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

ST. ANDREW'S JUNIOR COLLEGE
2024 JC2 PRELIMINARY EXAMINATIONS

H2 BIOLOGY **9744/03**

Paper 3

Wednesday 11th September 2024 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	/7
3	/13
4 or 5	/25
Total	**/75**

This document consists of **12** printed pages.

[Turn over]

Answer **all** *questions*.

Question 1

Colorectal cancer is the cancer of the colon and the rectum. Colorectal cancer is Singapore's top killer, affecting more than 1,865 cases each year. Colorectal cancer usually starts as a non-cancerous polyp (a growth of tissue) on the inner lining of the colon or rectum which may develop into cancer over time.

The Wnt signaling pathway is associated with the widest array of biological processes, including cell proliferation, differentiation, and diseases such as neurodevelopmental diseases and cancer.

Fig. 1.1 shows the Wnt signalling pathway. When Wnt signalling pathway is activated by binding of ligand Wnt to the LPR5/6-Frizzled receptor, β-catenin binds to other transcription factors and activate transcription of target genes.

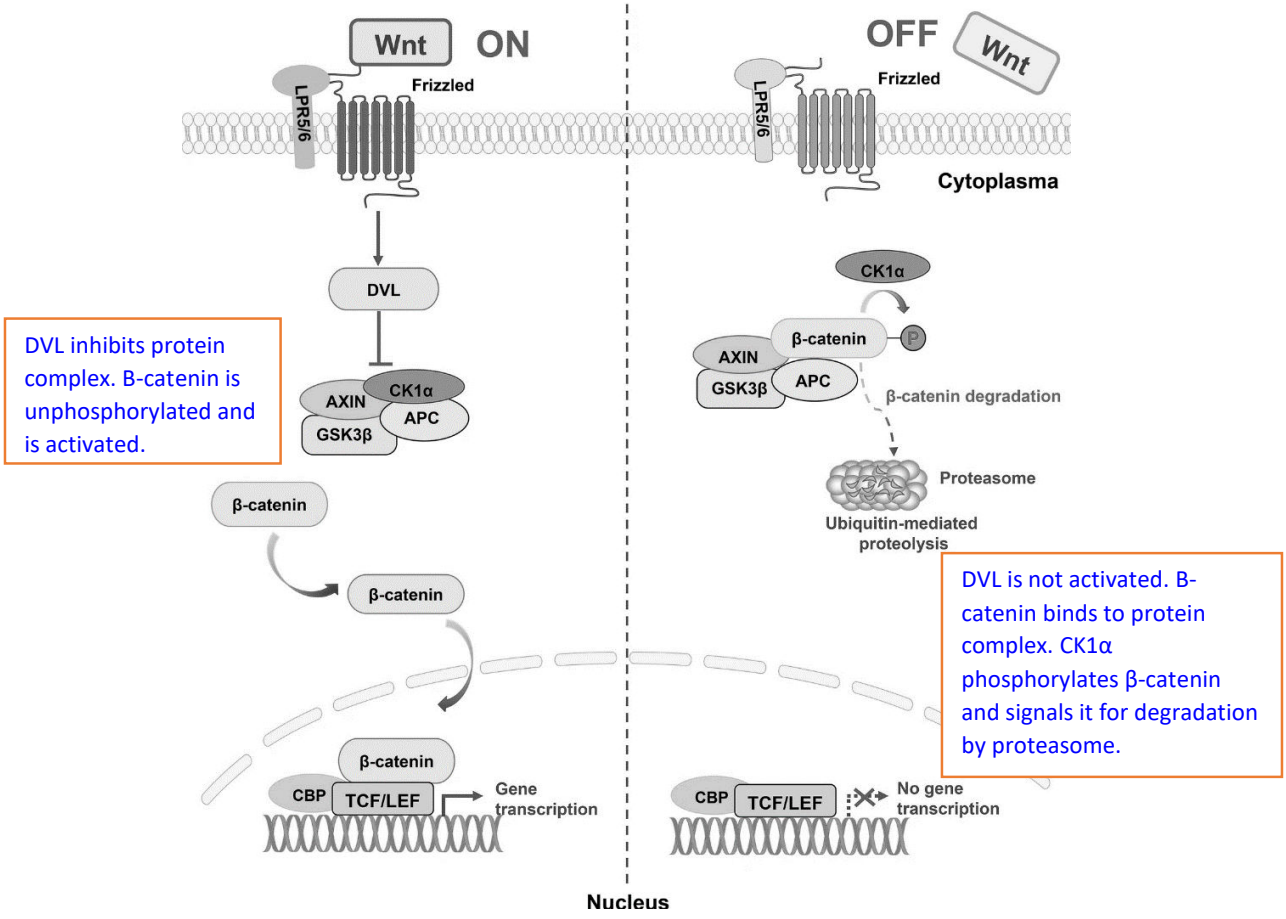


Fig. 1.1

(a) With reference to Fig. 1.1, state the level of gene expression that regulates β-catenin.

..... [1]

1 Post translational

(b) Suggest how does β-catenin bind to proteins APC and AXIN when the signalling pathway is inactivated.

..... [2]

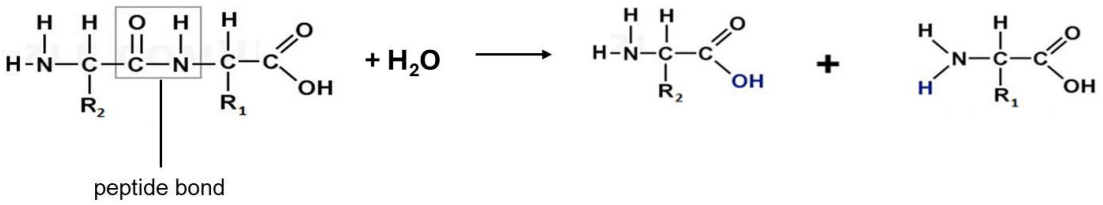
1 β-catenin is phosphorylated (by CK1α)
2 (ref, to recognise and bind via complementary conformation/ 3D shape) β-catenin has binding sites that recognizes the 3D conformation of APC and AXIN.;
3 (Ref. to R group interactions) PC and AXIN is held at the binding site via R group interactions such as hydrogen bonds and ionic bonds

(c) In development of colorectal cancer, APC gene is one of the first mutation that occurs. Using Fig. 1.1 and your knowledge, explain why cancer requires the accumulation of mutation [6]

1 Cancer is a **multi-step process**;
2 Loss-of-function mutation of APC gene/any of the protein in the complex (TSG) results in non-functional APC protein;
3 Gain-of-function mutation of proto-oncogene encoding for LPR5/6-Frizzled receptor results in **hyperactive receptor/ over production of receptors on cell surface membrane** (Accept β-catenin/DVL as example)
4 This leads to uncontrolled/excessive cell division (resulting in a large mass of cells known as tumour);
5 Progress through cell cycle checkpoints unchecked/ despite DNA damage (leading to accumulation of mutation in a **single cell lineage)**
6 Ref. to mutations resulting in loss of contact inhibition/ anchorage dependence
7 Other mutations such as **activation of telomerase genes** needs to occur for **cells to divide indefinitely**;
8 Mutations resulting in **angiogenesis** to form new blood vessels to **supply oxygen and nutrients** to cancer cells;
9 Further mutations results in metastasis occurs to invade other tissues/ develop secondary tumours (elaboration is required) [as long as idea of mutation is clear]

(d) Within the proteasome, β-catenin is digested into amino acids. Using a diagram, show how two amino acids are digested from a dipeptide.

..... [2]



1 Correct drawing of two amino acids (all atoms are clearly shown) + Correct drawing of the dipeptide ;
2 Shows peptide bond broken + Addition of a water molecule;

Accept if bonds not shown in NH2 and COOH.
Reject if written as NH_2-C-COOH (show bonding to wrong atom)

Fig. 1.2 shows the cell cycle and types of cyclin and CDK that promotes each stage of the cell cycle. Cyclin D is a positive regulator of the cell cycle and promotes G1 to S phase transition when bound to CDK4.

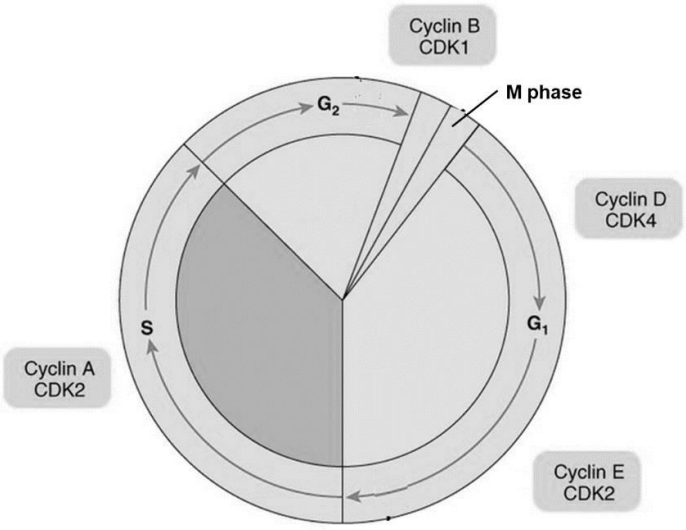


Fig. 1.2

(e) (i) State two events that happens during G1 phase of the cell cycle.

..... [2]

Any 2

1 Cell growth (increase in size)
2 Organelle synthesis
3 Proteins and enzymes synthesis
4 Free deoxyribonucleoside triphosphates synthesis
5 G1 checkpoint to ensure sufficient nutrients are available for S phase

(ii) With reference to Fig. 1.2 and the information provided, explain how does increase in gene expression of cyclin D increase the risk of cancer development.

..... [3]

1 Increase in expression of cyclin D may result in the cell **by-passing G1 checkpoint;**/not regulating cell cycle from G1 to S/ transition from G1 to S phase dysregulated
2 Continue to divide even if there are insufficient raw materials for DNA replication/ cell size is too small/absence of growth factors/ DNA damage;
3 Resulting in uncontrolled/excessive cell division/ mutation/DNA damage passed down to daughter cells/single cell lineage;

(f) One of the target genes activated by β-catenin is cyclin D. State the type of gene β-catenin is and explain your answer.

..... [2]

1 Proto-oncogene;

2 Controls expression of cyclin D which is responsible for **stimulating normal cell proliferation.**

Reject: regulatory gene

A commonly used therapy for patients diagnosed with an advanced stage of colon cancer is vinblastine, which destabilizes the structures of tubulins in microtubules by binding to them. Fig. 1.3 shows the action of vinblastine.

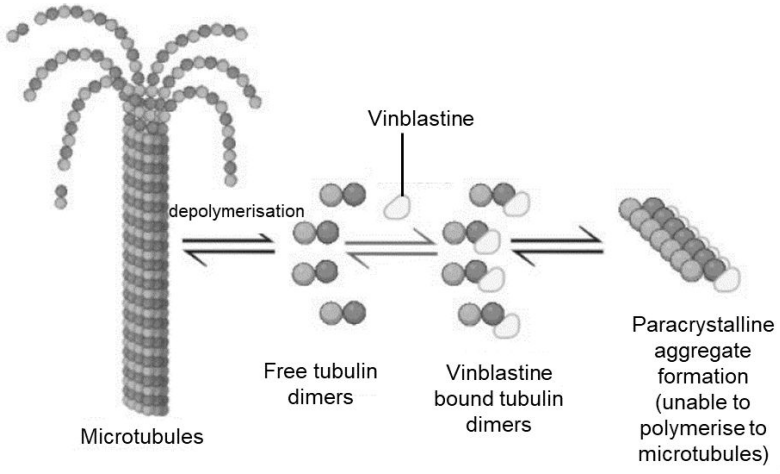
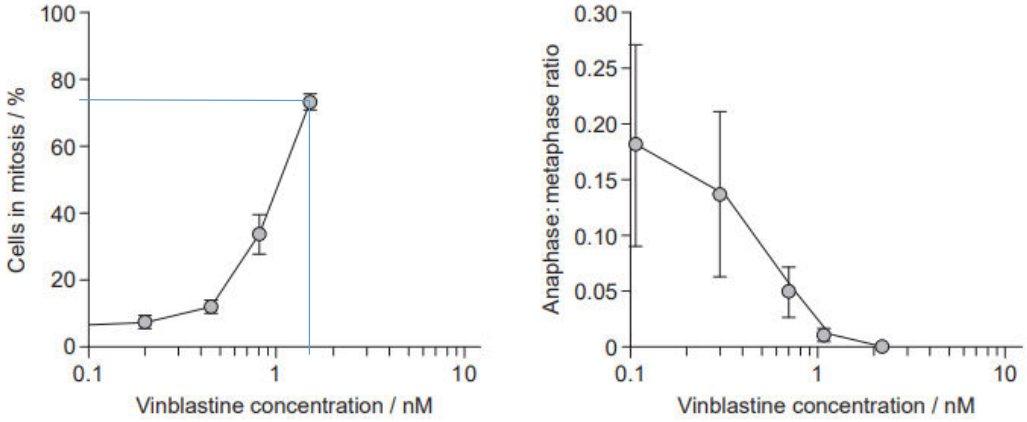


Fig. 1.3

The mechanism of action of vinblastine was investigated over a range of concentrations. The percentage of cells in mitosis and ratio of anaphase to metaphase in cells exposed to this drug *in vitro* for a fixed time were recorded. The data are displayed in Fig. 1.4. The x-axis in both graphs are of unequal intervals to allow the concentrations of vinblastine used



to be represented.

Fig. 1.4

(g) With reference to Fig. 1.3 and Fig. 1.4, explain how vinblastine work as an anti-cancer drug. [6]

1. As vinblastine concentration increases from 0.1 – 1.4nM (accept 1.2 – 1.6 nM), concentration of cell in mitosis increases from 6% (accept 4 – 8%), to 75% (accept 72 – 76%)
2. As vinblastine concentration increases from 0.1 – 2.2 nM (accept more than 2 – 2.4), anaphase to metaphase ratio decreases from 0.17 (accept 1.6 – 1.9) to 0;
3. Cells are in prophase/metaphase **OR** no cells progress to anaphase/metaphase
   Only accept cells are in metaphase/ does not progress to anaphase? (since there's no prophase data provided and from data, metaphase cannot be 0?)
4. (ref. to no formation of microtubules) Vinblastine prevents polymerisation of microtubules (in prophase) (Reject: metaphase); Accept insufficient microtubules formed
5. Kinetochore microtubules not formed to pull chromosomes/sister chromatids apart during anaphase/ chromosomes do not align at metaphase plate
6. Ref. preventing cancer cells from dividing/ proliferating

Colon cancer has a high mortality rate as it has a high recurrence rate. Despite recent improvements in treatments, early diagnostic techniques are required. With early detection and diagnosis, prognosis for the disease should improve.

Long non-coding RNAs (lncRNAs) are a class of RNAs whose transcripts are over 200 nucleotides in length, which do not have a protein coding capacity. They are found to have various roles in carcinogenicity and molecular mechanisms. Research has shown that the lncRNA small nucleolar RNA host gene 1 (SNHG1) contributes to the promotion of tumor development.

A group of researchers would like to investigate if SNHG1 is a potential biomarker to be used for early detection of colon cancer. They obtained colon cancer cells and adjacent non-cancerous colon cells from 16 patients. The relative expression of SNHG1 in the cancerous cells (tumour) and normal cells are shown in Fig. 1.5. Each line connects samples taken from the same patient.

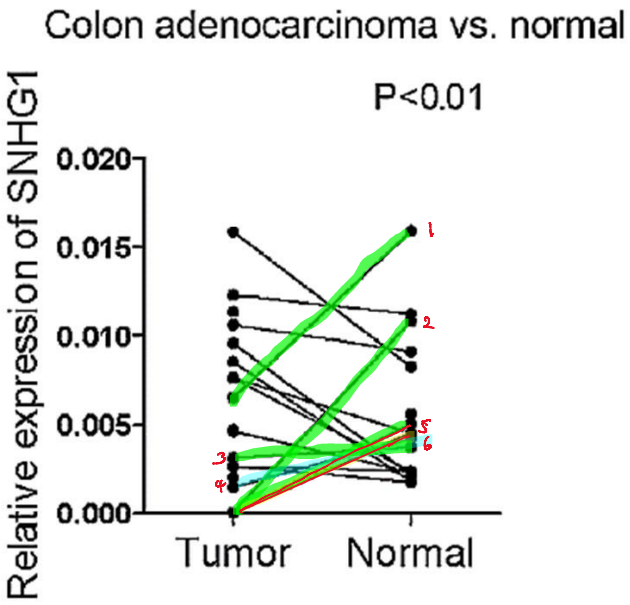


Fig. 1.5

(h) (i) Explain what a line with a positive gradient represents.

..... [1]

1 The relative expression of SNHG1 is higher in **normal cells than in tumour cells**.

(ii) Based on the results, the researchers concluded that SNHG1 is a suitable biomarker for early detection of colon cancer. Do you agree or disagree with their conclusion? Explain your answer.

..... [2]

1 Yes, I agree;
2 Relative expression of SNHG1 is higher in tumour cells than normal cells for 10 samples
OR
3 Ref. to more samples with higher relative expression of SNHG1 in tumour cells than normal cells

OR

1 No, I disagree;
2 (ref. to no clear trend/ inconclusive results due to higher in normal cells in some sample and higher in tumour cells in other samples) In 6 patients, SNHG1 expression is higher in normal cells than tumour cells, which is inconclusive
OR
sample size of 16 patients is too small;

The same group of researchers wanted to find out if SNHG1 promote tumour development via Wnt signalling pathway. They used a colon cancer cell line (HCT-116) and knocked down the expression SNHG1 (i.e., SNHG1 not expressed). Cell line with SNHG1-knock down was labelled as sh-SNHG1. The control had normal expression of SNHG1.

Protein analysis on concentration of β-catenin and cyclin D was carried out in the control and sh-SNHG1 group. Fig. 1.6 shows the results. The darker the band, the higher the concentration of protein present.

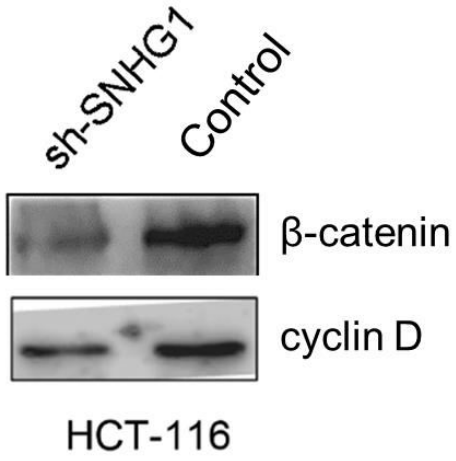


Fig. 1.6

(i) With reference to Fig. 1.6, describe the results and comment if SNHG1 promotes tumour development via the Wnt signalling pathway.

..... [3]

[Describe]

1 Control shows a **higher concentration** of β-catenin and higher concentration of cyclin D.
OR
Sh-SNHG1 cell line shows **lower concentration** of β-catenin and cyclin D/accept OWTTE

[Comment]

2 (ref. to SNHG1 affecting expression of β-catenin/cyclin D expression or β-catenin/ cyclin D protein production) SNHG1 affects the expression/is required for expression of β-catenin and cyclin D

3 SNHG1 **likely to promote** tumour development via Wnt signalling pathway;

[Total: 30]

QUESTION 2

Human cytomegalovirus (HCMV) is a common virus affecting humans. In people with a fully functioning immune system, infection by HCMV usually causes no, or only mild, symptoms.

Fig. 2.1A is a diagram of a section through HCMV. In Fig. 2.1B, only the outer part of HCMV is sectioned.

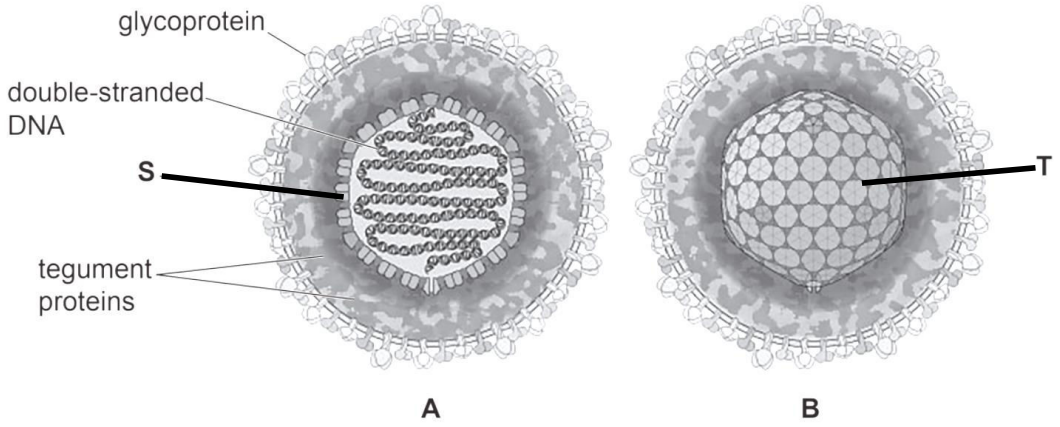


Fig. 2.1

The viral DNA shown in Fig. 2.1 contains genes that code for proteins important in viral replication and viral structure, including viral DNA polymerase and proteins known as tegument proteins.

Viruses can only replicate in host cells as they need to use processes and contents of the host cell. Complete viral particles that are released from the host cell are known as virions.

(a) Structure **S** in Fig. 2.1A is a subunit of structure **T** in Fig. 2.1B.

Name the biological molecule used to make structure S

S ..... [1]

S = protein ; Accept: amino acid

Reject protein coat, capsomere

(b) The virus in Fig. 2.1 is drawn as a spherical shape. Structure T is always the same shape.

However, electron micrographs show that HCMV virions are not all the same shape.

Suggest why HCMV virions can appear in different shapes.

.....[1]

1 presence of viral envelope made up of phospholipid bilayer therefore fluid / flexible resulting in different shapes ;
2 ref. to preparation for electron microscopy that results in distortion / squashed sample / artefact

3 AVP e.g. suggestion of variation in number / arrangement / organization of tegument protein

(c) With reference to Fig. 2.1A, state one similarity and one difference between the genetic material of HCMV and the genetic material of a typical bacterial cell.

..... [2]

similarity, one mark:

1 both have double stranded DNA;

difference, one mark:

1 Bacterial have circular DNA while HCMV has linear DNA

or

2 bacterial DNA (also) has genes for metabolism whereas HCMV does not have metabolic gene

or

3 bacterial DNA free in cytoplasm/nucleoid region but HCMV DNA surrounded by capsid / protein coat / T ;

(d) Suggest the role of viral DNA polymerase within the host cell.

..... [1]

1 viral DNA replication OR synthesis viral DNA ;

Accept stated function of DNA polymerase e.g. forms phosphodiester bonds between adjacent DNA nucleotides

Reject joins complementary nucleotides

Fig. 2.2 shows the reproductive cycle of HCMV.

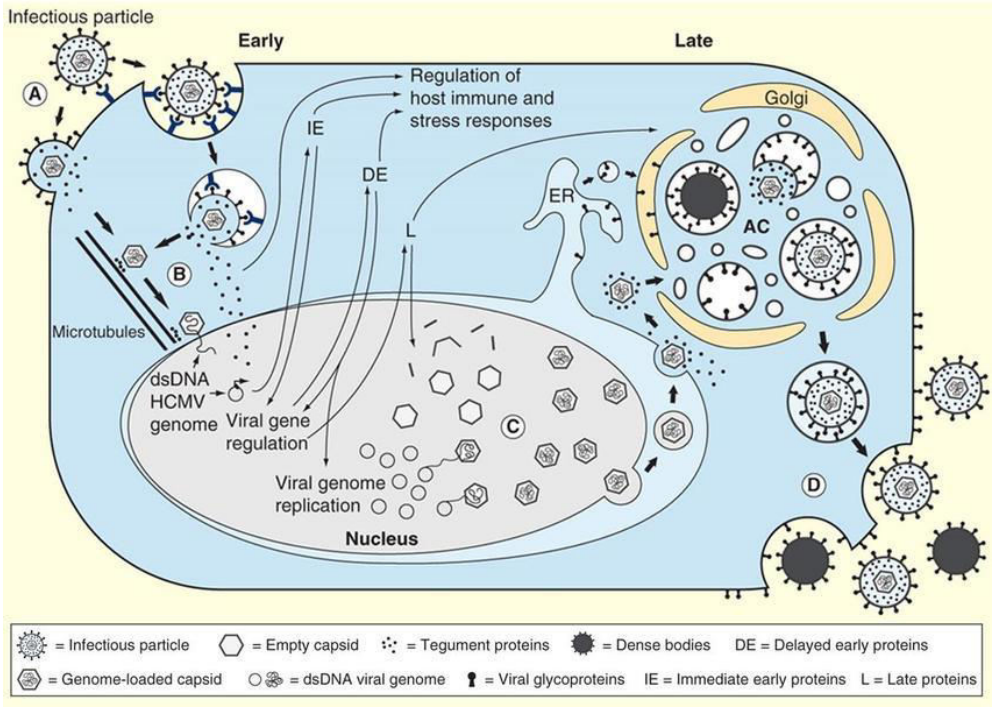


Fig. 2.2

(e) With reference to Fig. 2.2, briefly describe how HCMV enters the cell.

…… [2]

1. Via receptor mediated endocytosis
2. Fusion of endosome membrane with viral envelope to release the capsid.
3. Nucleocapsid travels to nuclear envelope via microtubules to release its genome into the nucleus.
   OR
4. Fusion of viral envelope with cell surface membrane
5. Nucleocapsid travels to nuclear envelope via microtubules to release its genome into the nucleus.

[Total: 7]

QUESTION 3

Malaria is a serious and often fatal disease that is transmitted by the mosquito *Anopheles gambiae*. One method of reducing the incidence of malaria is to control the numbers of these mosquitoes. In mosquitoes, as in humans, males have an X chromosome and a Y chromosome, while females have two X chromosomes.

Researchers investigated the possibility of producing genetically modified (GM) fertile male mosquitoes in which most of the sperm contained a Y chromosome and not an X chromosome. They predicted that introducing these males into a population of *A. gambiae* could greatly reduce the number of females in each generation and therefore reduce the numbers of eggs laid.

In order to produce the GM males, the researchers inserted the gene coding for a restriction endonuclease called I-PpoI. This restriction endonuclease was known to destroy the X chromosome of *A. gambiae*.

(a) The researchers found that I-PpoI destroyed the X chromosome during meiosis in the GM male mosquitoes. This prevented these males from producing sperm containing an X chromosome. However, I-PpoI was still active in zygotes produced by the fusion of female gametes with sperm containing a Y chromosome. Explain why this meant that the GM males produced no offspring at all.

……[2]

1 zygotes contain an **X chromosome** (from female gamete) which will be **destroyed by I-PpoI**;

2 so zygote **will die/ not develop** due to **only one Y chromosome present/no X chromosome in zygote**;

(b) The researchers modified the gene for I-PpoI, so that it produced a version of I-PpoI that was active only during meiosis in the males, and was not active in the zygote. They then tested the effect of introducing these GM males into a mosquito population.

• Several cages were set up. 50 adult male mosquitoes and 50 adult female mosquitoes without the I-PpoI gene were placed in each cage.

• 150 adult GM males were introduced into each cage. In half of the cages (A), these GM males had the normal gene for I-PpoI (all offspring will die). In the rest of the cages (B), the GM males had the modified gene for I-PpoI (reduction in female, gametes with y chromosome, only male offspring).

• The mean number of adult female offspring per cage was determined over the next six generations.

Fig. 3.1 shows the results.

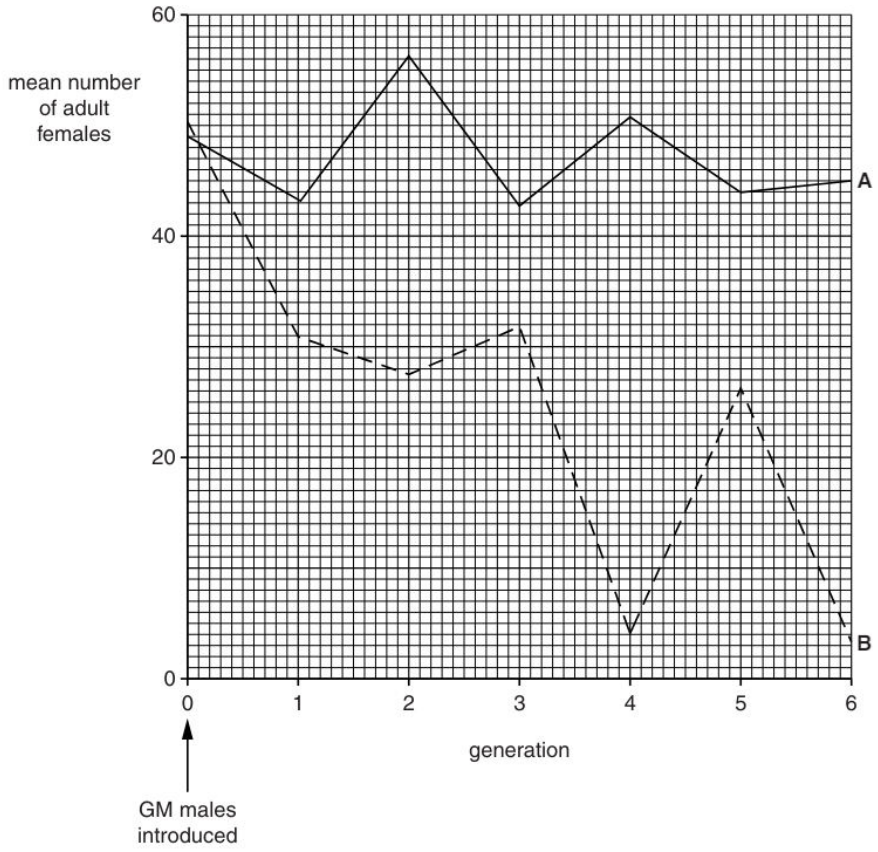


Fig. 3.1

(i) Describe and suggest explanations for the differences between the mean numbers of adult females in the two sets of cages during the experiment.

……[3]

1 generally more female mosquitos in cage A than in cage; Numbers of females mosquitos was **higher in A and oscillate/fluctuate between 43 to 56 mean female mosquitos in A from generation 1 to 6**. In contrast, the number of female mosquitos was **lower in B** and the **numbers decrease from 50 to 27 from generation 1 to 2 and oscillate/fluctuate between 3 to 32 mean female from generation 3 to 6** ;

suggest (max2)

3 **Zygote will die** as I-PpoI was still active in zygotes and X chromosome destroyed in zygote→ **GM males have no effect on the number of females in A;**

4 All adult female **offspring in A were from non-GM males** Or **all offspring from GM males die in A** ;

5 **In B, no female offspring from GM males** because **GM males cannot produce a sperm carrying an X chromosome**;

6 In B, **GM males can pass on the modified I-PpoI genes to male offsprings** resulting in further reduction of female mosquitos across generation 1-6.

(ii) Suggest possible difficulties that might arise if the technique of releasing GM male mosquitoes with the modified I-PpoI gene were used to try to control populations of *A. gambiae* that occur naturally in the wild.

……..[2]

Any two

1 idea that large numbers of GM males needed to be frequently release to have effect the wild population ;

2 Gene flow of non-GM mosquitoes from other areas ;
3 GM males might not survive in the wild/AW ;
4 people not prepared to accept the release of (GM) mosquitoes ;
5 High cost in producing GM mosquitos as need to release in large number

AVP Need to carry out long term in order to see the effect

Malaria vaccines stimulate an immune response with the production of antibodies.

(d)(i) Elaborate on how malaria vaccines result in the activation of naïve CD4 T cells.

……..[3]

1 Malaria antigens are engulfed by **antigen presenting cells (APC) such as macrophages/Dendritic cells/phagocytes via phagocytosis**

2 Malaria antigens are broken down into small fragments and presented on **MHC** II protein

3 naïve CD4 T cells with T cell receptor complementary to the antigen fragment will bind to the antigen presented and APC will secrete cytokines to activate the CD 4 T cells.

(ii) Describe how the antibodies can reduce the spread of the malarial pathogen through the bloodstream.

……..[3]

1 antibodies with complementary shape to **antigens on surface of malarial pathogen** bind to antigens / epitopes to prevent malaria parasite/ pathogen from entering **red blood cells / liver cells** ;
2 **Mark malaria parasite for phagocytosis** by phagocytes reducing the number of malaria parasite that **can infect the red blood cells**.
3 **Mark infected red blood cells/ liver cells for destruction** to prevent the infected red blood cells from releasing the progeny malaria parasites into the blood stream to infect more red blood cells;

Accept stimulates phagocytosis / opsonisation /phagocytes have receptors for constant region of antibodies

Must make reference to malaria pathogen/antigen to score

[Total : 13]

Essay

Answer **one** question only in this section.

Write your answers on the lined paper provided at the end of this question paper. Indicate the choice of question clearly on your answer.

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)** Biochemical modifications to chromatin structure alters the structural organization of chromatin packing of a cell's DNA into a form that helps to regulate gene expression. Describe how chemical modification regulates gene expression. [15]

(b) Evolution by natural selection over time reduces variation in a population. Compare evolution by natural selection between asexually reproducing populations and sexually reproducing populations. [10]

5 **(a)** In nature, many mechanisms preserve and restore variation in a population. Describe the various mechanisms that help to preserve variation in a population. [15]

(b) In cells, cycles play important roles in many biological processes. Explain the significance of cycles. [10]

Biochemical Modifications to Chromatin structure alters the structural organization of chromatin packing of a cell's DNA into a form that helps to regulate gene expression. Describe how chemical modification regulates gene expression. [15]

Chromatin Remodelling

1 the chromatin fibre when complexed with histones and folded into various levels of compaction, makes the DNA molecule **inaccessible** to proteins,
2 Chromatin-modifying enzymes provide initial control of gene expression by **making a region of DNA either more or less accessible to the proteins and enzymes** in the transcription machinery to bind to.
3 The **two best-studied chromatin remodelling processes** involve ***histone modification*** (i.e. acetylation / deacetylation, methylation / demethylation, phosphorylation of histones) and ***DNA methylation***.

4 **Histone acetylation + DNA demethylation → loosened** chromatin fibre (euchromatin) → **gene can be expressed**

5 **Histone deacetylation + DNA methylation → compact** chromatin fibre (heterochromatin) → **gene cannot be expressed / gene is inactivated**

HISTONE ACETYLATION

6 Histone acetylation – **addition** of **acetyl groups** ($-COCH_3$) **to the lysine** (amino acid) **residues** in histone tails.
7 This process is catalyzed by **histone acetyltransferases**.
8 The **positive charge of lysine residues** in histone tails is **neutralized** with the **addition of acetyl groups**.
9 This reduces the affinity of histone tails for binding to DNA / nucleosomes no longer able to bind to neighboring nucleosomes and gives transcription proteins and enzymes **easier access** to genes.

HISTONE METHYLATION / DEMETHYLATION

10 Histone methylation – **addition** of **methyl groups** to **lysine** or **arginine** amino acid residues on histone proteins.
11 This process is catalyzed by **histone methyltransferases**.
12 Can cause **transcriptional activation or repression**, depending on position of the amino acid methylated and the number of the methyl groups added to the amino acid residue.
13 The methylation of histones coordinates **recruitment of chromatin-modifying enzymes**, such as histone acetyltransferases, deacetylases, chromatin-remodelling enzymes etc, which then regulate chromatin condensation and nucleosome mobility to activate / inactivate transcription, as well as DNA repair and replication.
14 Histone demethylation – the removal of methyl groups from lysine residues on histone proteins.
15 This process is catalyzed by **histone demethylases**.

DNA METHYLATION / DNA DEMETHYLATION

16 DNA methylation – **addition** of **methyl groups** to certain bases (usually **cytosines**) in DNA. This process is catalyzed by **DNA methyltransferases**.
17 May physically impede binding of transcriptional proteins to the gene, or May facilitate recruitment of additional proteins such as histone deacetylases and other chromatin-remodeling proteins that can modify histones, to form heterochromatin and reduces transcription and genes that are heavily methylated in cells are not expressed.
18 Essential for **long-term inactivation of certain genes** which occurs during **normal cell differentiation.**

19 DNA demethylation – the removal of the extra methyl groups can turn on the expression of these genes.
20 This process is catalyzed by **DNA demethylases**.

QWC (1 m): Coherent, comprehensive and well-organised accounts of histone and DNA modifications.

Evolution by natural selection over time reduces variation in a population. Compare evolution by natural selection in asexually reproducing populations with evolution by natural selection in sexually reproducing populations. [10]

S – Similarities (max 5)

In both asexually reproducing and sexually reproducing populations:

1. Natural selection occurs due to preexisting **genetic variation** within the population;
2. Genetic variation can arise due to spontaneous / **random mutations**, which introduce **new** alleles into the population;
3. **Phenotypic variation** will therefore exist in the population;
4. Different niches/environments present **different selection pressures**, which act on phenotypic differences within the sub-populations;
5. Individuals with **favourable traits** for that niche/environment have a **selective advantage**, and hence are **selected for**;
6. These individuals have a higher chance of **surviving and reproducing** to **pass on their alleles** to the next generation;
7. Thus, resulting in an **increase in frequency of favourable alleles** within the population;

D – Differences (max 4)

1. For an asexually reproducing population, all members are formed by **mitosis and are genetically identical**, whereas for a sexually reproducing population, individuals result from **meiosis and fertilization between two gametes**, leading to greater genetic variation.
2. In an asexually reproducing population, spontaneous mutation contributes to variation in the population whereas in a sexually reproducing population, spontaneous mutation, crossing over, independent assortment, and random fusion of gametes contribute to even **greater genetic diversity**.
3. For an asexually reproducing population, as **genetic diversity is reduced/lacking** in the population, natural selection can lead to stabilising selection or all organisms are killed due to a selection pressure whereas for a sexually reproducing population, directional, stabilising and disruptive/diversifying selection can occur as the species has a greater gene pool for selection pressure to act on.
4. For an asexually reproducing population, populations may not be able to adapt in the presence of a selection pressure, whereas for a sexually reproducing population, populations can **adapt fast and population can recover** due to a selection pressure.
5. For an asexually reproducing population, population is **more susceptible to be wiped out** when the environment change as the organism have the same genotype, whereas for a sexually reproducing population, the population will be **less susceptible to be wiped out** when the environment changes

Feature of comparison	**asexually reproducing populations:**	**Sexually reproducing populations:**
Genetic variation of members in the population	All the members in the population area formed by **mitosis** and are **genetically identical.** There is less genetic variation in an asexually reproducing population.	All individuals are formed as a result of **meiosis and fertilisation** between two gametes and hence there is greater genetic variation in the population.
Sources of variation	Spontaneous mutation in population	Greater variation due to Spontaneous mutation, crossing over, independent assortment and random fusion of gametes
Adaptability	Slower adaptations to changing environment as organisms are genetically similar/smaller species diversity	Faster adaptations to changing environment as organisms have greater species diversity/gene pool
Modes of natural selection	It can lead to stabilising selection or all organisms are killed as genetic diversity is reduced/lacking in the population.	It can lead to directional, stabilising and disruptive/diversifying selection as the species has a greater gene pool.
Susceptibility to be wiped out	The population will be **more susceptible to be wiped out** when the environment change as the organism have the same genotype.	The population will be **less susceptible to be wiped out** when the environment changes;

R:

- all individuals in asexually reproducing populations are **genetically identical**;
- natural selection occurs **at random / is a random process**;

QWC (1m):

- Describes **at least 2 relevant** similarities and differences (about natural selection);
- Includes **both** comparisons from the first two rows* (D1 to D4) for flow of points;

Differences must be **point-for-point** + have **consistently clear features of comparison** (instead of one entire paragraph on asexually reproducing populations followed by another on sexually reproducing populations);

In nature, many mechanisms to preserve and restore variation in a population. Describe the various mechanisms that help to preserve variation in a population. [15]

1 For **Diploidy,** an organism has **2 sets of chromosomes/is diploid** and genetic variation is maintained and hidden from selection in the **form of recessive alleles**

2 Recessive alleles that are less favourable than their dominant counterparts, or even harmful in the current environment, can **persist because they are propagated in heterozygous individuals.**
3 When a heterozygote containing the recessive allele is able to survive and reproduce, the recessive allele is passed down to the offspring, and is preserved in the population.
4 **Heterozygote protection** maintains a huge pool of alleles that might not be favoured under present conditions but some could bring **new benefits when the environment changes**

5 Balancing selection occurs when **natural selection maintains stable frequencies of two or more phenotypic forms** in a population
6 It includes heterozygous advantage and frequency-dependent selection

7 Heterozygous advantage are for individuals who are heterozygous at a particular locus have greater fitness than those who are **homozygous at that loci**.
8 Natural selection will tend to maintain **two or more alleles** at that locus.
9 For sickle-cell allele, individuals homozygous for Hb^S (genotype Hb^SHb^S) suffer from sickle cell anaemia and Hb^A Hb^A are individuals who are normal
10 Individuals who are heterozygous (genotype Hb^AHb^S) suffer from the sickle cell trait. Hb^A and Hb^S alleles are **codominant** with respect to each other so heterozygous individuals produce both normal and abnormal haemoglobins
11 Malaria parasite acts as a **selection pressure** in places with malaria ;
12 Individuals without Hb^S allele / individuals of Hb^AHb^A genotype are at **selective disadvantage**, decrease in fitness due to mortality from malaria ;
13 Heterozygotes (who show the sickle cell trait carry a Hb^S/mutated/recessive allele) are at a **selective advantage** (as compared to individuals of Hb^AHb^A genotype) as **malaria parasite inside sickle-shaped red blood cells are removed by the immune system**

14 Frequency-dependent selection is when the fitness of a phenotype depends on how common it is in the population i.e. it is dependent on its frequency relative to other phenotypes in a given population.
15 The fitness of any form declines if it becomes too common in the population.
16 The **scale-eating cichlid fish attacks other fishes** from behind, darting in to remove a few **scales from the side of their prey**.
17 Some scale-eating fish are "left-mouthed" while some are "right-mouthed". Left-mouthed fish always attack their prey from the right side of the prey, while right-mouthed fish always attack from the left.
18 Prey species **guard against attack from whatever phenotype of scale-eating fish** is most common in the lake. Thus from year to year, **selection favours which ever mouth phenotype is least common** (this minority phenotype will be able to eat more scales).
19 The minority phenotype has a selective advantage compared to the majority phenotype and survives till reproductive age to pass on their genes to their offspring.
20 Results in increase in frequency of the minority phenotype.
21 Frequency of left- and right-mouthed fish oscillates over time, and balancing selection keeps the frequency of each phenotype close to 50%.

QWC (1 m): Coherent, comprehensive and well-organised accounts with relevant examples. Must mention diploidy and balancing selection.

In cells, cycles play important roles in many biological processes. Explain the significance of cycles.
[10]

Cell Cycle [include pt 7 for QWC]

1. The cell cycle is the **sequence of events** which occurs **between the formation of a cell and its division into daughter cells,** with the cycle **repeating** for each daughter cell;
2. Three main stages: **interphase, nuclear division, cytokinesis**;
3. During interphase - Cell produces many materials and or organelles required for carrying out all its functions;
4. Cell **replicates its DNA** (during **S phase of interphase**) to prepare for nuclear division;
5. Nuclear division – **mitosis** – forming **identical** cells for **growth / repair / asexual reproduction** AND **meiosis** – forming **gametes**;** (significance)
6. Cytokinesis - Division of **cytoplasmic contents** into **2 daughter cells**;
7. **Fusion** of a **haploid** sperm and **haploid** egg during **fertilisation** results in the formation of a **diploid zygote**;** (significance)
8. After fertilisation, the zygote undergoes a process of nuclear division **(mitosis)**; **(**This generates cells that are **genetically identical** to the original zygote)

Biochemical cycles - Krebs Cycle [include pt 10 for QWC]

1. **Pyruvate** from glycolysis is converted to **acetyl-CoA** via **oxidative decarboxylation**;
   Krebs cycle involves 3 main stages:
2. Acetyl CoA (2C) joins the cycle by combining with **oxaloacetate** (4C) to form **citrate** (6C);
3. Citrate is **decarboxylated** and **oxidised by dehydrogenation** to form **α-ketoglutarate** (5C) and **NADH;** (A: **oxidative decarboxylation**)
4. **Oxaloacetate** (4C) is **regenerated**; (idea of a cycle)
5. Krebs cycle involves multiple reactions, including **1 substrate-level phosphorylation**, **1 decarboxylation**, and **3 dehydrogenation reactions**;
6. As a result, **1 ATP, 1 CO_2, 2 NADH, and 1 $FADH_2$** are produced **per molecule of ⟨-ketoglutarate**;
7. For **each** molecule of glucose, glycolysis yields **2 molecules of pyruvate**, and hence **2 molecules of acetyl CoA**. As such, **two rounds of Krebs cycle** are needed to **completely oxidise one molecule of glucose**;
8. All 6 carbon atoms in glucose are lost as 6 CO_2;
9. For each 6C glucose molecule, **2 CO_2** are released via **link reaction**, and **4 CO_2** are released via **Krebs cycle;**
10. The mobile electron carriers (**NADH and $FADH_2$**) with their reducing power will next be transported to the **electron transport chain**, where the bulk of **ATP** is generated;** (significance)

Electron Transport Chain and Cyclic Photophosphorylation [include pt 8 for QWC]

1. The **photo-excited electron from P700** is captured by the **PS I primary electron acceptor;**
2. and then passed on to the middle part of the **first electron transport chain (ETC);**
3. As the photo-excited electron travels down the ETC, which consists of **electron carriers** of **progressively lower energy levels**, energy lost is **coupled to the formation of ATP via chemiosmosis;**
4. This electron eventually **fills the electron "hole" left in P700**, completing the cycle; (idea of cycle)
5. This way of synthesizing ATP using light energy is called **cyclic photophosphorylation.**
6. **No NADPH** is produced but passing the excited electrons to the second electron transport chain as in the non-cyclic light-dependent reaction, they are transferred to the first electron transport chain;
7. **No O_2** is produced as there is **no photolysis of water;**
8. Hence, **only ATP** is produced by **cyclic light-dependent reaction;**** (significance)

OR

Calvin Cycle [include pt 8 for QWC]

1. Calvin cycle is a pathway that reduces carbon dioxide to produce carbohydrates. It comprises of 3 phases:
2. Carbon fixation - This step involves **carbon dioxide** combining with **RuBP** (ribulose bisphosphate, a 5C sugar);
3. Product is an unstable 6C intermediate that will immediately split to form 2 molecules of **glycerate phosphate (GP) / phosphoglycerate (PG)** (for every one molecule of CO_2);
4. PGA reduction - **GP is reduced (gains electrons)** to form a 3C compound, **glyceraldehyde-3-phosphate (G3P)**;
5. This reaction requires the reducing power of **NADPH** and energy of **ATP** (products of non-cyclic light-dependent reaction);
6. RuBP regeneration - G3P has to be used to regenerate **RuBP;** (idea of cycle)
7. **5** molecules of **G3P** (a 3C molecule; total 15C) used to regenerate **3 RuBP** (a 5C molecule; total 15C);
8. In each round of Calvin cycle, **1 G3P channeled out** for eventual synthesis into **glucose**, and glucose can be polymerized into **starch** and **cellulose** AND regenerates **NADP**$^+$;** (significance)

QWC (1 m): Coherent, comprehensive and well-organised accounts of relevant cycles (minimum of two such accounts, each clearly indicating the cyclical nature, importance or significance of the cycle.