Achievement Standard 91159

Demonstrate understanding of gene expression

BIOLOGY

2.7

Externally assessed 4 credits

This Achievement Standard is about the genetic code, carried by all living organisms, and how the information in the genetic code is expressed to show the phenotype of the organism.

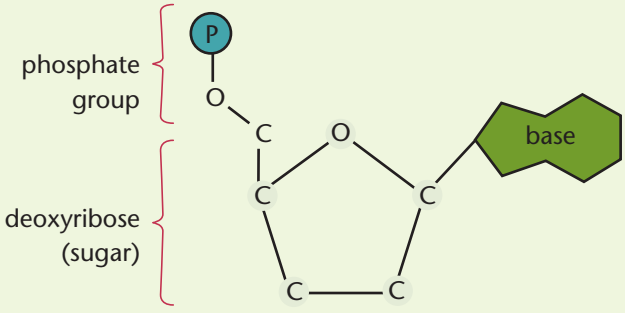
Nucleic acids, proteins and the genetic code

This section discusses molecular components and their role in carrying the genetic code: nucleotide monomers, deoxyribose and/or ribose (sugar), phosphate, nitrogenous bases, and complementary base pairing resulting in coding and template strand formation.

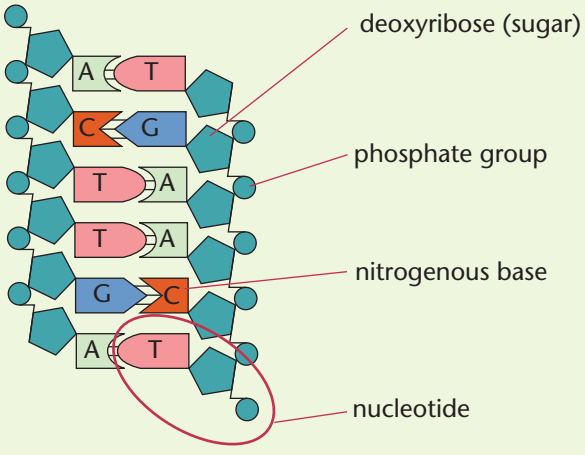
Nucleic acid structure

Nucleic acids, such as DNA, are essential to the operation of a living cell. They are long molecules made up of a repeating unit called a **nucleotide**. Each nucleotide in DNA has three parts attached together in the following order:

- phosphate group
- deoxyribose (sugar)
- nitrogenous base – one from adenine (A), cytosine (C), guanine (G), thymine (T).



A DNA molecule is a ladder shape. The sides of the ladder are formed from a chain of phosphate groups joined by strong chemical bonds to the sugars from the nucleotides on either side. Pairs of bases held together by weak hydrogen bonds form the steps on the ladder. The bases always pair A with T, C with G.



Messenger RNA (mRNA) is another important nucleic acid. The following table compares the structure of DNA and mRNA molecules.

Comparison	DNA	mRNA
Sugar	deoxyribose	ribose
Nitrogenous bases	A, T, C, G	A, U, C, G
Base-pairing rule	A with T, C with G	A with U, C with G
Strands	Two strands running in opposite directions	Single strand
Purpose	The genetic code – master copy of information	Transcribed copy of part of the genetic code
Location	In nucleus	Formed in nucleus and used in cytoplasm
Length	Very long – can contain millions of nucleotides	Very short
Duration	For the life of the cell	Constantly being formed, used, then broken down

The order of the bases along the DNA molecule forms the information called the **genetic code**. One strand of DNA, called the **template strand**, is transcribed into mRNA to carry information for protein synthesis. The other DNA strand, called the **non-template** or **coding strand**, has the same base sequence as the transcribed mRNA.

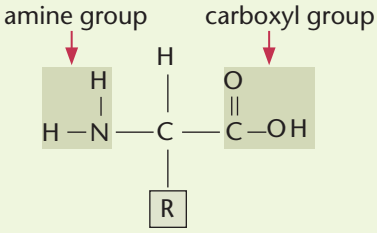
Proteins

Significance of proteins

This section discusses:

- proteins as the products of gene expression: DNA → mRNA → polypeptide or protein
- identification of one gene → one polypeptide relationship
- significance of proteins, limited to their structural and catalytic role in living things.

Proteins are molecules made up of long chains of amino acid molecules joined by peptide bonds. There are 20 different amino acids. Each has an amine and a carboxyl group and a different 'R group' that is specific to each amino acid.



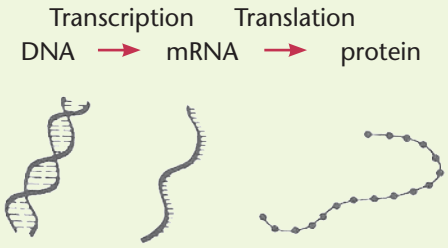
Proteins are important to a living cell as enzymes that act as catalysts to control the large number of chemical reactions that occur inside or surrounding a cell. For example, respiration and digestion are two processes that involve enzymes. Other proteins form structures in the body, e.g. keratin in hair, and the actin and myosin proteins in skeletal muscle.

The purpose of DNA and mRNA is to provide a way for the cell to make proteins that have a set structure and to make the proteins in the same way repeatedly – whenever and wherever the proteins are required.

When part of the DNA molecule, called a **gene**, takes part in making a protein, the gene is said to be **expressed**. Each time a particular gene is expressed, a particular protein is produced. Expression of a different gene produces a different protein.

Gene A → **Protein A (e.g. lipase, enzyme)**

Gene B → **Protein B e.g. keratin in hair)**



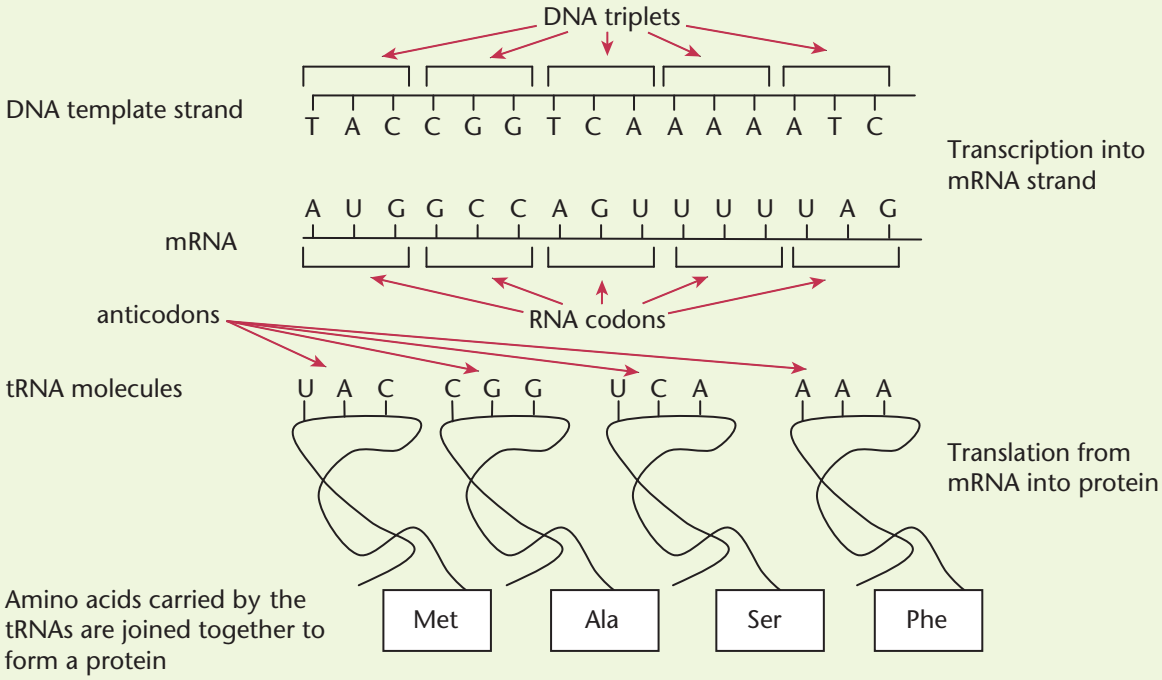
Gene expression involves two processes – **transcription** of the DNA code into mRNA code, which is followed by **translation** of the mRNA code that ensures amino acids are placed in the correct order to form a protein. This is often shown by the following diagram.

Nature of the genetic code

This section discusses:

- nature of the genetic code, including triplets, codons and anticodons
- redundancy due to degeneracy within the code.

'Genome' is the name given to all the hereditary information carried in the DNA – including genes and non-coding areas of DNA. The bases along DNA make up the genetic code and are transcribed into mRNA in sets of three, called **triplets**. The matching set of three bases on the mRNA is called a **codon**. Another type of RNA called **transfer RNA** (tRNA) carries the **anticodon**.



The genetic code has four bases (A, C, G and T/U) in triplets and codons three at a time – this produces 64 different combinations such as AAT, CGC, GAT. However, there are only 20 different amino acids and the 'stop' signal that must be coded for, so more than one codon is used to code for the same amino acid. For example UCU, UCC, UCA, UCG, AGU, AGC all code for the amino acid, serine – this idea is called **redundancy due to degeneracy** within the genetic code.

The genetic code table

The following table shows the mRNA codons that code for each amino acid and the abbreviations commonly used for the amino acids.

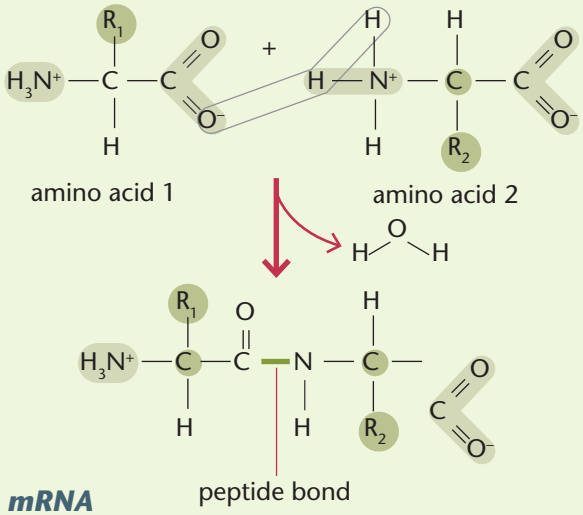
Second base / First base	U	C	A	G	Third base
U	Phenylalanine (Phe)	Serine (Ser)	Tyrosine (Tyr)	Cysteine (Cys)	U
					C
	Leucine (Leu)		STOP	STOP	A
				Tryptophan	G
C	Leucine (Leu)	Proline (Pro)	Histidine (His)	Arginine (Arg)	U
					C
			Glutamine (GluN)		A
					G
A	Isoleucine (Ile)	Threonine (Thr)	Asparagine (AspN)	Serine (Ser)	U
					C
			Lysine (Lys)	Arginine (Arg)	A
	Methionine (Met) / START				G
G	Valine (Val)	Alanine (Ala)	Aspartic acid (Asp)	Glycine (Gly)	U
					C
			Glutamic acid (Glu)		A
					G

Protein synthesis

This section discusses:

- the role of the DNA sequence in determining the structure of a protein
- how that protein is produced (transcription and translation)
- the role of enzymes in controlling the process (specific names of enzymes are not required).

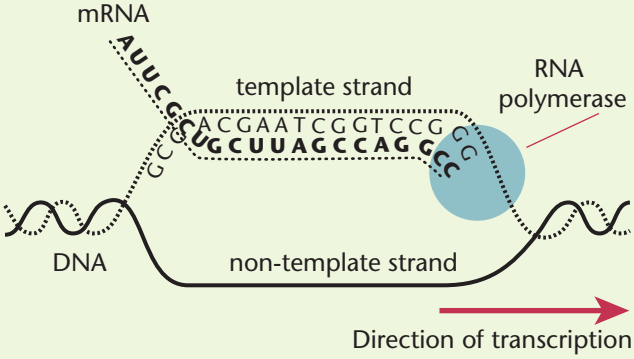
Protein synthesis is a process involving the formation of peptide bonds between the amine group of one amino acid and the carboxyl group of another amino acid so that the amino acids form a long chain. Water is produced in this reaction.



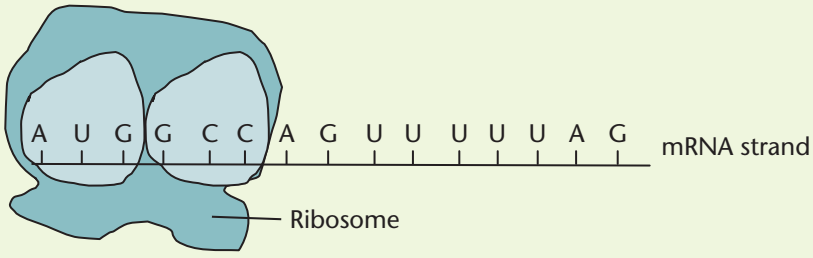
Transcription of the DNA base sequence into mRNA

The DNA double helix unwinds, and the hydrogen bonds between the nucleotides are broken so the two DNA strands separate. The enzyme RNA polymerase then makes a molecule of mRNA according to the base sequence in the triplets on the DNA template strand.

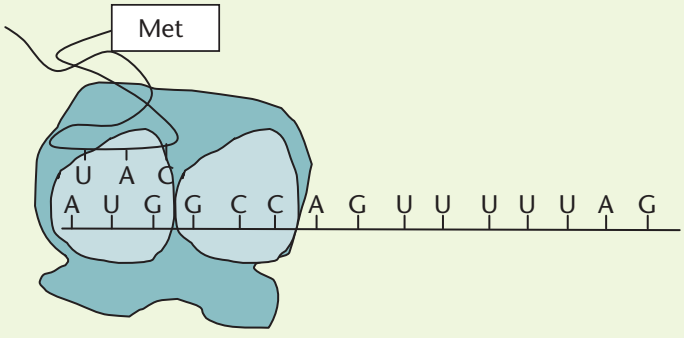
The mRNA produced is modified to remove any non-coding parts. The mRNA then moves out of the nucleus into the cytoplasm, where the mRNA attaches to a ribosome and **translation** begins.



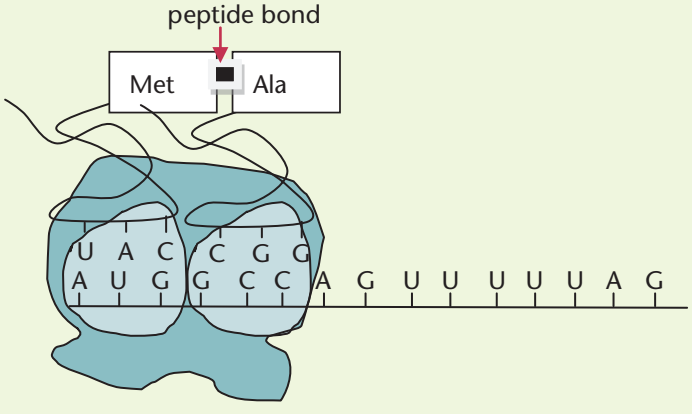
Translation



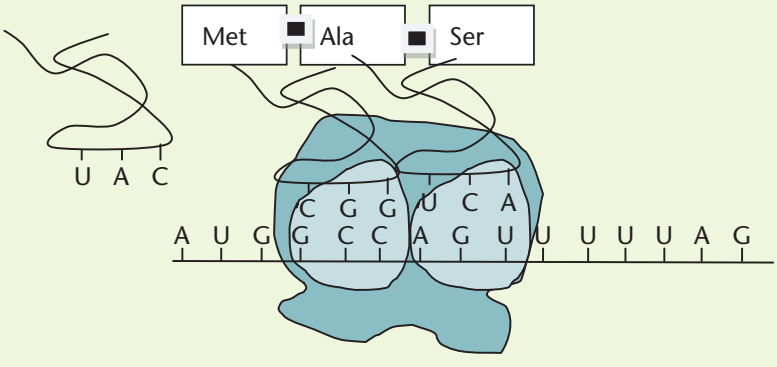
A tansfer RNA (tRNA) with the anticodon UAC, which matches the mRNA start codon AUG, brings the amino acid 'Met' to the ribosome.



Another tRNA, with the anticodon that matches the next codon, brings the next amino acid to go into the chain. A peptide bond is formed between the two amino acids.



The mRNA moves along the ribosome, the first tRNA is released, and the next tRNA moves into place on the ribosome. A peptide bond forms to join the next amino acid to the polypeptide chain. This process continues until a stop codon (UAA, UAG or UGA) occurs on the mRNA.



Once translation has stopped, the polypeptide chain is released and the chain folds into the final shape of the protein.

Questions: Nucleic acids, proteins and the genetic code

Year 2017
Ans. p. 116

Question One: Protein synthesis

1. In the table, draw a DNA and an RNA molecule, each composed of the FOUR different nucleotides that are specific to each molecule.

   In your answer you **must** include and label where appropriate:

   - phosphate
   - sugar (deoxyribose or ribose)
   - nitrogenous bases (adenine, cytosine, guanine, thymine, and uracil)
   - hydrogen bond.

DNA	RNA

2. Discuss the relationship between DNA, mRNA, and tRNA in protein synthesis. In your answer include:
   - an explanation of the key stages of protein synthesis
   - an explanation of why tRNA is shorter than mRNA, when considering their function
   - a discussion, with two justified reasons, why DNA is not directly translated into a polypeptide chain.

Question Two: Genetic code

Year 2017
Ans. p. 117

mRNA (codon) : Amino acid table

First position	Second position: U	Second position: C	Second position: A	Second position: G	Third position
U	**UUU** Phe	**UCU** Ser	**UAU** Tyr	**UGU** Cys	U
	UUC Phe	**UCC** Ser	**UAC** Tyr	**UGC** Cys	C
	UUA Leu	**UCA** Ser	**UAA** STOP	**UGA** STOP	A
	UUG Leu	**UCG** Ser	**UAG** STOP	**UGG** Trp	G
C	**CUU** Leu	**CCU** Pro	**CAU** His	**CGU** Arg	U
	CUC Leu	**CCC** Pro	**CAC** His	**CGC** Arg	C
	CUA Leu	**CCA** Pro	**CAA** Gln	**CGA** Arg	A
	CUG Leu	**CCG** Pro	**CAG** Gln	**CGG** Arg	G
A	**AUU** Ile	**ACU** Thr	**AAU** Asn	**AGU** Ser	U
	AUC Ile	**ACC** Thr	**AAC** Asn	**AGC** Ser	C
	AUA Ile	**ACA** Thr	**AAA** Lys	**AGA** Arg	A
	AUG Met	**ACG** Thr	**AAG** Lys	**AGG** Arg	G
G	**GUU** Val	**GCU** Ala	**GAU** Asp	**GGU** Gly	U
	GUC Val	**GCC** Ala	**GAC** Asp	**GGC** Gly	C
	GUA Val	**GCA** Ala	**GAA** Glu	**GGA** Gly	A
	GUG Val	**GCG** Ala	**GAG** Glu	**GGG** Gly	G

2.7

1. A point mutation on the haemoglobin β gene can cause sickle-cell disease. The template DNA sequence for part of the normal and mutated haemoglobin protein is shown in the table below. The affected base is shown in red, and indicated with an arrow.

   Complete the normal and mutated amino acid sequence using the mRNA : Amino acid table above.

	Normal	Mutation causing sickle cell disease
DNA template strand	GAC TGA GGA CTC AAC	GAC TGA GGA C  AC AAC
mRNA strand		
amino acid sequence		

2. Discuss the effects of point mutations on final protein structure.

   In your answer include:

   - identification and a description of the type of mutation leading to sickle-cell disease
   - an explanation of how this mutation affects the amino acid sequence and final protein structure
   - a discussion of how the degeneracy of the code can reduce the impact of point mutations on final protein structure, and on an organism's survival.

Question Three: Nucleic acids

Year 2016
Ans. p. 117

1. Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are both involved in protein synthesis. Describe the structure of DNA and RNA. You may use diagrams in your answer.

2. DNA, mRNA, and tRNA are all involved in the formation of proteins. Discuss the significance of these molecules in forming proteins, and why the cell continually makes mRNA molecules, but not DNA molecules, during protein synthesis. In your answer include:
   - an explanation of the function of DNA, mRNA, and tRNA molecules
   - an explanation of how mRNA is produced
   - a discussion of the significance of DNA, mRNA, and tRNA in forming specific proteins.

Year 2015
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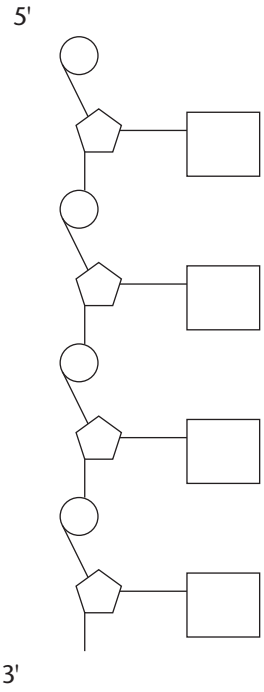
Question Four: Protein formation

1. The structure of DNA is made up of nitrogen bases, deoxyribose sugars, and phosphates. Draw the corresponding **anti-parallel** complementary strand in the box. In your answer:
   - fill in the template strand containing the bases adenine (A), thymine (T), guanine (G), cytosine (C)
   - draw the corresponding anti-parallel complementary strand
   - draw and label the sugars
   - draw and label the phosphates.



2. Protein synthesis is the process of making proteins. Triplets, codons, and anti-codons are important components in the process. Discuss the relationship between triplets, codons, and anti-codons, and how they interact to form a protein. In your answer include:
   - a description of a triplet, codon, and anti-codon
   - an explanation of what a start codon and a stop codon are
   - a discussion of how triplets, codons, and anti-codons interact during transcription and translation to form a protein.

   You may use diagrams in your answer.

Answers and explanations

A ('Achieved') is given if answer includes relevant **descriptions** and *M* ('Merit') when answer includes relevant **explanations**. *E* ('Excellence') is given when answer includes **relevant descriptions and explanations linked together into a discussion** that gives a full answer to the question.

Words/phrases like 'therefore', and 'however' show the linking of ideas and are what makes a piece of text an explanation (*M*) or discussion (*E*) rather than a description (*A*).

Use the tick boxes as you check your answers to make sure you have covered the important points.

Achievement Standard 91156 (Biology 2.4): Demonstrate understanding of life processes at the cellular level

2.4 Cells and cell division

Question One: DNA replication and mitosis

p. 7

1. • When – during growth of cell, before mitosis / cell division.
   • Why – copy DNA, two daughter cells have complete set of DNA/instructions, so both cells can function.

For example:

During DNA replication, copies of the DNA are made. This occurs during the growth of the cell before cell division occurs so that each daughter cell produced by mitosis has a complete copy of all the DNA from the original cell and can function correctly.

2. • Mitosis greatest – growing parts – root tips, shoot tips, meristem.
   • Why rate greater – new cells needed for growth, repair.
   • Effect of factors on rate of mitosis throughout year – winter – low light and cooler temperatures therefore low rate of photosynthesis, less energy and materials available, so low rate of mitosis; summer – warm and light therefore high rate of photosynthesis, high energy availability, high rate of mitosis.

For example:

The rate of mitosis will be highest in parts of the plant that are actively growing – e.g. the root tips and shoot tips. The rate of mitosis is greater in the growing tips of a plant because a plant needs to produce new cells needed for growth to occur. When mitosis occurs, one of the daughter cells produced will grow longer and then develop into a special cell needed in that area of the plant thus making the plant grow bigger.

The rate of mitosis changes throughout the year – e.g. in winter, temperatures are cooler and there is less sunshine – therefore, the rate of photosynthesis is lower – meaning less energy and materials are available so the rate of mitosis is lower in winter. However, in summer, temperatures are warmer and light intensity is higher therefore the rate of photosynthesis is higher – this means that more energy is available for the plant cells to use so the rate of mitosis is higher in summer.

(**A** – describes three out of when DNA replication occurs, copy DNA, two parts of plant where mitosis greatest, more light or warmth more photosynthesis;

M – explains two out of why DNA replication is needed, how factors affect rate of mitosis, how rate of photosynthesis affects rate of mitosis;

E – discusses why the rate of mitosis varies in different parts of the plant and at different times of the year)

Question Two: Mitosis

p. 8

Check that your answer has the following important points.

- Purpose – produce more cells with complete set of chromosomes, for growth, repair, replacement.
- How mitosis occurs – DNA in each chromosome replicates, replicated chromosomes line up on equator of cell, spindle attaches to centromeres, chromatids are pulled apart, spindle pulls chromatids to opposite ends of the cell, nuclear membrane forms around the two groups of chromatids/chromosomes, cytoplasm divides to produce two identical daughter cells each with a complete set of chromosomes.
- Reasons rate of mitosis varies – different cells grow at different rates; some cells need to be repaired or replaced more often.
- Rate of mitosis and cell function.

  Skin cell: protective cover, high rate of mitosis, frequently damaged or frequently rubbed off.

  Liver cell: storage and chemical reactions, cells have a slower rate of mitosis, liver doesn't grow and damage is limited so little replacement needed.

  Intestinal – internal lining: releases digestive juices, protects and absorbs food, very high rate of mitosis, food travelling down intestine rubs off the cells in the lining.

  Intestinal – muscles and other tissues: contract, causing food to move through intestine, very low rate, don't grow, don't get damaged or rubbed off as they are not in contact with food.

For example:

The purpose of mitosis is to produce more cells for growth and repair of the body and to replace, for example, cells rubbed off from the skin. Mitosis occurs at different rates in the different types of cells in the human body because different parts of the body grow at different rates and also require replacement cells at different rates.

When mitosis occurs, a single cell produces two daughter cells each with a complete set of chromosomes. Firstly, the DNA in the chromosomes is replicated. The two chromatids of each chromosome coil up and line up on the equator of the cell. The nuclear membrane breaks down and a spindle forms that attaches to the centromeres. The two halves of each chromosome are pulled to opposite ends of the cell, the nuclear membrane reforms around each group of chromosomes and the cytoplasm divides.

The rate of mitosis varies because different parts of the body grow at different rates, so more cells need to be produced by mitosis in some parts of the body but fewer are needed in slower-growing

parts. Repair and replacement of cells occur at different rates in different tissues because some parts are damaged more easily and more frequently than other parts. For example, skin cells and intestinal lining cells have a high rate of mitosis because they are frequently damaged (e.g. cuts, wounds or damaged by food) and frequently rubbed off (e.g. when drying the skin with a towel and when food passes through the intestine). High rates of mitosis ensure these cells are replaced quickly.

However, the cells in the liver (involved in storage and chemical reactions) have a much lower rate of mitosis because the organ is not growing and the cells are less likely to be damaged or lost so don't need to be replaced at a high rate. Intestinal muscle cells, which contract to move food, also have a low rate of mitosis because their function results in limited need for repair of damaged cells or replacement of lost cells.

(**A** – describes three out of: purpose of mitosis, how mitosis occurs (describes two out of: cell division, two cells, same number of chromosomes), how mitosis rate varies, cell function;

M – explains two out of: purpose of mitosis, how mitosis occurs, a reason for varying rates of mitosis;

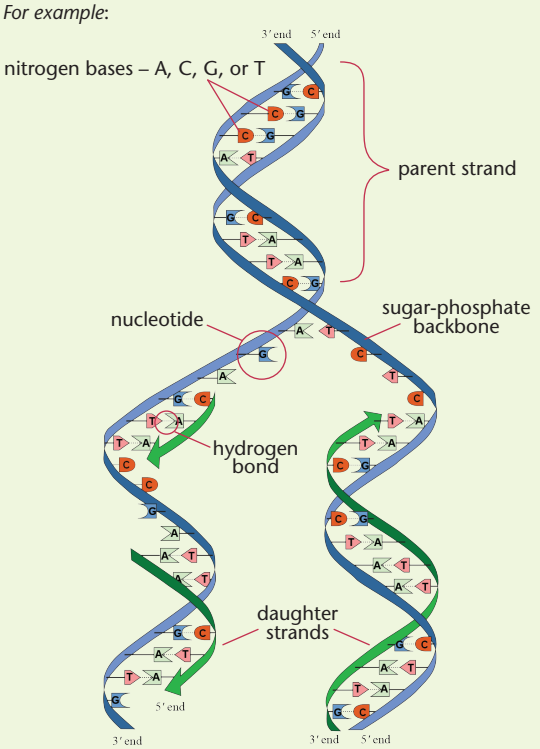
E – discusses, using examples from the table, how rate of mitosis is linked to repair/replacement of cells in skin, liver and intestine)

Question Three: Replication of DNA

p. 9

1. *Check that your answer contains the following labels.*
   - nucleotide – sugar, phosphate and base
   - nitrogen base – A, C, G, or T
   - hydrogen bond – bond between two bases
   - parent strand – top part of diagram
   - daughter strands – bottom part of diagram
   - sugar-phosphate backbone – ribbon like structure down outside of molecule.

   For example:



2. *Check that your answer contains the following important point.*

   Purpose – produce two copies of DNA so all new cells have same function as parent cell.

   For example: DNA replication is the process that uses the two strands of the parent DNA as templates to produce two identical daughter copies so new cells can carry out same function as orignal cell.

3. *Check that your answer contains the following important points.*
   - Enzyme structure – chain of amino acids/protein, specific folded shape, specific-shaped active site where substrate binds.
   - How enzymes function – use energy from ATP to lower activation energy needed for reaction, reaction rate increases, specific so can catalyse only the one reaction, substrate fits in the active site, shape changes/lock and key, product released.
   - Examples of enzymes – an enzyme causes a cut in one strand of the DNA to allow it to unwind, helicase enzyme unzips DNA by breaking the hydrogen bonds between bases, DNA polymerase adds nucleotides.
   - Factors that affect enzymes –
     1. Temperature: Enzymes have an optimum temperature at which they work most quickly. Temperatures lower or higher than the optimum reduce the rate of reaction, high temperatures denature enzyme so it stops functioning.
     2. Availability of substrate: Free nucleotides are required during DNA replication. If few are available, enzyme activity is reduced / reaction rate is below optimum.
     3. Poison: Some chemicals bond with the enzyme, enzyme shape changes/blocks active site, enzyme activity is reduced.
     4. pH: Enzymes have an optimum pH at which enzyme activity is greatest. pH above or below optimum gives reduced activity/reaction rate.

   For example: An enzyme is a protein molecule that is folded into a particular shape. Each enzyme has an area called an active site where the substrate binds, a shape change happens and a chemical reaction occurs. Products of the reaction are released from the enzyme. Enzymes function by using energy from ATP to lower the activation energy needed for a reaction to occur, therefore allowing a reaction to occur many times more quickly than it would occur without the enzyme. Enzymes are specific so they can catalyse only the one reaction; for example helicase can only unzip DNA, RNA polymerase can only add nucleotides to the new strand.

   The rate of DNA replication is affected by temperature. Each enzyme has an optimum temperature at which it works most quickly. Temperatures lower or higher than the optimum reduce the rate of reaction and high temperatures denature enzymes so they stop functioning.

   Free nucleotides are found in the nucleus and required during DNA replication. If there are few free nucleotides available DNA replication takes place more slowly. The growth and repair of the organism is slowed.

   Certain poisonous chemicals can bind to the enzyme so that the enzyme's shape changes and the enzyme can no longer function. If the poisons are in high concentrations all the molecules of the affected enzyme can become inactive so DNA replication does not occur.

(**A** – describes *three* out of: DNA structure (five labels correct), purpose DNA replication, enzyme structure, enzymes in DNA replication, factors that affect enzymes in DNA replication (*three* from temperature, enzyme concentration, substrate concentration, pH, co-enzymes, inhibitors, poisons);

M – explains two out of: how enzymes function, how a factor affects an enzyme, how a second factor affects an enzyme;

E – discusses function of enzymes in DNA replication and two factors that affect enzymes during DNA replication)

Question Four: Mitosis and movement of materials

p. 10

1. DNA in chromosomes has replicated and then chromosomes have lined up on the equator of the cell. Centromeres are attached to the spindle.