H

Anglo-Chinese Junior College

JC2 Biology Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		FORM CLASS	
TUTORIAL CLASS		INDEX NUMBER	

BIOLOGY **9744/03**

Paper 3 Long Structured and Free-response Questions 29 August 2023
2 hours

Candidates answer on the Question Paper.
Additional Materials: Writing paper(s)

READ THESE INSTRUCTIONS FIRST

Write your Name, Class and Index number in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Section A
Answer **all** questions.

Section B
Answer any **one** question on the separate writing paper(s) provided.

The use of an approved scientific calculator is expected, where appropriate.
You may lose marks if you do not show your working or if you do not use appropriate units.

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

At the end of the examination, fasten all the writing paper(s) used securely together.

For Examiners' use only	
Section A	
1	/ 30
2	/ 10
3	/ 10
Section B	
4 or 5	/ 25
Total	/ 75

For Examiner's Use

Section A

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

1 Polyethylene terephthalate (PET) is one of the common polymers used to make plastic bottles. A bacterial species, *Ideonella sakaiensis*, was found to have the ability to break down PET through a two-step process catalysed by two enzymes.

Fig. 1.1 shows the first step in which the enzyme PETase resulted in the degradation of PET into monohydroxylethyl terephthalate (MHET), and Fig. 1.2 shows the second step where the enzyme MHETase breaks down MHET into ethylene glycol (EG) and terephthalic acid (TPA).

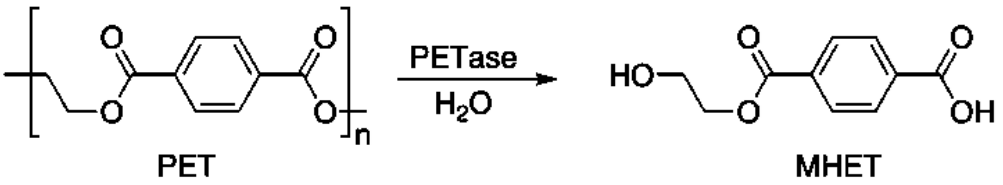

Fig. 1.1

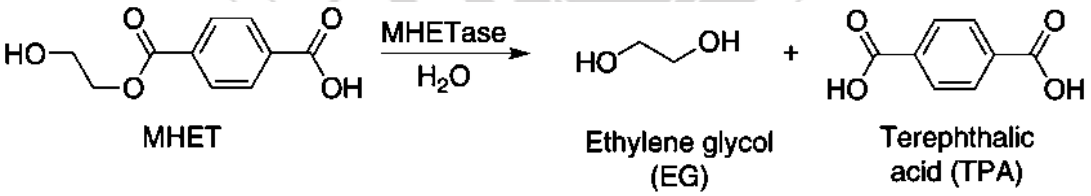

Fig. 1.2

The structures of PETase and MHETase are shown in Fig. 1.3 and Fig. 1.4 respectively.

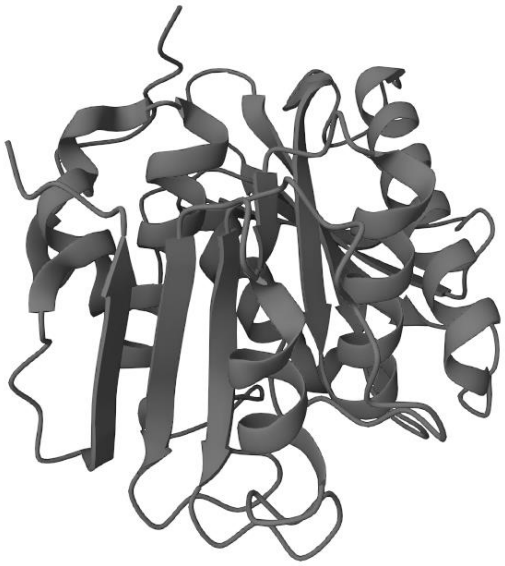

Fig. 1.3

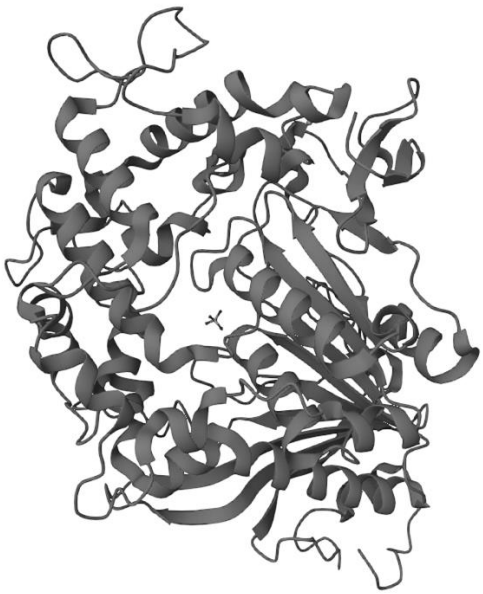

Fig. 1.4

For Examiner's Use

(a) (i) With reference to Fig. 1.1 and Fig. 1.2, state the type of reaction that PETase and MHETase catalyse.

1. hydrolysis;

…… [1]

(ii) Describe the secondary structures present in PETase and MHETase in Fig. 1.3 and Fig. 1.4.

1. Alpha helices and beta-pleated sheets can be found within the polypeptide;

……

2. In an alpha helix, each N-H forms hydrogen bond with C=O four amino acids apart in the same polypeptide backbone;

……

3. In beta-pleated sheets, each N-H forms hydrogen bond with C=O on adjacent part of the polypeptide backbone;

……

See hydrogen bond and backbone at least once.

…… [3]

[Turn over

During the investigation of the rate of MHETase activity under different conditions, scientists attempted to find the most effective method to quench the enzyme activity (stop further enzymatic action) at the end of an experiment to accurately determine the true enzymatic rate.

However, the solutions used for quenching the enzyme MHETase may also directly react with the substrate MHET and break the bonds in MHET. This unintended chemical reaction gives rise to inaccurate determination of the enzymatic rate.

Table 1.1 shows the results from using four different quenching methods to stop further enzymatic activity of MHETase.

Table 1.1

quenching method	proportion of MHET degraded due to quenching method and not the enzyme / %	success in quenching enzyme activity
Method 1: highly concentrated hydrochloric acid (6 M HCl) at 85 °C	39.40	cannot be determined, as high levels of products from the breakdown of MHET are found
Method 2: 100% methanol at 85 °C	0.25	yes
Method 3: 100 nM PMSF at 85 °C	1.30	no
Method 4: pH 2.5 buffer solution at room temperature	0.00	no

Methanol, used in Method 2, is an amphipathic solvent with the molecular formula, CH_3OH.

Fig. 1.5 shows the structure of phenylmethylsulfonyl fluoride (PMSF), used in Method 3, which acts as an inhibitor that binds at the active site.

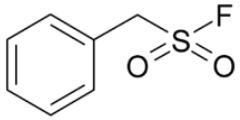

Fig. 1.5

For Examiner's Use

(b) (i) With reference to Table 1.1, identify the quenching method that should be used for the experiment and justify your answer.

1. ***Method 2 / 100% methanol at 85 °C;**

……

2. **The proportion of MHET degraded due to the quenching method is low at 0.25%, which will allow for a more accurate determination of enzymatic rate;**

……

3. **Method 2 also allowed for the enzyme activity to be quenched unlike the other three methods;**

……

…… [3]

(ii) Explain the effect of dissolving an enzyme MHETase in an amphipathic solvent such as methanol.

1. **The hydrophobic R groups of the amino acid residues in MHETase will interact with the hydrophobic CH_3 group on methanol via hydrophobic interactions;**
   A! hydrophilic R groups of the amino acid residues in MHETase forms hydrogen bonds with the OH group on methanol instead of within itself

……

2. **This disrupts the bonds holding the 3D conformation of the enzyme together, causing denaturation;**

……

……

…… [2]

(iii) Suggest why PMSF does **not** effectively quench the enzyme activity.

1. **The substrate MHET concentration could be high enough to outcompete the competitive inhibitor;**
   A! opposite phrasing – PMSF concentration is too low/lower than the substrate MHET concentration, hence PMSF is outcompeted

……

2. **The PMSF does not form permanent bonds with the active site;**
3. **Higher frequency of effective collisions between MHET and MHETase so / Enzyme-Substrate complexes can still form;**

…… [2]

[Turn over

For Examiner's Use

The scientists examined how proximity of the two enzymes, PETase and MHETase, influences overall rate of MHET degradation.

Chimaeric proteins refer to two or more different proteins that are joined together artificially. Chimaeric proteins of MHETase and PETase were synthesised by using amino acid residues to covalently link the C terminus of MHETase to the N terminus of PETase, giving rise to MP8, MP12 or MP20 (see Table 1.2 and Fig. 1.6). Different linker lengths of amino acid residues resulted in varying mobility between the two enzymes.

Table 1.2

chimaeric protein	number of amino acid (aa) residues found in the linker
MP8	8
MP12	12
MP20	20

Fig. 1.7 shows the rate of MHET degradation with PETase only, MHETase only, MP8, MP12 or MP20 added to the substrate MHET.

Asterisks indicate statistically significant comparisons between MHETase only and each chimaeric protein with *P $\leqslant$ 0.01, **P $\leqslant$ 0.001, and ***P $\leqslant$ 0.0005.

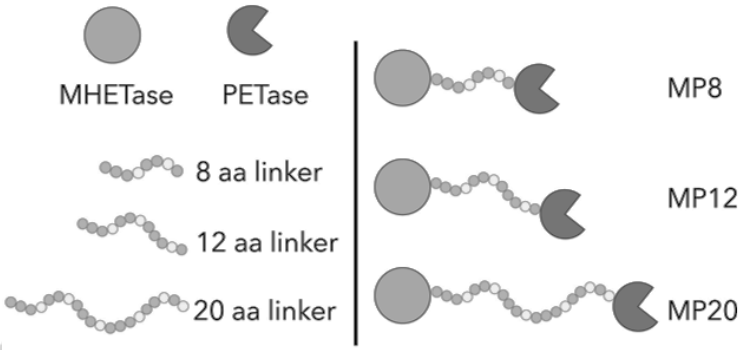

Fig. 1.6

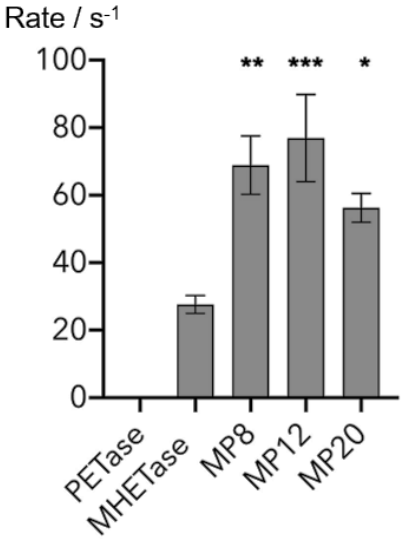

Fig. 1.7

(c) (i) Suggest why an experiment with PETase alone is added to substrate MHET to increase confidence in the results in Fig. 1.7.

1. This shows that PETase alone does not catalyse the breakdown of MHET / only the presence of MHETase can break down MHET;

……...

……. [1]

For Examiner's Use

(ii) Fig. 1.7 indicated the statistical significance with $P \leqslant 0.01$ when comparing the rate of MHET degradation with MHETase only and MP20.

Explain what is meant by "significant at $P \leqslant 0.01$".

1. **The probability that the difference between the 2 means of the 2 samples/treatments (MHETase only vs. MP20) is due to chance is less than 1% / The probability that the difference between the 2 means is caused by a factor other than chance is more than 99%;**

……..

…….. [1]

[Turn over

MHETase is composed of 611 amino acids.

Table 1.3 shows:

- the sequence of the first 10 amino acids in the primary structure of MHETase;
- DNA triplets in the non-transcribed strand in the gene that codes for the first 10 amino acids in the primary structure of MHETase.

Table 1.3

amino acid position	1	2	3	4	5	6	7	8	9	10
amino acid	leu	leu	gly	asp	phe	phe	arg	lys	ser	lys
DNA triplet	CTG	CTG	GGT	GAT	TTC	TTC	CGG	AAA	TCT	AAA

Table 1.4 shows the triplets of bases in DNA and the amino acids which they code for.

Table 1.4

first base	second base: T		C		A		G		third base
T	TTT	phe	TCT	ser	TAT	tyr	TGT	cys	**T**
	TTC		TCC		TAC		TGC		**C**
	TTA	leu	TCA		TAA	stop	TGA	stop	**A**
	TTG		TCG		TAG		TGG	try	**G**
C	CTT	leu	CCT	pro	CAT	his	CGT	arg	**T**
	CTC		CCC		CAC		CGC		**C**
	CTA		CCA		CAA	gln	CGA		**A**
	CTG		CCG		CAG		CGG		**G**
A	ATT	ile	ACT	thr	AAT	asp	AGT	ser	**T**
	ATC		ACC		AAC		AGC		**C**
	ATA	ile	ACA		AAA	lys	AGA	arg	**A**
	ATG	met	ACG		AAG		AGG		**G**
G	GTT	val	GCT	ala	GAT	asp	GGT	gly	**T**
	GTC		GCC		GAC		GGC		**C**
	GTA		GCA		GAA	glu	GGA		**A**
	GTG		GCG		GAG		GGG		**G**

For Examiner's Use

(d) Mutations in the base sequence of a gene can affect the primary structure of proteins.

Use the information in Table 1.3 and Table 1.4 to describe the effect on the primary structure of MHETase when there is:

(i) a substitution of the base T with the base A in the middle of the triplet at position 5;

1. (TTC to TAC) amino acid changes from phe to tyr (at position 5);

……

…….. [1]

(ii) an insertion of base G between bases G and T in the triplet at position 3.

1. Frameshift mutation / change in reading frame during translation;
2. Peptide is 3 amino acids in length / shortened polypeptide;

……

3. Stop codon is in position 4;

……

4. Third amino acid is still glycine / the first 3 amino acids are the same;

……

…….. [3]

(e) Explain why the genetic code is described as universal.

1. The genetic code is the same / similar in all organisms / each triplet/codon codes for the same amino acid in all living organism;

……

…… [1]

(f) With reference to Table 1.4, explain why some mutations have no effect on the primary structure of a protein.

1. (most) amino acids are coded for by more than one codon;

……

2. Award any correct examples from Table 1.4 (only met and try are coded for by 1 codon);

……

3. Genetic code is degenerate;

……

4. There are 61 possible codons for 20 different amino acids; A! 64
5. Silent mutations have no effect on the primary structure; R! neutral

……

…… [4]

[Turn over

Fig. 1.8 shows the annual production of plastics around the world, including PET. PET was first invented in 1941 but was only used to make plastic bottles for carbonated drinks since 1973.

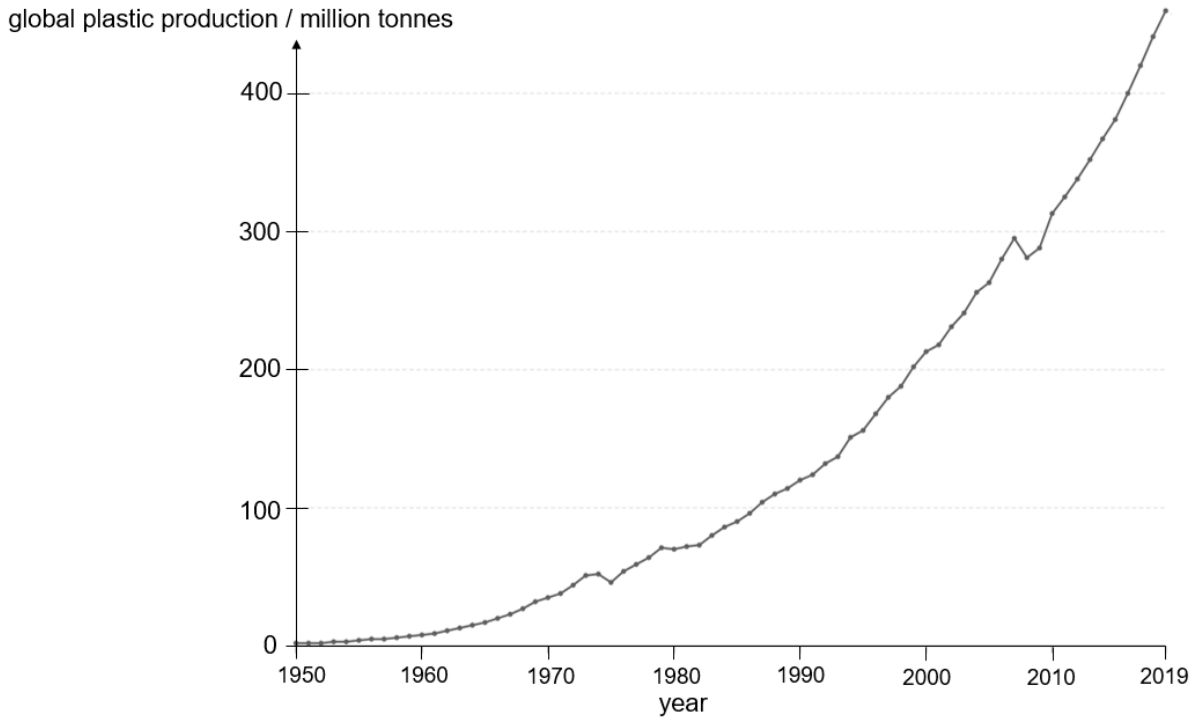

Fig. 1.8

The bacterial species, *I. sakaiensis* was first discovered in 2016, in the soil containing waste discharge from a plastic bottle recycling facility.

(g) Describe the change in global plastic production from 1973 to 2016.

1. **The global plastic production increases exponentially/sharply/at an increasing rate from 50 million tonnes to 400 million tonnes from 1973 to 2016;**

.....

2. **There were some exceptions when the production dips slightly e.g. from 1974-1975 / from 2007-2008;**

.....

..... [2]

For Examiner's Use

A colony of *I. sakaiensis* takes about six weeks to completely degrade a sheet of PET. After MHET is broken down into EG and TPA, the products are converted to Krebs cycle intermediates giving rise to carbon dioxide.

As the rate of degradation is too slow to break down the huge amount of plastic waste generated globally, two different methods are used to develop an *I. sakaiensis* strain with more effective PETase and MHETase that will break down PET faster:

- artificial selection, in which the *I. sakaiensis* cells from each generation that degrade PET at the fastest rate are allowed to reproduce; and

- directed evolution, in which different mutations are introduced to create a large number of variants of the PETase gene. These gene variants are then transformed into cells. Cells with the fastest PETase activity are selected and the particular gene variant in these cells will undergo further mutations again. This allows for repeated cycles of creating gene variants and selecting for the cells with the fastest PETase activity.

Evolution through natural selection can take a long time. *I. sakaiensis* was only discovered about 50 years after the production and intensive use of PET.

The two methods, artificial selection and directed evolution, developed *I. sakaiensis* strains that degrade PET faster than wild type *I. sakaiensis* over the past 5 years.

(h) **(i)** Explain why variation is important in natural selection.

1. **Variation gives rise to different phenotypes / Without variation, a population of individuals is genetically identical;**
2. **Variation allows for differential reproductive success to occur / selection pressure acts differently on the individuals / some individuals will have higher reproductive success if they are selected for / all individuals will die if all are selected against; R! more adapted to environment**

……

…… [2]

[Turn over

For Examiner's Use

(ii) Suggest why the two methods, artificial selection and directed evolution, take a much shorter time to develop *I. sakaiensis* strains that degrade PET faster than evolution through natural selection.

1. **Mutation rates are very high / mutation is not spontaneous or occur by chance in directed evolution, so there is a huge amount of variation that the selection pressure can act on;**

……

2. **The selection pressures applied in artificial selection and directed evolution are more intense than in nature / cells that are able to break down PET to produce energy slower can still reproduce to pass on their alleles to the offspring hence the removal of these alleles from the gene pool is slower (though fewer of these cells), while in the laboratory settings, these cells are not allowed to reproduce at all / speed of PET degradation is sufficient for survival for the cells in the wild;**

……

3. **The conditions for growth and reproduction are optimised in the laboratory;**

……

…… [2]

(iii) Using a named species concept, explain why the cells that are grown from these two methods are considered *I. sakaiensis strains* and not a different species from wild type *I. sakaiensis*.

1. **Using the genetic species concept;**
2. **the genetic distance between the strains is too little to consider them as a distinct species as only the PETase and MHETase genes are mutated while the entire genome remain largely similar;**

……

3. **Using the phylogenetic species concept;**
4. **there remains a high degree of homologies / similarities in the protein and DNA sequences among the strains and wild type even as PETase and MHETase genes are mutated, the genes are homologous, and so the strains and wild type shares a common ancestor;**

5. **Using the ecological species concept;**
6. **The strains and wild type are able to utilise the same substrates PET to synthesise respiratory substrates, hence they share the same ecological niche;**

……

Pt 1 and 2 OR pt 3 and 4 OR pt 5 and 6

…… [2]

[Total: 30]

For Examiner's Use

2 Patients infected with influenza virus often present common symptoms such as runny nose, blocked nose and sore throat.

(a) Explain how the influenza virus causes such symptoms.

1. **the virus infected the epithelial cells in the respiratory tract;**
2. **viral replication results in expression and insertion of viral glycoproteins on the epithelial cell surface membrane, causing the epithelial cells to be recognised as foreign by the body's immune cells;**
3. **leading to a local inflammatory response, e.g. vasodilation, increasing blood vessel permeability, fluid entering tissues, induced by the release of histamine by mast cells;**
4. **Cytokines also recruit more white blood cells to the site of infection, causing damage to the epithelial tissue resulting in production of mucus;**
5. **Release / budding of Influenza virus causes death of host cells which also result in production of mucus;**
   see "mucus" once

…… [3]

In the United States (US), the flu season usually occurs in the fall and winter, which is between September to March. People are encouraged to go for their seasonal flu vaccination yearly.

(b) **(i)** State the first class of antibody secreted by the plasma cells after vaccination.

Ig M;

…… [1]

(ii) Complete Table 2.1 to show the type of bonds found in the antibody mentioned in **(b)(i)**. Use a "yes" to indicate presence and "no" to indicate absence. The first two blanks have been filled in for you.

Table 2.1

type of bond	presence in first class of antibody secreted after vaccination
hydrophobic interactions	**yes**
hydrogen bonds	**yes**
ionic bonds	**yes**
disulfide bridges	**yes**
peptide bonds	**yes**
phosphodiester bonds	**no**

[1]

[Turn over

For Examiner's Use

The vaccine for seasonal flu is designed to be effective against a few strains of influenza virus that are predicted for the next season. There was also another vaccine that targeted the prevailing flu virus (H1N1) which emerged in April 2009.

Fig. 2.1 shows the number of vaccinations administered for seasonal flu and H1N1 in the US between August 2009 and March 2010. Vaccination data was collected weekly.

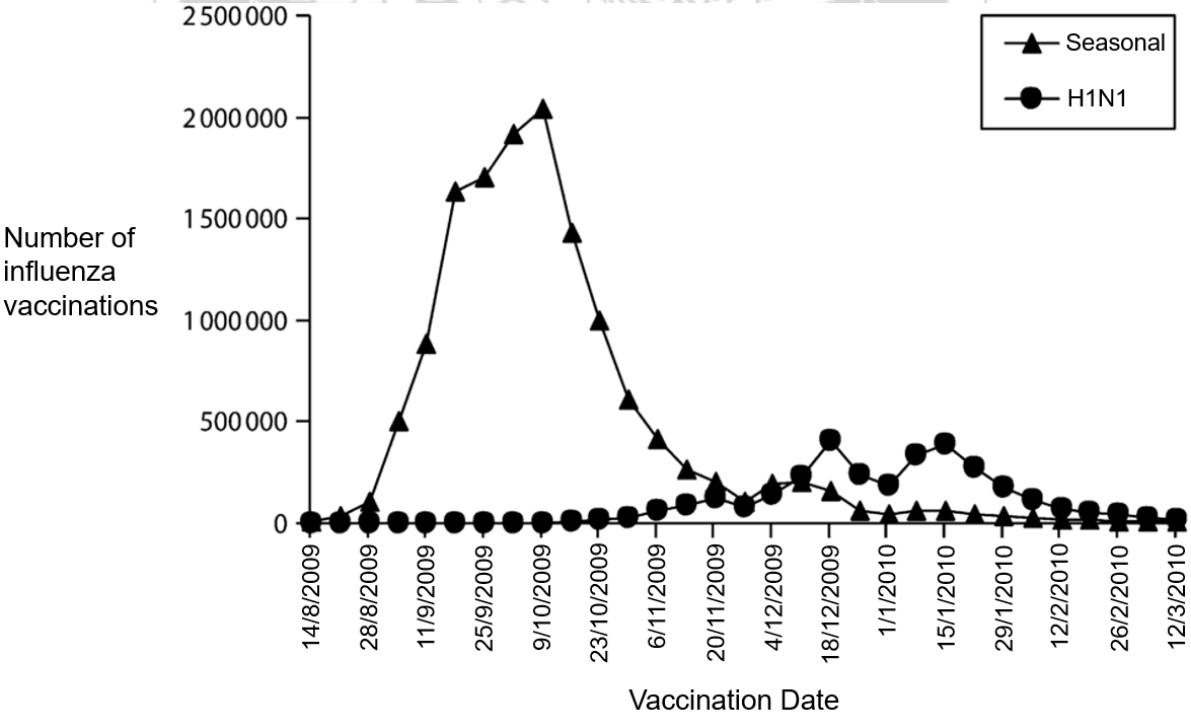

Fig. 2.1

(c) (i) Describe the change in the number of vaccinations administered for seasonal flu over the period.

1. From 0 vaccinations on 14/8/2009, it increased to a peak of 2,000,000 (A! 2,050,000 and 2,100,000) vaccinations on 9/10/2009;
2. Then it started to decrease slowly to 0 vaccinations on 26/2/2010 and remained at 0 till 12/3/2010 (A! any dates from 12/2/2010 to 12/3/2010) ;

…… [2]

(ii) Suggest why the number of vaccinations administered for H1N1 remained at zero for the first 8 weeks.

H1N1 virus first appeared in April 2009, the vaccine was not ready until end of October;

…… [1]

For Examiner's Use

Number of vaccinations administered for seasonal flu were not as high as expected due to claims that flu vaccinations caused Guillain-Barré Syndrome (GBS).

GBS is a rare autoimmune disorder where the body's immune system damages nerve cells.

A study was conducted to determine if flu vaccinations cause GBS. The number of actual cases of GBS that occurred after vaccination were tracked to give the observed rate and compared against a predicted rate. The predicted rate is computed based on the predicted number of GBS cases if GBS was caused by flu vaccinations.

Fig. 2.2 shows the results of the study for seasonal influenza vaccination.

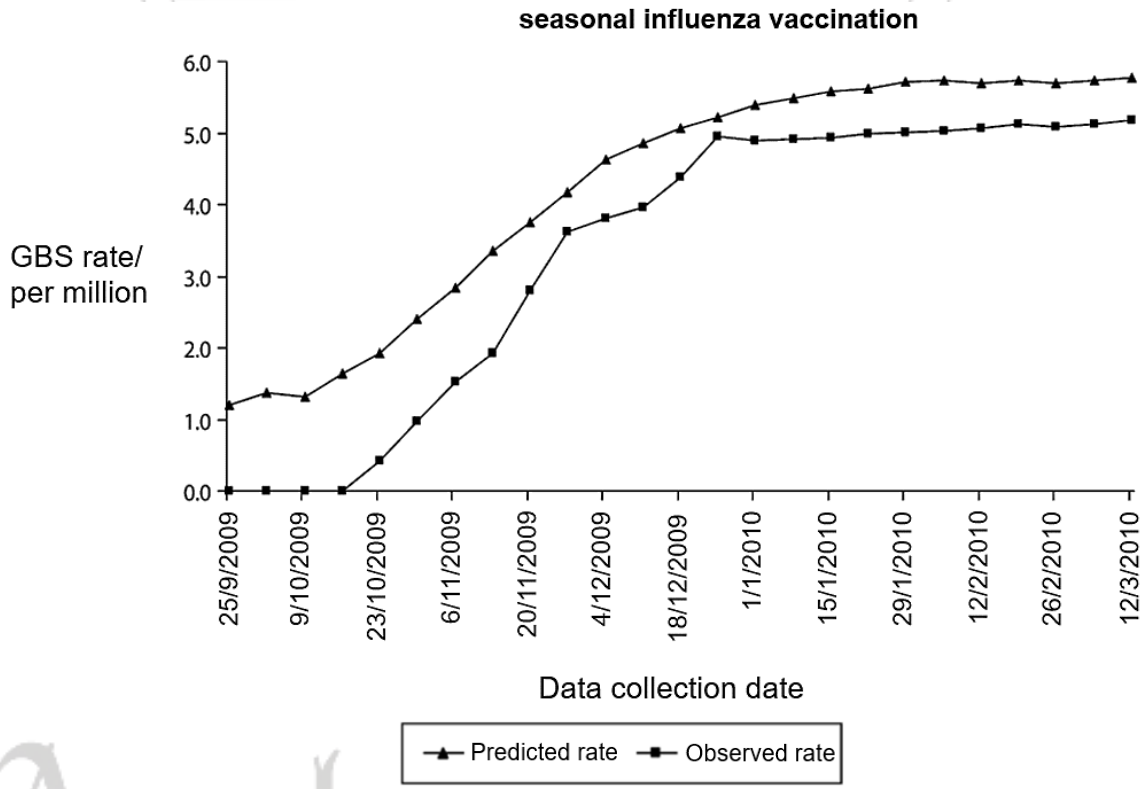

Fig. 2.2

(d) With reference to Fig. 2.2, explain why the claim that flu vaccination causes GBS is untrue.

1. **For seasonal flu vaccinations, the observed rate is lower than the predicted rate (A! the predicted rate is consistently higher than observed rate);**
2. **Quoting of any paired data to support: For seasonal flu vaccinations on 12/3/2010, observed rate was 5.2 (A! 5.0-5.2) cases per million while predicted rate was 5.8 (A! 5.6-5.8) cases per million;**

.....

..... [2]

[Total: 10]

[Turn over

For Examiner's Use

3 Fig. 3.1 shows the regions where wheat, rice and maize are cultivated in the world.

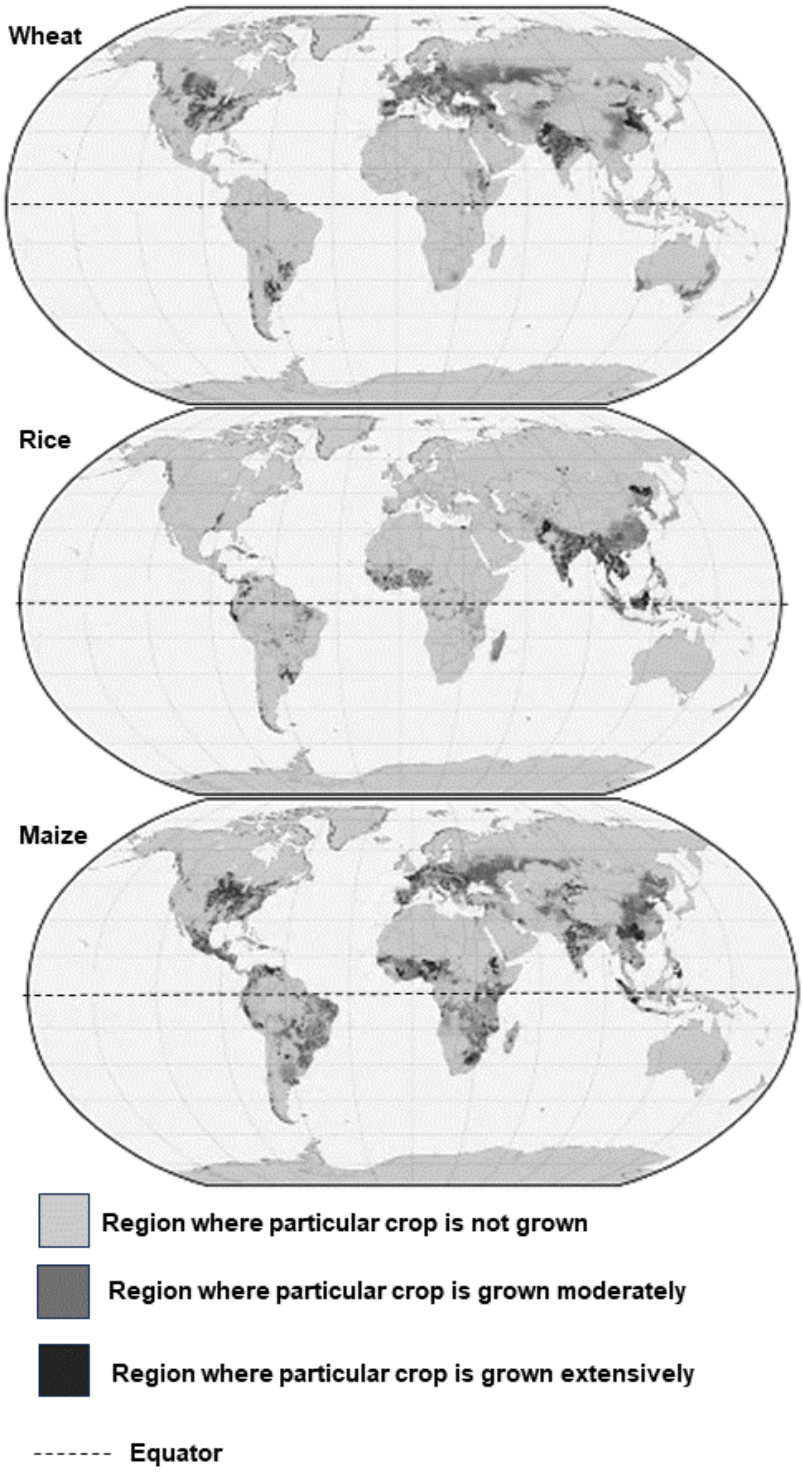

Fig. 3.1

For Examiner's Use

Fig. 3.2 shows the projected total global crop yield losses of wheat, rice and maize in megatonnes per year (Mt/yr) due to increased insect pests' metabolic activities (triangles on each graph) when temperature rises from 0 to 5 °C (reflected on x-axis) above pre-industrial levels.

The dashed horizontal line on each graph reflects the current amount of crop losses as a result of insect pests.

An estimation of crop population growth rate is also reflected (as ovals on each graph) to show the predicted trends across the range of temperature increase.

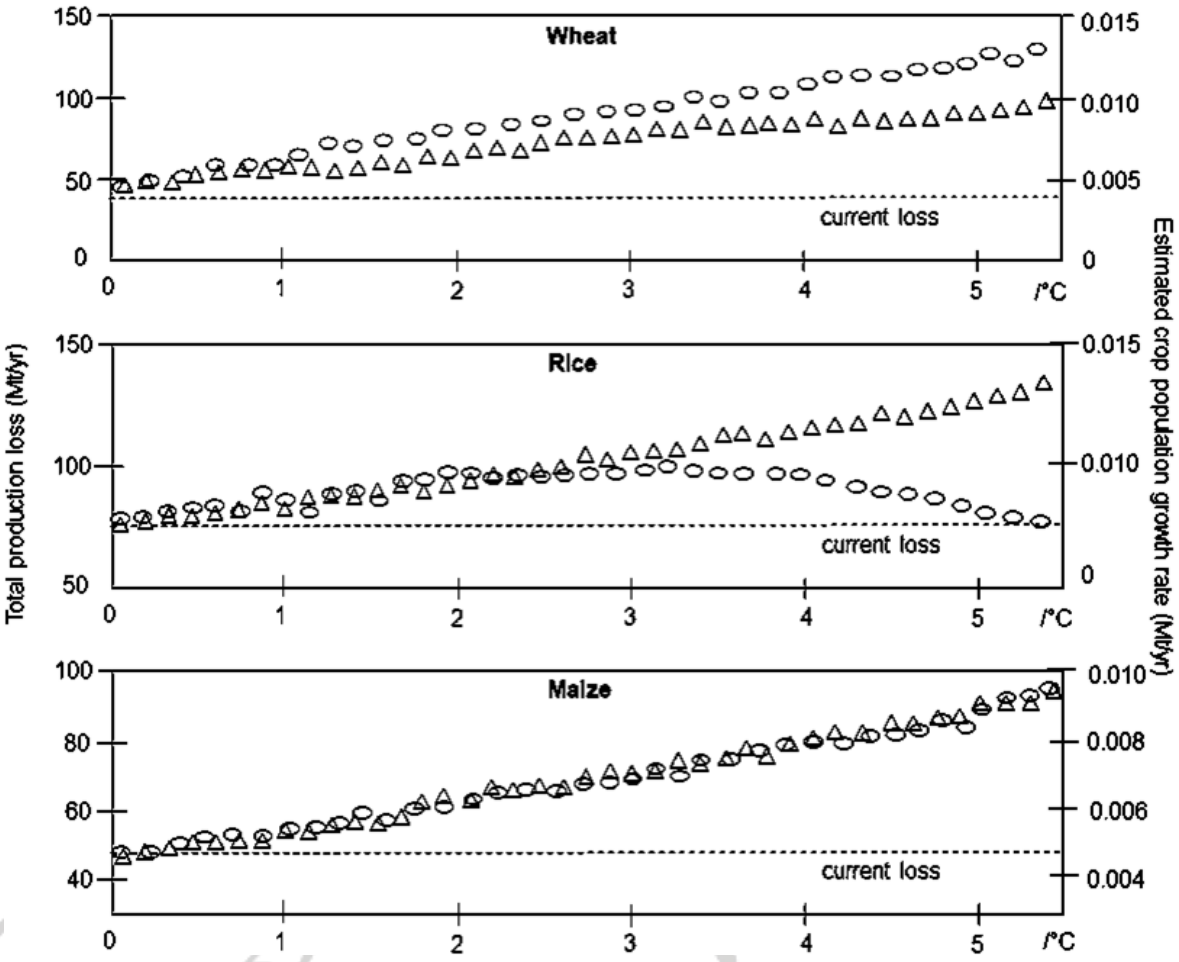

Fig. 3.2

(a) (i) Calculate the percentage increase in pest-related crop yield losses for rice and maize at a temperature rise of 5 °C above pre-industrial levels. Show your working.

1. % increase for rice = (125 (A! 125-135) – 75) Mt/yr /75 Mt/yr x 100% = 67%

……

2. % increase for maize = (90 (A! 89-92) – 47 (A! 46-49)) Mt/yr /47 (A! 46-49) Mt/yr x 100% = 91%

@1m each with working shown and % ans in whole numbers

…… [2]

[Turn over

For Examiner's Use

(ii) With reference to Fig. 3.1 and Fig. 3.2, suggest reasons for the difference in the percentage increase in pest-related crop yield losses between rice and maize.

1. **Percentage increase for maize is larger than rice because maize is mostly grown in temperate regions where warming is expected to increase the population of insect pests; (A! poleward shift of insect distribution)**

……

2. **whereas rice is grown mostly in tropical regions where temperatures are very close to/already optimal for insect reproduction and further temperature increases are likely to result in slight decrease in the population of insect pests;**

……

OR

3. **Predicted rice crop population growth shows a smaller increase when temperature rises by 5°C due to a drop in photosynthetic efficiency as temperature surpasses optimal temperature for photosynthetic enzymes hence fewer rice crops available for insect pests to infest;**

……

4. **whereas predicted maize population growth increases when temperature rises by 5 °C as temperature approaches/reaches optimal temperature hence there will be an even greater number of maize crops available for insect pests to infest than rice.**

……

@points 1 & 2 or 3 and 4 to be scored together, max 2m

…… [2]

(iii) Given that the trend shown in Fig. 3.2 continues, calculate the total crop yield loss of wheat due to pests if temperature increases to 6.5°C above pre-industrial levels. Show your working.

1. **Average crop production loss per year per 1°C temperature rise is: ((A! 80-90)-40 Mt/yr) / 5°C**
   = A! 8 – 10 Mt/yr per °C
2. **A further increase in 1.5°C (from 5°C) will result in a further increase in crop production loss of = (A! 8-10) x 1.5 = (A! 12-15) Mt/yr and therefore a prediction of a total crop production loss of wheat due to pests at 6.5°C above pre-industrial levels = ((A! 80-90) + (A! 12-15) = (A! 92-105) Mt/yr**

OR

3. **Average crop production loss per year per 1°C temperature rise is: ((A! 80-90)--40 Mt/yr) / 5°C**
   = A! 8 – 12.5 Mt/yr per °C
4. **There will be an total increase of A! 8 – 10 x 6.5 = A! 52 – 65 Mt/yr when temperature increases to 6.5°C above pre-industrial levels hence a prediction of a total crop production loss of wheat due to pests at 6.5°C above pre-industrial levels = 40 + (A! 52 – 65) = (A! 92-105) Mt/yr**

[2]

For Examiner's Use

(b) Increase in insect pests due to climate change can contribute to a change in biodiversity on a cropland and subsequently impact crop yield.

(i) List two examples of organisms, excluding insect pests, that can increase the biodiversity in a particular cropland and explain how these organisms can change crop production as temperature becomes more permissive for other species to migrate to the area in Table 3.1. The first example of organisms has been filled in for you.

Table 3.1

	Organisms (excluding insect pests) that increase the biodiversity in a particular cropland	impact on crop production
Example 1	**butterflies and birds**	**1. Increased pollination and hence enhanced crop production;** **2. Increased seed dispersal and enhanced crop production / increased non-intended seed dispersal from outside cropland and competition of plants/weeds with crops, hence decreased crop production** **(R! butterflies eat the crops hence decreased crop production)**
Example 2	**3. Invasive plant species;** **4. Soil bacteria e.g. nitrogen-fixing bacteria, etc or bacteria causing plant diseases;** **5. Herbivore/ omnivore that feed on crop plant;** **AVP: Earthworms; Ladybugs** **(R! pollinators if pollination is cited above)** **(R! insect pests including caterpillars)** **(R! livestock animals)** **(R! humans)**	**6. Crop production decreases due to competition for e.g. space, nutrients with invasive plants [linked to point 3]** **7. More nitrogen fixed in the soil hence better crop growth and crop yield or bacteria causing plant diseases in crops decreases crop yield [linked to point 4]** **8. Increased consumption of crops by herbivore/omnivore and reduced crop yield [linked to point 5]** **9. Increased pollination by herbivores as they move across and hence enhanced crop production [linked to point 5]** **10. Increased seed dispersal by herbivores as they move across and enhanced crop production [linked to point 5]** **11. Increased fertilisation via herbivore excretions and enhanced crop production [linked to point 5]** **AVP: Earthworm tunnels enhances soil nutrients / porosity and draining / aeration / space for roots; Ladybugs eat insect pests such as aphids hence increase crop production** **(R! pollinators or seed dispersal if either is cited above)**

[3]

[Turn over

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(ii) Suggest why dietary habits can be affected by the decline of crop production due to climate change.

1. **With a lack / scarcity of certain crops due to the impact of climate change, consumers would no longer have easy/cheap access to those food produce**

……..

2. **As a result, consumers may switch to other alternatives that are easily accessible/cheaper, resulting in a change in dietary habit.**

……

AVP: Crops grown to feed livestock will decline and hence farmers will not have cheap and ready access to such animal feed, causing this particular poultry meat to increase in price thus resulting in consumers looking for cheaper alternatives.

…….. [1]

[Total: 10]

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Section B

Answer **one** question in this section.

Write your answers on the separate writing paper provided.

Your answers should be illustrated by large, clearly labelled diagrams, where appropriate.

Your answers must be in continuous prose, where appropriate.

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

4 **(a)** Explain how viruses challenge the cell theory while prokaryotes and eukaryotes comply with the cell theory. [14]

(b) "Proteins are the most important biomolecules for cell signalling."

Discuss the validity of this statement. [11]

[Total: 25]

5 **(a)** Explain how errors during various stages of the mitotic and meiotic cell cycles can lead to cancer. [14]

(b) Stem cell therapy involves the differentiation of stem cells into specialised cells before transplanting into patients. However, complete differentiation may not have occurred in every cell, and there could still be undifferentiated cells remaining within the transplanted cells.

Discuss the possible outcomes in a patient who received transplanted cells with the presence of undifferentiated stem cells. [11]

[Total: 25]

[Turn over

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4 (a) Explain how viruses challenge the cell theory while prokaryotes and eukaryotes comply with the cell theory. [14]

Cell Theory

1. **All living things are composed of one or more cells;**
2. **The cell is the smallest unit of life;**
3. **All cells come from pre-existing cells;**

Viruses Challenge cell theory	**Prokaryotes and Eukaryotes Comply with cell theory**
4. Challenges the cell theory in that it has living characteristics but it is acellular / not a cell; **5. It is not as cell as it is simpler/less complex in structure than a cell; R! smaller**	**6. Even though single-celled, they still possess characteristics of life: able to respond to stimuli / reproduce / grow in size / carry out metabolic reactions / evolve;**
Living characteristics: **7. It has its own genetic material/genome, in the form of DNA (bacteriophage) or RNA (influenza / HIV), which codes for viral proteins;** **8. They are able to reproduce in a host cell;** **9. They are also able to undergo mutation and evolve into new viral strains; R! "adapt to"**	**10. Prokaryotic cells reproduce via binary fission to produce genetically identical daughter cells;** **11. Eukaryotic cells reproduce via mitosis and cytokinesis/cell division for somatic cells, to produce genetically identical daughter cells;** **12. Eukaryotes can also undergo meiosis and cytokinesis to produce gametes for sexual reproduction;** **13. During sexual reproduction, fertilisation occurs where a zygote is formed which develops into multicellular blastocyst;**
Not a cell / Simpler than a cell: **14. It does not have cytoplasm /organelles;** **15. It contains ONLY protein capsid and genome (and a viral envelope);** **16. It does not contain enzymes necessary for metabolism / replication / transcription / translation to take place;**	**17. prokaryotic and eukaryotic cells have cytoplasm and many cellular organelles inside them, surrounded by a cell surface membrane/ plasma membrane;** **18. Prokaryotes/ Bacteria are usually unicellular/ single-celled,** **19. Eukaryotes could be unicellular/ singled or multicellular;** **(Note: membrane-bound organelles are only present in eukaryotic cells not in prokaryotic ones)**

20. QWC: 1 correct point from Cell Theory (pt 1-3), 2 correct points from Viruses and 2 correct points from Prokaryotes and Eukaryotes;

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4 (b) "Proteins are the most important biomolecules for cell signalling."

Discuss the validity of this statement. [11]

Cell Signalling
(award if contextualised too)

1. **Ligand-receptor interactions: Receptor has a specific binding site with a 3D conformation complementary to that of the ligand;**
2. **Signal-transduction: Signal is transduced upon the change in 3D conformation of a receptor, recruiting and activating/inhibiting the next immediate intracellular relay protein;**
3. **Cellular response: transduced signal triggers a specific cellular activity (award for valid e.g.);**

Proteins (MAX 8)

4. **Receptors / G-Protein Linked Receptor/ Receptor Tyrosine Kinase are usually transmembrane proteins which are embedded in the cell surface membrane;**
5. **hormones / ligands / insulin / glucagon that are proteins bind and activate the receptors;**
6. **Relay protein e.g. G protein which is activated when GDP is displaced by GTP**
7. **Relay protein e.g. adenyl cyclase, which catalyses the formation of cAMP from ATP;**
8. **Relay protein e.g. kinases are enzymes which transfer phosphate groups from ATP to a specific amino acid residue on the protein;**
9. **Relay protein e.g. phosphatases are enzymes which remove phosphate groups from proteins;**
10. **Relay protein e.g. phosphodiesterase are enzymes that hydrolyses cAMP;**
11. **Relay protein e.g. transcription factor to activate/inhibit gene expression;**
12. **Effector protein e.g. glycogen phosphorylase/synthase which catalyses the breakdown of glycogen to glucose/synthesis of glycogen;**
13. **Effector protein e.g. glucose transporters/ GLUT which will alter membrane permeability to the transport of glucose;**

Carbohydrates

14. **Transmembrane proteins/lipids could be added with short sugar chains/ oligosaccharides to allow ligand binding; (Mark once: glycoprotein or glycolipid)**

Lipids

15. **Cell surface membranes/ plasma membrane are made of phospholipid bilayer which allows embedment of proteins via hydrophobic interactions (with hydrophobic core) and hydrogen bonds and ionic (with phosphate head);**
16. **Ligands could be lipid-soluble hormones like steroid hormones which can pass through the hydrophobic core of cell surface membrane;**
17. **Steroid hormone receptor complex acts as transcription factor to activate gene expression;**

[Turn over

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Nucleic Acids

18. **Activation / inhibition of gene expression as part of cellular response;**
19. **Gene are DNA sequence which code for receptors/ proteins/ enzymes involved in cell signalling;**
20. **Increased / decreased transcription of gene to produce more/ less mRNA;**
21. **Increased / decreased translation of mRNA to produce more/ less polypeptide/ protein;**
22. **ATP, a nucleotide, is converted to cAMP, a modified nucleotide, which is the second messenger for signal amplification;**

Others

23. **Second messengers are small and non-protein in nature, e.g. Ca^{2+} and cAMP;**

Validity of statement

24. **there are many molecules in the signal transduction pathway that are made of proteins but there are also other molecules such as lipids, nucleic acids and carbohydrates involved as well, all types of biomolecules are equally important to ensure successful cell signalling;**

25. **QWC: 1 correct point from Cell Signalling (pt 1 – 3), 2 correct points from Proteins (pt 4 – 13)), 2 correct points from other biomolecules and validity (pt 14 – 24);**

5 (a) Explain how errors during various stages of the mitotic and meiotic cell cycles can lead to cancer. [14]

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Errors in mitotic and meiotic cell cycle

1. **The G1 checkpoint checks for DNA damage, and if this checkpoint is dysfunctional, cell cycle will past this checkpoint even when DNA damage is not repaired;**
2. **During S phase, wrong nucleotides may be added during DNA replication;**
3. **If G2 checkpoint is dysfunctional, cell cycle will proceed even when newly-replicated DNA contains errors or is damaged;**
4. **During prophase/prophase I/II, spindle fibres do not properly attach to the kinetochore proteins at the centromeres of certain/all chromosomes;**
5. **During prophase I of meiosis, errors in crossing over as the pair of homologous chromosomes may not be properly aligned may result in chromosomal aberrations;**
6. **Non-disjunction can occur during mitosis and meiosis;**
7. **the M checkpoint during metaphase/metaphase I/II checks for the successful formation of spindle fibres and attachment to kinetochore complex, and if this check point is dysregulated, cell cycle will proceed when the spindle fibres are not properly attached to all chromosomes;**
8. **During anaphase/anaphase I/II, as spindle fibres are not properly attached to certain chromosomes, there will be an uneven/failure of separation/movement of chromosomes to opposite poles of the cell;**

Chromosomal aberrations (structure) leading to Cancer (max 8 for pt 9 – 21)

9. **Translocation can occur, where a section of a chromosome breaks off and attaches to a non-homologous chromosome;**
10. **A proto-oncogene may be moved from its normal location in one chromosome to another, where it is placed under the control of enhancers / a more active promoter which stimulates cell division;**
11. **A tumour suppressor gene could be moved and placed under the control of silencers / a less active promoter which inhibits cell division;**
12. **Deletion involves the loss of a section of the chromosome (where the breaks occur at two points along the length of a chromosome);**
13. **The possible loss of tumour suppressor genes in the deleted section will lead to a lack of expression of its gene product which inhibits cell division;**
14. **Inversion occurs when a segment of nucleotide sequences/section of chromosome separates, reversed its sequence and rejoins at original position;**
15. **Which may result in the nucleotide sequence of the tumour suppressor gene being read in the reversed manner / wrongly / results in different mRNA / a.a. sequence;**
16. **resulting in the formation of a non-functional (A! mutant) tumour suppressor protein to inhibit cell division/initiate DNA repair/promote apoptosis;**
17. **Duplication/ resulting in gene amplification involves replication of a section of the chromosome, resulting in an increased number of copies of certain genes / a set of gene loci is repeated;**
18. **The multiple copies of a proto-oncogene will lead to an increased expression of its gene product / excess (onco)proteins which stimulates cell division;**

[Turn over

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Chromosome aberrations (number) leading to Cancer (max 8 for pt 9 – 21)

19. After cytokinesis, daughter cells may have extra or missing chromosomes which is also known as aneuploidy/ daughter cells may have extra sets of chromosomes which is also known as polyploidy;

20. An increase in the number of copies of a proto-oncogene will lead to an increased expression of its gene product / excess (onco)proteins which stimulates cell division;

21. A loss of chromosome/n-1 may lead to loss of tumour suppressor gene which leads to a lack of expression of its gene product which inhibits cell division.

Cancer traits (max 4)

22. Accumulation of mutations in several genes occur in a single cell lineage;
23. For example, gain-of-function mutation in at least one copy of the proto-oncogene;
24. and loss-of-function mutations in both copies / several tumour suppressor genes;
25. Cancer cells can display traits such as loss of anchorage dependence or density-dependent inhibition / presence of active telomerase / stimulating angiogenesis;
26. Leading to uncontrolled cell division;
27. Cancer cells may spread to other locations distant from their original site in the body via lymph vessels or blood vessels, and form secondary tumours in a process known as metastasis;
28. Inheritance of the mutated cancer-critical genes from errors arising from meiotic cell cycle results in predisposition to cancer in the offspring;

29. QWC: At least 2 points from errors in mitotic and meiotic cell cycle (pts 1-8), 2 points from chromosomal aberrations leading to cancer (points 9 - 21), 1 point from Cancer traits (pt 22 – 28)

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5 (b) Stem cell therapy involves the differentiation of stem cells into specialised cells before transplanting into patients. However, complete differentiation may not have occurred in every cell, and there could still be undifferentiated cells remaining within the transplanted cells.

Discuss the possible outcomes in a patient who received transplanted cells with the presence of undifferentiated stem cells. [11]

Cytokines and Cell signalling involved in differentiation of stem cells

1. **Cytokines serve as ligands that bind to receptors on stem cells;**
2. **inducing a signal transduction pathway within the stem cell;**
3. **to express genes specific for the differentiated cell types;**
4. **repress genes that are not required / maintain potency;**

thus allowing stem cells to be able to differentiate under appropriate conditions

Outcomes of presence of undifferentiated stem cells:

(A) Differentiation into intended cell types

5. **Extracellular conditions/signals present will still induce the remaining undifferentiated stem cells to differentiate into the intended tissue types;**
6. **this may be beneficial as the small extent of *in vivo* differentiation of stem cells to the correct differentiated cells can increase the number of specialised cells for therapy;**

(B) Differentiation into other cell types

7. **Undifferentiated stem cells within the differentiated cells/tissues may differentiate into other non-intended cell types;**
8. **The presence of other cell types within the transplanted tissue may interfere with proper tissue function and hence affect the efficacy of the stem cell therapy;**

(C) Stem cell remain undifferentiated

9. **Stem cells remains undifferentiated;**
10. **Stem cells is able to carry out self-renewal / divide via mitosis for long periods of time / long-term;**
11. **a small population of stem cells is maintained;**
12. **The small population of stem cells can be activated to differentiate to replace cells that are worn out / damaged;**
13. **Proliferation of stem cells to get a larger pool of cells (A! increase number);**

(D) Cancer

14. **Undifferentiated stem cells may continue to proliferate / undergo uncontrolled cell division;**
15. **resulting in an unintended large population of stem cells within the transplanted/treated tissue / benign growth / tumour that may need to be surgically removed;**
16. **Certain undifferentiated stem cells (within the benign growth) may become cancerous due to presence of telomerase / accumulated mutations;**
17. **Cancerous cells may interfere with proper tissue function;**
18. **spread to nearby tissues/organs /metastasise to other parts of the body;**

19. **QWC: At least 1 point from 2 different categories A (5,6) / B (7,8) / C (9-13) / D (14-18).**

[Turn over