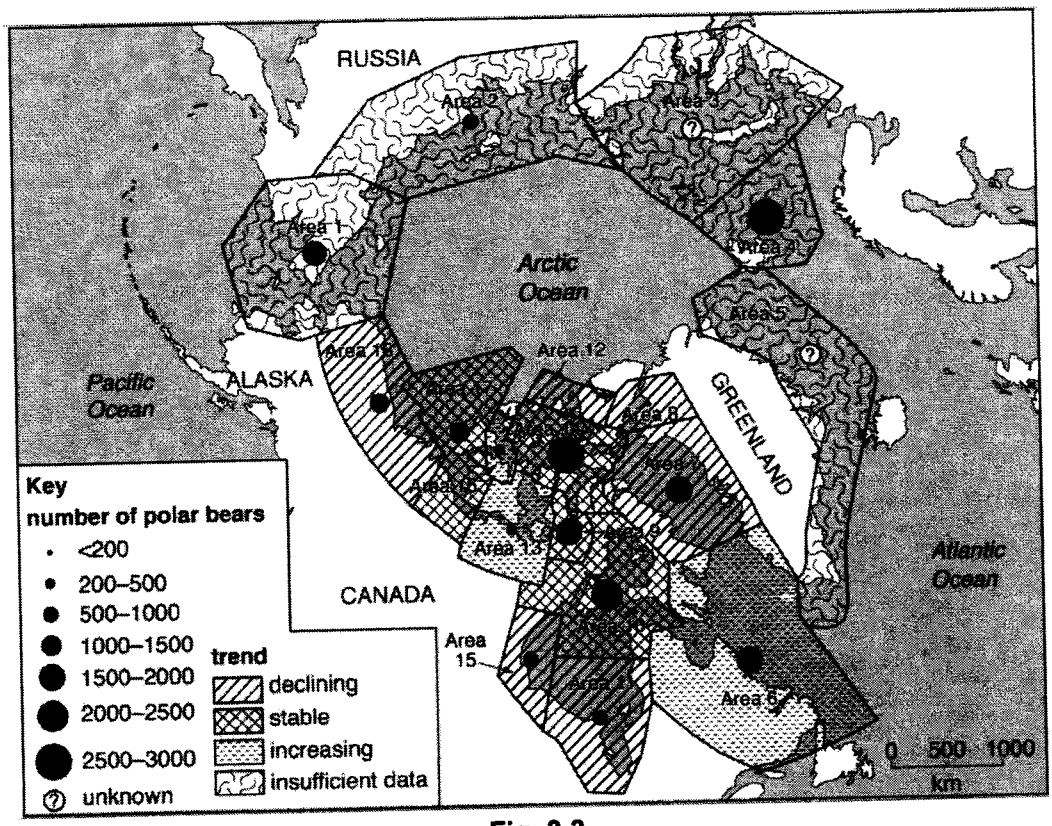


Fig. 3.3

(d) With reference to Figs. 3.2a, 3.2b and 3.3, describe and explain the evidence which suggest that polar bears are at risk of extinction as a result of climate change.

.....[4]

1 Climate change results in global warming / rising temperatures, shrinking of sea ice floating in the Arctic ocean and ice sheets on the island of Greenland as seen from Fig.3.2b

2 As seen from Fig. 3.2a, the increase in loss of ice mass from 0 to 3800 gigatonnes from 1992-2018 for Greenland

3 This contributes to habitat loss / fewer hunting grounds for polar bear

any two from:

4 which is evident from the very low populations of polar bears in some areas, e.g. less than 200 in Area 12 and Area 8 (Lancaster Sound / Kane Basin)

5 declining populations in 6 / 50% / of areas e.g. Area 7, 8, 11, 12, 15, 18

6 a population range of less than 2000 in areas where the populations are declining e.g. Area 7, 8, 11, 12, 15, 18

7 there are only a few, areas e.g. Area 6, 13, where the population is currently increasing

[Total: 11]

Essay

Answer **one** question only 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 prose, where appropriate.

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

4 **(a)** Microorganisms such as *Escherichia coli* (*E. coli*) colonise the intestine and obtain nutrients from their surroundings. [15]

Describe how *E. coli* responds to the presence of lactose and absence of glucose in the intestine and explain how a mutation in the regulatory sequences of the *lac* operon may affect how *E. coli* respond to changes in lactose supply.

(b) The green fluorescent protein (GFP) gene was isolated from the jellyfish *Aequorea Victoria* and inserted into DNA of a species of mice, *Mus musculus*. The gene was expressed throughout the genetically modified mice resulting in the mice exhibiting bright green fluorescence when exposed to light in the blue to ultraviolet range. [10]

With the use of the various species concepts, discuss whether the genetically modified mice can be considered as the same or different species as the unmodified mice.

5 **(a)** 'Eukaryotic life is impossible without membranes.' [15]

Discuss how regulation of membrane fluidity is achieved in living organisms and justify why the statement above may be true using specific examples.

(b) With reference to named examples, describe the role of water in reactions involving biomolecules. [10]

End of Paper

4(a) Microorganisms such as *Escherichia coli* (*E. coli*) colonise the intestine and obtain nutrients from their surroundings.

Describe how *E. coli* respond to the presence of lactose and absence of glucose in the intestine and explain how a mutation in the regulatory sequences of the *lac* operon may affect how *E. coli* respond to changes in lactose supply. [15]

10 green 5 yellow

[Describe how *E coli* responds to changes] [Max 8]
[Presence of lactose]

1 Lactose **isomerizes** to form allolactose;
2 ref. allolactose as an inducer;
3 allolactose binds to the (allosteric site of) the lac repressor, and **alters its 3D conformation** (at the DNA-binding site);
4 lac repressor become **inactive** and is no longer able to bind to the operator (lacO);
5 RNA polymerase can **access and transcribe** the **structural genes**;
6 ref. lacZ , lacY and lacA genes being transcribed and translated into β-galactosidase, lac permease and lactose transacetylase enzymes respectively;

[Absence of glucose]

7 **cyclic adenosine monophosphate / cAMP concentration increases** and binds to (allosteric site of) catabolite activator protein (CAP) site;
8 alters its **3D conformation** of the (DNA-binding site of) CAP;
9 CAP is **active** and binds to the CAP-binding site;
10 ref. facilitates more **efficient positioning of RNA polymerase** at the promoter;
11 **High rate of transcription** of lac operon;

[Effect of mutation of regulatory sequences] [Max 6]
Max 3
12 Mutation of the **promoter** results in a **change in the sequence/structure/shape** of the promoter;

Mutation of lac promoter (increases binding affinity)
13 ref. **RNA polymerase** able to **bind** to the (mutated) promoter with **greater affinity**; [Reject: permanently/ irreversibly]
14 … hence **increase the rate of the transcription** of structural genes **in the presence of lactose**;
OR
Mutation of lac promoter (decrease binding affinity)
15 ref. **3D shape/conformation** of the promoter is **no longer complementary** to the (active site) of **RNA polymerase**;
/ RNA polymerase **no longer able to bind** to the (mutated) promoter;
16 ref. **No transcription** of structural genes **even in the presence of lactose**;

Max 3
Mutation of operator
17 Mutation of the **operator** results in a **change in the sequence/structure/shape** of the operator;

18 ref. repressor binds to the operator **permanently/irreversibly;**
19 ref. **No transcription** of structural genes **even in the presence of lactose**;
OR

20 ref. **3D shape/conformation** of the operator is **no longer complementary** to the of the **repressor**;
/ (active) repressor can **no longer bind** to the operator;

21 ref. RNA polymerase is now able to **access / bind** to promoter, **allowing transcription** of structural genes **even in the absence of lactose**.

QWC [1]
Accurate communication of the **response to lactose and absence of glucose** in *E.coli*, and to include at least **one mutation in both promoter and operator**

4(b) The green fluorescent protein (GFP) gene isolated from the jellyfish *Aequorea Victoria* and inserted into DNA of a species of mice, *Mus musculus*. The gene was expressed throughout the genetically modified mice resulting in the mice exhibiting bright green fluorescence when exposed to light in the blue to ultraviolet range.

With reference to the various species concepts, discuss whether the genetically modified mice can be considered as the same or different species with the unmodified mice. [10]

Biological species concept

1 [*Definition*] Closely related organisms which are **capable of interbreeding in nature** to produce viable, fertile offspring and are **reproductively isolated from other species**;

2 [*Support for same species argument*]
ref. Coat colour of GM mice not affected as green fluorescent protein genes only affect colour of the mice under UV light, thus **traits which affect their ability to interbreed** with non-GM mice not affected;

3 [*Does not support same species argument*]
ref. sexual selection, i.e. non-GM mice that do not fluoresce under UV light prefer to breed with other non-GM mice;
/ preferential breeding of specific mice with colour, hence GM mice do not interbreed with non-GM mice;

Genetic species concept

4 [*Definition*] Group of **genetically compatible (i.e. similar DNA) interbreeding natural populations** that are **genetically isolated** from other such groups.

5 [*Support for same species argument*]
ref. GM and non-GM mice being **genetically similar** / low genetic variation / do not have sufficient genetic differences/distance / difference only in 1 gene (i.e. the GFP gene from jellyfish);

6 [*Does not support same species argument*]
ref. sufficient genetic differences (an entire additional gene not present in original species);

Phylogenetic species concept

7 [*Definition*] The smallest group of organisms that shares a **most recent common ancestor** forming one branch on the tree of life.
/ Defines a species based on their genetic history and **evolutionary relationships**, with reference to their homologous structures, and nucleotide and protein sequences;

8 [*Support for same species argument*]
ref. both GM and non-GM mice form the smallest group that shares a same / recent common ancestor;
/ ref. comparison of homologous structures or high homology of nucleotide/protein sequences;

Morphological species concept

9 [*Definition*] A group of organisms sharing **similar body shape, size** and other **structural/ physical (anatomical) features**;

10 [*Support for same species argument*]
GM and non-GM mice **look** largely **similar** to each other based on **physical characteristics**;

11 [*Does not support same species argument*]
ref. coat colour of GM and non-GM mice is different under UV light;
/ GM mice look very different from non—GM mice due to the green florescence;

Ecological species concept

12 [*Definition*] Organisms sharing the same ecological niche (i.e its unique and particular role in an ecosystem);

13 [*Support for same species argument*]
GM and non-GM mice still occupy the same ecological niche, ref. predator-prey relationship / food source / position in food chain etc (give at least one example);

Accept argument if support opposing viewpoints in different species concept/same species concept.

QWC [1]
Logical flow of information + **at least 3 species concepts** to support argument

5(a) 'Eukaryotic life is impossible without membranes.' Discuss how regulation of membrane fluidity is achieved in living organisms and justify why the statement above may be true using specific examples. [15]

How membrane fluidity is regulated [max 5]

1 Dependent on the **proportion of phospholipids** with unsaturated hydrocarbon/fatty acid tails and cholesterol;

[At low temperatures]

2 ref. Unsaturated hydrocarbon/fatty acid tails have kinks that prevent phospholipids from **close packing**, enhancing membrane fluidity; (Accept reverse argument)

3 Cholesterol prevents **close packing of phospholipids** in the membrane, preventing membrane from freezing;

[At high temperatures]

4 Membrane prevented from being overly **fluid / integrity of the membrane is maintained** as cholesterol **restricts phospholipid movement**;

5 ref. hydrophobic interactions between cholesterol and fatty acids tails, stabilize lipid bilayer;
/ ref. hydrophobic interactions between fatty acids stabilise the membrane;

6 ref. length of fatty acid tails also helps maintain membrane fluidity, since longer tails will result in **more hydrophobic interactions** between the tails and hence, decrease membrane fluidity (Accept reverse argument);

Diverse roles of membranes in named processes [max 10]

Note: Students should be able to phrase their answer as to how eukaryotic life is impossible without membranes.

e.g. Without membranes, compartmentalisation within a cell cannot take place. Hence, it will be impossible to concentrate enzymes and substrates into a localised area to speed up the rate of biochemical pathways.

e.g. It will also be impossible to establish a concentration gradient between two compartments, such as in mitochondria and chloroplasts, making it impossible for chemiosmosis and ATP synthesis to occur.

e.g. It will be impossible to separate molecules involved in different biochemical pathways from each other, hence they either cannot occur simultaneously.

Context	Roles
Selectively permeable / S	**7** Regulates movement of substances into and out of cell; **[Max 1]** **8** Non-polar/uncharged molecules are able to dissolve and diffuse through; **9** Ions/charged and/or most polar molecules are repelled; (Generic principle cannot be replaced by H^+)
Compart-mentalisation / C	1. Formation of unique environment for highly specialised activities in the cells; 2. e.g. lysosomes maintain an acidic environment that favours its enzymes to work;

	3. localization of enzymes for reactions to take place so that they are not suppose to catalyse reactions that they are not supposed to; 4. e.g.: enzymes in Calvin Cycle in stroma; 5. accumulation of ions to generate a concentration gradient; 6. e.g. proton gradient established across a named memberane/H^+ in intermembranal space in mitochondria/within thylakoid space/ in chloroplasts establishes a proton gradient for *chemiosmosis** and formation of ATP; (no need to talk abt atp synthase if mention abt chemiosmosis) 7. Storage of food source; 8. e.g. starch in plant cells are stored in amyloplasts; R: starch grain, make sure it is membrane bound
Localisation of proteins of a related function / L	9. Allows functionally-related proteins to be grouped together to enhance sequential biochemical processes; 10. e.g. enzymes and proteins are grouped into photosystems II and I on thylakoid membrane of chloroplast so that electrons from photosystem II are shuttled to photosystem I during photophosphorylation;
Increase surface area / I	11. Highly folded increases surface area to hold more; 12. e.g.: electron transport chains/ ATP synthase in cristae/inner mitochondrial membrane of mitochondria;
Cell-cell recognition and adhesion / R	13. Glycoproteins / glycolipids are involved in cell-cell recognition; 14. (any 1 e.g.) eg: T cell receptor on membranes of naïve T cells + how it helps to recognize peptide: MC on antigen presenting cells;
Signal transduction / T	15. Some transmembrane proteins serve as cell surface receptors to transfer information from environment into cell when specific molecules (ligands) bind to them; 16. E.g. glucagon (hormone) bind to glucagon receptor in membrane which triggers a cascade of chemical reactions leading to hydrolysis of glycogen to glucose; E.g. insulin

QWC: explanation of one mechanism of regulation of membrane fluidity + ref to 3 different context

5(b) With reference to named examples, describe the role of water in reactions involving biomolecules. [10]

1 [role] ref. Condensation reactions to form covalent bonds involving loss of water molecule;
2 [role] ref. Hydrolysis reactions to break bonds using water molecule;

Accept these condensation/hydrolysis of these example

3 α(1,4) and α(1,6) glycosidic bonds between α glucose molecules in amylose, amylopectin;
4 β(1,6) glycosidic bonds between β-glucose residues in cellulose;
5 peptide bonds between amino acids in proteins;
6 ester bond between glycerol and fatty acid in lipids;
7 phosphodiester bonds between deoxyribonucleotides / ribonucleotides in DNA / RNA;

AVP Accept labelled drawing/diagram

8 [role] ref. metabolic water as a solvent for reactions involving biomolecules to take place;
9 i.e. aqueous medium in cytoplasm for glycolysis to occur / stroma/matrix for enzymatic reactions in photophosphorylation/oxidative phosphorylation;
10 i.e. aqueous medium in RBCs for folding of haemoglobin / packing into RBCs;
AVP transport of sucrose

11 [role + example] photolysis of water for non-cyclic photophosphorylation which generates ATP and NADPH for formation of carbohydrates in Calvin cycle;

QWC: Logical flow of information + At least 3 different named examples describe 2 different roles of water