6. Nucleic Acids and Protein Synthesis

6.2 Protein Synthesis

Paper 2

Question Paper

1 Antibodies are produced by plasma cells.

Fig. 6.1 shows antigens bound to antigen-binding sites of an antibody molecule.

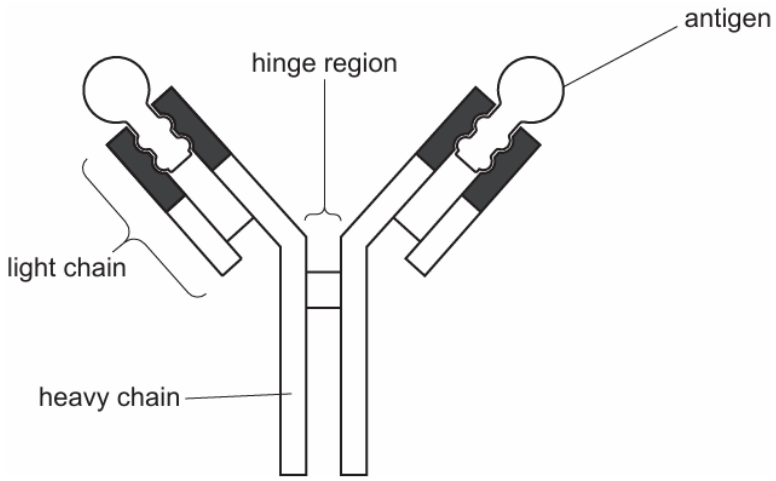


Fig. 6.1

(b) It is estimated that the immune system of each person can make enough antibodies to bind to over 10^{12} different antigens.

When plasma cells make antibody molecules they combine the polypeptides produced by the expression of genes for heavy chains and the genes for light chains.

Research has shown that producing this very large number of antibodies is only possible by modifying the primary transcripts of the genes that code for heavy chains and the genes that code for light chains.

Suggest how this modification of the primary transcripts occurs in plasma cells.

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2 Smooth muscle is a tissue composed of smooth muscle cells. The cells contain cytoplasm packed with proteins that are involved in contraction and relaxation.

(d) Caldesmon is a large protein with a number of binding sites to attach to other proteins.

Caldesmon exists in two different forms, H-caldesmon and L-caldesmon.

H-caldesmon helps to regulate contraction and relaxation in smooth muscle cells.

L-caldesmon is found in some non-muscle cells, where it also acts as a regulatory protein.

- Caldesmon is coded for by a gene known as *CALD1*.
- *CALD1* has 17 exons.
- The primary structure of H-caldesmon has a repeating sequence in the middle of the amino acid chain that is **not** present in L-caldesmon.

(i) Researchers have discovered that a gene mutation is **not** the cause of the two different forms of caldesmon.

Explain what is meant by a gene mutation.

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(ii) Researchers now know that the two different forms of caldesmon are the result of events occurring **directly after** transcription of DNA. Changes occur to the primary transcript that is formed by DNA transcription.

Suggest how the smooth muscle cells and non-muscle cells can produce different forms of caldesmon from the same primary transcript.

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3 In the mesophyll tissue of leaves, products of photosynthesis can be used to synthesise organic compounds, such as the polysaccharide cellulose and some amino acids.

A source of nitrogen for amino acid synthesis can be provided by nitrate ions that have been taken up in the roots and transported to the leaves.

(b) Studies of nitrate uptake and nitrate metabolism help to provide information to scientists who are investigating ways to increase the yield of crop plants.

The first step of nitrate metabolism in leaf cells is the reduction of nitrate to nitrite, catalysed by the enzyme nitrate reductase. The activity of the enzyme can be studied by detecting the presence of nitrite formed.

(i) Researchers have found that adding nitrate to leaf tissue results in an increase in messenger RNA (mRNA) molecules of the gene *NR*, which codes for nitrate reductase.

State **one** benefit to leaf cells of an increase in mRNA molecules of gene *NR* after the addition of nitrate.

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4 **(c)** Sucrose is a sweet-tasting sugar found in many foods.

Some people become ill when they have sucrose in their diet. These people have a gene mutation in the gene coding for sucrase and cannot hydrolyse sucrose in the digestive system.

Scientists studying the DNA of people with this condition identified a deletion mutation in the gene coding for sucrase.

Suggest **and** explain why a person with this deletion mutation cannot digest sucrose.

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5 The gene for the enzyme catalase is on chromosome 11 in humans.

(a) Explain the meaning of the term gene.

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6 The alveoli of the lungs are the main gas exchange surface in humans.

(d) The gene *ABCA3* codes for protein ABCA3. The gene is 80 kb (80 000 base pairs) long and is composed of introns and exons. Protein ABCA3 is composed of 1704 amino acids.

(i) Fig. 4.1 shows the flow of genetic information in the production of ABCA3.

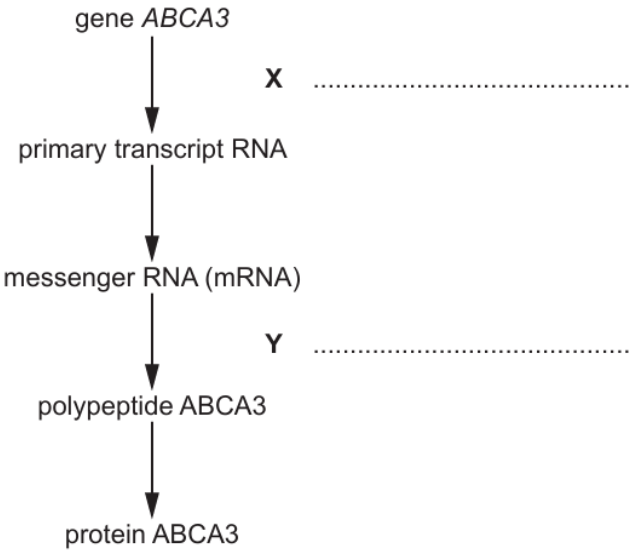


Fig. 4.1

Complete Fig. 4.1 to name the processes occurring at **X** and **Y**. [2]

(ii) A triplet of bases codes for one amino acid. This fact only partly explains how the activity of gene *ABCA3*, which is 80 kb long, can result in the protein ABCA3, which is only 1704 amino acids long.

Suggest **other** reasons to explain the difference in the number of base pairs in gene *ABCA3* compared with the number of amino acids in protein ABCA3.

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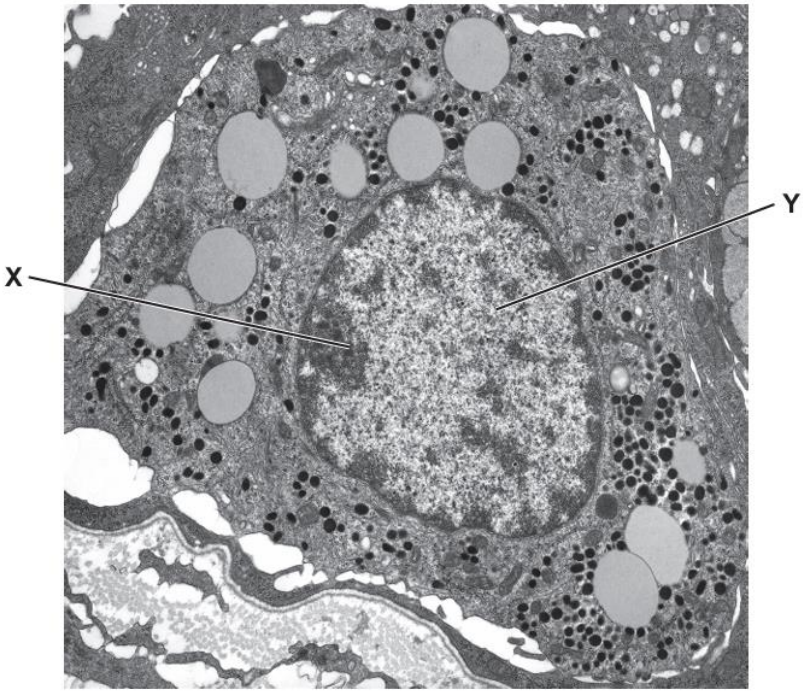
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7 Fig. 2.1 is a transmission electron micrograph showing a section of a specialised epithelial cell found in the lining of the stomach. This cell produces extracellular proteins that are released into the bloodstream.



×6000

Fig. 2.1

(c) Scientists have discovered that the gene coding for ghrelin contains 5000 base pairs. This is a much larger number of base pairs than is needed to code for the ghrelin molecule shown in Fig. 2.2.

(i) Calculate the percentage of base pairs found in the gene that codes for the ghrelin molecule shown in Fig. 2.2.

Show your working and give your answer to one decimal place.

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(ii) The primary transcript produced from the ghrelin gene is a longer molecule than the mRNA found in the cytoplasm.

Explain how the primary transcript is modified before translation.

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8 The enzyme carbonic anhydrase has been found in a wide range of organisms and acts as a catalyst in many tissues.

Studies have shown that there are differences in the protein structure of the enzyme and differences in the number and organisation of introns and exons of the gene coding for the enzyme.

All carbonic anhydrase enzymes catalyse the same reversible reaction, shown in Fig. 4.1.

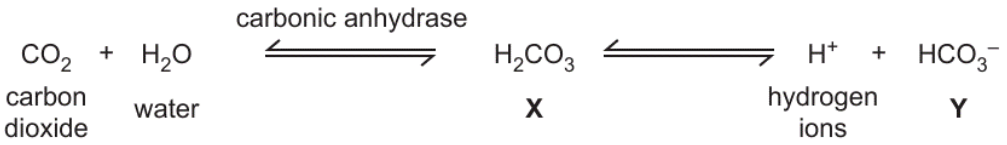


Fig. 4.1

(c) Genes coding for proteins in eukaryotes consist of introns and exons.

Outline the similarities and differences between the introns and the exons of genes coding for proteins such as carbonic anhydrase.

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9 Cotransporter proteins are membrane proteins found in companion cells of phloem tissue.

Messenger RNA (mRNA) is the molecule in cells that carries genetic information in the DNA that codes for cotransporter proteins to the sites of protein synthesis in the cytoplasm.

(b) Fig. 6.1 shows the events that occur in the nucleus of a companion cell in phloem tissue to synthesise molecules of mRNA.

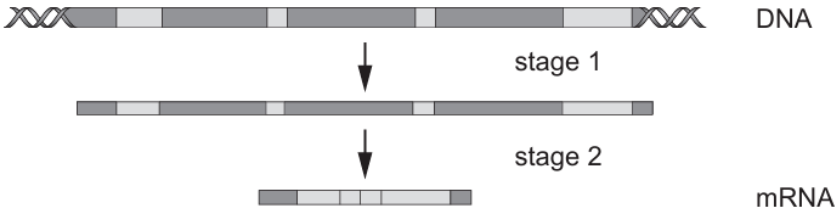


Fig. 6.1

(i) Name stage 1 shown in Fig. 6.1.

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(ii) Describe what happens at stage 2, shown in Fig. 6.1, to shorten the length of the RNA molecule.

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(c) Cotransporter molecules are proteins produced in companion cells.

Fig. 6.2 shows what happens in the cytoplasm of a companion cell to a transfer RNA molecule before the cotransporter proteins can be produced.

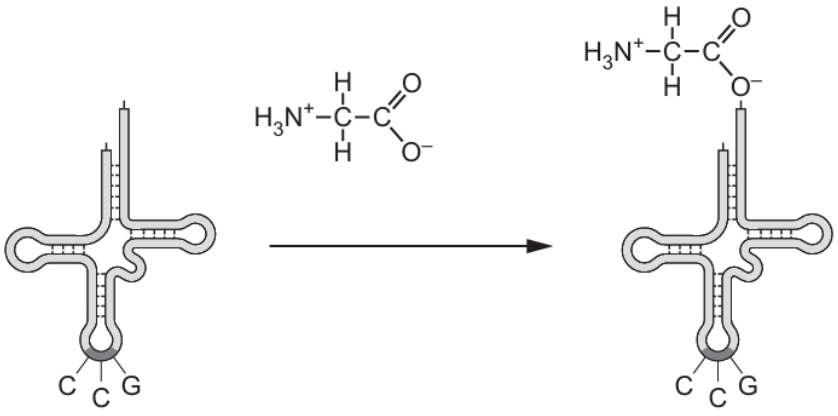


Fig. 6.2

(i) Describe the role of the transfer RNA shown in Fig. 6.2 in the synthesis of a cotransporter protein.

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10 *Plasmodium falciparum* is one species of *Plasmodium* that causes the life-threatening disease malaria. With early diagnosis and the correct drug treatment, the pathogen can be eliminated from the body, particularly if the disease is not severe.

(c) ACT can act on the stage of the life cycle of *P. falciparum* that occurs within red blood cells. The cells of *P. falciparum* in this stage are known as trophozoites.

Fig. 3.1 is a photomicrograph of a blood smear (thin layer of cells). Some of the red blood cells contain trophozoites.

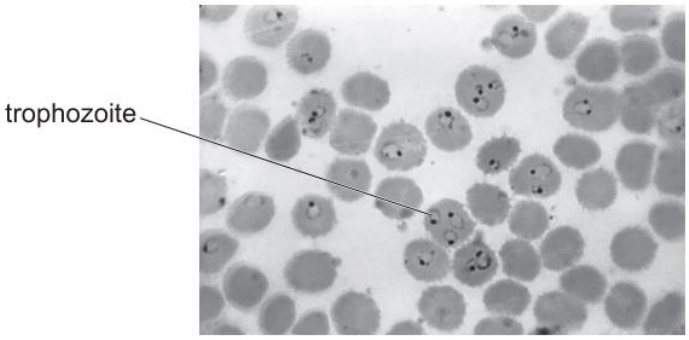


Fig. 3.1

PfK13 is a protein that has an important role in the development of the trophozoite stage of *P. falciparum*. The gene *kelch13* codes for PfK13.

Two different mutations of *kelch13*, known as F446I and C580Y, were investigated to see if they were associated with partial artemisinin resistance. Details of these mutations are summarised in Table 3.1.

Table 3.1

name of mutation	change in DNA		change in protein PfK13	
	nucleotide present in *kelch13*	**nucleotide present after mutation**	**amino acid before mutation**	**amino acid after mutation**
F446I	thymine (T)	adenine (A)	phenylalanine (phe)	isoleucine (ile)
C580Y	guanine (G)	adenine (A)	cysteine (cys)	tyrosine (tyr)

(i) Using gene *kelch13* and mutation F446I as examples, explain the difference between a gene and a gene mutation.

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11 Carbonic anhydrase is a globular protein found in red blood cells.

(b) A protein such as carbonic anhydrase is coded for by a gene. A gene forms part of a DNA molecule.

Fig. 3.1 is a diagram of a small section of a DNA molecule.

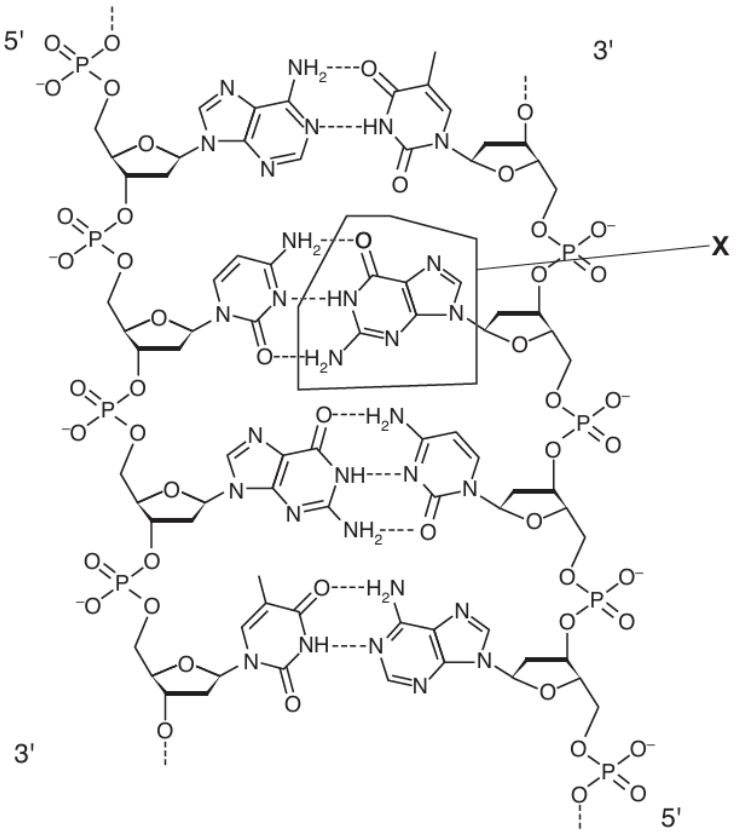


Fig. 3.1

(ii) The section of the DNA molecule in Fig. 3.1 is part of a gene coding for a polypeptide.

Base **X**, shown in Fig. 3.1, is located in an exon on the strand of DNA that is transcribed during protein synthesis. A mutation that results in the deletion of base **X** will affect the polypeptide produced.

Explain how this deletion may affect the polypeptide produced during protein synthesis.

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(iii) Gene mutations can occur in either introns or exons.

Suggest the effect of a gene mutation in an intron.

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12 In mammals, some cell signalling molecules are steroid (lipid) hormones. These hormones are transported in the bloodstream to reach capillary networks.

At a capillary network, hormones pass out of the blood into tissue fluid.

(d) The hormone-receptor complex shown in Fig. 3.2 enters the nucleus and binds to DNA. This switches on a gene coding for a polypeptide that is synthesised in the cytoplasm.

(i) Name the structure through which the hormone-receptor complex enters the nucleus.

..... [1]

(ii) Name the processes occurring at **B** and **C**.

B .....

C ..... [2]

(iii) Name structure **G**.

..... [1]

13 Baculovirus is a virus that kills some of the insect pests of major crops. When the virus is released to the outside of the insect body, it is contained within stable, protective structures known as polyhedrons.

The main component of the polyhedron is a protein molecule, polyhedrin.

Polyhedrons can be sprayed onto plants as a bioinsecticide. They are ingested by feeding insect larvae and once inside the insect gut they break down to release the virus.

(d) The sequence of DNA nucleotides for the gene in baculovirus that codes for the polyhedrin polypeptide has been determined.

Explain why the amino acid sequence of the polypeptide **cannot** be used to deduce this sequence of nucleotides in the gene that codes for the polyhedrin polypeptide.

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14 **(b)** Telomeres are located at the ends of each chromosome.

Telomeres progressively shorten each time a healthy human cell divides, until the cell is no longer able to divide.

Stem cells have an enzyme called telomerase that prevents the telomeres shortening during the cell cycle.

(iii) Scientists have researched the possibility of treating cancer by inhibiting the action of telomerase.

One method that has been studied involves inserting small, single-stranded DNA into cancer cells. These sections of DNA have a base sequence that is complementary to a section of the mRNA transcribed from the gene coding for telomerase.

Explain how inserting small, single-stranded DNA could prevent **translation** of the mRNA to produce telomerase.

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15 Fig. 6.1 shows the formation of a polypeptide during translation in a eukaryotic cell.

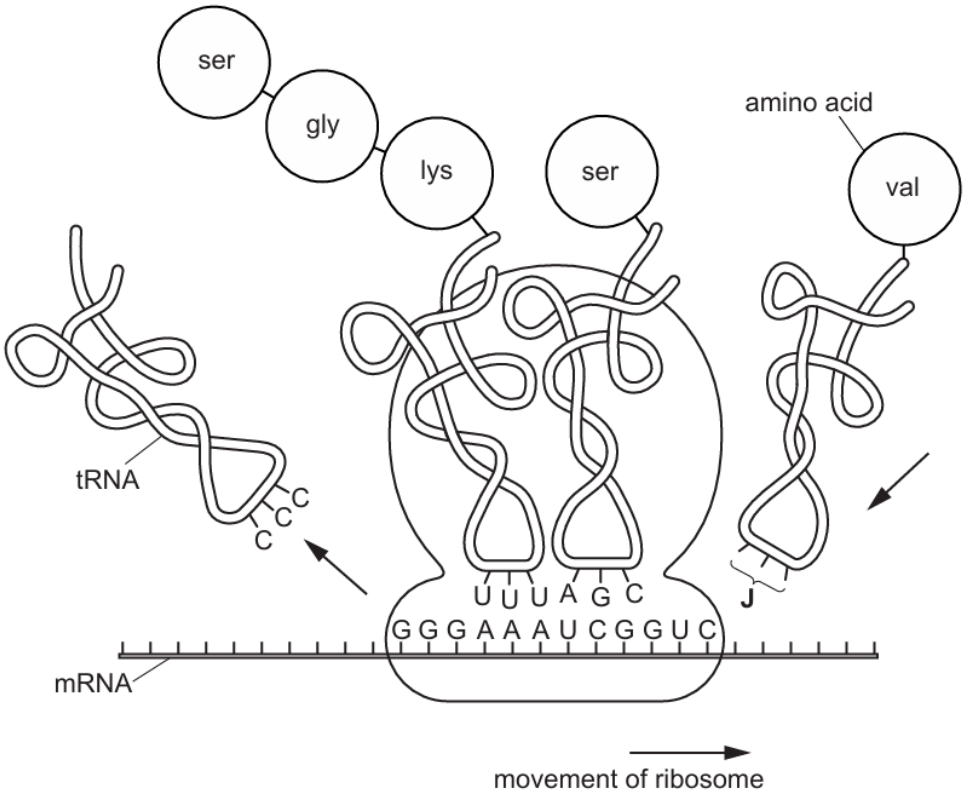


Fig. 6.1

(b) State the name given to the group of three bases found at **J** on the tRNA molecule.

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(c) Identify the three bases at **J**.

..... [1]

(d) State how the three bases at **J** on tRNA interact with the bases on mRNA.

..... [1]

16 **(a)** Mutations in body cells can sometimes result in a tumour. Some tumours are cancerous.

(ii) Tumour cells have antigens on their cell surface that are not present on non-tumour cells.

These antigens are the result of gene mutations and are known as tumour specific antigens (TSA).

One type of TSA differs in structure from the protein found on the cell surface of non-tumour cells by a single amino acid.

Explain how a gene mutation could result in the production of this TSA.

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17 The treatment for people with active tuberculosis (TB) lasts six months and involves a combination of antibiotics. This is usually very effective if the person has a susceptible (non-resistant) strain of *Mycobacterium tuberculosis*, the causative organism of TB.

Table 2.1 summarises one recommended treatment strategy that involves a combination of antibiotics.

Table 2.1

antibiotic	length of treatment	mode of action of antibiotic
rifampicin (R)	6 months	enters bacterial cells and inhibits protein synthesis
isoniazid (H)	6 months	prevents the synthesis of cell wall components known as mycolic acids
ethambutol (E)	first two months	prevents mycolic acids from being added to the cell wall
pyrazinamide (Z)	first two months	prevents the synthesis of fatty acids

Rifampicin binds tightly to an RNA polymerase molecule close to its active site. This affects the activity of the enzyme.

(b) (i) RNA polymerase catalyses the formation of messenger RNA (mRNA) from DNA.

State the term for this process.

..... [1]

(c) RNA polymerase is composed of five different polypeptides. Gene *rpoB* codes for one of these polypeptides known as the β-subunit.

One or more mutations in a specific region of *rpoB* result in strains of *M. tuberculosis* that are resistant to rifampicin. In these strains, mutations often occur in two DNA triplets in this region, in positions 526 and 531.

Table 2.2 summarises the results of an investigation into seven rifampicin-resistant strains, **A** to **G**, that have amino acid changes for positions 526 and 531.

Table 2.2 includes:

- the change in the **mRNA codon** for position 526 or position 531
- the amino acid change that has occurred as a result of the mutation
- the minimum concentration of rifampicin required to inhibit growth of the bacterial strain (MIC)
- the number of **other** mutations occurring within the specific region of *rpoB*.

Table 2.2

Key
≈ approximately ⩾ greater than or equal to ⩽ less than or equal to

strain	codon involved	mRNA codon change	amino acid change	MIC / $\mu g\,cm^{-3}$	number of other mutations in the specific region
A	526	CAC → UAC	His → Tyr	⩽50	0
B	526	CAC → AAC	His → Asn	⩾100	1
C	526	CAC → CGC	His → Arg	≈50–75	2
D	526	CAC → CGC	His → Arg	⩾100	3
E	526	CAC → CGC	His → Arg	≈50	3
F	526	CAC → UUC	His →	⩾100	3
	531	UCG → UUG	Ser → Leu		
G	526	CAC → UAC	His →	⩾100	3
	531	UCG → UUC	Ser → Phe		

(i) Complete Table 2.2 to show the amino acid changes that have occurred in strains **F** and **G**.

[1]

(ii) With reference to Table 2.2, list the strains of *M. tuberculosis* that show the greatest resistance to rifampicin.

..... [1]

(iii) Suggest reasons to explain why strains **C**, **D** and **E** show:

- resistance to rifampicin
- different levels of resistances to rifampicin.

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18 **(b)** Floxuridine is a drug used to treat cancer.

(ii) Floxuridine prevents thymine nucleotides being produced.

Explain why floxuridine does **not** affect transcription.

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19 A red blood cell goes through a number of stages in the bone marrow before it is released into the circulation to carry out its role of oxygen transport.

Fig. 3.1 is a transmission electron micrograph of developing red blood cells in the bone marrow. Each cell is known as an erythroblast.

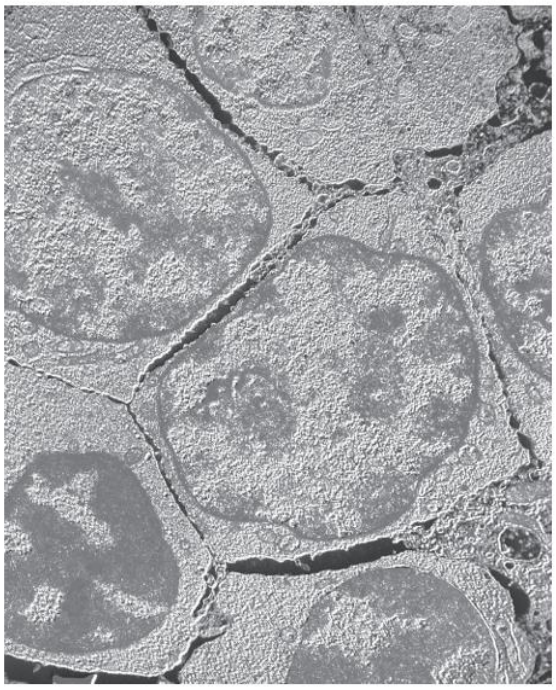


Fig. 3.1

(c) The maturing red blood cell synthesises haemoglobin and other proteins.

(i) Complete Table 3.1 to:

- name **three** organelles (cell structures) that are involved in the synthesis of a fully functioning protein
- state **one** way in which the named organelle is involved in protein synthesis.

Table 3.1

organelle	how the organelle is involved in protein synthesis

[3]

20 **(b)** Fig. 6.1 is a diagram of a molecule of tRNA.

The region labelled **R** shows detail of part of the tRNA molecule.

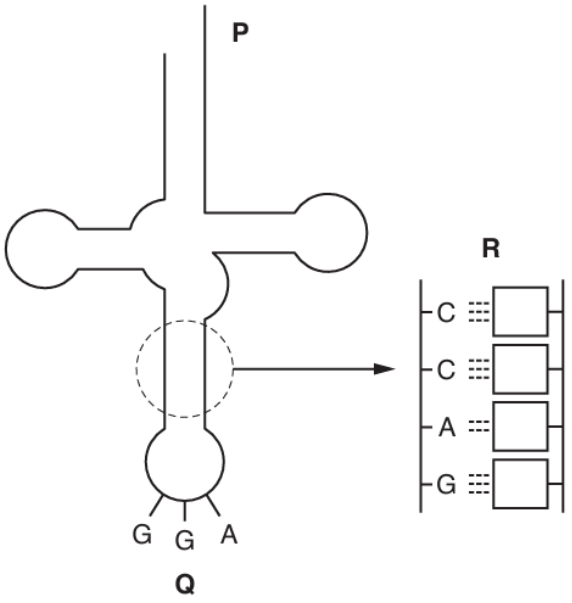


Fig. 6.1

(i) Complete Fig. 6.1 by writing the sequence of bases in the region labelled **R**. [1]

(ii) State the name of region **Q and** explain the role of region **Q** in translation.

name .....

explanation .....

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(iii) State the function of region **P**.

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21 Some tissues of the gas exchange system include cells that are able to produce and secrete mucins. Mucins are stored in vesicles in these cells, ready for secretion. Once outside the cell, mucins adsorb water to form mucus.

(c) The processes that occur in the production and secretion of mucins are listed.

translation **exocytosis** **glycosylation** **transcription**

Complete Table 2.1 by writing the processes in the correct order in which they would take place.

Table 2.1

first process	
second process	
third process	
fourth process	

[2]

22 Fig. 3.1 is a photomicrograph of human blood cells from a healthy individual who lives at sea level. The cells labelled **C**, **D** and **E** are white blood cells.

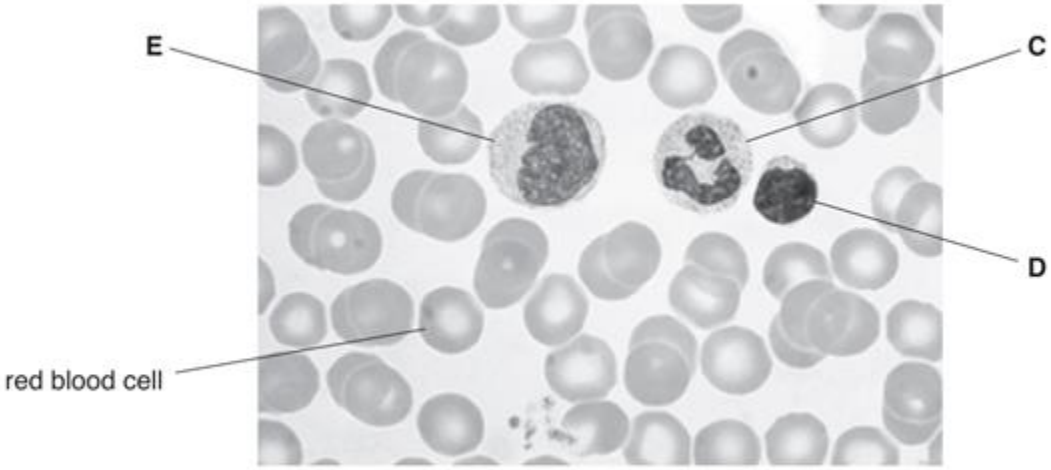


Fig. 3.1

(d) Polypeptide synthesis occurs before a red blood cell is released into the circulation.

The *HBB* gene codes for the β-globin polypeptide of haemoglobin.

There are two alleles of *HBB*, known as Hb^A and Hb^S.

Describe the difference between the Hb^A allele and the Hb^S allele **and** state how this difference affects:

- the β-globin polypeptide
- the haemoglobin molecule.

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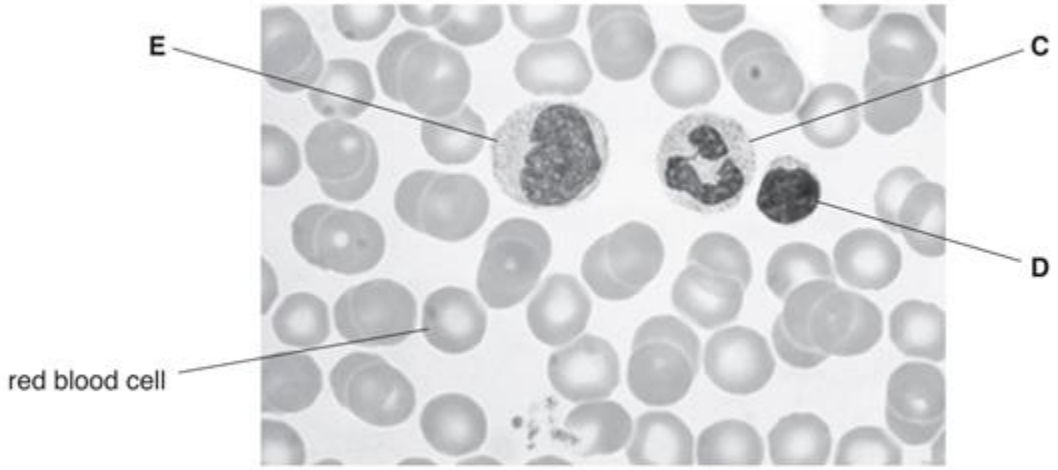


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- the β-globin polypeptide
- the haemoglobin molecule.

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24 Bacteria may be classified according to differences in cell wall structure. The differences are shown by using the Gram stain.

- A Gram-positive bacterium has a cell wall mainly composed of a thick layer of peptidoglycan (murein).
- A Gram-negative bacterium has a more complex cell wall. This wall is composed of a much thinner layer of peptidoglycan and an outer layer known as the outer membrane.

Escherichia coli is a Gram-negative bacterium.

Fig. 3.1 is a diagram through the cell surface membrane **and** the cell wall of *E. coli*.

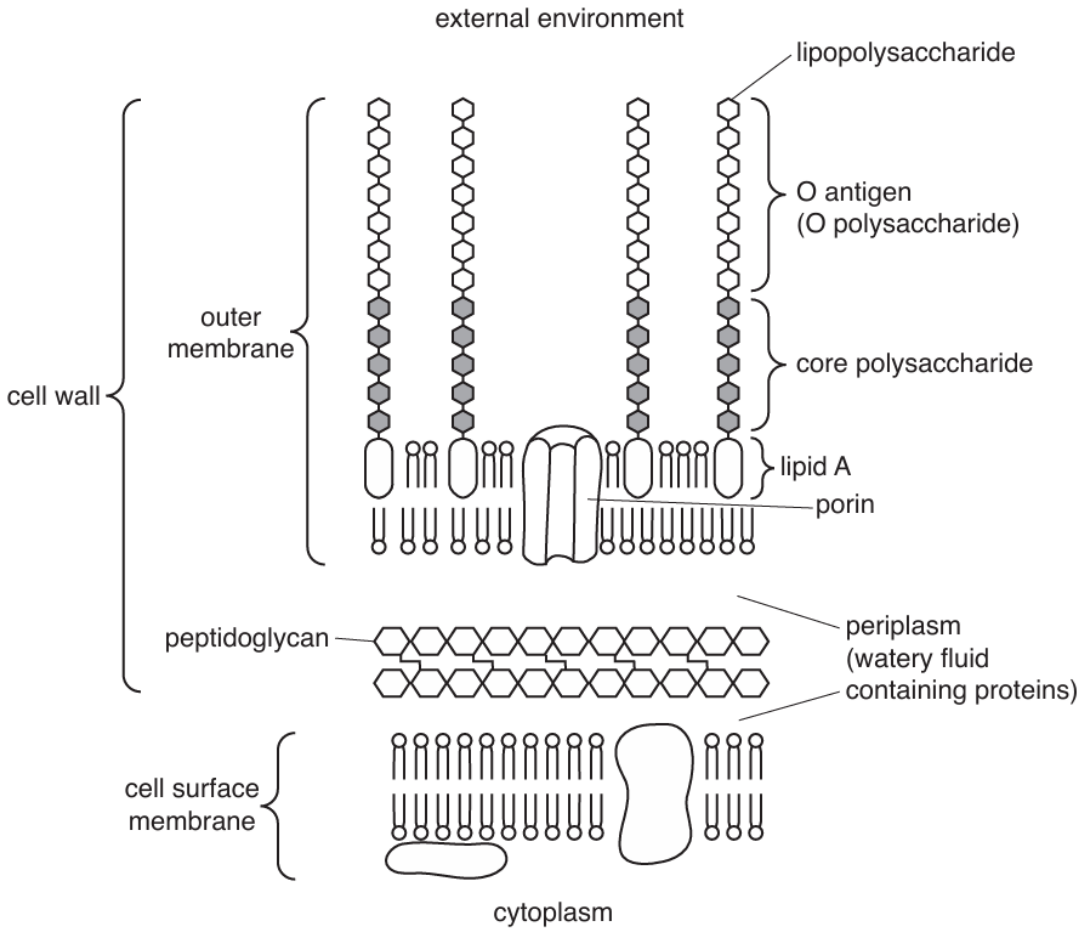


Fig. 3.1

(b) The outer membrane contains transport proteins called OmpF porins. These porins allow the passive movement of water, ions and small, polar molecules across the outer membrane. Each OmpF porin is formed from three identical polypeptides.

(iii) *E. coli* can regulate the number of OmpF porins in the outer membrane to adapt to changing conditions. One control mechanism used by *E. coli* involves the production of a small mRNA molecule known as micF.

MicF binds to the part of the mRNA molecule containing the START codon for the OmpF polypeptide.

Suggest **and** explain how the presence of micF prevents production of OmpF porins.

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