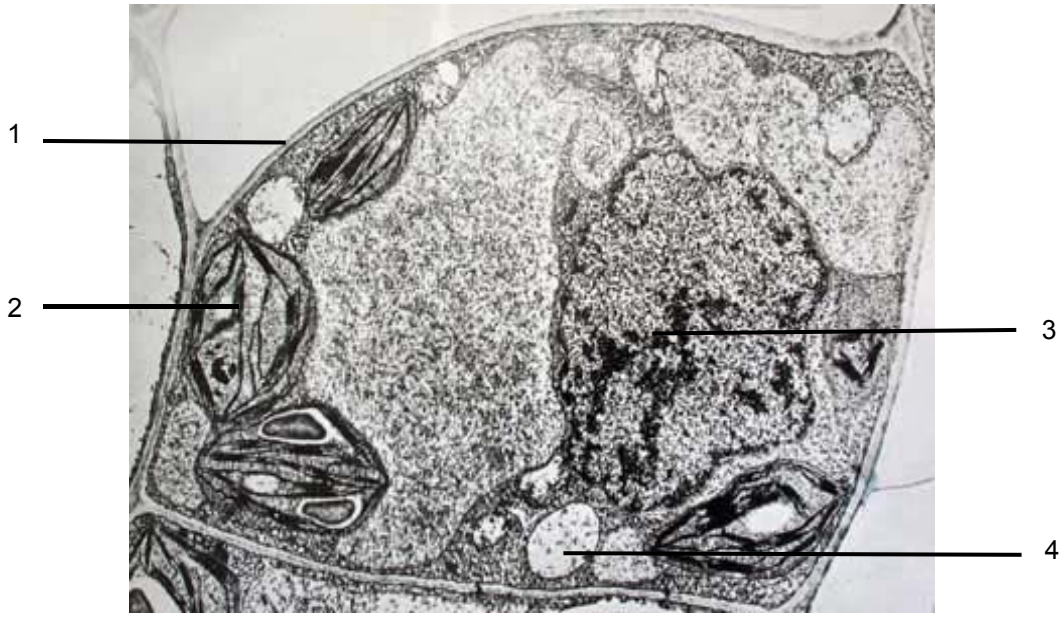
1 The electron micrographs show two different types of cells (not shown to scale).



Cell A

Cell B

Which row matches the structures to their correct function?

	Structure in cell A	Structure in cell B	Function
A	3	7	Provide energy for the cells
B	1	5	Maintain the shape of the cells
C	2	6	Photosynthesise
D	4	6	Secrete proteins

2 The plasma membrane is the cell's protective barrier as it prevents foreign molecules from entering the cell. However, in drug research experiments, foreign molecules such as drugs or short DNA fragments need to be transported into the cell.

Electroporation is a technique used to increase the permeability of the membrane transiently by treating the cell with short electrical pulses.

Which statement most likely explains how electroporation works?

A The short electrical pulses denature the membrane proteins, allowing foreign molecules to pass through.

B The short electrical pulses cause the foreign molecules to be attracted to the surface of the membrane.

C Electricity increases the hydrophobic nature of foreign molecules, allowing them to pass through the hydrophobic core of the phospholipid bilayer.

D Electroporation causes the phospholipids to move apart to create pores for foreign molecules to pass through.

3 Which row matches the descriptions of biological molecules to where they are found?

1 Polymer of glucose molecules linked by β-1,4 glycosidic bonds to form a straight chain

2 An unbranched and helical polymer of glucose molecules linked by α-1,4 glycosidic bonds

3 An amphipathic, phosphate-containing molecule

	1	2	3
A	Cell wall of eukaryotes only	Storage granules in animal cells	Plasma membrane of prokaryotes and eukaryotes
B	Cell wall of prokaryotes and eukaryotes	Storage granules in plant cells	Plasma membrane of eukaryotes only
C	Cell wall of prokaryotes and eukaryotes	Storage granules in animal cells	Plasma membrane of prokaryotes only
D	Cell wall of eukaryotes only	Storage granules in plant cells	Plasma membrane of prokaryotes and eukaryotes

4 Proteins can be categorised as globular or fibrous, depending on their structure.

How many of the following statements describes fibrous proteins only?

1 Monomers are linked by peptide bonds formed during translation
2 Long molecules which are insoluble in water
3 Helical molecules consisting of non-repeating sequences of amino acids
4 Contains hydrogen bonds between polypeptides

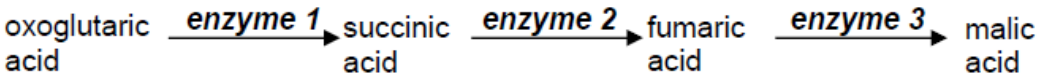
A 0

B 1

C 2

D 3

5 Malic acid is produced by a series of enzyme-catalysed reactions.



The addition of malonic acid results in an accumulation of succinic acid, a near absence of both fumaric acid and malic acid, and has no effect on the concentration of oxoglutaric acid.

Further addition of fumaric acid results in the formation of malic acid.

What does this information indicate about malonic acid?

A It is an inhibitor of enzyme 1.

B It catalyses the formation of succinic acid.

C It is an inhibitor of enzyme 2.

D It reacts with fumaric acid.

6 Which statement is correct regarding the enzymatic activity of catalase under the following conditions?

1 Addition of a non-competitive inhibitor

2 Addition of pH 13 buffer solution

3 Incubation at 10°C

A The hydrogen and ionic bonds between R groups of residues are broken in conditions 2 and 3, hence the rate of reaction decreases.

B The catalytic and binding residues in all active sites are affected in condition 1, hence the rate of reaction decreases.

C The chances of effective collisions to form enzyme-substrate complexes are low in condition 3, hence the rate of reaction decreases.

D The changes in the 3D conformation of enzymes are irreversible in conditions 1, 2 and 3, hence the rate of reaction decreases.

7 Which statements regarding stem cells are true?

1 Researchers can induce embryonic stem cells to differentiate into various cells and tissue types to repair damaged tissue.

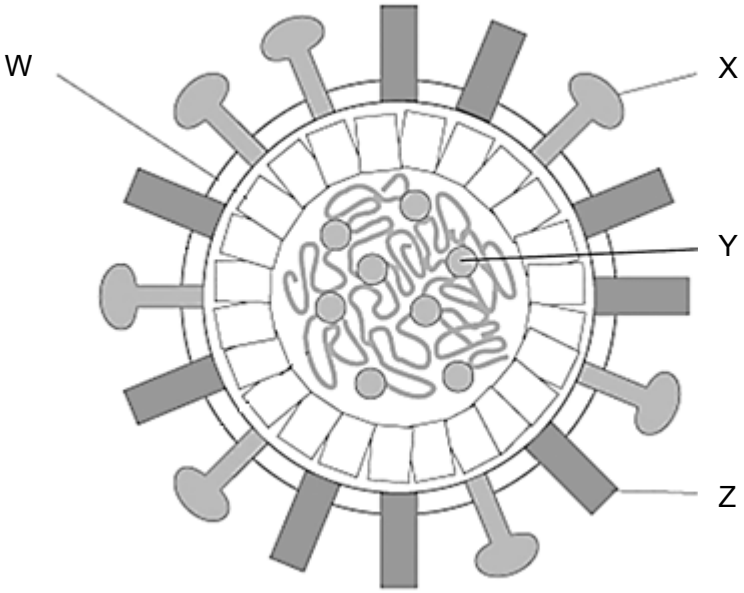
2 The use of embryonic stem cells for research can be an ethical challenge as the continued destruction of embryos could desensitise medical communities to the destruction of life.

3 One of the normal functions of blood stem cells in a living organism is the transplantation of such stem cells from normal healthy bone marrow donors to leukemia patients for treatment.

4 Blood stem cells can potentially differentiate into neurones under appropriate chemical signals.

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

8 The figure below shows a simplified representation of an influenza virus.



Which option does **not** describe the significance of the labelled structure?

	Structure	Significance
A	W	Acts as an additional protective coat obtained from host cell membrane via budding
B	X	Aids virus in its penetration of the mucus layer by breaking down mucoproteins
C	Y	Allows synthesis of viral genome and proteins
D	Z	Binds to sialic acid-containing receptors on epithelial cells and cleaves them for entry

9 Binary fission allows the bacteria to divide and gives rise to genetically identical daughter cells. Scientists are interested in uncovering the genetic mechanisms that regulate and drive binary fission, so as to design novel antibiotics that could specifically target and interfere with the process.

They found out that during binary fission, bacteria produce the protein FtsZ which assemble into a ring-like structure at the centre of the cell. This causes the cytoplasm to divide into two, before synthesis of a new wall begins.

Which of the following statements can be deduced from the description above?

1 The genes that code for FtsZ can be found within a plasmid.

2 An antibiotic that inhibits the action of FtsZ will result in only one cell with more than one chromosomes.

3 Mutations in genes coding for FtsZ will prevent the replication of DNA in binary fission.

4 The replicated chromosomes attach at the opposite ends of the parent bacterial cell before it divides into two daughter cells.

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

10 Which statement(s) about DNA polymerases and RNA polymerases is/ are correct?

1 They read the DNA template in the 3’ to 5’ direction.

2 They unwind and unzip double-stranded DNA.

3 They read the terminator sequence and stop adding nucleotides to nucleic acid chains.

4 They bind to the same specific sequences to start their processes.

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

11 The following steps describe a method to study the structure and localisation of protein kinase c in yeast cells.

- tRNAs with anticodon AAG were isolated and chemically modified to carry their specific fluorescent amino acids.
- During translation, chemically modified amino-acyl tRNAs bind to the large ribosomal subunit.
- Fluorescent amino acids are incorporated into the elongating polypeptide chain.
- After translation, the polypeptide chain folds into its native conformation and the positions of the fluorescent amino acids can be detected and studied.

Which of the following describes a condition which will allow the above method to be carried out?

A Peptidyl transferase is specific to the fluorescent amino acid and the elongating polypeptide chain in order to catalyse the formation of a peptide bond.

B Synthetic amino-acyl tRNA synthetase is specific to the fluorescent amino acid and chemically modified tRNA in order to form modified amino-acyl tRNA.

C The ribosome is specific to the mRNA sequence in order to synthesise protein kinase c.

D Chemically modified amino-acyl tRNA is specific to the P site of a large ribosomal subunit in order to add the fluorescent amino acid to the elongating polypeptide chain.

12 Which of the following statement(s) regarding the polymerase chain reaction (PCR) is/ are **not** true?

1 Without knowing the target sequence to be amplified, PCR cannot be carried out because primers cannot be synthesized.

2 There is a high fidelity of target sequence amplification due to the proof-reading activity of *Taq* polymerase.

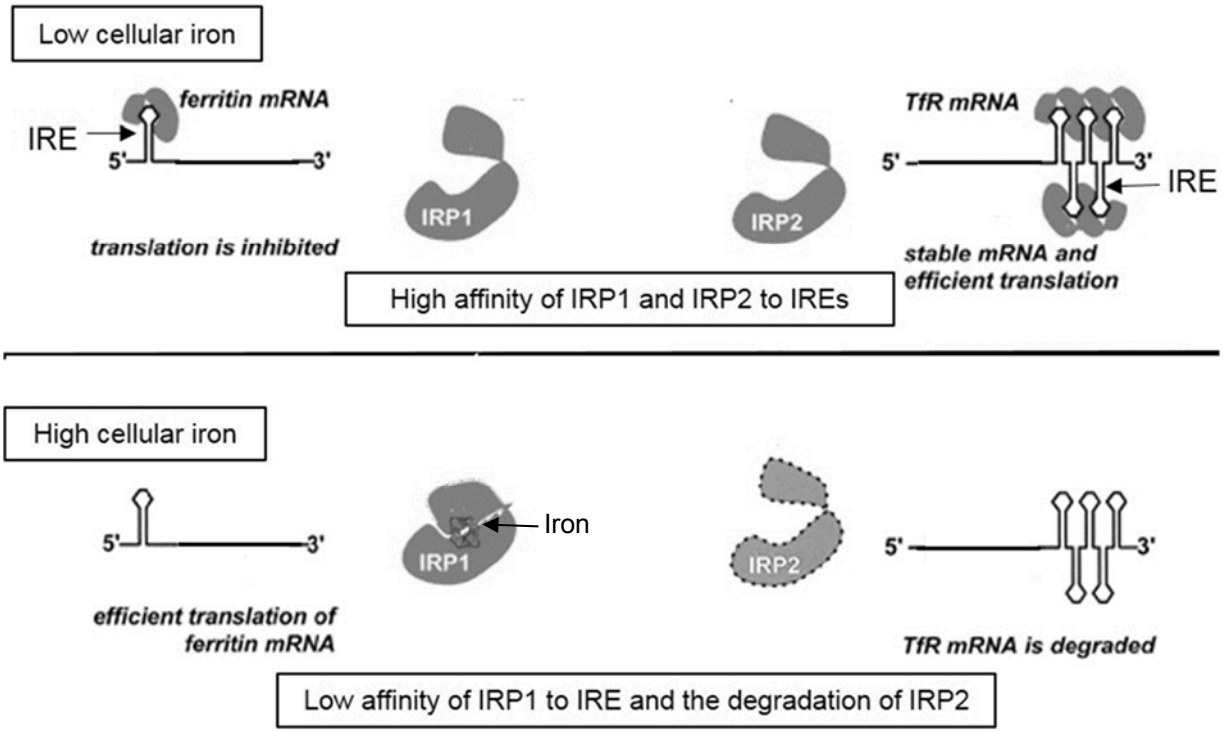
3 The amplification of the target sequence can still continue even when the starting PCR mixture is contaminated with DNA molecules from another origin.

4 If four copies of the target sequence are present after the first PCR cycle, there will be 2^{201} copies of the target sequence after 200 cycles.

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

13 In mammalian tissues, iron enter cells via transferrin receptors (TfR) and are stored when they are bound by ferritin proteins. The synthesis of TfR and ferritin is regulated through translational controls by regulatory proteins IRP1 and IRP2, which bind to iron-responsive elements (IREs) found on mRNAs.

IREs are loops found at the 5' UTR of ferritin mRNA and 3' UTR of TfR mRNA respectively. The effects of different iron levels on IRP1 and IRP2 are shown in the figure.



Which row correctly describes the translational control of ferritin mRNA and TfR mRNA?

	Cellular iron (Fe) levels	Ferritin levels	TfR levels
A	High	High	High
B	Low	Low	Low
C	High	High	Low
D	Low	High	Low

14 The table shows the genome size, number of genes and chromosome number of the following organisms:

Organism	Genome size (bp)	Number of genes	Chromosome number
E.coli bacterium	4 369 000	4289	n = 1
Baker's yeast	12 069 000	6200	2n = 32
Amoeba	290 000 000 000	Data not available	500 – 1000 (possibly polyploidy)
Rodent	3 399 900 000	Data not available	2n = 64
Humans	3 200 000 000	30 000	2n = 46

From the data provided, it is possible to conclude that

1 The less complex the organism, the smaller the genome size.

2 Amoeba has more non-coding DNA than humans.

3 The larger the genome size, the higher the number of chromosomes.

4 The number of housekeeping genes is the same for all organisms.

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

15 The arginine (*arg*) operon is present in some bacteria to regulate the synthesis of the essential amino acid arginine. The operon consists of structural genes that code for the enzymes that synthesise arginine. The operon is switched off when arginine is in excess.

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

A Excess arginine acts as the co-repressor which binds to the repressor.

B Excess arginine acts as the repressor which binds to the operator.

C The *arg* operon is repressible.

D The regulation of *arg* operon is similar to that of the *trp* operon.

16 A species of lizards, Whiptail lizards, reproduce only by parthenogenesis. This mode of asexual reproduction allows females to produce offspring alone, without the genetic contribution of a male.

Scientists are worried that this species may become endangered as a result of climate change.

Which statements support the scientists' concerns?

1 Offspring of parthenogenetic species are genetically identical.

2 Parthenogenesis produces too few offspring for a viable population.

3 Genetic contribution of a male is required in order for the offspring to survive.

4 In asexual reproduction, meiosis does not occur to produce genetically different gametes.

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

17 Elephants have been found to be strangely resistant, though not immune, to cancer. They are four times less likely to develop cancer as compared to humans. Elephants have 40 copies of the *p53* gene while humans only have two. In addition, three genes which code for DNA repair proteins have found to be very active.

What do these observations suggest?

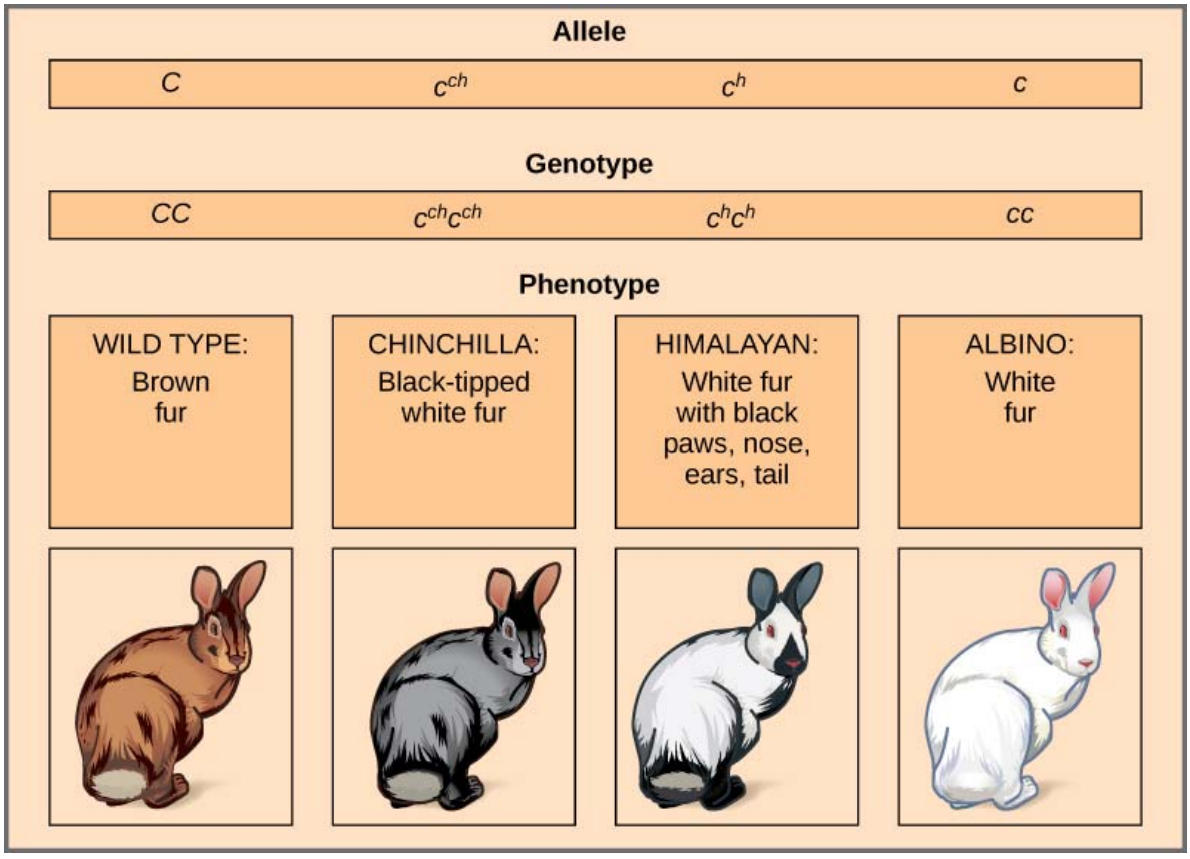
A All DNA mutations in the elephant are repaired.

B When elephants develop cancer, it is due to environmental causative factors such as excessive exposure to UV light.

C The occurrence of cancer is due to the *p53* oncogene, which stimulates the cell to divide rapidly, bypassing the cell cycle checkpoints.

D There is large amount of p53 proteins in an elephant cell which prevent cells with mutations from moving past the cell cycle checkpoints.

18 Rabbits carry the *C* gene which is required for the development of pigments in their fur. The alleles show a hierarchy of dominance when present in heterozygous individuals as shown in the figure. The order of dominance of these alleles, in descending order, is C, c^{ch}, c^{h}, c.



A scientist observed that the fur on the paws, noses and ears of Himalayan rabbits tends to be black while the rest of its body tends to be white. The scientist extracted a section of skin from the ear of a Himalayan rabbit and cultured the follicle cells. He discovered that when the cells are exposed to temperatures between 15°C to 25°C, they synthesise certain pigments. However, at temperatures beyond 35°C, these pigments are not synthesised.

Which statement best explains the results of the scientist's experiments?

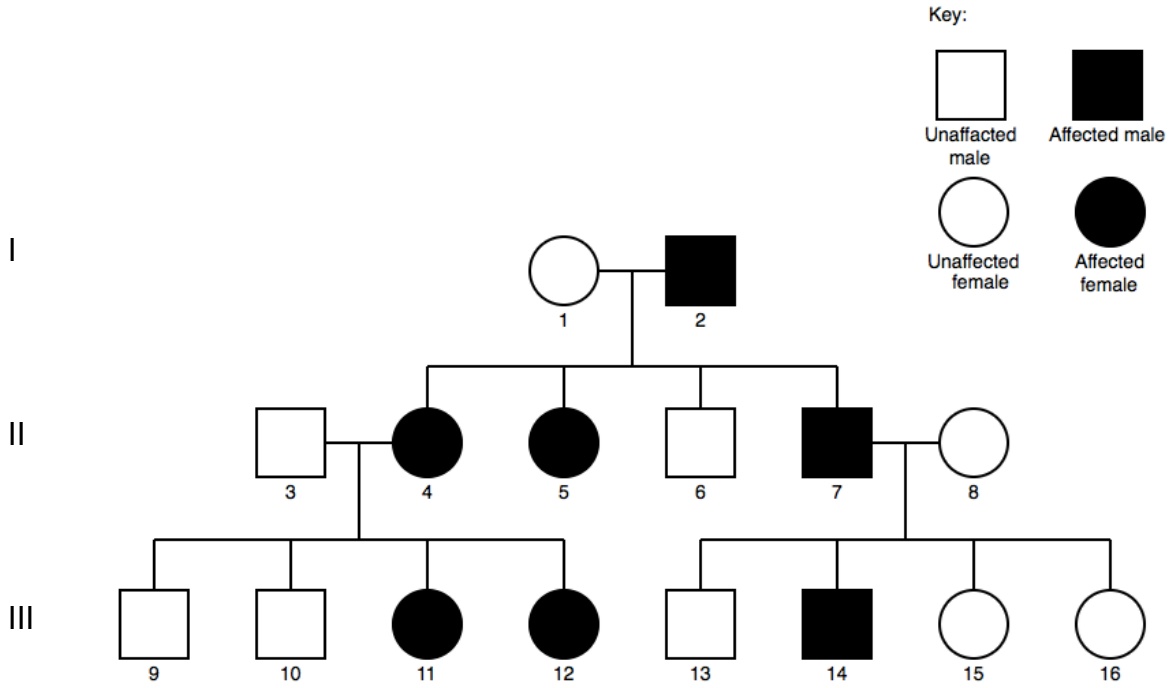
A Temperatures beyond 35°C alter the structure of the pigments produced by the skin cells, hence the rest of the Himalayan rabbit's body tends to be white.

B The Himalayan phenotype is a result of the c^{h} allele that produces a temperature-sensitive gene product which controls the production of the pigments.

C Multiple alleles of the *C* gene can give rise to white fur with black patches or white fur under different temperatures.

D The Himalayan phenotype is an example of incomplete dominance where it is an intermediate of the chinchilla ($c^{ch}c^{ch}$) and albino (cc) genotypes.

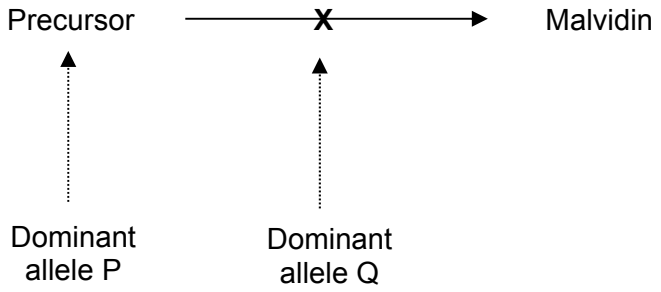
19 The figure shows the pedigree for the inheritance of polycystic kidney disease.



Assuming that the letters R and r denote dominant and recessive alleles respectively, what is the mode of inheritance for this disease and the possible genotype of individual 11?

	Mode of inheritance	Genotype of individual 11
A	Autosomal dominant	RR
B	Autosomal recessive	rr
C	X-linked dominant	$X^R X^r$
D	X-linked recessive	$X^r X^r$

20 In the *Primula* plant, production of the pigment malvidin creates blue-coloured flowers. Synthesis of malvidin is controlled by dominant allele P at the P/p gene locus which codes for a precursor substance. However, the conversion of the precursor substance to malvidin can be suppressed by the dominant allele Q at the gene locus Q/q as shown in the biochemical pathway. Flowers with the absence of malvidin will appear white.



When two plants with white flowers are crossed, the F1 generation has 44 plants with white flowers and 10 plants with blue flowers.

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

A The probability of obtaining a pure-breeding offspring at both loci with white flowers is 1 of 8.

B The deviation from the Mendelian ratio (9:3:3:1) is due to gene interaction in which gene Q alters the phenotypic expression of gene P.

C The genotypes of the parents must be PpQq x PpQq.

D The genotypes PPQQ, PPQq, PpQq and ppQq produce the same phenotype.

21 Through a series of energy transfers, chemiosmosis results in the generation of ATP during aerobic respiration and photosynthesis.

Which of the following statements describe the conditions necessary for the chemiosmotic synthesis of ATP in both processes?

1 The transport of a lipid-soluble molecule against its concentration gradient.

2 The presence of oxygen as a final electron and proton acceptor.

3 The impermeability of the phospholipid bilayer to substances which are polar or charged.

4 The transmembrane nature of electron carrier proteins.

5 The provision of a pore which allows the facilitated diffusion of molecules.

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

22 The electronmicrograph shows structures found in a cell.

Which row matches the events occurring at the labelled structures?

	X	Y	Z
A	ADP + Pi → ATP	ADP + Pi → ATP	$NADPH \rightarrow NADP^+ + H^+ + 2e^-$
B	ATP → ADP + Pi	ATP → ADP + Pi	$NADP^+ + H^+ + 2e^- \rightarrow NADPH$
C	$NAD^+ + H^+ + 2e^- \rightarrow NADH$	$H_2O \rightarrow 2H^+ + 2e^- + ½\ O_2$	CO_2 + RuBP → 2PGA
D	$FAD + 2H^+ + 2e^- \rightarrow FADH_2$	$2H^+ + 2e^- + ½\ O_2 \rightarrow H_2O$	Acetyl CoA + Oxaloacetate → Citrate

23 Nerve cells in the brain communicate by chemical molecules known as neurotransmitters. The following events, in the order shown, describe how binding of a neurotransmitter to a nerve cell will elicit a cellular response.

1 Neurotransmitter binds to a G-protein linked receptor (GPLR) at the cell surface

↓

2 A change in conformation of the GPLR allows the binding of a G protein to its intracellular domain

↓

3 G protein releases a GDP molecule in exchange for GTP

↓

4 The alpha subunit of the G protein dissociates from the other subunits

↓

5 The alpha subunit of the G protein activates adenylyl cyclase, which in turn converts ATP into cyclic AMP (cAMP)

↓

6 cAMP activates protein kinase A (PKA), which in turn phosphorylates transmembrane protein channels

↓

7 Phosphorylated protein channels open, allowing the facilitated diffusion of specific ions into the nerve cell

How many of the events allow for the amplification of signal to occur?

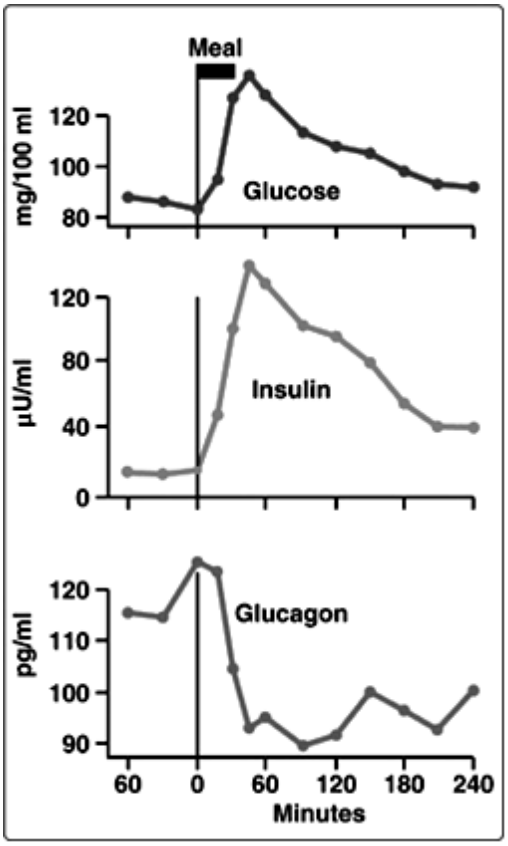
A 3

B 4

C 5

D 6

24 The figure shows the levels of glucose, insulin and glucagon found in blood, before and after a carbohydrate-containing meal was ingested.



Which row correctly identifies the events occurring at the respective timings?

	Timing	Events
A	60 minutes before meal	Glucagon results in the activation of glycogen phosphorylase, leading to increased rates of glycogenolysis in liver cells and an increase in blood glucose levels.
B	30 minutes before meal	Glucagon binds to G protein-linked receptors, leading to the activation of G proteins due to the hydrolysis of GTP molecules. Cellular responses lead to the maintenance of blood glucose levels.
C	At the start of meal (0 minutes)	Insulin binds to tyrosine kinase receptors, resulting in the cross-phosphorylation of receptor monomers. Cellular responses lead to a decrease in blood glucose levels.
D	60 minutes after meal	Insulin results in the translocation of glucose transporters to the cell surface, leading to increased rates of glucose uptake in muscle cells and a decrease in blood glucose levels.

25 Scientists examined the evidences used to establish the relationships between whales and other mammals such as hippopotamuses, pigs and cows.

The DNA sequences of common genes were examined in mammals, such as the haemoglobin beta-globin gene and the beta-casein gene. The beta-casein gene codes for beta-casein protein which is secreted in milk. The number of nucleotide differences in the beta-casein gene for four mammals is shown in the table.

	Whale	**Hippopotamus**	**Cow**
Pig	11	11	13
Cow	9	8	
Hippopotamus	3		

In addition, the fossil records showed that the most recent common ancestors of whales lived in the aquatic environment between India and Asia and their diet consisted mainly of fish or meat. However, the most recent common ancestors of hippopotamuses lived along the swampy coastal areas on the Asia continent and mainly fed on plants.

Which of the following deductions can be made from the evidences that scientists have gathered?

A Based on the molecular data, whales and pigs are more closely related than whales and hippopotamuses.

B Divergent evolution of the whales and hippopotamuses occurred due to limited gene flow between the ancestors.

C As there are no homologies present in the molecular data, whales are not related to the pigs and cows.

D Hippopotamus diverged from a common ancestor more recently than pigs, cows and whales.

26 Due to various human activities, there are many species that have become endangered. As these species face a reduction in population size, they are at risk of becoming extinct. It is found that the endangered species lose their genetic variation as the population size is reduced. Should the endangered population size increases, the genetic variation will not increase much within the next hundred years.

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

A A population would need to accumulate many heritable mutations over many generations in order to increase its genetic variation.

B As the population size of the endangered species is reduced, there will be a loss of alleles due to the death of the individual organisms.

C Epidemics could kill the endangered species easily as the population has low genetic variation, increasing their chance of extinction.

D As the population size is reduced, sexual reproduction with random mating within the endangered species will increase heterozygosity, resulting in higher relative fitness in the population.

27 A population of green anole lizards (*Anolis carolinensis*) is native to the trees in Florida in the United States of America (USA). They tend to occupy the lower branches of the trees which are thicker, instead of the higher branches which are thinner and snap more easily.

In the 1950s, the brown anole lizards (*Anolis porcatus*) from Cuba were introduced into Florida. These lizards are larger and heavier than the green anole lizards and also prefer the lower branches. Both the green and brown anole lizards feed on flying insects that fly around the branches. The adults of both species also tend to feed on the hatchlings of the other species.

Studies have shown that after 20 years, the green anole lizards have occupied the higher branches. Their toe pads are also larger than before, with sticky scales so that they can perch on the higher branches.

Which statement best explains how the evolution of the green anole lizard in Florida has occurred?

A Mating between the green and brown anole lizards during the 20 years results in the green anole lizards having larger toe pads and sticky scales, on which natural selection could act upon.

B Within the original green anole lizard population, there were some individuals that already had larger toe pads and sticky scales, on which natural selection could act upon.

C Green anole lizards climbed onto higher branches as the brown anole lizards could not do so.

D Green anole lizards which live longer usually leave more offspring since they have more reproductive opportunities.

28 The Varivax® vaccine contains attenuated varicella zoster virus for the immunisation and prevention of chickenpox.

The virus was propagated in human diploid cell cultures, where trace quantities of an antibiotic known as neomycin were introduced to prevent bacterial contamination during the manufacturing process.

The first dose of the vaccine is administered by injection into the fatty layer under the skin, and a booster dose is given at least 3 months after the first dose.

Which of the following statements about the Varivax® vaccine is **not** true?

A A booster dose is required because it is possible for memory cells to decline over time, causing immunity to fall below protective levels.

B The vaccine should not be used on a patient who is immunodeficient.

C The vaccine confers natural, active immunity in individuals who are injected with it.

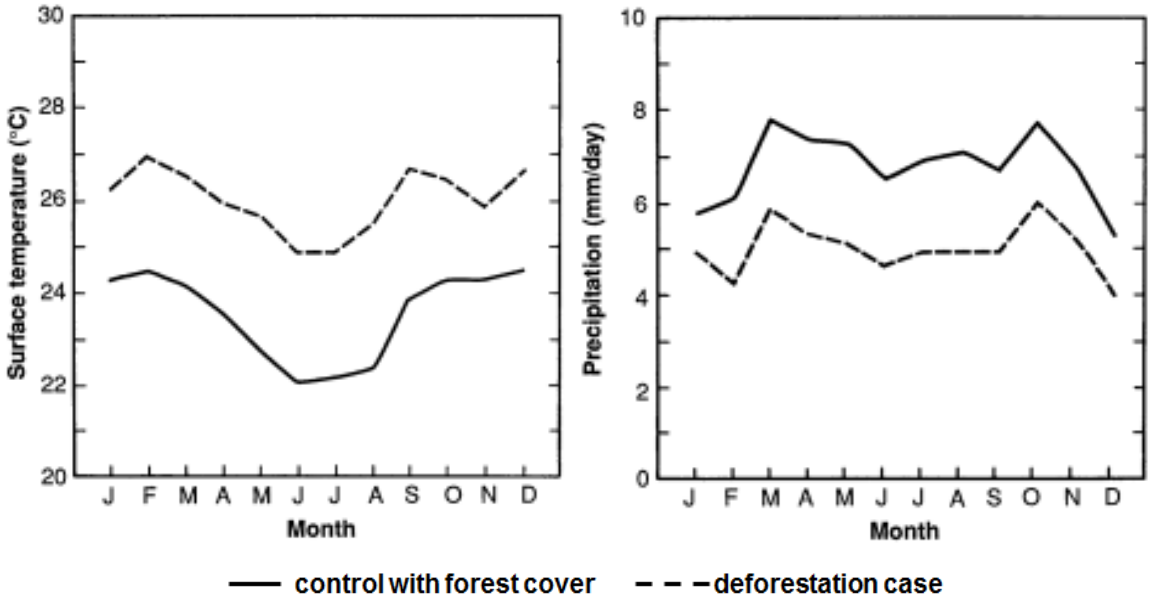
D Allergic reactions in the form of rashes may be expected in some individuals who are given the vaccine.

29 During an infection by the dengue virus (DENV), the pathogen which causes dengue fever, the secretion of antibodies by plasma cells forms part of the immune response mounted by the body.

Which option correctly explains why antibodies may or may not be effective against DENV?

	Effective against DENV	Not effective against DENV
A	Antibodies bind to extracellular DENV, preventing uptake by host cell through receptor-mediated endocytosis.	The extracellular phase constitutes a large part of the DENV reproductive cycle.
B	Antibodies bind to DENV, triggering the release of histamine by mast cells which results in an inflammatory response.	The RNA genome of DENV is prone to mutations, hence antibodies produced may not be able to bind to new viral strains.
C	Antibodies neutralise toxins secreted by viruses by preventing the binding of toxins to host cells.	DENV may undergo a latent phase where no viral proteins are synthesised and secreted.
D	Antibodies bind to extracellular DENV, facilitating their uptake by phagocytes.	Antibody-mediated opsonisation may facilitate the infection of macrophages which are target cells of DENV.

30 Scientists created a simulation of the effects of Amazon deforestation on the climate. In the simulation, an area of the tropical forest was replaced by a pasture of grass. The simulation provided monthly data on the temperature of the ground surface (surface temperature) and rainfall (precipitation) over a year-long period.



Which statements could explain these data?

1 Grass is a more effective carbon sink than trees.

2 The removal of forest cover disturbed the soil layers and resulted in carbon emissions.

3 Without the trees, the reduced transpiration rate resulted in less water vapour released into the atmosphere.

4 Increase in surface temperature could lead to increase in the rate of evaporation.

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

H2

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

1 Cholesterol is synthesised in the smooth endoplasmic reticulum (SER) in liver cells by a series of enzyme-catalysed reactions. Cholesterol is then transported to the Golgi apparatus where they are packaged into vesicles and subsequently released into a membrane-bound duct of the liver.

Fig. 1.1 is an electron micrograph of a section of a liver tissue.

Fig. 1.1

(a) Name structure **T** in Fig. 1.1 and describe its role in liver cells.

[2]

(b) Both prokaryotes and structure **T** have membrane proteins to help them perform the role described in (a). Suggest how prokaryotes perform this role.

[3]

(c) Describe the role of cholesterol in the cell surface membrane.

[1]

(d) Suggest how cholesterol is transported from the Golgi apparatus to the membrane-bound duct of the liver.

[2]

[Total: 8]

For examiner's use

2 Fig. 2.1 shows the activation of a G-protein linked receptor (GPLR) found in the cell surface membrane upon binding of a drug, salbutamol. Salbutamol is often used in the treatment of asthma – a long-term condition which narrows the airways in the lungs. The G protein consists of three subunits - α, β, and γ.

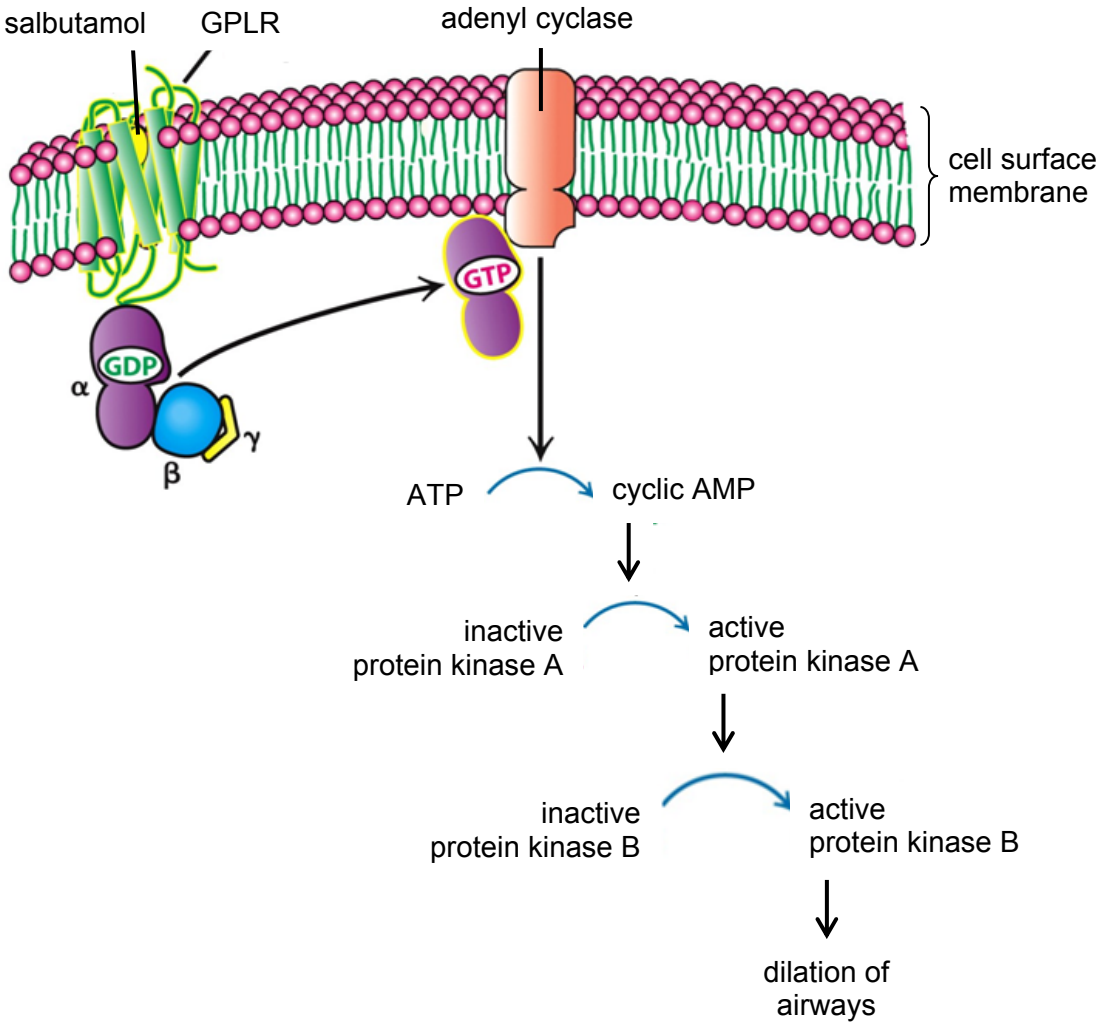


Fig. 2.1

(a) Describe how GPLR is held within the cell surface membrane.

[2]

(b) With reference to Fig. 2.1, describe how the use of salbutamol can relieve symptoms of asthma.

[4]

(c) There are many different types of receptors used by a cell to transduce extracellular signals. Some are located on the cell surface membrane while others are located within the cell.

Explain why some receptors are found on the cell surface membrane while others are found within the cell.

[2]

[Total: 8]

For examiner's use

3 tRNA molecules have an important role in gene expression. They can be found in the cytoplasm, mitochondria and chloroplasts of eukaryotic cells. Fig. 3.1 shows the structure of a tRNA molecule that is able to carry the amino acid threonine in the cytoplasm of a eukaryotic cell. It is 77 ribonucleotides long.

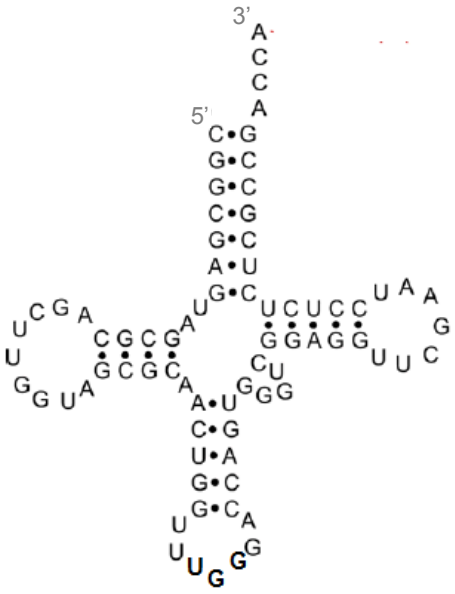


Fig. 3.1

(a) (i) With reference to Fig. 3.1, describe how the structure of a tRNA molecule differs from the structure of a mRNA molecule.

.....

.....

.....

.....[2]

(ii) Explain how these differences allow tRNA and mRNA molecules to perform their roles.

.....

.....

.....

.....[2]

Fig. 3.2 shows a tRNA molecule that is able to carry the amino acid threonine in mitochondria. It is 62 ribonucleotides long.

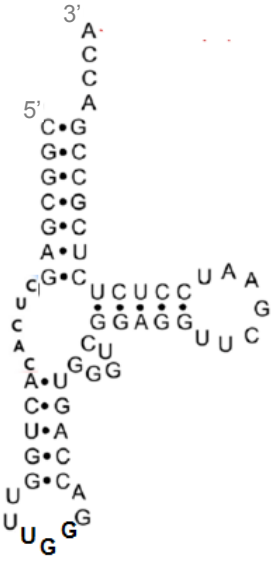


Fig. 3.2

(b) The structures of the tRNA molecules in the mitochondria and the cytoplasm of a eukaryotic cell are different although they are both able to carry the amino acid threonine. Suggest a reason for this difference.

[2]

There are 61 unique tRNA molecules in the cytoplasm of a eukaryotic cell.

(c) (i) Explain why there are 61 unique tRNA molecules in the eukaryotic cell.

[2]

(ii) Scientists found that there are more than 120 gene loci coding for tRNA molecules in the nuclear DNA, many of which are duplicate copies of the same tRNA gene.

Suggest an advantage of having more than 120 gene loci coding for the 61 tRNA molecules in the eukaryotic cell.

.....

.....[1]

(d) Explain how the structure of RNA polymerase allows for the synthesis of tRNA molecules.

.....

.....

.....

.....

.....

.....[3]

[Total: 12]

For examiner's use

4 Fig. 4.1 shows the reproductive cycles of a temperate bacteriophage.

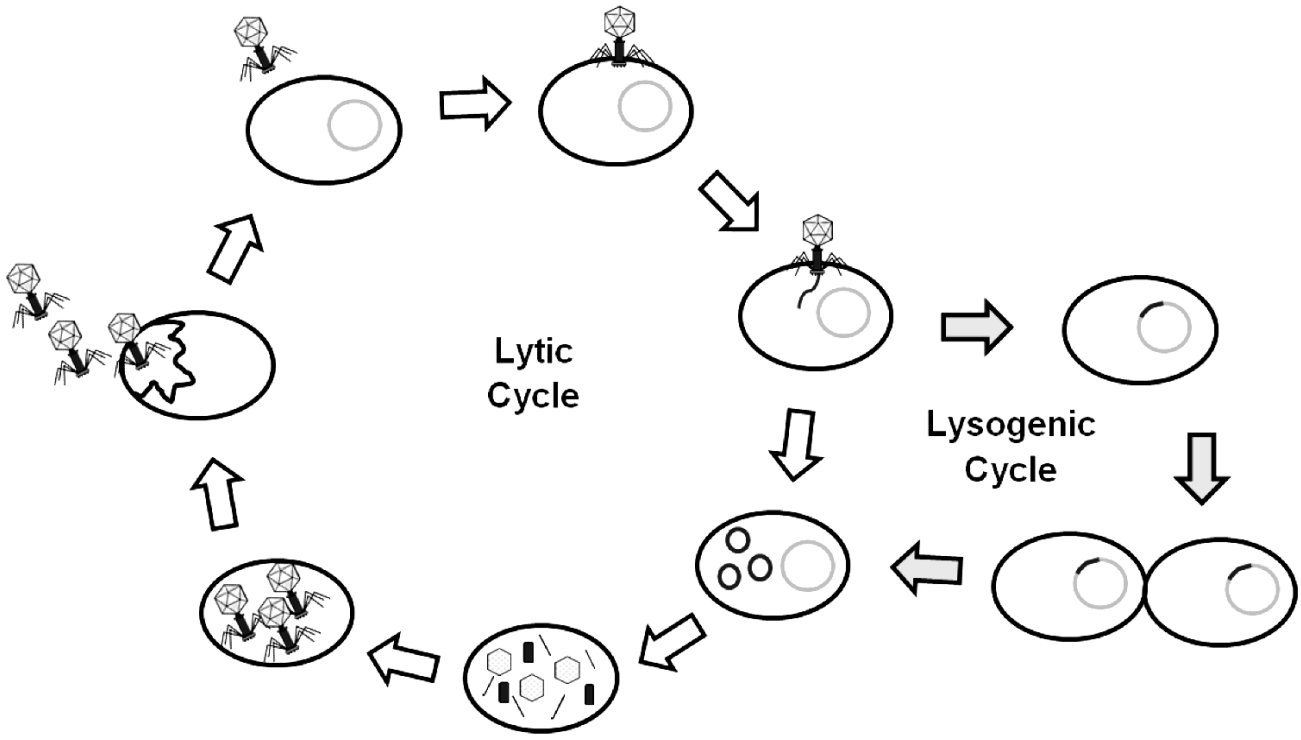


Fig. 4.1

(a) With reference to Fig. 4.1, describe the roles of the bacteriophage structures in its reproductive cycles.

[4]

(b) While their prokaryotic hosts contain both DNA and RNA, bacteriophages contain only DNA. Suggest why it is sufficient for bacteriophages to contain only DNA for their reproductive cycles.

[2]

(c) Describe an advantage of the lysogenic cycle of a bacteriophage to a population of bacteria.

[2]

[Total: 8]

5 Telomerase reverse transcriptase (TERT) is a component of the enzyme telomerase, which is responsible for maintaining telomere lengths in epidermal stem cells. These cells will differentiate to form specialised skin cells such as keratinocytes**.** A study on the role of the regulatory protein c-MYC in the synthesis of TERT mRNA was conducted in these cells. Fig. 5.1 shows the relative levels of TERT mRNA and c-MYC mRNA.

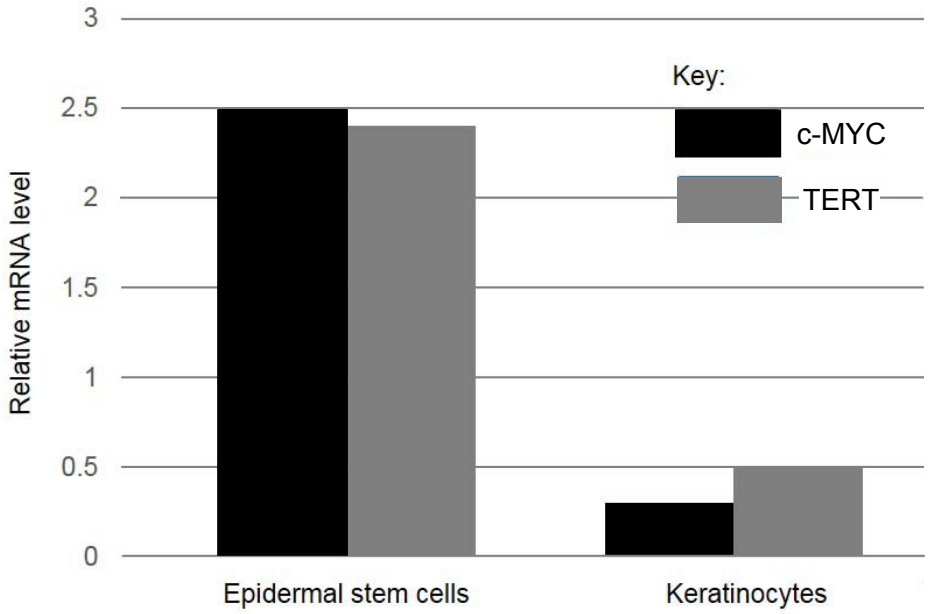


Fig. 5.1

(a) (i) With reference to Fig. 5.1, describe the relationship between the relative levels of TERT mRNA and c-MYC mRNA.

[2]

(ii) Suggest a role of the c-MYC protein in the regulation of *TERT* gene expression.

[3]

(b) Explain why TERT has a significant role in epidermal stem cells.

[3]

(c) Suggest why *TERT* gene is absent in bacteria.

[2]

[Total: 10]

6 Many diseases arise due to gene mutations and/or chromosomal aberrations.

(a) Distinguish between gene mutations and chromosomal aberrations.

[2]

Fig. 6.1 shows an error occurring during meiosis II.

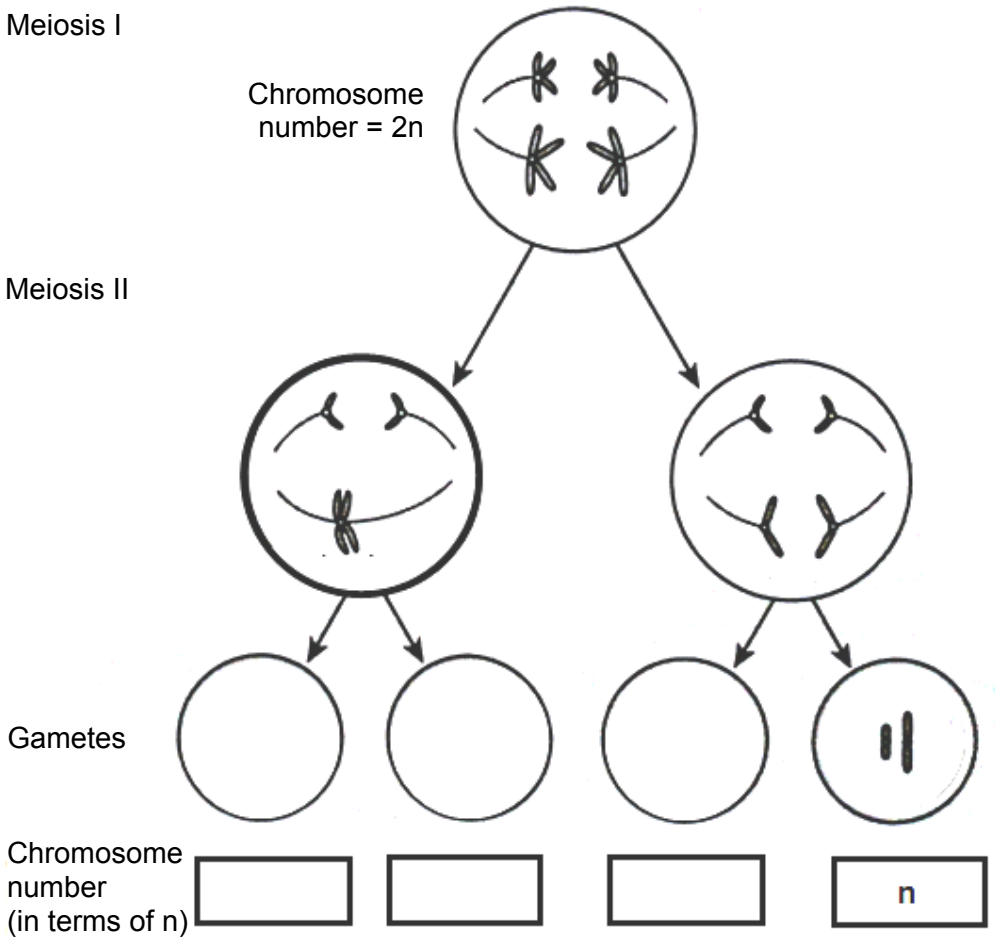


Fig. 6.1

(b) (i) Complete Fig. 6.1 with the correct chromosome structures and chromosome number (in terms of n) in the gametes. [2]

(ii) Explain the error shown in Fig. 6.1.

.....

.....

.....

.....[2]

(iii) Predict the chromosomal number (in terms of n) in each of the four gametes if a similar error had occurred in meiosis I instead of meiosis II.

.....

.....[1]

(c) Such errors can occur during mitosis too. Comment on whether this would lead to changes in the gene pool of a population.

.....

.....[1]

[Total: 8]

7 **(a)** Explain how genotype is linked to phenotype.

[3]

In the fruit fly, *Drosophila*, a gene determines the appearance of a dark transverse band on the thorax. Another gene determines the presence of crossveins on the wings. Two pure-breeding *Drosophila* were crossed, where one is banded with crossveins on the wings while the other is non-banded without crossveins on the wings. The F1 offspring were then test-crossed to produce offspring in the following ratio:

banded without crossveins	21
banded with crossveins	483
non-banded without crossveins	512
non-banded with crossveins	35

(b) Using the symbols **B** for non-banded thorax and **b** for banded thorax, **D** for presence of crossveins and **d** for absence of crossveins, draw a genetic diagram to show the results of the test-cross.

[4]

(c) Explain how the new combination of alleles arose in the gametes of the test-cross in part (b).

[3]

(d) Distinguish sex linkage from the mode of inheritance of the two genes observed in *Drosophila*.

[2]

[Total: 12]

For examiner's use

8 Concentrations of ribulose bisphosphate (RuBP) and reduced NADP were measured in samples of actively photosynthesising green algae in an experimental chamber. CO_2 is supplied continuously into the chamber throughout the experiment.

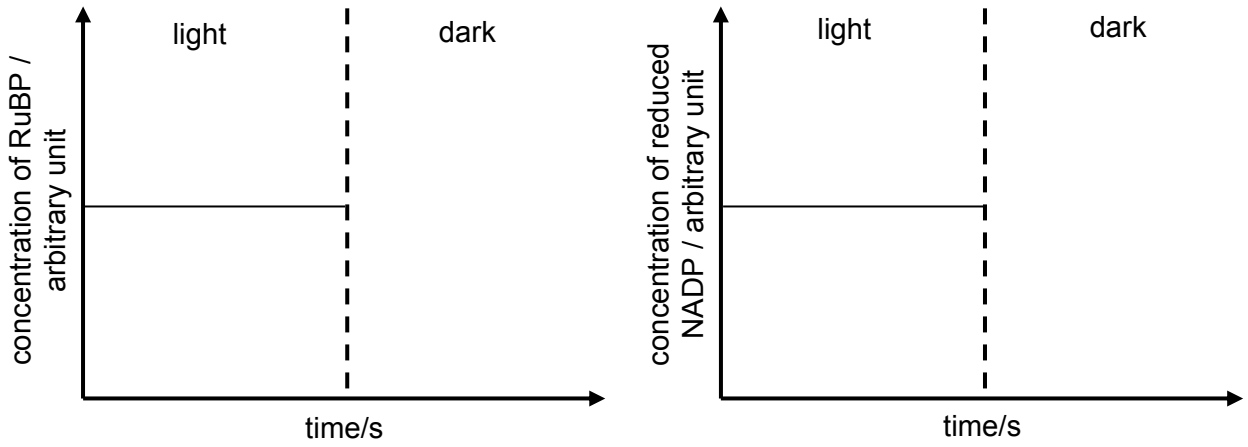


Fig. 8.1

(a) (i) In Fig. 8.1, complete each graph to show the concentrations of RuBP and reduced NADP when the light source was turned off. [2]

(ii) Explain the shape of the two graphs when the light source was turned off.

.....

.....

.....

.....

.....

.....

.....

[4]

(b) 'Calvin cycle is the reverse of Krebs cycle'. Comment on this statement.

[3]

(c) The Krebs cycle must be carefully regulated by the cell. If it is permitted to proceed unchecked, large amounts of metabolic energy would be wasted in the over-production of reduced coenzymes and ATP. α-ketoglutarate dehydrogenase is an enzyme in the Krebs cycle which catalyses the conversion of α-ketoglutarate to succinyl coA.

Suggest how reduced NAD can inhibit the action of α-ketoglutarate dehydrogenase.

[3]

[Total: 12]

9 A study reported on the change in beetle sizes in a population due to climate change. Larger beetles are affected when compared to smaller beetles. This could be because larger beetles are less likely to get enough oxygen to sustain a higher metabolic rate caused by higher atmospheric temperatures. Fig. 9.1 shows the effect of a temperature rise of 2°C on the size of larger and smaller beetles in a population over 100 generations.

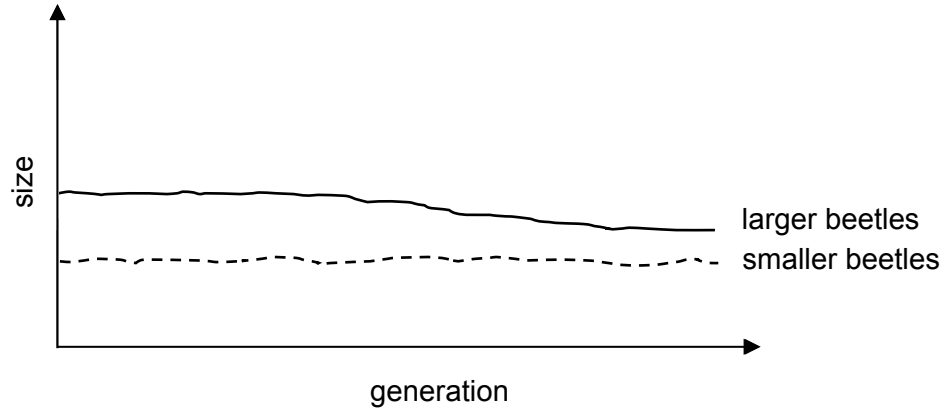


Fig. 9.1

(a) Explain how a temperature rise of 2°C may cause a change in the gene pool of the population of beetles over time.

[4]

(b) Suggest why a speciation event is unlikely to occur in this population of beetles as a result of climate change.

[2]

(c) Suggest the consequences of a decrease in beetle size on the ecosystem.

[2]

(d) Describe how molecular methods can be used to confirm that two beetles with similar morphology are of the same species.

[4]

[Total: 12]

For examiner's use

10 Multidrug-resistant tuberculosis (MDR-TB) is a form of tuberculosis (TB) caused by the bacterium *Mycobacterium tuberculosis,* which is resistant to treatment with the antibiotic rifampin. The first antibiotic treatment for TB began in 1943 and some strains *M. tuberculosis* developed resistance to rifampin through genetic changes. Fig. 10.1 shows rifampin binding to RNA polymerase in bacterial cells.

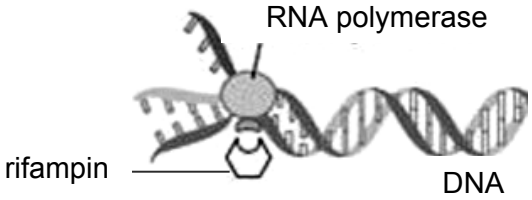


Fig. 10.1

(a) With reference to Fig. 10.1, explain why rifampin may be used to treat tuberculosis.

[2]

(b) Suggest how the genetic changes which caused rifampin resistance could be transferred within a population of *M. tuberculosis* through direct contact of bacteria cells.

[3]

Bacilli Calmette-Guérin (BCG) is a vaccine containing attenuated bacteria and can provide protection against tuberculosis. The attenuated bacteria have antigens which stimulate an immune response. Recent studies have shown that BCG can also give protection against leprosy, a disease caused by the bacterium *Mycobacterium leprae*.

(c) (i) Outline the roles of T lymphocytes in the adaptive immune response after the administration of BCG.

[3]

(ii) Suggest why BCG can also provide protection against leprosy.

[2]

[Total: 10]

1 Cholesterol is synthesised in the smooth endoplasmic reticulum (SER) in liver cells by a series of enzyme-catalysed reactions. Cholesterol is then transported to the Golgi apparatus where they are packaged into vesicles and subsequently released into a membrane-bound duct of the liver.

Fig. 1.1 is an electron micrograph of a section of a liver tissue.

Fig. 1.1

(a) Name structure **T** in Fig. 1.1 and describe its role in liver cells.

1. **Structure T is the mitochondrion;**
2. **Site of ATP synthesis for synthesis of cholesterol/glycogen (or other liver-specific functions);**

[2]

(b) Both prokaryotes and structure **T** have membrane proteins to help them perform the role described in (a). Suggest how prokaryotes perform this role.

1. **Presence of electron carriers / ATP synthase;**
2. **Embedded in cell surface membrane;**
3. **Electron carriers use the energy from the transport of the electrons to pump H^+ across the membrane, generating a proton gradient/pool;**
4. **ATP synthase which uses the energy of the proton gradient/proton motive force/flow of protons for chemiosmotic synthesis of ATP;**
5. **AVP;**

[3]

(c) Describe the role of cholesterol in the cell surface membrane.

Maintain fluidity of the membrane by preventing close packing of phospholipids at low temperature / prevent phospholipids from moving too far apart when temperature is high;

[1]

(d) Suggest how cholesterol is transported from the Golgi apparatus to the membrane-bound duct of the liver.

1. **Secretory vesicles containing cholesterol pinch off the GA and move along microtubules to the cell surface membrane;**
2. **They fuse with the cell surface/duct membrane and discharge cholesterol outside the cell via exocytosis;**

[2]

[Total: 8]

For examiner's use

2 Fig. 2.1 shows the activation of a G-protein linked receptor (GPLR) found in the cell surface membrane upon binding of a drug, salbutamol. Salbutamol is often used in the treatment of asthma – a long-term condition which narrows the airways in the lungs. The G protein consists of three subunits - α, β, and γ.

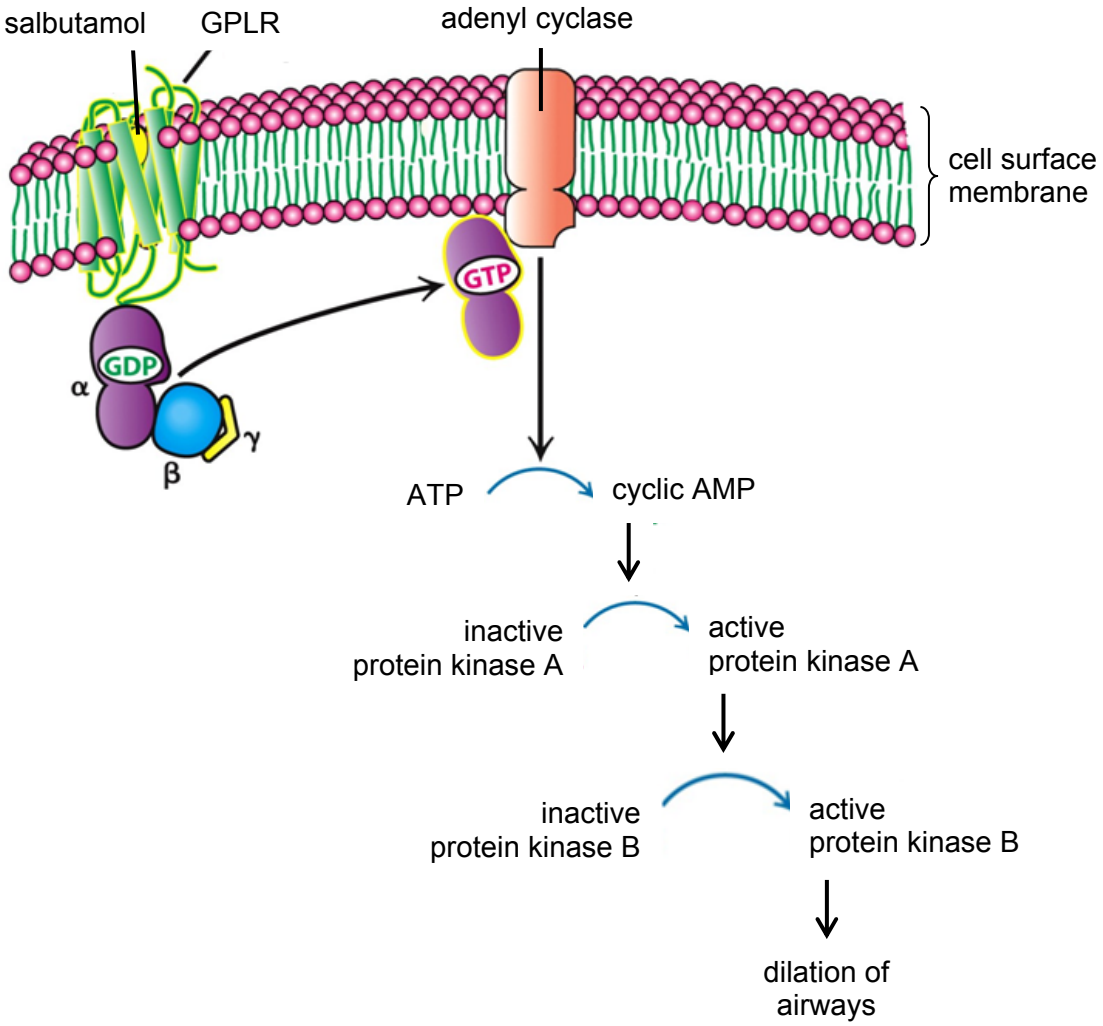


Fig. 2.1

(a) Describe how GPLR is held within the cell surface membrane.

1. **Hydrophobic interactions occur between the hydrophobic core/hydrocarbon tails of phospholipid bilayer and hydrophobic R groups of amino acid residues of GPLR;**

2. **Hydrogen/ionic bonds formed between charged/ hydrophilic phosphate heads of phospholipids and hydrophilic R groups of amino acids in cytoplasmic + extracellular regions of GPLR;**

[2]

For examiner's use

(b) With reference to Fig. 2.1, describe how the use of salbutamol can relieve symptoms of asthma.

1. **Binding of salbutamol to a specific/complementary binding site of GPLR result in conformational change of receptor;**
2. **Activated GPLR activates G protein, where GTP replaces GDP;**
3. **α subunit dissociates from βγ subunits;**
4. **α subunit binds to and activates adenyl cyclase (at the membrane), which catalyses the conversion of ATP to cAMP;**
5. **cAMP act as second messengers and activates protein kinase A;**
6. **trigger a phosphorylation cascade resulting in amplification of signal, causing to dilation of airways;**

[4]

(c) There are many different types of receptors used by a cell to transduce extracellular signals. Some are located on the cell surface membrane while others are located within the cell.

Explain why some receptors are found on the cell surface membrane while others are found within the cell.

1. **Ligands which are lipid-soluble/hydrophobic/non-polar bind to specific nuclear receptors within the cell;**
2. **Ligands which are not lipid-soluble/hydrophilic/charged/polar bind to specific receptors on the membrane;**
3. **Ref to size;**

[2]

[Total: 8]

3 tRNA molecules have an important role in gene expression. They can be found in the cytoplasm, mitochondria and chloroplasts of eukaryotic cells. Fig. 3.1 shows the structure of a tRNA molecule that is able to carry the amino acid threonine in the cytoplasm of a eukaryotic cell. It is 77 ribonucleotides long.

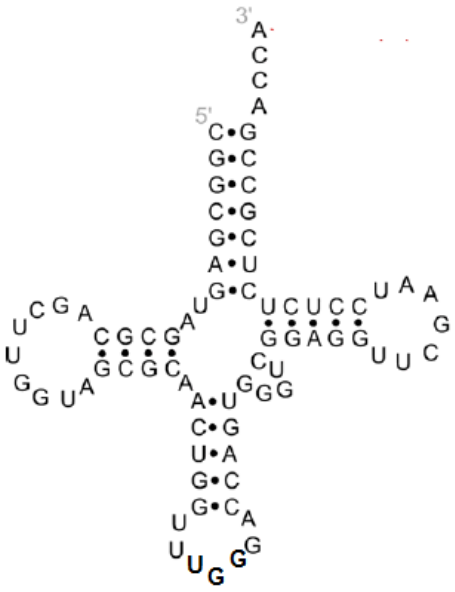


Fig. 3.1

(a) (i) With reference to Fig. 3.1, describe how the structure of a tRNA molecule differs from the structure of a mRNA molecule.

Category	tRNA	mRNA
1. Presence of double-stranded regions / Overall structure	Double-stranded regions / clover-leaf struct	Single-stranded / Linear structure
2. Presence of hydrogen bonds / complementary base pairing	Present	Absent
3. 3' end	3' CCA sequence	3' poly-A tail
4. 5' modified guanosine cap	Absent	Present
5. Anticodon	Has an anticodon	Made up of many codons
		@1m per valid comparison

[2]

(ii) Explain how these differences allow tRNA and mRNA molecules to perform their roles.

	tRNA	mRNA
Overall structure (Presence of hydrogen bonds to bring about double-stranded regions)	1. Specific 3D conformation / clover-leaf structure is complementary to (active site of) aminoacyl-tRNA synthetase / (A, P-sites of) large ribosomal subunit;	2. Linear structure allows it to be read by the ribosomes / binding to the small ribosomal subunit;
3' end	3. 3' CCA sequence allows binding to the amino acid;	4. The 3' poly-A tail determines the stability of the mRNA / duration of translation of the mRNA;
Anticodon	5. Anticodon can complementary base-pair to codon for the correct amino acid to be added; (1 tRNA can only carry one amino acid)	6. Sequence of codons specify the sequence of amino acids in a polypeptide;
		@1m per structure-function relationship

[2]

Fig. 3.2 shows a tRNA molecule that is able to carry the amino acid threonine in mitochondria. It is 62 ribonucleotides long.

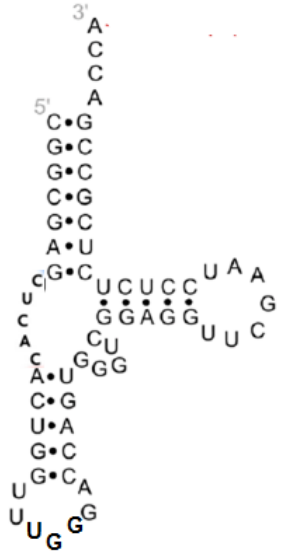


Fig. 3.2

(b) The structures of the tRNA molecules in the mitochondria and the cytoplasm of a eukaryotic cell are different although they are both able to carry the amino acid threonine. Suggest a reason for this difference.

1. **Mitochondria have 70S ribosomes, while 80S ribosomes are found in the cytoplasm;**
2. **Different tRNA molecules have specific 3D conformation that are complementary to the different A and P sites in mitochondrial and cytoplasmic ribosomes; OR**
3. **They are coded for by the different genes found in the mitochondrial DNA and nuclear DNA respectively;**
4. **Different sequences result in the formation of hydrogen bonds at different locations;** **[2]**
5. **AVP e.g. evolutionary reasons;**

There are 61 unique tRNA molecules in the cytoplasm of a eukaryotic cell.

(c) (i) Explain why there are 61 unique tRNA molecules in the eukaryotic cell.

1. **The codon / anticodon is made up of 3 nucleotides and there are 4 different bases, hence 64 possible unique permutations of triplet codes;**
2. **Stop codons do not code for amino acids/ bind to a release factor;**
3. ***There are 3 stop codons, hence this gives 61 unique codons. 61 tRNA molecules will have anticodons that can complementary base pair to these 61 unique codon sequences;**

Pt 3 is compulsory to score full marks

[2]

(ii) Scientists found that there are more than 120 gene loci coding for tRNA molecules in the nuclear DNA, many of which are duplicate copies of the same tRNA gene.

Suggest an advantage of having more than 120 gene loci coding for the 61 tRNA molecules in the eukaryotic cell.

1. **Rapid synthesis of tRNA molecules;**
2. **If one copy of the tRNA gene is mutated, there are other / duplicate copies to ensure functional tRNA is synthesised;** [1]

(d) Explain how the structure of RNA polymerase allows for the synthesis of tRNA molecules.

1. **The active site has a specific/complementary 3D conformation, and it binds to the promoter/template strand of the tRNA genes;**
2. **The specific 3D conformation of the active site is also specific/complementary to ribonucleotides and the DNA template;**
3. **Catalytic residues in the active site help to catalyse the formation of the phosphodiester bonds between the 3' OH group of the one nucleotide and 5' phosphate group of the other nucleotide;**
4. **Active site contains catalytic residues that break hydrogen bonds between the strands in DNA molecules to expose the template strand;**
5. **Ref to action of enzymes, e.g. lower activation energy, binding sites for general transcription factors;** [3]

[Total: 12]

For examiner's use

4 Fig. 4.1 shows the reproductive cycles of a temperate bacteriophage.

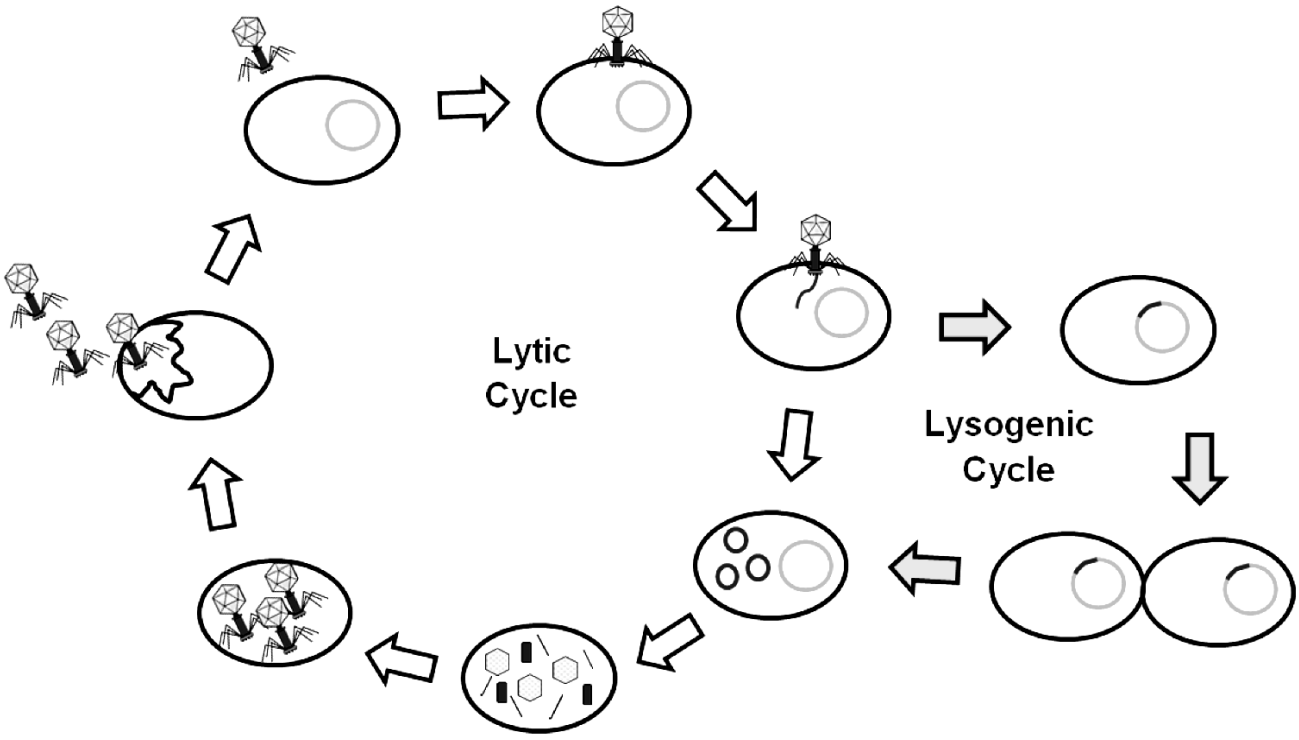


Fig. 4.1

(a) With reference to Fig. 4.1, describe the roles of the bacteriophage structures in its reproductive cycles.

1. **Tail fibres/tips - Host recognition & Adsorption: contains proteins which bind to specific receptors on specific host bacteria for phage to attach to host;**
2. **Tail sheath - Penetration & Injection: contracts to inject phage genome/DNA into host cell;**
3. **DNA/Genetic material - Lytic cycle > Phage DNA replication: replicates to form many copies of phage genome for subsequent assembly & release of phages;**
4. **DNA/Genetic material - Lytic cycle > template for synthesis of phage proteins (capsid, tail sheath and tail fibres) for subsequent assembly & release of phages;**
5. **DNA/Gen matl - Lysogenic cycle > Prophage carries viral genes which will be expressed when environment is right/replicates along with the host/integrated in host genome;**
6. **Capsid - proteins assemble around nucleic acid / carry /protect nucleic acid;**

[4]

(b) While their prokaryotic hosts contain both DNA and RNA, bacteriophages contain only DNA. Suggest why it is sufficient for bacteriophages to contain only DNA for their reproductive cycles.

1. **Bacteriophages contain DNA as it is their genetic material/contains genes coding for phage proteins;**
2. **Phages are acellular/obligate parasites;**
3. **Host cells have RNA polymerase which transcribes phage DNA into phage mRNA;**
4. **Host cells have ribosomes/tRNAs for translation of phage mRNA into phage proteins required for maturation/assembly of phages;** [2]

(c) Describe an advantage of the lysogenic cycle of a bacteriophage to a population of bacteria.

1. **Specialised transduction/ Prophage is inaccurately excised and so some host bacteria genes/DNA is transferred to another bacteria/ Horizontal gene transfer;**
2. **Genetic variation in the population,**
3. **Therefore higher chance of survival under different selection pressures;**
4. **AVP;**

[2]

[Total: 8]

For examiner's use

5 Telomerase reverse transcriptase (TERT) is a component of the enzyme telomerase, which is responsible for maintaining telomere lengths in epidermal stem cells. These cells will differentiate to form specialised skin cells such as keratinocytes**.** A study on the role of the regulatory protein c-MYC in the synthesis of TERT mRNA was conducted in these cells. Fig. 5.1 shows the relative levels of TERT mRNA and c-MYC mRNA.

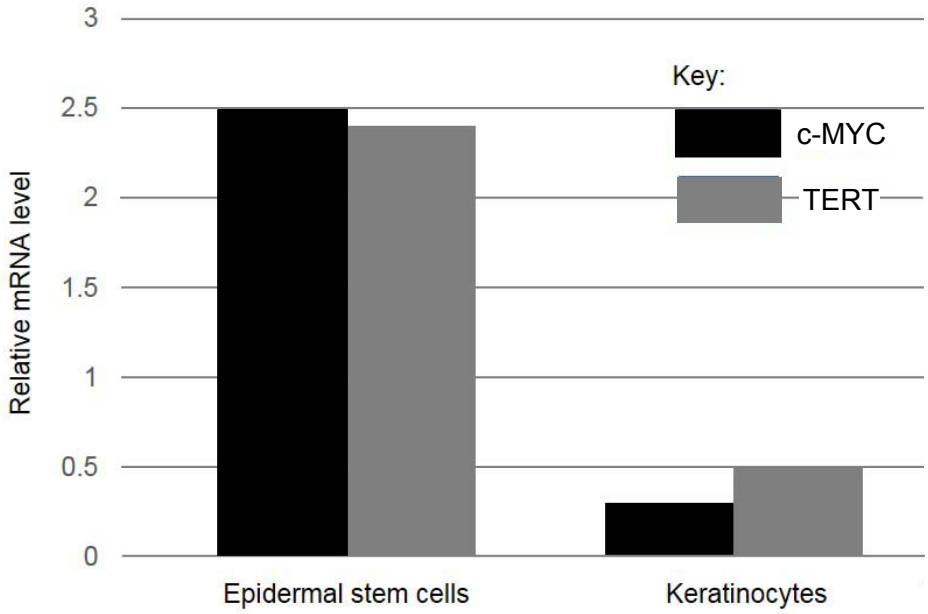


Fig. 5.1

(a) (i) With reference to Fig. 5.1, describe the relationship between the relative levels of TERT mRNA and c-MYC mRNA.

1. **Positive/ direct relationship;**
2. **In epidermal stem cells, mRNA levels of c-Myc and TERT are both high at 2.5 and 2.4 respectively/ in keratinocytes, mRNA levels of c-Myc and TERT are both low at 0.3 and 0.5 respectively;**

[2]

(ii) Suggest a role of the c-MYC protein in the regulation of *TERT* gene expression.

1. **c-Myc is an activator which binds to enhancer of *TERT* gene;**
2. **Ref. to recruitment of DNA bending proteins, mediator proteins and other transcription factors to form transcription initiation complex (TIC);**
3. **Allows formation of a more stable TIC/ Higher affinity of RNA polymerase to promoter and hence, high rate of transcription of TERT mRNA; OR**
4. **c-Myc as histone acetylase which adds acetyl group to histone tails;**
5. **Reduces affinity of histones for DNA, chromatin becomes less compact;**
6. **TERT gene is transcribed at a high rate; OR**
7. **c-Myc as histone demethylase which removes methyl groups from histone tails;**
8. **Proteins no longer bound to DNA, chromatin becomes less compact;**
9. **TERT gene is transcribed at a high rate;**

[3]

(b) Explain why TERT has a significant role in epidermal stem cells.

1. **Ref to end replication problem;**
2. **Therefore telomere length will be shortened to the point where the cell undergoes programmed cell death/replicative senescence is triggered;**
3. **Epidermal stem cells can *continue* to divide by mitosis/self-renewal for a long period of time to form a pool of cells;**
4. ***TERT maintains telomere length by synthesizing multiple DNA repeats at the 3' OH end of the DNA molecule;**

[3]

(c) Suggest why *TERT* gene is absent in bacteria.

1. **Bacteria has circular DNA;**
2. **Ref to lack of end replication problem;**

[2]

[Total: 10]

6 Many diseases arise due to gene mutations and/or chromosomal aberrations.

(a) Distinguish between gene mutations and chromosomal aberrations.

	Gene mutation	Chromosomal aberration
1. Definition	**1a. Change in nucleotide sequence**	**1b. Change in chromosomal structure or number;**
2. No. of genes affected	**2a. Affects a single gene**	**2b. Usually affects multiple genes (because involves a segment or an entire chromosome hence);**
3. Mechanisms	**3a. Substitution, deletion or addition of nucleotides (any 2)**	**3b. Translocation, deletion or inversion of chromosomal structures or non-disjunction events during nuclear division (any 2);**

Any 2@1m each

[2]

Fig. 6.1 shows an error occurring during meiosis II.

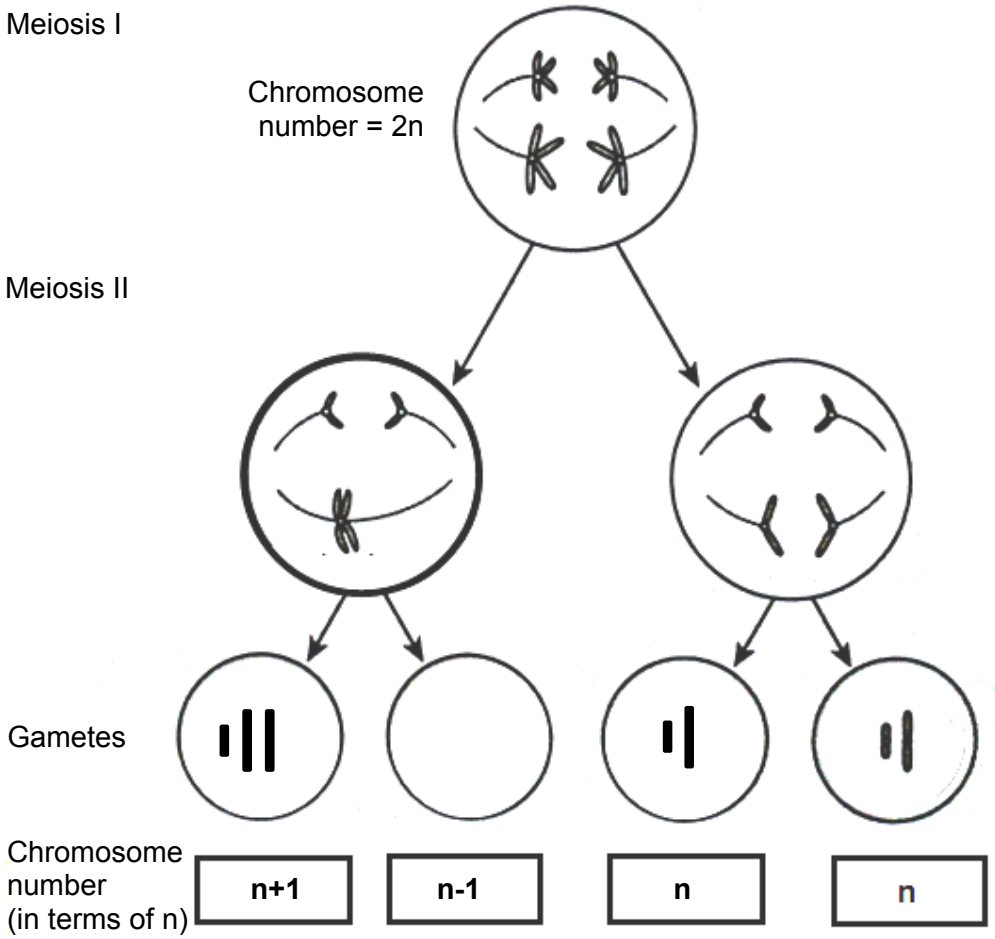


Fig. 6.1

(b) (i) Complete Fig. 6.1 with the correct chromosome structures and chromosome number (in terms of n) in the gametes. [2]

(ii) Explain the error shown in Fig. 6.1.

1. **Non-disjunction caused by the failure of sister chromatids to separate during anaphase II;**
2. **due to problems in the shortening of the spindle fibres/ centromeres fail to divide;**

[2]

(iii) Predict the chromosomal number (in terms of n) in each of the four gametes if a similar error had occurred in meiosis I instead of meiosis II.

n+1, n+1, n-1, n-1

[1]

(c) Such errors can occur during mitosis too. Comment on whether this would lead to changes in the gene pool of a population.

1. **If this occurs in somatic cells only / does not affect the germ line cells, it only affects the individual / not passed down to offspring, so no effect on overall gene pool in population; OR**
2. **If this occurs in germ line cells, it will be passed to gametes, and possibly to offspring, so gene pool of a population will be affected;**
3. **If this occurs in zygotic / embryonic stem cells, the whole individual will be affected, so gene pool of a population will be affected;** [1]

[Total: 8]

For examiner's use

7 (a) Explain how genotype is linked to phenotype.

1. **Genotype, the genetic makeup of an organism, is made up of genes which are sequences of deoxyribonucleotides;**
2. **Genes are transcribed to form mRNAs, and mRNAs are translated into proteins;**
3. **These proteins have particular functions/roles and may affect metabolic pathways, giving rise to the phenotype of the organism;**

[3]

In the fruit fly, *Drosophila*, a gene determines the appearance of a dark transverse band on the thorax. Another gene determines the presence of crossveins on the wings. Two pure-breeding *Drosophila* were crossed, where one is banded with crossveins on the wings while the other is non-banded without crossveins on the wings. The F1 offspring were then test-crossed to produce offspring in the following ratio:

banded without crossveins	21
banded with crossveins	483
non-banded without crossveins	512
non-banded with crossveins	35

(b) Using the symbols **B** for non-banded thorax and **b** for banded thorax, **D** for presence of crossveins and **d** for absence of crossveins, draw a genetic diagram to show the results of the test-cross.

Parental phenotypes	**non-banded with crossveins**	**X**	**banded without crossveins**	
Parental genotypes	**(Bd)(bD)**	**X**	**(bd)(bd)**	**;**
Gametes	**(Bd)** **(bD)**		**(bd)**	**;**
	(bd) **(BD)**			

Offspring genotypes	**(Bd)(bd)**	**(bD)(bd)**	**(BD)(bd)**	**(bd)(bd)**	
Offspring phenotypes	**non-banded without crossveins**	**banded with crossveins**	**non-banded with crossveins**	**banded without crossveins**	**;**
	512	**438**	**35**	**21**	
	parental		**recombinant**		**;**

[4]

For examiner's use

(c) Explain how the new combination of alleles arose in the gametes of the test-cross in part (b).

1. **Crossing over between non-sister chromatids of homologous chromosomes;**
2. **at the chiasma in prophase I;**
3. **Allele coding for non-banded thorax/absence of crossveins from one chromosome swap with corresponding allele coding for banded thorax/presence of crossveins from the other chromosome;**

(Resulting in recombinant chromosomes containing genetic material from both parents)

[3]

(d) Distinguish sex linkage from the mode of inheritance of the two genes observed in *Drosophila*.

Basis of comparison	Sex linkage	Autosomal linkage
1. Location of genes	Genes are located on the sex chromosomes (mostly located on the X chromosome)	Genes are located on (the same) autosomes for autosomal linkage;
2. Distribution of phenotypes	Genes transmitted on sex chromosomes show unequal distribution of the particular trait between the sexes	Breeding experiment produce approximately equal numbers of the parental phenotypes and a significantly smaller number of phenotypes showing new combinations of characteristics, also in equal number;
3. Results of reciprocal crosses	The reciprocal crosses would result in different phenotypic ratios in the offspring	Results of reciprocal crosses would not differ

[2]

[Total: 12]

8 Concentrations of ribulose bisphosphate (RuBP) and reduced NADP were measured in samples of actively photosynthesising green algae in an experimental chamber. CO_2 is supplied continuously into the chamber throughout the experiment.

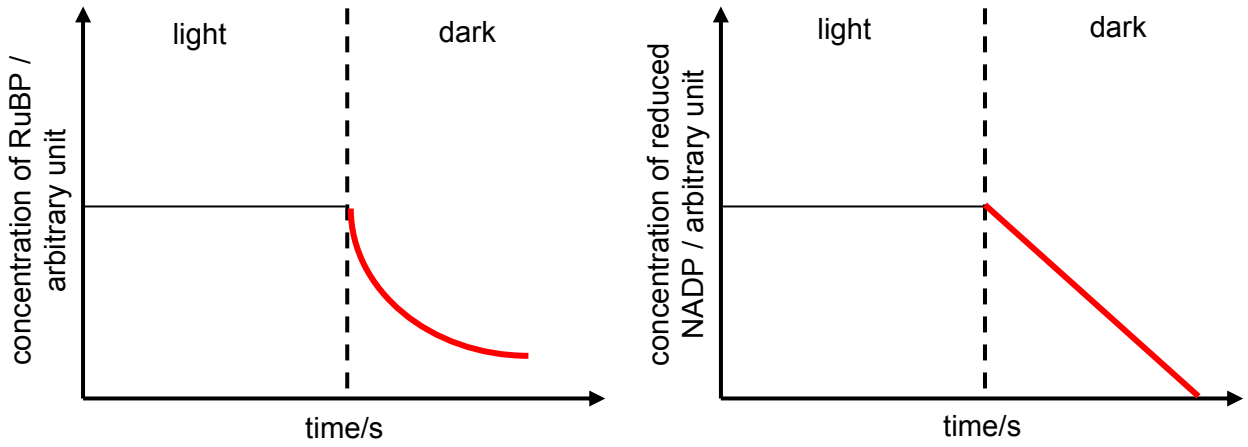


Fig. 8.1

(a) (i) In Fig. 8.1, complete each graph to show the concentrations of RuBP and reduced NADP when the light source was turned off. [2]

(ii) Explain the shape of the two graphs when the light source was turned off.

1. **Photophosphorylation/light dependent reaction ceased, reduced NADP and ATP is not produced;**
2. **Existing reduced NADP is used up to reduce glycerate-3-phosphate (PGA) to glyceraldehyde-3-phosphate (GALP) in the Calvin cycle/ light independent reaction;**
3. **Ribulose bisphosphate (RuBP) is not regenerated due to the absence of ATP;**
4. **RuBP combines with CO_2 to form PGA/carbon fixation, and its concentration decreases;**
5. **AVP;**

[4]

For examiner's use

(b) 'Calvin cycle is the reverse of Krebs cycle'. Comment on this statement.

1. **Calvin cycle results in the reduction of substrates to form carbohydrates while Krebs cycle results in the oxidation of respiratory substrates / carbohydrates OR Calvin cycle is an anabolic process while Krebs cycle is a catabolic process;**
2. **Calvin cycle used CO_2 while Krebs cycle produces CO_2;**
3. **Calvin cycle uses ATP while Krebs cycle produces ATP (overall);**
4. **Calvin cycle uses reduced hydrogen carriers while Krebs cycle produces reduced hydrogen carriers;**
5. **Contrast one e.g. of enzyme in cycle (e.g. carboxylase is involved in Calvin cycle vs decarboxylase in Krebs cycle / both processes involve dehydrogenases;**
6. **AVP;**

[3]

(c) The Krebs cycle must be carefully regulated by the cell. If it is permitted to proceed unchecked, large amounts of metabolic energy would be wasted in the over-production of reduced coenzymes and ATP. α-ketoglutarate dehydrogenase is an enzyme in the Krebs cycle which catalyses the conversion of α-ketoglutarate to succinyl coA.

Suggest how reduced NAD can inhibit the action of α-ketoglutarate dehydrogenase.

1. **Excess/ accumulation of reduced NAD inhibit the action of α-ketoglutarate dehydrogenase by end product inhibition;**
2. **Reduced NAD binds to the active site on α-ketoglutarate dehydrogenase (as it is a co-enzyme);**
3. **It competes with NAD^+ for the active site, so oxidative decarboxylation of α-ketoglutarate cannot occur to form succinate, Krebs cycle stops / slows down;**

OR

2. **Reduced NAD binds to the allosteric site of the enzyme;**
3. **Changing the 3D configuration of the active site of enzyme, so oxidative decarboxylation of α-ketoglutarate cannot occur to form succinate;**

[3]

[Total: 12]

9 A study reported on the change in beetle sizes in a population due to climate change. Larger beetles are affected when compared to smaller beetles. This could be because larger beetles are less likely to get enough oxygen to sustain a higher metabolic rate caused by higher atmospheric temperatures. Fig. 9.1 shows the effect of an increase of 2°C in temperature on the size of larger and smaller beetles in a population over 100 generations.

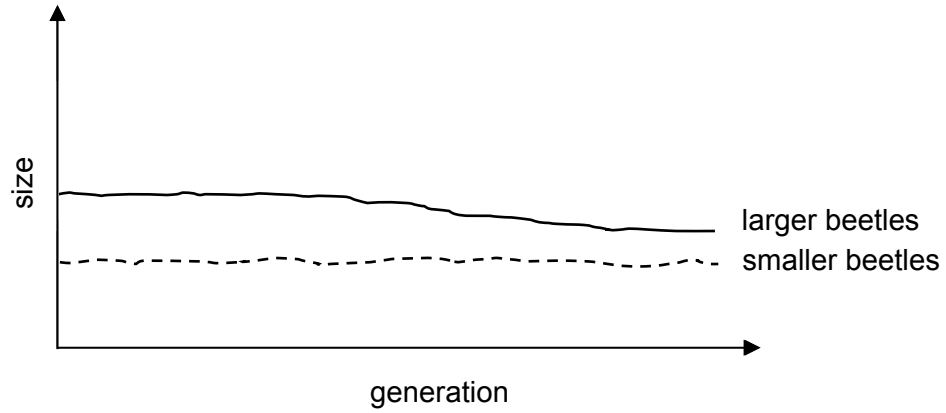


Fig. 9.1

(a) Explain how a temperature rise of 2°C may cause a change in the gene pool of the population of beetles over time.

1. **Genetic variation in population expressed as phenotypic variation, i.e. range of sizes;**
2. **Higher temperature is the selection pressure;**
3. **Smaller beetles are selected for because they are more likely to… (ref to preamble);**
4. **Resulting in more of these surviving and reproducing and passing on alleles coding for small size to their offspring;**
5. **Over time, gene pool changes where there is a higher frequency of alleles coding for smaller sizes in the population;**

[4]

(b) Suggest why a speciation event is unlikely to occur in this population of beetles as a result of climate change.

1. **No reproductive isolation between the 2 beetle phenotypes / there is gene flow within the population;**
2. **No accumulation of different mutations, i.e no new diff in behaviour, no new diff in size of copulatory organs, no new difference in pheromones;**
3. **Less differences in beetle size in the population, resulting in a more homogenous population and less genetic differences;**

[2]

For examiner's use

(c) Suggest the consequences of a decrease in beetle size on the ecosystem.

1. **Beetles are preyed upon, so less food for animals higher up in food chain;**
2. **Beetles act as detritivores, smaller beetles mean slower rate of decomposition and hence recycling of nutrients;**
3. **Beetles can be pollinators of plants, so lower rate of pollination leads to reduction in certain plant populations/loss of certain plant species;**
4. **Ref to biodiversity**;

[2]

(d) Describe how molecular methods can be used to confirm that two beetles with similar morphology are of the same species.

1. **Extract/Obtain DNA from both beetles;**
2. **Amplify it via polymerase chain reaction;**
3. **Use the same restriction enzyme to cut the gene/DNA sequence to result in different fragment lengths (optional) / RFLP analysis**
   OR
   Designing specific primers that bind to the ends of a target gene/sequence;
4. **Subject it to gel electrophoresis to separate DNA fragments by size**
   OR
   separate DNA segments by size;
5. **Conduct autoradiography with single-stranded, radioactive probe to confirm presence of target sequences in the fragments/segments;**
6. ***Same/similar banding pattern for both beetles → same species;**
7. **AVP, e.g. DNA-DNA hybridization, DNA sequencing;**

Pt 6 is a compulsory point to get full marks

[4]

[Total: 12]

10 Multidrug-resistant tuberculosis (MDR-TB) is a form of tuberculosis (TB) caused by the bacterium *Mycobacterium tuberculosis,* which is resistant to treatment with the antibiotic rifampin. The first antibiotic treatment for TB began in 1943 and some strains *M. tuberculosis* developed resistance to rifampin through genetic changes. Fig. 10.1 shows rifampin binding to RNA polymerase in bacterial cells.

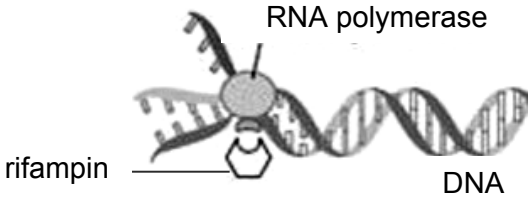


Fig. 10.1

(a) With reference to Fig. 10.1, explain why rifampin may be used to treat tuberculosis.

1. **RNA polymerase inhibited in bacterial cells and hence, no transcription/ expression of genes;**
2. **Proteins/ enzymes crucial for cellular processes name 1 (e.g. no enzymes for respiration) absent, , hence resulting in bacterial cell death;**
3. **Rifampin does not bind to eukaryotic RNA polymerase so host cells are not affected;**

[2]

(b) Suggest how the genetic changes which caused rifampin resistance could be transferred within a population of *M. tuberculosis* through direct contact of bacteria cells.

1. **bacterial conjugation;**
2. **F^+ cell/donor bacterial cell with F factor produces sex pilus to attach itself to F^- cell/recipient cell, forming a mating bridge/conjugation tube between the two bacterial cells;**
3. **which allows F^+ cell to transfer its F plasmid containing the antibiotic resistance gene to the F^- cell (by rolling circle mechanism);**

[3]

Bacilli Calmette-Guérin (BCG) is a vaccine containing attenuated bacteria and can provide protection against tuberculosis. The attenuated bacteria have antigens which stimulate an immune response. Recent studies have shown that BCG can also give protection against leprosy, a disease caused by the bacterium *Mycobacterium leprae*.

(c) (i) Outline the roles of T lymphocytes in the adaptive immune response after the administration of BCG.

1. **Naïve helper T cells with specific/ complementary T cell receptors bind to the MHC-peptide complexes and are activated by the cytokines released from antigen-presenting cells;**
2. **Activated helper T cells in turn (releases cytokines) which activate naïve B cells/ cytotoxic T cells;**
3. **B cells/ (effector cells) secrete antibodies to perform opsonisation/ agglutination/activation of complement system**
   OR
   Cytotoxic T cells secrete proteins (perforin/ granzymes) to kill infected cells;
4. **Formation of memory T/B cells at the end of primary immune response;**

[3]

(ii) Suggest why BCG can also provide protection against leprosy.

1. ***Bacteria which causes leprosy has antigens/epitopes with similar 3D conformation as those in *Mycobacterium tuberculosis*;**
2. **Receptors of memory T and B cells can bind to antigens/epitopes of *Mycobacterium laprae*;**
3. **AVP;**

[2]

[Total: 10]

For examiner's use

For Examiner's Use

Section A

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

1 Variant Creutzfeldt-Jakob disease (vCJD) is a rare infectious disease in humans that was first described in 1996 in the United Kingdom. It is thought to be caused by the same infectious agent which causes "mad cow" disease in cattle populations, where infected cows experience progressive deterioration of the nervous system and eventual death.

The infectious agent is a misfolded form of the protein PrP, which is normally found in nerve cells. This misfolded PrP protein is known as a prion, which can be transmitted to humans when eating food contaminated with these prions. In the brain, prions may bind to normal PrP proteins and induce them to change their conformation, forming more infectious prions which propagate the disease. Prions will bind to each other to form protein aggregates which are resistant to degradation, causing the death of nerve cells.

(a) Describe how an infectious disease differs from a genetic disease.

[2]

(b) Discuss how prions challenge the tenets of the cell theory.

[3]

(c) Suggest how protein aggregates may be resistant to degradation in infected cells.

[2]

While vCJD is described as an infectious disease, scientists have noted that there is little or no immune response in patients diagnosed with vCJD.

(d) Suggest why there is a lack of a significant immune response in these patients.

[2]

Similar to the prions causing vCJD, the human immunodeficiency virus (HIV) is thought to have originated from a related strain of viruses which infects wild chimpanzees.

A HIV infection is characterised by a brief initial period of viral replication. This is followed by a long period of latency, where no symptoms are manifested. Eventually, reactivation of the provirus and rapid viral replication results in immunodeficiency.

Progression of the disease in HIV-positive individuals can be monitored by measuring the concentration of HIV particles (also known as the viral load) in their blood sample. One laboratory method measures the viral load by quantifying the activity of viral reverse transcriptase using the following procedure:

1. The HIV particles are separated from other blood plasma components.
2. The viral particles are lysed by disruption of the viral envelope and the resulting lysates are added to a mixture containing a RNA template and deoxyribonucleotides.
3. Viral reverse transcriptase found in the lysate will then synthesise complementary DNA (cDNA).
4. The amount of cDNA formed is detected by adding artificially synthesised antibodies which recognise and bind to the cDNA. These antibodies are linked covalently to an enzyme, which catalyses the formation of a coloured product.
5. The colour intensity of the resulting mixture is compared to those of standard solutions, from which the concentration of reverse transcriptase in the starting mixture can be deduced.

(e) Explain how the structure of antibodies allow them to be used for the procedure described.

[3]

Antibodies are produced naturally by B lymphocytes in the human body, after exposure to foreign antigens.

(f) Justify the claim that "B lymphocytes are exceptions to the generalisation that all nucleated cells in the body have exactly the same DNA".

[4]

Another method to measure the HIV viral load involves quantifying the amount of viral genetic material present in the blood sample, using the procedure in Fig. 1.1.

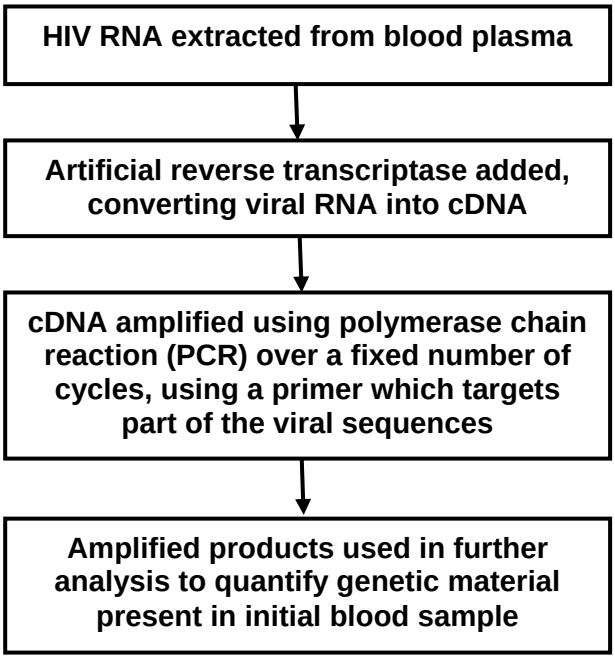


Fig. 1.1

(g) Describe how PCR is used in the amplification of HIV cDNA.

[4]

There are two major strains of HIV known to man, HIV-1 and HIV-2. The different methods used to measure viral load vary in their ability to distinguish between the different HIV strains, as shown in Table 1.1.

Table 1.1

Method of measuring viral load	Able to distinguish between HIV strains
Quantification of viral reverse transcriptase activity	No
Quantification of viral genetic material	Yes

(h) Explain the difference in the two measurement methods in their ability to detect different HIV strains.

[3]

While HIV is sexually-transmitted, dengue virus is transmitted by a mosquito vector. To study the influence of weather conditions on the incidence of dengue viral infection in Singapore, scientists recorded the amount of rainfall, mean weekly temperatures and the number of dengue cases over a one-year period. The recorded data is shown in Fig. 1.2.

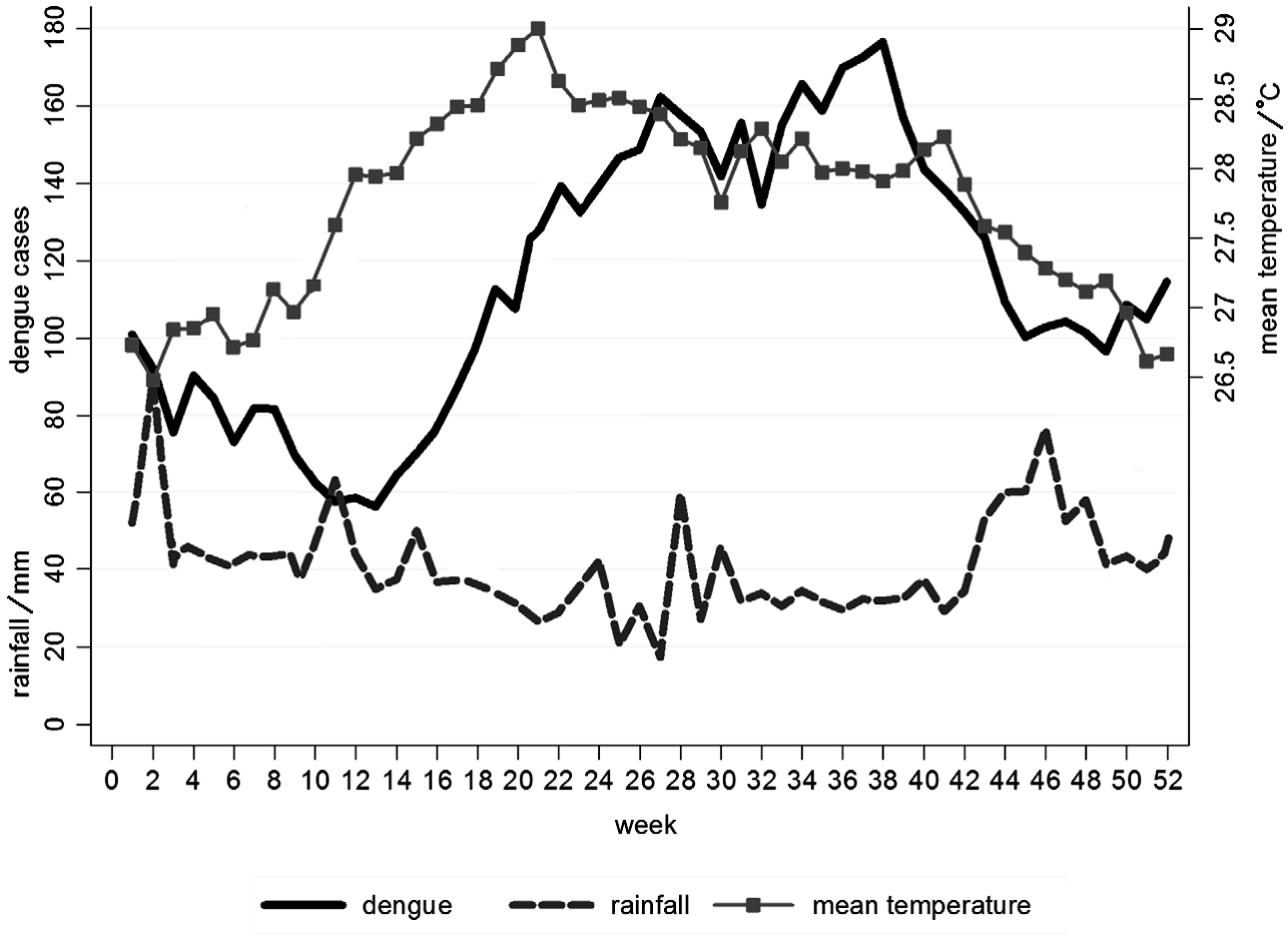


Fig. 1.2

(i) Based on the information provided, comment on which weather condition is a better predictor of dengue cases in Singapore.

[4]

(j) Suggest explanations for the relationship between the weather condition chosen in part (i) and the number of dengue cases recorded.

[2]

[Total: 29]

2 In order to solve the problems of malnutrition and nutritional deficiencies that are faced by two billion people worldwide, scientists have turned to genetic engineering. This involves the introduction of foreign genes into organisms to increase food production. One technique used in plant biotechnology to generate transgenic crops (crops with foreign genes introduced) involves the use of protoplast culture. It is designed to work as follows:

1. Cut a leaf into pieces.
2. Soak the leaf in a solution of microbial enzymes, sugars and salts. The enzymes digest the cellulose cell wall. The sugars and salts maintain the osmotic potential.
3. Centrifuge the cells to remove the cell wall debris. The protoplasts (plant cells with cell wall removed) will be found in the supernatant.
4. Apply an electric field to introduce the foreign genes into the protoplasts via transformation.
5. Isolate transformed protoplasts and culture them into transgenic plants.

(a) (i) Before a foreign gene is introduced into the protoplasts, the photosynthetic activity of the protoplasts must be checked to ensure that they are viable.

One way to do this is to mix the protoplast extract with 2,6-dichlorophenolindophenol (DCPIP), a redox dye. When reduced, DCPIP is changed from blue to colourless.

A protoplast mixture with DCPIP is placed under unfiltered white light, while another mixture is placed under white light passed through a blue filter.

Assuming that light intensity of the white light is constant, explain whether the DCPIP in the protoplast extract would decolourise faster under the unfiltered or filtered white light.

[4]

(ii) Suggest why it is necessary to digest the cellulose cell wall to allow for the introduction of a foreign gene into the protoplast.

[1]

Using the protoplast culture technique, scientists have introduced three β-carotene biosynthesis genes into a particular variety of the rice plant to form a new variety – the golden rice plant. The golden rice plant looks morphologically similar to other rice varieties except that its rice grains are yellow in colour due to the production of β-carotene in its rice grains. The β-carotene contained in the rice grains will be converted into vitamin A when it is consumed by humans.

(b) Discuss whether the β-carotene biosynthesis genes will be preserved in the gene pool of a population of rice plants, containing both the original and the new varieties, without any human intervention.

[4]

Genetic engineering can also be used to treat genetic diseases in humans which are caused by mutations involving single genes. This is done by introducing copies of the normal allele into human cells. In germline cell therapy, the normal alleles are introduced into germ cells.

(c) Comment on the ethical aspects of germline cell therapy.

[2]

[Total: 11]

3 Plants have long been regarded as carbon sinks because they take in carbon dioxide for photosynthesis. However, when temperatures rise, plants increase their rate of respiration, resulting in increased carbon release. Some research has suggested that this could convert forests from a long-term carbon sink to a carbon source, aggravating climate change.

(a) Outline how a rise in temperature could lead to increased carbon release by plants.

[3]

In 2016, a team of scientists conducted a short-term study of five years to find out the net carbon exchange of trees when the temperature was increased. In order to determine this, the increase in leaf respiration at higher temperatures was evaluated using 1000 young trees of 20 different boreal and temperate tree species grown in an open-setting.

Scientists compared the data observed to the expected results in Fig. 3.1.

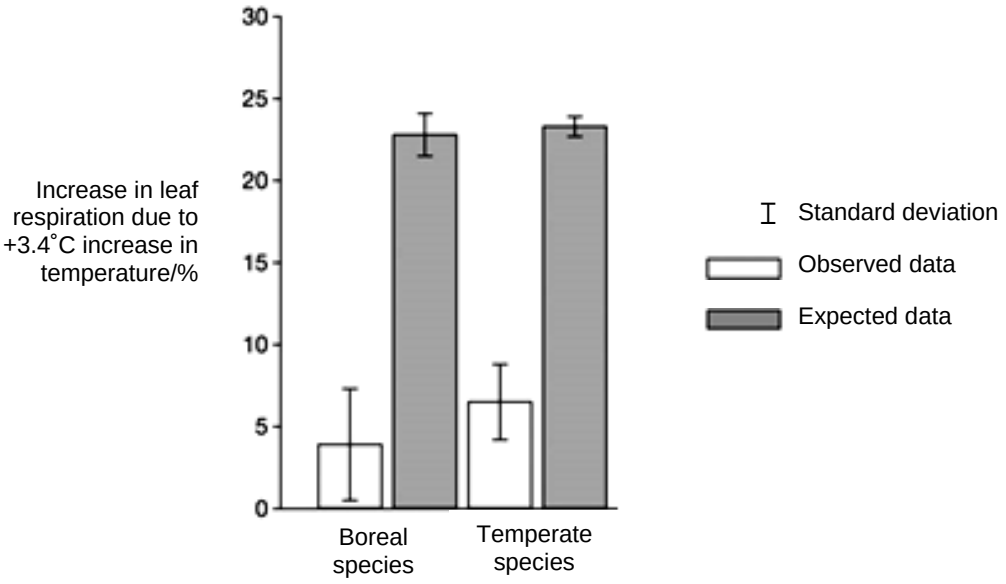


Fig. 3.1

(b) (i) With reference to Fig. 3.1, describe one difference between the data observed and the expected results.

[2]

(ii) In Fig. 3.1, the data observed shows a difference in the increase in leaf respiration between boreal and temperate tree species. Explain whether this difference is significant.

[1]

(iii) Based on the results of the study, comment on whether forests will remain as carbon sinks or be converted to carbon sources if temperatures rise.

[2]

(iv) Based on the results, scientists concluded that plants can acclimatise to changing climates, adjusting their metabolism according the environment. It was thus suggested that crop yield and hence food supply would not change drastically in light of climate change.

With reference to the design of the experiment, discuss the validity of this conclusion.

[2]

[Total: 10]

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 Biological polymers are large molecules composed of many individual smaller molecules called monomers. For instance, amino acids are taken into an animal cell for the synthesis of collagen. The synthesised collagen is then secreted out of the cell to form the connective tissue.

(a) Explain how the structural features of amino acids contribute to the function of collagen. [10]

(b) Explain how temperature and pH may affect the transport of substances across the cell surface membrane of eukaryotes. [15]

[Total: 25]

5 There are similarities in the ways that prokaryotes and eukaryotes regulate gene expression. In both groups of organisms, cyclic adenosine monophosphate (cAMP) is an important molecule in many biological processes, including the regulation of gene expression.

(a) Describe the role of cAMP in altering gene expression in organisms and suggest why they are usually small and non-protein in nature. [10]

(b) The eukaryotic genome is considered to be more complex than the prokaryotic genome. Describe the differences between the eukaryotic and prokaryotic genomes and explain the significance of these differences. [15]

[Total: 25]

Section A

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

1 Variant Creutzfeldt-Jakob disease (vCJD) is a rare infectious disease in humans that was first described in 1996 in the United Kingdom. It is thought to be caused by the same infectious agent which causes "mad cow" disease in cattle populations, where infected cows experience progressive deterioration of the nervous system and eventual death.

The infectious agent is a misfolded form of the protein PrP, which is normally found in nerve cells. This misfolded PrP protein is known as a prion, which can be transmitted to humans when eating food contaminated with these prions. In the brain, prions may bind to normal PrP proteins and induce them to change their conformation, forming more infectious prions which propagate the disease. Prions will bind to each other to form protein aggregates which are resistant to degradation, causing the death of nerve cells.

(a) Describe how an infectious disease differs from a genetic disease.

1. **Caused by a pathogen (e.g. viruses & bacteria) vs caused by mutant alleles / mutations in the genetic material / mutagenic factors (e.g. radiation, chemical carcinogen);**
2. **Elicits an immune response vs immune response may not be elicited;**
3. **Acquired vs inherited / can be passed on to offspring;**
4. **AVP**

Max 2 [2]

(b) Discuss how prions challenge the tenets of the cell theory.

1. **Cell theory states that all living things consist of cells OR cell theory states that the smallest unit of a living thing is a cell;**
2. **However the prion challenges the cell theory in that it has living characteristic but it is not a cell / is acellular OR it has living characteristics but is a simple protein molecule;**
3. **Since they are able to replicate themselves by converting normal proteins into more prions;**

[3]

(c) Suggest how protein aggregates may be resistant to degradation in infected cells.

1. **Ref. to enzymes are unable to bind to proteins due to changed 3D conformation, hence not complementary / specific to active site;**
2. **Ref. to enzymes are unable to access the binding site of proteins due to the formation of aggregates;**
3. **Hence not recognised / accessed by enzymes which attach ubiquitin to these proteins;**
4. **Thus cannot be hydrolysed by proteasomes / proteases into short peptides / amino acids;**

Max 2

[2]

While vCJD is described as an infectious disease, scientists have noted that there is little or no immune response in patients diagnosed with vCJD.

(d) Suggest why there is a lack of a significant immune response in these patients.

1. **Misfolded proteins are produced by host cells and are not recognised as foreign;**
2. **Misfolded proteins are found within host cells / not found on the cell surface, hence not recognised by phagocytes or antibodies;**
3. **Prions are not presented as part of MHC-peptide complexes to stimulate the adaptive immune response;**

Max 2

[2]

Similar to the prions causing vCJD, the human immunodeficiency virus (HIV) is thought to have originated from a related strain of viruses which infects wild chimpanzees.

A HIV infection is characterised by a brief initial period of viral replication. This is followed by a long period of latency, where no symptoms are manifested. Eventually, reactivation of the provirus and rapid viral replication results in immunodeficiency.

Progression of the disease in HIV-positive individuals can be monitored by measuring the concentration of HIV particles (also known as the viral load) in their blood sample. One laboratory method measures the viral load by quantifying the activity of viral reverse transcriptase using the following procedure:

1. The HIV particles are separated from other blood plasma components.
2. The viral particles are lysed by disruption of the viral envelope and the resulting lysates are added to a mixture containing a RNA template and deoxyribonucleotides.
3. Viral reverse transcriptase found in the lysate will then synthesise complementary DNA (cDNA).
4. The amount of cDNA formed is detected by adding artificially synthesised antibodies which recognise and bind to the cDNA. These antibodies are linked covalently to an enzyme, which catalyses the formation of a coloured product.
5. The colour intensity of the resulting mixture is compared to those of standard solutions, from which the concentration of reverse transcriptase in the starting mixture can be deduced.

(e) Explain how the structure of antibodies allow them to be used for the procedure described.

1. **The Fab region / variable (V) domains / antigen binding sites of the antibodies have a unique 3D conformation;**
2. **due to a specific sequence of amino acids in these regions / domains of the heavy and light chains;**
3. **This allows specific / complementary binding to cDNA of a particular nucleotide sequence;**
4. **The Fc region / constant (C) domains of the antibodies provide a site for the linking of enzymes by covalent bonds(for the detection of cDNA formed);**
5. **AVP (e.g. hinge region)**

Max 2 from pt 1 to 3; Max 3 total

[3]

Antibodies are produced naturally by B lymphocytes in the human body, after exposure to foreign antigens.

(f) Justify the claim that "B lymphocytes are exceptions to the generalisation that all nucleated cells in the body have exactly the same DNA".

1. **Mature B cells have different DNA sequences due to somatic recombination / VDJ recombination (occurring in immature B cells);**
2. **where DNA rearrangements of the V and J segments of the gene coding for the variable (V) domain of the antibody's light chain / V, D and J segments of the gene coding for variable (V) domain of the antibody's heavy chain occurs;**
3. **Activated B cells have different DNA sequences due to somatic hypermutation;**
4. **where random point mutations are introduced at a high rate in the genes coding for the variable (V) domains of both light and heavy chains;**
5. **Activated B cells have different DNA sequences due to class switching;**
6. **where recombination of the gene segments coding for the constant (C) domains of the heavy chain occurs;**

Max 4

[4]

Another method to measure the HIV viral load involves quantifying the amount of viral genetic material present in the blood sample, using the procedure in Fig. 1.1.

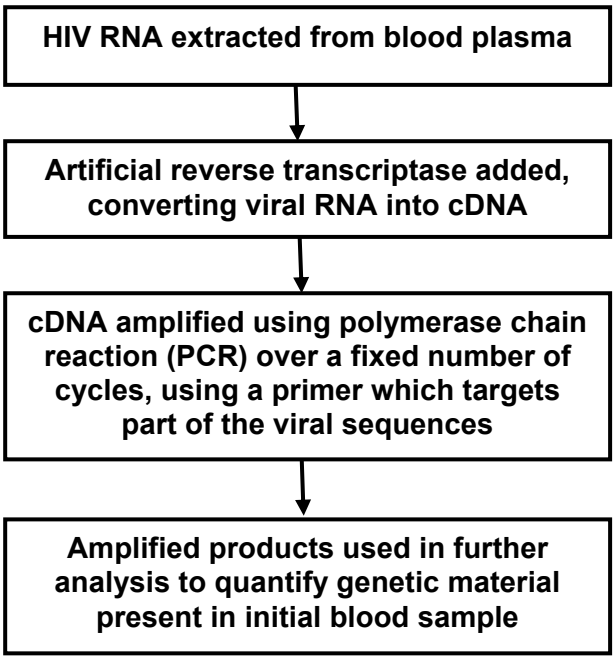


Fig. 1.1

(g) Describe how PCR is used in the amplification of HIV cDNA.

1. **HIV cDNA is incubated with *Taq* polymerase / heat-stable DNA polymerase, deoxyribonucleotides and the forward and reverse primers;**
2. **Temperature is raised (in a thermal cycler) to 95ºC, which denatures the cDNA / breaks hydrogen bonds between complementary bases, to form single-stranded DNA / to separate the two strands of DNA;**
3. **Temperature is cooled to 55ºC, allowing primers to anneal / form complementary base pairs with the two (3') ends of the target viral sequences;**
4. **Temperature is raised to 72ºC, allowing synthesis of the daughter DNA strands by elongation of the primers;**
5. **Cycle is repeated many times, where the number of DNA molecules doubles after each cycle;**

Pt 2, 3 and 4 compulsory
Max 4

[4]

There are two major strains of HIV known to man, HIV-1 and HIV-2. The different methods used to measure viral load vary in their ability to distinguish between the different HIV strains, as shown in Table 1.1.

Table 1.1

Method of measuring viral load	Able to distinguish between HIV strains
Quantification of viral reverse transcriptase activity	No
Quantification of viral genetic material	Yes

(h) Explain the difference in the two measurement methods in their ability to detect different HIV strains.

1. **HIV strains differ in their RNA sequences / have different genes or genetic makeup;**
2. **Hence PCR primer used in the method which quantifies the viral genetic material may be designed to bind to sequences found in a particular strain but not the other; (R! mention of gene coding for RTase, integrase or protease)**
3. **In the quantification of viral reverse transcriptase activity, the reverse transcriptase of either HIV strain would be able to reverse transcribe the RNA template used in the method / Ref. to not sequence-specific / Ref. to different HIV strains have the same type of reverse transcriptase;**

Note: Reverse transcriptase is essential for viral replication, hence assumed to be functional regardless of viral strain

[3]

While HIV is sexually-transmitted, dengue virus is transmitted by a mosquito vector. To study the influence of weather conditions on the incidence of dengue viral infection in Singapore, scientists recorded the amount of rainfall, mean weekly temperatures and the number of dengue cases over a one-year period. The recorded data is shown in Fig. 1.2.

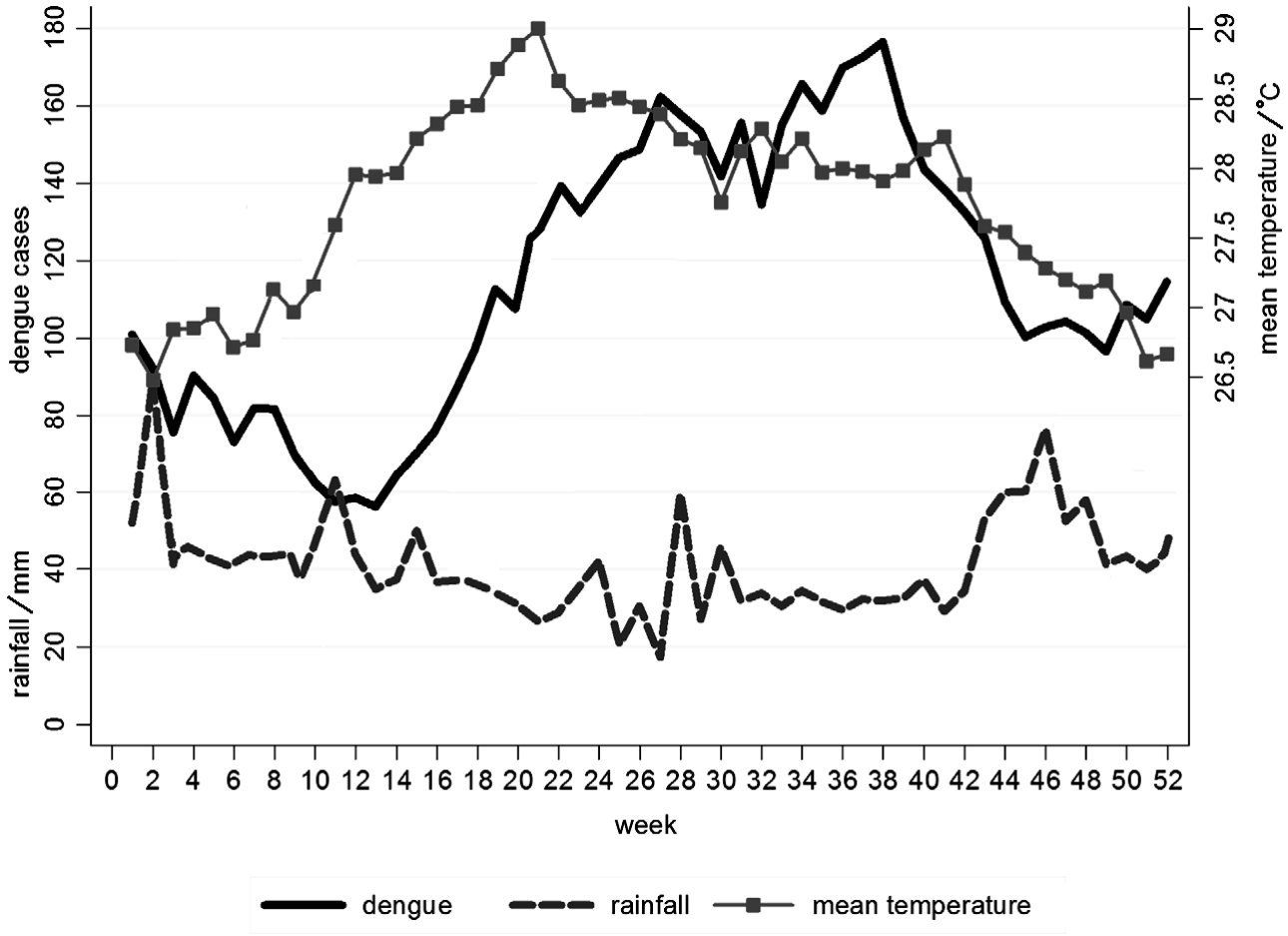


Fig. 1.2

(i) Based on the information provided, comment on which weather condition is a better predictor of dengue cases in Singapore.

1. **Mean weekly temperatures was a better predictor of the number of dengue cases;**
2. **Quoting relevant data to support correlation between temperature and dengue cases for upward trend e.g. When temperatures increased from 26.7ºC at week 1 to 28.4ºC at week 27, number of dengue cases increased from 100 to 160;**
3. **Quoting relevant data to support correlation between temperature and dengue cases for downward trend e.g.When temperatures decreased from 28ºC at week 40 to 27.1ºC at week 48, number of dengue cases decreased from 142 to 100;**
4. **Quoting relevant data to show that there is little correlation between rainfall and dengue cases (e.g. When rainfall remained relatively constant around 32mm between week 32 and week 41, number of dengue cases increased sharply from 138 to 178, before decreasing to 140);**

[4]

(j) Suggest explanations for the relationship between the weather condition chosen in part (i) and the number of dengue cases recorded.

1. **Increase in temperature increases the rate of enzymatic activity and hence metabolism of *Aedes* mosquitos / mosquito vectors, increasing their activity and facilitating spread of dengue;**
2. **The development time of mosquito larvae shortens as temperature increases, increasing the number of mosquito vectors to spread the dengue virus;**
3. **Rate of dengue viral replication increases with increase in temperature, hence more infected individuals developing viremia for a longer period of time, facilitating spread of dengue;**

R! Increase in precipitation brought about by increased temperature leads to the creation of standing water spots for the breeding of mosquitos (not supported by data)

Max 2

[2]

[Total: 29]

2 In order to solve the problems of malnutrition and nutritional deficiencies that are faced by two billion people worldwide, scientists have turned to genetic engineering. This involves the introduction of foreign genes into organisms to increase food production. One technique used in plant biotechnology to generate transgenic crops (crops with foreign genes introduced) involves the use of protoplast culture. It is designed to work as follows:

1. Cut a leaf into pieces.
2. Soak the leaf in a solution of microbial enzymes, sugars and salts. The enzymes digest the cellulose cell wall. The sugars and salts maintain the osmotic potential.
3. Centrifuge the cells to remove the cell wall debris. The protoplasts (plant cells with cell wall removed) will be found in the supernatant.
4. Apply an electric field to introduce the foreign genes into the protoplasts via transformation.
5. Isolate transformed protoplasts and culture them into transgenic plants.

(a) (i) Before a foreign gene is introduced into the protoplasts, the photosynthetic activity of the protoplasts must be checked to ensure that they are viable.

One way to do this is to mix the protoplast extract with 2,6-dichlorophenolindophenol (DCPIP), a redox dye. When reduced, DCPIP is changed from blue to colourless.

A protoplast mixture with DCPIP is placed under unfiltered white light, while another mixture is placed under white light passed through a blue filter.

Assuming that light intensity of the white light is constant, explain whether the DCPIP in the protoplast extract would decolourise faster under the unfiltered or filtered white light.

1. **Unfiltered white light;**
2. **Unfiltered white light has a broader spectrum which includes red and blue light;**
3. **The rate of light-dependent reactions / photophosphorylation and photolysis is increased;**
4. **The rate of electron emission from chlorophyll a would be faster and this will allow for a faster rate of DCPIP being reduced and decolourised;**

[4]

(ii) Suggest why it is necessary to digest the cellulose cell wall to allow for the introduction of a foreign gene into the protoplast.

1. **DNA molecule is large and may not pass through the cell wall easily / effectively; (R! cell wall is impermeable)**
2. **To expose the selectively permeable membrane;**
3. **To increase the efficiency of the transformation process / OWTTE;**

Max 1 [1]

Using the protoplast culture technique, scientists have introduced three β-carotene biosynthesis genes into a particular variety of the rice plant to form a new variety – the golden rice plant. The golden rice plant looks morphologically similar to other rice varieties except that its rice grains are yellow in colour due to the production of β-carotene in its rice grains. The β-carotene contained in the rice grains will be converted into vitamin A when it is consumed by humans.

(b) Discuss whether the β-carotene biosynthesis genes will be preserved in the gene pool of a population of rice plants, containing both the original and the new varieties, without any human intervention.

Yes, will be preserved

1. **The genes do not confer any advantageous traits nor disadvantageous traits on the growth and reproductive success of the rice plant. Hence, the trait does not come under selection pressure;**
2. **The golden rice plant also looks morphologically similar to the other rice variety, hence animals will feed equally on both varieties of plants. Hence, the trait does not come under selection pressure;**
3. **Animals that feed on rice preferentially consume the most common varieties of plants. Golden rice is rare and thus tend to be at a selective advantage;**
4. **AVP; (Must have idea of selected for + reason why)**

Max 2m

No, will not be preserved

5. **Animals may preferentially consume the golden rice plant (due to valid reason given). Hence, it be selected against in the natural environment;**
6. **The plant may spend available resources in producing β-carotene that it does not require. Hence, it be selected against in the natural environment;**
7. **Genetic drift may occur and a chance event may eliminate the entire Golden rice population which is small;**
8. **AVP; (Must have idea of selected against + reason why)**

Max 2m [4]

Genetic engineering can also be used to treat genetic diseases in humans which are caused by mutations involving single genes. This is done by introducing copies of the normal allele into human cells. In germline cell therapy, the normal alleles are introduced into germ cells.

(c) Comment on the ethical aspects of germline cell therapy.

It is ethically unacceptable:

1. **because there is a possibility of introducing an inheritable mutation/trait and all descendants of the patient would be affected;**
2. **due to unknown risks of altering the genome;**
3. **as it may be used for genetic enhancement / enhancement of traits in the offspring by altering the genome;**
4. **due to potential exploitation of women for collection of their oocytes;**

R! desensitise the society to more unethical practices

R! harming of embryos

It is ethically acceptable:

5. **because it may be used to treat incurable conditions/ leads to savings in healthcare cost;**
6. **AVP;**

Max 2m [2]

[Total: 11]

3 Plants have long been regarded as carbon sinks because they take in carbon dioxide for photosynthesis. However, when temperatures rise, plants increase their rate of respiration, resulting in increased carbon release. Some research has suggested that this could convert forests from a long-term carbon sink to a carbon source, aggravating climate change.

(a) Outline how a rise in temperature could lead to increased carbon release by plants.

1. **An increase in temperature leads to increased kinetic energy and hence an increase in effective collision between enzyme and substrate/ rate of enzyme-substrate complex formation;**
2. **This leads to an increase in rate of the link reaction/ Krebs cycle;**
3. **More carbon is released in the form of carbon dioxide from oxidative decarboxylation reactions;**

[3]

In 2016, a team of scientists conducted a short-term study of five years to find out the net carbon exchange of trees when the temperature was increased. In order to determine this, the increase in leaf respiration at higher temperatures was evaluated using 1000 young trees of 20 different boreal and temperate tree species grown in an open-setting.

Scientists compared the data observed to the expected results in Fig. 3.1.

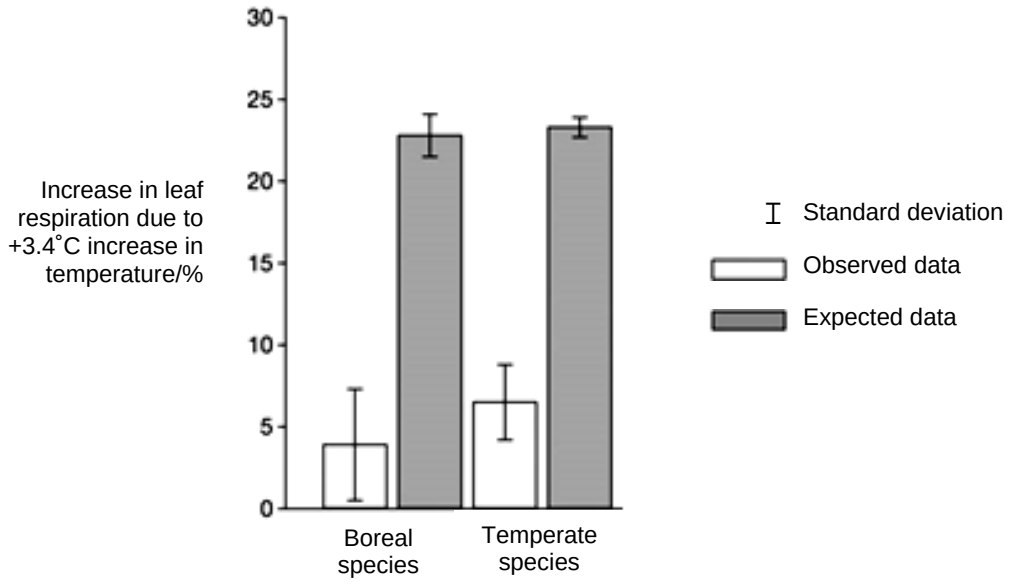


Fig. 3.1

(b) (i) With reference to Fig. 3.1, describe one difference between the data observed and the expected results.

1. **For both types of trees, the expected increase in leaf respiration was higher than that of the data observed;**
2. **The expected increase in leaf respiration was 23 and (22.5 to) 24% while that observed showed an increase in (3.5 to) 4% and (6.5 to) 7% respectively for boreal and temperate species;**

OR

3. **For both types of trees, the standard deviation for expected results was smaller than that for the data observed;**
4. **The standard deviation for expected data was (3 to) 4% and (1 to) 2% respectively for boreal and temperate species compared to 7 (to 8%) and 5% for the data collected;**

Pt 1 & 2 OR Pt 3 & 4

[2]

(ii) In Fig. 3.1, the data observed shows a difference in the increase in leaf respiration between boreal and temperate tree species. Explain whether this difference is significant.

1. **The difference is not significant as the standard deviation bars overlaps;**

[1]

(iii) Based on the results of the study, comment on whether forests will remain as carbon sinks or be converted to carbon sources if temperatures rise.

1. **The rate of plant respiration did not increase as much as expected, suggesting that the rate of photosynthesis may still be higher than the rate of respiration;**
2. **Overall, plants will take in more carbon dioxide than it gives out / remain as carbon sinks;**

OR

3. **The rate of plant respiration did not increase as much as expected. However, there is still an increase in respiration which may result in the rate of respiration becoming higher than the rate of photosynthesis;**
4. **Plants might become carbon sources instead of carbon sinks;**

Pt 1 & 2 OR Pt 3 & 4

[2]

(iv) Based on the results, scientists concluded that plants can acclimatise to changing climates, adjusting their metabolism according the environment. It was thus suggested that crop yield and hence food supply would not change drastically in light of climate change.

With reference to the design of the experiment, discuss the validity of this conclusion.

<u>Valid</u>

1. **A large sample size of 1000 trees were used, increasing the confidence of this conclusion;**
2. **AVP;** **Max 1m**

<u>Invalid</u>

3. **This study was only conducted on 20 boreal and temperate species and a conclusion cannot be made for plants in general;**
4. **This was a short term study and there is no evidence on the long term implication;**
5. **The study was conducted in an open setting, which might be affected by changes in other variables besides temperature;**
6. **AVP;** **Max 1m**

[2]

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 Biological polymers are large molecules composed of many individual smaller molecules called monomers. For instance, amino acids are taken into an animal cell for the synthesis of collagen. The synthesised collagen is then secreted out of the cell to form the connective tissue.

(a) Explain how the structural features of amino acids contribute to the function of collagen. [10]

(b) Explain how temperature and pH may affect the transport of substances across the cell surface membrane of eukaryotes. [15]

[Total: 25]

5 There are similarities in the ways that prokaryotes and eukaryotes regulate gene expression. In both groups of organisms, cyclic adenosine monophosphate (cAMP) is an important molecule in many biological processes, including the regulation of gene expression.

(a) Describe the role of cAMP in altering gene expression in organisms and suggest why they are usually small and non-protein in nature. [10]

(b) The eukaryotic genome is considered to be more complex than the prokaryotic genome. Describe the differences between the eukaryotic and prokaryotic genomes and explain the significance of these differences. [15]

[Total: 25]

4(a) Explain how the structural features of amino acids contribute to the function of collagen. [10]

1. Collagen has a structural role;

Structure of amino acid	Features of amino acids	Properties of collagen
2. Amino group and carboxyl group **(need to link point 2 with other points)**	**3. Amino and carboxyl groups allow for peptide bond formation between them;** **4. Via a condensation reaction;** **5. Allowing for the joining of (~1000) amino acid residues to form an alpha-chain;** **6. –NH and –CO groups are involved in forming hydrogen bonds between alpha-chains;**	**7. Allows formation of large molecule;** **8. This renders collagen insoluble in water;** **9. Three α-chains can wind tightly together to stabilise the triple helix structure (A! ref. to being compact);** **10. These properties account for the high tensile strength in collagen;**
11. R group (which may be polar or non-polar)	**12. The α-chains of collagen have a tripeptide sequence of gly-X-Y, where X is often proline and Y is often hydroxyproline or hydroxylysine;** **13. Glycine and proline have non-polar R groups that render them hydrophobic;** **14. Polar R groups (such as hydroxyproline and hydroxylysine) are already involved in hydrogen bonding between α-chains;** **15. Glycine has a small R group that is found in every third position;** **16. R groups of amino acid residues (lysine) allow for formation of covalent cross-links between tropocollagen;**	**17. This renders collagen insoluble in water;** **18. Three α-chains can wind tightly together to stabilise the triple helix structure;** **19. These properties account for the high tensile strength in collagen;**

*** Properties to be awarded once (pt 8, 9 and 10 vs pt 17, 18 and 19)**

+QWC: Mentions at least 1 structural features of amino acids and linking correctly to one property of collagen (insolubility in water and high tensile strength)

(b) Explain how temperature and pH may affect the transport of substances across the cell surface membrane of eukaryotes. [15]

Transport that does not involve proteins	Transport that involves proteins
1. Diffusion is the net movement of particles (molecules or ions) from a region where they are at a relatively high concentration to a region where they are at a lower concentration;	**11. Facilitated diffusion of substances occurs with the assistance of channel / carrier proteins in the membrane, along a concentration gradient;**
2. Osmosis is the movement of water from a region of higher water potential (Ψ) to a region of lower water potential;	**12. Active transport is the transport of substances into and out of cells regardless of the presence of a concentration gradient with the expenditure of ATP;**
3. When temperature increases, kinetic energy of particles increases;	**13. In receptor-mediated endocytosis, specific molecules/ligands bind to specific receptors / glycoproteins / glycolipids before being taken up by the cell;**
4. Rate of diffusion of particles (for diffusion) and water molecules (for osmosis) increases across cell surface membrane;	**14. At high temperatures; the hydrogen bonds, hydrophobic interactions and ionic bonds (name 2 out of 3) between amino acid residues of proteins are broken;**
5. Endocytosis (including phagocytosis and pinocytosis) is the uptake of mostly large material into a cell by an invagination of the plasma membrane / engulfing and its internalisation in a membrane-bound vesicle;	**15. When there are drastic changes in pH, ionic charges of the acidic and basic R-groups of the amino acid residues at the binding site may be changed;**
6. Exocytosis is the process where the cell secretes certain large molecules by the fusion of vesicles with the cell surface membrane;	**16. Changes in pH also affect hydrogen bonds and ionic bonds between amino acid residues (name 1 out of 2);**
7. When temperature increases, fluidity of membrane increases because phospholipid movement increases;	**17. These changes in temperature / pH can denature / change the 3D conformation of the channel and carrier proteins involved in facilitated diffusion or active transport;**
8. Hence increasing the rate of endocytosis and exocytosis of substances;	**18. E.g. of transport protein affected;**
9. If the temperature is high enough, hydrophobic interactions between phospholipid tails may be disrupted;	**19. Hence increasing / decreasing the rate of facilitated diffusion / active transport;**
10. This causes membrane leakages, allowing larger substances to enter or leave the cell;	

Points 3 and 4 apply for both diffusion and osmosis; Accept reverse argument for all points

+ QWC: Mentions at least 3 different modes of transport that allows explanation of effects of temperature and pH

5(a) Describe the role of cAMP in altering gene expression in organisms and suggest why they are usually small and non-protein in nature. [10]

1. **In eukaryotes, it acts as a second messenger;**
2. **In the presence of the ligand (first messenger), an activated G protein binds to adenyl cyclase, converting ATP to cAMP;**
3. **cAMP binds to and activates protein kinase A during signal transduction;**
4. **Ref. to idea of signal amplification + example (e.g. one adenyl cyclase catalyses the synthesis of many molecules of cAMP / one protein kinase phosphorylates more than one kinase and activates them);**
5. **Protein kinase A then activates other protein kinases via a phosphorylation cascade;**
6. **Finally activating an effector / activator / repressor / transcription factor protein that alters gene expression;**
7. **In the absence of the ligand, cAMP will be converted to an inactive product (AMP) by phosphodiesterase to cease signal transduction;**

8. **In bacteria, it is involved in the positive regulation of the *lac* operon;**
9. **When glucose levels are low (and lactose is present), ATP is converted to cAMP by adenyl cyclase;**
10. **cAMP binds to and activates the catabolite activator protein (CAP) which binds to the CAP binding site within the *lac* promoter;**
11. **This increases the affinity of RNA polymerase to bind to the *lac* promoter and increases rate of transcription of structural genes;**

12. **cAMP is small in nature as they need to diffuse rapidly through the cytoplasm, enabling quick transduction of signal throughout the cell;**
13. **cAMP is non-protein in nature as proteins are sensitive to conditions in the cell (such as pH and temperature), hence activity may be easily affected/proteins are easily degraded;**
14. **cAMP is small in nature as larger molecules may take a longer time to synthesise and hence unsuitable for rapid action;**
15. **cAMP is non-protein in nature as protein synthesis may take a longer time and hence unsuitable for rapid action;**
16. **cAMP is small in nature as larger molecules requires a lot of energy/resources to synthesise;**
17. **cAMP is non-protein in nature as protein synthesis requires a lot of energy/resources;**

18. **Ref to Glucagon binding to GPLR and its role in regulating blood glucose concentration;**

Max 4 for eukaryotes
Max 3 for small, non-protein nature
Max 9 in total

+ QWC:
1 role of cAMP in eukaryotes and 1 role of cAMP in prokaryotes (bacteria)
1 reason why it is small or why it is non-protein in nature

(b) The eukaryotic genome is considered to be more complex than the prokaryotic genome. Describe the differences between the eukaryotic and prokaryotic genomes and explain the significance of their differences. [15]

Level of comparison	Prokaryotic Genome	Eukaryotic Genome	Significance
1. Size of genome	**Smaller**	**Larger**	**1a. In eukaryotes, there are more genes / coding regions;** **1b. Allows more proteins need to be coded for;**
2. Number of chromosomes	**Single / haploid**	**Multiple / diploid or more**	**2a. In eukaryotes, there is pairing of homologous chromosomes;** **2b. Allows for crossing over of non-sister chromatids during meiosis, giving rise to genetic diversity;** **2c. In prokaryotes, there is a smaller genome which allows for faster binary fission;**
3. Organisation of genes/operon	**Polycistronic mRNA / operons present**	**Monocistronic mRNA / operons absent**	**3a. In prokaryotes, there is coordinated control of metabolic enzymes involved in the same pathway;** **OR:** **In eukaryotes; individual enzymes are controlled individually by separate promoters (which can be produced in different amounts or not at all);** **3b. In prokaryotes, a coordinated control allows for a more rapid response as all substrate will be channeled into that one single pathway;** **3c. In eukaryotes, this way of organization allows for different metabolic intermediates to be used in different metabolic pathways to suit the cells' needs;**
4. Amount of coding and non-coding DNA	**Mainly coding, little non-coding DNA;**	**Greater proportion of non-coding than coding DNA;**	**4a. In eukaryotes, non-coding DNA in eukaryotes with regulatory functions, such as enhancers / silencers allows for different levels of expression of a particular gene depending on the activators / repressors present in the cell for a specific cell response;** **4b. In eukaryotes, the presence of introns allows for alternative splicing to occur, allowing one**

			gene to code for more than one type of mature mRNA / protein; **4c. In eukaryotes, specific proteins bind to centromere and forms the kinetochore which is the site of spindle fibre attachment for the accurate segregation of sister chromatids during mitosis and chromatids in meiosis II / the segregation of homologous chromosomes during meiosis I to opposite poles, and hence to daughter nuclei; OR** **Centromere also allow the adhesion of sister chromatids to ensure accurate segregation of sister chromatids during mitosis and chromatids in meiosis II** **4d. In eukaryotes, centromeres also help organise the chromatin within the nucleus during interphase;** **4e. In eukaryotes, telomeres protect genes at the ends of chromosomes from being eroded / other functions** **4f. But prokaryotes have circular DNA and do not face the end-replication problem;**
5. Association of genetic material with histones	**No association with histones**	**Association with histones**	**5a. In eukaryotes, this allows for folding of DNA to higher degree of condensation so that there is less breakage during cell and nuclear divisions;** **5b. Control of rate of gene transcription by allowing for increased DNA condensation/conversion between euchromatin and heterochromatin states;**
6. Location of genetic material	**In nucleoid region**	**In (membrane-bound) nucleus**	**6a. Without the nuclear envelope, transcription and translation takes place simultaneously;** **6b. Translational control is less significant in prokaryotes;**

R! Comparisons without reference to the genome, such as size of cell

+QWC: Explain at least one difference between eukaryotic and prokaryotic genomes with corresponding significance(s)