2019 H2 A level Paper 3

Section A

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

1 (a) (i) Name the term used to describe the organisation of species according to their evolutionary relationships, as shown in Fig. 1.1. [1]

Phylogeny*

(ii) State how the information needed to construct a diagram such as that shown in Fig. 1.1 can be obtained through molecular techniques. [4]

1. Amplify DNA sequences of a ***homologous* gene*** common to all the species of organisms being compared via polymerase chain reaction;
2. Sequence the DNA fragments obtained from the different organisms;
3. Align the DNA sequences and calculate/compare the differences between them;
4. Species that are closely related have more similar nucleotide sequences than do distantly related species and should be shown to diverge from a more recent common ancestor in the phylogenetic tree.

(iii) The five species named in Fig. 1.1 all share the characteristic of making curcumin. These five species have never all been classified together in a single genus.

Explain why the characteristic of making curcumin is **not** sufficient to place all five species in the same genus. [2]

1. Compared only 1 characteristic which is insufficient evidence to show that they belong to the same genus;
2. The 5 species could still be significantly different morphologically compared to those in the same genus.

R: successful interbreeding to give fertile viable offspring.

(iv) The five species named in Fig. 1.1 occur in just two of the 400 or more families of flowering plants that exist.

Suggest why the ability to make curcumin is limited to these two families of plants. [2]

1. The two families must have diverged from a common ancestor which had the ability to make curcumin;

2. The trait for making curcumin first emerged in this common ancestor.

(b) (i) With reference to Fig. 1.2, describe the effect of curcumin on the percentage of cancer cells in each phase of interphase nine hours after entering G_1 phase. [3]

1. The higher the concentration of curcumin the cells were exposed to, the greater the percentage of cancer cells still in ***G_1 phase**** nine hours later;

2. cite data from graph comparing 2 curcumin concentrations and the percentage of cancer cells at G_1 phase. E.g. 76% of cells at G_1 phase in 40 μmol dm^{-3} curcumin higher than 20% of cells at G_1 phase in 0 μmol dm^{-3} curcumin.

3. The higher the concentration of curcumin the cells were exposed to, the lower the percentage of cancer cells in ***S phase**** nine hours later;

4. cite data from graph comparing 2 curcumin concentrations and the percentage of cancer cells at S phase. E.g. 17% of cells at S phase in 40 μmol dm^{-3} curcumin lower than 74% of cells at S phase in 0 μmol dm^{-3} curcumin.

5. No significant effect of curcumin on the percentage of cancer cells at ***G_2 phase****;

6. Around 6%-9.5% cancer cells across all four different curcumin concentrations in the culture media.

(ii) With reference to Fig. 1.2, suggest how curcumin affects the mitotic cell cycle and how this could help in the treatment of cancer. [4]

1. Curcumin halts the mitotic cell cycle at the G_1 checkpoint;
2. Eg. of possible reasons to halt cell cycle:
   cause DNA damage, signal absence of growth factors / nutrients;
3. Cancer cells will be unable to progress in the cell cycle / proceed to S phase;
4. Prevent uncontrolled cell division in cancer cells;

(iii) CDK2 affects the multiplication of cancer cells.

Identify one **other** molecule in Fig. 1.3 that affects the multiplication of cancer cells and explain how curcumin's effect on it could help to treat or prevent cancer. [3]

1. ***p53****;
2. Curcumin could increase the expression / frequency of transcription of the p53 gene, resulting in production of more p53 proteins;
3. which will result in increased ability to inhibit cell cycle / repair damaged DNA / promote apoptosis;

OR

4. growth factors (***FGF*/TGFβ1****)/ transcription factor ***NFκB****
5. bind to growth factors to prevent their binding to receptors;
6. prevent stimulation/progression of the cell cycle leading to reduced cell division**;**

R: ***CDK2****
Note: Using the information provided in Fig. 1.4, PhK and TNFα are possible answers to this question too. However, points 4-6 would still be necessary in order to link PhK and TNFα to the treatment of cancer.

(c) **(i)** With reference to Fig. 1.3 and Fig. 1.4, explain why curcumin is useful in the treatment of burns to prevent changes in the appearance of skin. [4]

1. Curcumin reduces the activity of ***PhK**** and ***TNFα**** which are released by damaged/burned skin;
2. Lower levels of PhK activity will decrease activation of NFκB;
3. which upregulates the expression of genes involved in scar tissue formation;
4. Lower levels of TNFα activity will decrease attraction of white blood cells and the release of FGF and TGFβ1 by these cells;
5. reducing fibroblast proliferation and differentiation into scar tissue;

(ii) Curcumin is a non-competitive inhibitor of the enzyme phosphorylase kinase, PhK.

Explain how curcumin interacts with the PhK molecule to decrease its activity. [3]

1. Curcumin binds to site other than active site on PhK;
2. Alters the shape/conformation of the ***specific**** Phk ***active site****
3. so that active site is no longer ***complementary**** in shape and charge to substrate, hence substrate cannot bind so the rate of reaction is reduced;

(iii) Explain the roles of kinases (such as PhK) **and** phosphatases in cell signalling. [4]

1. Kinases catalyse the addition of ***phosphate**** groups from ***ATP**** to a protein;
2. Kinases activate a large number of molecules resulting in signal amplification;
3. Phosphatases catalyse the removal of ***phosphate**** groups from proteins by hydrolysis**.**
4. Phosphatases inactivate relay molecules so that propagation of the signal will be inhibited/signal will be terminated.

[Total: 30]

2 Lymphoid stem cells are a subset of blood stem cells that give rise to the B lymphocytes and T lymphocytes of the immune system.

(a) **(i)** State the level of potency of lymphoid stem cells. [1]

Multipotent*

(ii) Outline **two** defining features of stem cells. [2]

1. A stem cell is an ***undifferentiated/unspecialized**** cell capable of undergoing ***proliferation**** and ***self-renewal****;
2. and retains potential to ***differentiate**** to produce specialized cells upon receiving appropriate ***molecular signals****;

(b) Name precisely the genetic process occurring at:

(i) stage 1, to give naïve B lymphocytes capable of recognizing **different** antigens. [1]

Somatic recombination*

(ii) stage 2, to give an activated B lymphocyte that now produces IgG antibodies instead of the membrane-bound IgM antibodies. [1]

Class switching*

(iii) Stage 3, to give sub-clones that vary slightly in their ability to bind antigen **X**. [1]

Somatic hypermutation*

(c) **(i)** List the ways in which genetic variation is generated during meiosis, identifying all the stages of meiosis at which each process occurs. [4]

1. ***Independent assortment*** involving the random orientation ***of homologous chromosomes**** at the ***equator/metaphase plate**** during ***metaphase I****;
2. And separation of homologous chromosomes at ***anaphase I**** ultimately results in different combinations of parental chromosomes in the gametes;
3. ***Crossing over*** * between ***non-sister chromatids of homologous chromosomes**** occurs at ***prophase I**** at points called chiasmata;

4. Where equivalent portions of these chromatids break and rejoin, resulting in exchange of genetic material/alleles, hence new combination of alleles on the chromatid/chromosome;

5. Independent orientation of non-identical sister chromatids of each chromosome during ***metaphase II**** at the metaphase/equatorial plate & their subsequent separation during ***anaphase II****.

(ii) Both the process at stage 1 in Fig. 2.1 and the process of meiosis generate genetic variation.

State how the genetic variation generated by these two processes is different. [2]

1. Somatic recombination only alters the heavy and light chain gene loci whereas genetic variation in meiosis can alter any gene locus of the organism;
2. Somatic recombination involves removing and joining of gene segments whereas crossing over in meiosis involves exchange of equivalent segments;
3. Somatic recombination occurs on a single chromosome, whereas crossing over in meiosis involves non-sister chromatids on a pair of homologous chromosomes;

AVP

[Total: 12]

3 **(a)** With reference to Table 3.1, explain how a country's population size and wealth affects its percentage contribution to global carbon dioxide emissions. [4]

1. Both China and India have a large population size of approximately 19% and 17% with China being a more wealthy country at 15 % compared to India's wealth of 6%;
2. The percentage contribution to global carbon dioxide emissions from China is approximately 4 times higher at 23% compared to 6% from India;
3. Similarly, for USA and Russia, both countries have low population size (4% and 2% respectively) with USA being more wealthy at 17% compared to Russia at 4%;
4. The percentage contribution to global carbon dioxide emissions from USA is approximately 3 times higher at 14% compared to 5% from Russia;
5. From the data, the wealth of the country determines its higher contribution to carbon dioxide emissions;
6. This could be due to wealthier people burning more fuel to generate energy for electricity, transport, rearing livestock and other human activities;
7. There is also a lot of industrial processes in these countries which release CO_2 as well as burning of land and deforestation to clear land for agriculture;

(b) China, India and the United States of America plant young trees to increase the area of their land covered by forest. This counteracts part of their carbon dioxide emissions.

Explain, with reference to biochemical details, how planting young trees helps to counteract carbon dioxide emissions. [4]

1. As young trees grow, they continue to photosynthesise to produce sugars for their growth and survival;
2. Light energy is harvested by the photosystems in the thylakoids of the chloroplasts and converted into ATP and NADPH during the light dependent reaction;
3. In the light independent reaction, carbon dioxide combines with ***RuBP**** (5C compound) to form ***glycerate phosphate**** (GP), catalysed by enzyme, ***RuBP carboxylase**** (Rubisco);
4. GP (in the presence of ATP and NADPH) reduced to ***triose phosphate (G3P)**** and subsequently to RuBP;

5. Triose phosphate is the building block used in the formation of other carbohydrates or it can be redirected into other metabolic pathways to form proteins and fatty acids;
6. These macromolecules (proteins, carbohydrates and lipids) can be used to form structural tissues that is incorporated into the growing trees;
7. or it can be converted into storage molecules like starch or structural materials like cellulose that form part of the plant cell walls;

[Total: 8]

Section B

Answer **one** question in this section.

Your answers should be illustrated by large, clearly labeled 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) Describe the structure of the nuclear envelope, including the roles of each of the constituent biomolecules of cell membranes. [15]

1. The nuclear envelope is a double membrane that is perforated with ***nuclear pores****;
2. The outer membrane of the nuclear envelope is continuous with the rough endoplasmic reticulum;

3. Cell membranes contain ***phospholipids****, ***cholesterol**** and ***proteins****;

4. The double membrane is made up of 2 ***phospholipid bilayers****;
5. Each phospholipids are made up of 2 ***hydrophobic hydrocarbon tails / chains**** and a ***hydrophilic phosphate head**** are attached to a ***glycerol**;*
6. Phosphate heads are charged and hydrophilic and will interact with water and hydrocarbon tails are non-polar and therefore hydrophobic and arranged away from aqueous medium;
7. The hydrocarbon tails of phospholipids form hydrophobic interactions with each other, forming a ***hydrophobic core**** in the ***phospholipid bilayer** *;
8. The ***hydrophobic core**** of phospholipid bilayer serve as a barrier to movement of polar, charged and large molecules;
9. As interactions between the phospholipids are weak, phospholipids are able to move laterally in the bilayer, contributing to the ***fluidity**** of the membrane;

10. Cholesterol is an amphipathic molecule with ***hydrophobic**** four ringed structure and a ***hydrophilic**** hydroxyl group;
11. The OH group interacts with the phosphate heads of the phospholipids while the 4-ring structure forms hydrophobic interactions with the hydrophobic core of the membrane;
12. Cholesterol in involved in the regulation of ***membrane fluidity****
13. Cholesterol prevents the membrane from being overly fluid at warmer temperatures as cholesterol's rigidity restricts phospholipids' lateral movement;
14. Cholesterol prevents the membrane from being overly firm at lower temperatures as cholesterol prevents the close packing of phospholipids and hence prevents its solidification/ crystallization;

15. Transport proteins embedded in membranes control the movement of polar, charged and large molecules that are otherwise unable to diffuse across the membrane;

16. These proteins are ***transmembrane**** proteins with hydrophobic region that interact with the ***hydrophobic core**** of the membrane allow them to be embedded in the membrane;
17. They provide a ***hydrophilic**** channel which allows for the movement of polar and charged molecules across the membrane;
18. In the nuclear envelope, nuclear pores are formed by proteins that make up a nuclear pore complex;
19. Nuclear pores allow for the import of molecules such as ribonucleoside triphosphates into the nucleus, and the export of molecules such as the mature mRNA out of the nucleus;

(b) Explain the roles of the nuclear envelope in the functioning of a eukaryotic cell. [10]

1. Nuclear envelope encloses the cell's genome / DNA and protects the genome from reactions that are occurring in the cell;
2. It allows for compartmentalisation to occur, spatially separating ***transcription**** in the nucleus from ***translation**** in the cytoplasm;
3. This allows the formation of unique environments for these processes involving enzymatic reactions reactions;
4. The nuclear envelope serves as a barrier to large, polar and charged molecules, allowing only the selected molecules to move in and out of the nucleus via the ***nuclear pore****;
5. This allows for localisation of enzymes and substrates in the same compartment so that reactions can take place more efficiently;
6. The nuclear pores in the nuclear envelope allow for the diffusion of ribonucleoside triphosphate and the import of enzymes/proteins such ***as RNA polymerase**** into the nucleus to allow for ***transcription****;
7. Nuclear pore complexes recognises the ***3' poly-A tail**** and the ***5'-*** methylguanosine ***cap**** on ***mature mRNA****,
8. ensuring that only mature mRNA is exported out of the nucleus for ***translation**** in the cytoplasm;
9. The nuclear pores also allow for the import of ***ribosomal proteins****;
10. so that ribosomal proteins and ***rRNA**** can assemble to form ***ribosomal subunits**** in the ***nucleolus****;
11. Assembled ribosomal subunits are then recognised for ***export**** out of the nucleus into the cytoplasm;

[Total: 25]

5 (a) Many different polymers are formed in cells. A polymer is a chain of monomers. Describe how different polymers form in cells. [15]

1. Condensation reaction → formation of bonds with removal of a water molecule;
2. Hydrolysis reaction → breaking of bonds with the use of a water molecule;

A. Carbohydrates

3. Starch is made from ***condensation**** reaction of many ***α-glucose**** monomers;
4. ***Amylose**** - glucose monomers are linked by ***α(1-4) glycosidic**** bonds, forming a helical structure;
5. ***Amylopectin**** - glucose monomers are linked by α(1-4) glycosidic bonds within a branch and ***α(1-6) glycosidic**** bonds at branch points,
6. Cellulose is made from ***condensation**** reaction of many ***β-glucose**** monomers;
7. β-glucose monomers are joined by ***β(1-4) glycosidic bond**** → alternate monomers are inverted / monomers are inverted with respect to one another,

B. Proteins

8. A specific amino acid is covalently attached to ***3'CCA**** stem of a tRNA with a specific ***anticodon**** to form aminocyl-tRNA. This attachment is catalysed by

aminoacyl-tRNA synthetase*.

9. Translation initiation factors will facilitate binding of small ribosomal subunit and initiator tRNA carrying ***methionine**** to newly synthesized mRNA strand.
10. The anticodon (UAC) of initiator tRNA will complementary base pair with ***start codon (AUG)**** of mRNA.
11. Binding of large ribosomal subunit will complete ribosome forming translational initiation complex.
12. This positions initiator tRNA at ***peptidyl site (P site)**** leaving ***aminoacyl site (A site)**** vacant for incoming aminoacyl-tRNA molecules.
13. A second aminoacyl-tRNA with a specific ***anticodon**** and corresponding amino acid, binds to specific mRNA codon at A site via ***complementary base-pairing****.
14. A ***peptide bond**** is formed between adjacent amino acids, catalysed by ***peptidyl transferase**** of large ribosomal subunit. Methionine dissociates from initiator tRNA as a result and remains bound to second amino acid at A site.
15. Amino acids undergo ***condensation**** to form polypeptides with the removal of 1 water molecule;
16. The ribosome translocates in ***5' to 3'**** direction, shifting first tRNA to exit site (E site) allowing it to be released into cytosol. tRNA with growing polypeptide chain is now at P site and A site will hold a new incoming aminoacyl-tRNA with an anticodon complementary to next codon on mRNA.
17. This process continues until a ***stop codon (UAA/ UAG/ UGA)**** is reached at A site. ***Release factors**** will enter A site causing hydrolysis of bond between polypeptide chain and tRNA in P site.

C. Nucleic Acids

18. Replication of DNA is ***semi-conservative**** where the original strands of double helix separates and act as ***templates**** for synthesis of two new strands;
19. This gives rise to two new DNA molecules, each consisting of one original and one newly synthesised strand;
20. replication of DNA begins at ***origin of replication**** ;
21. where enzyme ***helicase**** will bind and ***unzip**** DNA molecule by breaking ***hydrogen bonds**** between complementary base pairs;
22. separated strands of DNA interact with ***single stranded DNA binding proteins**** so that it will remain single stranded and can serve as a ***template**** for replication;
23. ***Topoisomerase**** relieves overwinding strain ahead of replication forks by breaking, swivelling and rejoining DNA strands;
24. enzyme ***primase**** catalyses synthesis of a short ***RNA primer****; (Reject: RNA primase)
25. ***Complementary base pairing**** occurs between ***template**** strand and free incoming ***deoxyribonucleoside triphosphates****;
26. Whereby ***adenine**** forms 2 ***hydrogen bonds**** with ***thymine**** and ***guanine**** forms 3 hydrogen bonds with ***cytosine****;
27. ***DNA polymerase**** catalyses formation of ***phosphodiester bond**** linking DNA nucleotides;
28. and new DNA strand is synthesized in ***5' to 3' direction****; (A: template strand read from ***3' → 5' direction****)
29. ***RNA primers**** will then be removed and replaced by DNA by another DNA polymerase;
30. one of daughter strands known as ***leading strand**** will be synthesised continuously towards replication fork;
31. other strand known as ***lagging strand**** is synthesised discontinuously away from replication fork, giving rise to ***Okazaki fragments****;
32. ***DNA ligase**** catalyses formation of ***phosphodiester bond**** between Okazaki fragments, ***sealing the nicks****;
33. ***RNA polymerase**** will attach to ***promoter**** region of a gene on DNA molecule

with aid of protein factors;
34. RNA polymerase will then ***unzip**** DNA double helix by breaking ***hydrogen bonds**** between ***complementary base pairs****;
35. 3' to 5' DNA strand / one of the DNA strands will be used as the ***template**** strand for synthesis of a complementary mRNA strand;
36. ***Free ribonucleotides**** will bind by ***complementary base pairing**** to nucleotides on DNA template strand;
37. where ***adenine**** forms 2 ***hydrogen bonds**** with ***uracil****, ***thymine**** forms 2 ***hydrogen bonds**** with ***adenine****, ***cytosine**** forms 3 ***hydrogen bonds**** with ***guanine****;
38. RNA polymerase will catalyse formation of ***phosphodiester bonds**** between free ribonucleotides to form ***sugar phosphate backbone****;
39. Polymerisation of ribonucleotides will result in formation of a new mRNA strand that is synthesized in ***5' to 3' direction****;
40. RNA polymerase will dissociate from template DNA strand when it reaches ***termination sequence****;

(b) Explain why enzymes and transmembrane receptors must be made from a hundred monomers or more in order to fulfill their functions. [10]

1. Enzymes and transmembrane receptors need to have multiple domains/regions that serve different functions.

Enzymes

2. ***Active site**** contains numerous ***contact**** and ***catalytic**** residues.
3. Contact residues determine enzyme-substrate specificity.
4. Contact/binding residues bind reversibly with the ***substrate**** while positioning it in the correct orientation.
5. The substrate is held in ***active site**** by weak interactions like ***hydrogen bonds**** ***and ionic bonds****.
6. Catalytic residues act on the bonds in the substrate molecule and the ***R-groups**** of a few of the amino acids residues catalyse the conversion of the substrate to product.
7. Longer polypeptide chain allows for the formation of allosteric sites e.g. for inhibitor/activator allow regulation of enzyme activity.
8. Longer polypeptide chain allows for the formation of sites under than the active site for non-competitive inhibitors to bind to decrease enzyme activity.
9. ***Tertiary/quaternary structure**** of the enzyme is maintained via ***hydrogen bonds****, ***ionic bonds****, ***hydrophobic interactions**** and ***disulfide linkages**** which are formed between the ***R groups**** of the many different amino acids;
10. Structural residues interact to maintain an ***active site**** which is complementary in shape and charge to the substrate.
11. Large numbers of monomers allow the polypeptide to fold in a ***globular**** structure, where polar R groups are exposed to water molecules in the aqueous environment.
12. This allows the enzyme to be soluble since these polar groups can form ***hydrogen bonds**** with water molecules.

Transmembrane receptors

13. Transmembrane proteins have sufficient non-polar R groups of amino acids on its exterior surface that can form ***hydrophobic interactions**** with the non-polar hydrocarbon chains of the phospholipids in the bilayer;

14. The charged phosphate heads of the phospholipid bilayer interact with the charged / polar R groups of amino acids found on the exterior surface of the channel protein;

15. This allows the proteins to span the membrane;

16. In receptor proteins, the residues form a ligand-binding site which allows an extracellular signal to give rise to an intracellular response.

17. Intracellular domain, which will change shape to transduce signal to cytoplasm
    a. Binding sites to bind to relay proteins / G protein
    b. RTK enzymatic properties to catalyse reactions.

Total: 25]

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