



EDEXCEL INTERNATIONAL GCSE (9–1)

HUMAN BIOLOGY

Student Book

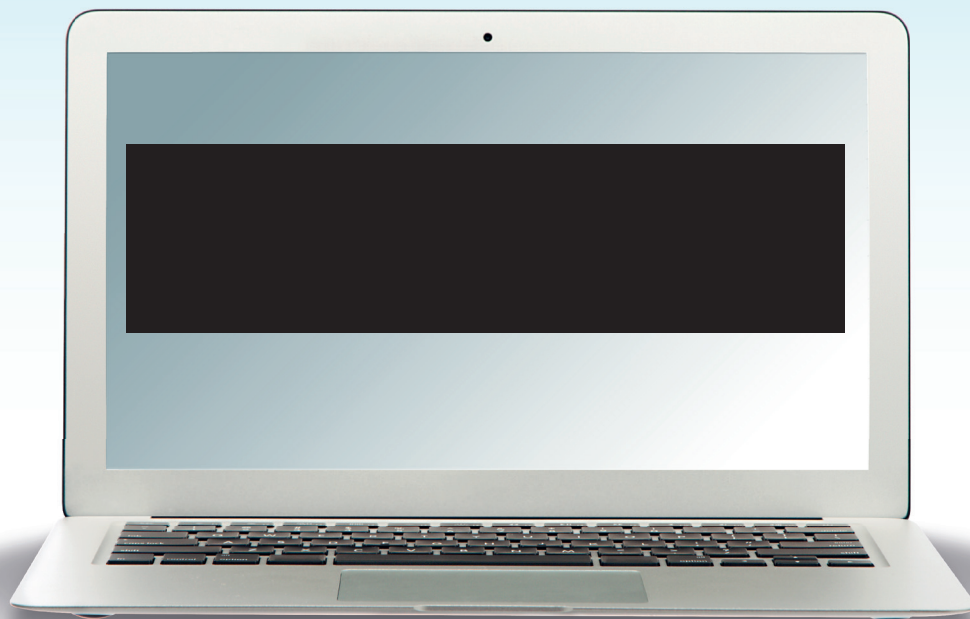
Phil Bradfield and Steve Potter



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Student Book

Phil Bradfield

Steve Potter

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ABOUT THIS BOOK

This book is written for students following the Edexcel International GCSE (9–1) Human Biology specification. You will need to study all of the content in this book for your Human Biology examinations, except content in Extension boxes, which is meant to extend your learning.

In each unit of this book, there are concise explanations and numerous exercises that will help you build up confidence. The book also describes the methods for carrying out all of the required practicals.

The language throughout this textbook is graded for speakers of English as an additional language (EAL), with advanced Human Biology-specific terminology highlighted and defined in the glossary at the back of the book. A list of command words, also at the back of the book, will help you to learn the language you will need in your examinations.

You will find that questions in this book have Progression icons and Skills tags. The Progression icons refer to Pearson's Progression scale. This scale – from 1 to 12 – tells you what level you have reached in your learning and will help you to see what you need to do to progress to the next level. Furthermore, Edexcel has developed a Skills grid showing the skills you will practise throughout your time on the course. The skills in the grid have been matched to questions in this book to help you see which skills you are developing. You can find Pearson's Progression scale, along with guidelines on how to use it at www.pearsonglobalschools.com/igscienceprogression.

32 UNIT 1 BIOLOGICAL MOLECULES

3 BIOLOGICAL MOLECULES

Many of the molecules found in the body are made from simple 'building blocks'. For example, DNA is built up from smaller molecules called nucleotides. In the same way, carbohydrates, lipids and proteins are made of simpler molecular sub-units. In this chapter, you will read about the structure of these biological molecules, and the functions of an important group of proteins called enzymes.

LEARNING OBJECTIVES

- Know the chemical elements present in carbohydrates, proteins and lipids (fats and oils)
- Understand the structure of carbohydrates, proteins and lipids as large molecules made up of smaller basic units:
 - carbohydrates (starch and glycogen) from simple sugars
 - lipids from fatty acids and glycerol
 - protein from amino acids
- Describe chemical tests for starch, glucose (reducing sugar), lipid and protein
- Explain the role of enzymes as biological catalysts in metabolic reactions
- Explain the action of enzymes
- Explain how enzyme activity is affected by:
 - temperature
 - pH
 - substrate concentration
 - competitive and non-competitive inhibitors
- Describe how to investigate the effect of temperature on enzyme activity
- Describe how to investigate the effect of pH on enzyme activity
- Describe the advantages of using immobilised enzymes in:
 - the production of lactose-free milk
 - the conversion of sucrose into glucose and fructose
 - glucose testing strips for diabetics
- Describe how to investigate the action of immobilised enzymes, including the preparation of alginate beads

CARBOHYDRATES, LIPIDS AND PROTEINS

There are three main types of biological molecule in the human body – **carbohydrates**, **lipids** and **proteins**. All three are composed of just a few chemical elements. Carbohydrates and lipids are entirely made of the elements carbon (C), hydrogen (H) and oxygen (O). Proteins also contain these elements, along with nitrogen (N) and small amounts of sulfur (S). However, the structures of these three types of molecule are very different.

THE STRUCTURE OF CARBOHYDRATES

The basic units that make up carbohydrates are simple sugars such as **glucose**. Glucose is an example of a **monosaccharide**, which is a 'single' sugar unit. This means that it cannot be broken down into a simpler sugar. Another monosaccharide is **fructose**, a sugar found in fruits. The chemical formula for glucose is $C_6H_{12}O_6$ – you can see from this formula that glucose contains only carbon, hydrogen and oxygen.

Learning objectives show you what you will learn in each chapter.

84 UNIT 2 RESPIRATION AND GAS EXCHANGE

DID YOU KNOW?
The breathing volumes depend on various factors, including age, sex of the person, size of the lungs, level of exercise and how healthy the subject is. The vital capacity varies from about 3.0 dm³ in a young woman to 6.0 dm³ in a trained athlete.

HINT
Notice that the trace in Figure 5.11 is not horizontal, but slowly slopes down to the right. This is because the oxygen in the spirometer is gradually being used up by the person's respiration, and is not replaced by carbon dioxide.

Figure 5.11 shows a trace from a subject breathing into a spirometer. The subject began by breathing normally into the spirometer, before taking a deep breath in. He then breathed out as much as possible.

The volume of air breathed in and out with a normal breath is called the **tidal volume**. In a normal healthy adult man, this is about 0.4 dm³. The difference between the maximum breath in and the maximum breath out is about 4.5 dm³. This is called the **vital capacity**.

The spirometer trace does not show the full amount of air in the lungs. There is always about 1.5 dm³ of air left in the lungs, even after a person has breathed out as much as possible. This is called the **residual volume**. The maximum total volume of the lungs is called the **lung capacity**. It is equal to the vital capacity plus the residual volume.

Figure 5.11 A spirometer trace showing breathing volumes.

If you have access to a spirometer, you can use it to measure lung capacity. An alternative, simpler method is shown in Activity 11.

ACTIVITY 11

▼ PRACTICAL: MEASURING LUNG CAPACITY

The apparatus in Figure 5.12 can be used to measure lung capacity. It works on the same principle as the spirometer. A large bell jar is marked in dm³ to a volume of at least 6 dm³. It is placed open-end downwards in a large bucket or sink of water. The rubber bung is removed so that the level of water is the same inside and outside the jar, and the position of the bell jar is adjusted until the water level is at the zero mark. The bung is then replaced.

Figure 5.12 A simple method of measuring lung capacity.

Hint boxes give you tips on important points to remember in your examination.

Practical activities describe the methods for carrying out all of the practicals you will need to know for your examination.

Did You Know boxes give interesting facts about the topic you are studying.

Looking Ahead features tell you what you will learn if you continue your study of Human Biology to a higher level, such as International A Level.

20 UNIT 1 CELLS

Figure 1.24 Genetically modifying plants using *Agrobacterium*.

This technique cannot be used on all plants. *Agrobacterium* will not infect cereals, so another technique was needed for these plants. The 'gene gun' was invented. This is a piece of laboratory equipment that fires tiny pellets made of gold (Figure 1.25). The pellets are coated with DNA that contains the required gene. These are fired directly into plant tissue. The gene gun has made it possible to genetically modify cereals and other crop plants.

Using *Agrobacterium* as a vector, biologists have produced genetically modified rice called 'golden rice'. This rice has three genes added to its normal DNA content. Two of these genes come from daffodils and one comes from a bacterium. Together, these genes allow the rice to make beta-carotene – the chemical that gives carrots their colour. It also colours the rice, which explains the name 'golden rice'. More importantly, the beta-carotene is converted to vitamin A when eaten. This could save the eyesight of millions of children in less economically developed countries, who go blind because they do not have enough vitamin A in their diet.

Figure 1.25 The gene gun.

EXTENSION WORK
Golden rice sounds like a good idea but there have been several problems with it. Some people believe that there are ethical and environmental reasons why golden rice should not be grown and that it is better to provide other, natural crops containing enough beta-carotene. You could research the pros and cons of golden rice on the internet.

UNIT 1 CELLS 21

DID YOU KNOW?
What if you could receive a 'vaccination' every time you ate a banana? Instead of extracting the proteins and using them to make a vaccine, it might be possible to 'vaccinate' a person by getting them to eat a GM banana. The person's immune system would make antibodies against the virus proteins in the banana, and these antibodies would be able to destroy the virus without any need for an injection.

KEY POINT
A nanometre (nm) is 10^{-9} m, or one millionth of a millimetre.

Genetically modified plants are also helping humans to fight infection. Biologists have succeeded in genetically modifying several species of plant in order to produce vaccines against different infectious diseases. For example, potatoes, bananas, lettuce, carrots and tobacco plants have all been engineered to produce proteins from the virus that causes hepatitis B. These proteins can be extracted from the plants and used to make a vaccine, which can be given to the patients by mouth or as an injection. At the time when this book was written, this vaccine had not been developed to the stage where it could replace vaccine from genetically modified yeast cells (described above). However, research in this area continues.

LOOKING AHEAD – MEMBRANES IN CELLS
If you continue to study biology beyond International GCSE, you will learn more about the structure and function of cells. You might like to look on the internet for some electron micrographs and do some further research about cell structure.

Electron microscopes allow us to see cells at a much greater magnification than by using a light microscope. They also reveal more detail. The image produced by a light microscope can only distinguish features that are about the size of a mitochondrion, but the electron microscope has a much greater resolution. Resolution is the ability to distinguish two points in an image as being separate. The maximum resolution of a light microscope is about 200 nanometres (nm) but with an electron microscope we can distinguish structures less than 1 nm in size. This is why ribosomes are only visible using an electron microscope – they are about 25 nm in diameter.

Electron microscopy (using an electron microscope) reveals that much of the cytoplasm is made up of membranes. As well as the cell surface membrane and the endoplasmic reticulum, there are membranes around organelles such as the nucleus and mitochondria, and sometimes there are membranes inside organelles as well.

All these membranes are needed because there are thousands of different chemical reactions happening in cells. A key function of membranes is to separate the different reactions into different compartments, so that they are not all happening in one big 'test tube'. For example, the reactions and enzymes of aerobic respiration (respiration that needs oxygen) are kept inside the mitochondria, separate from the rest of the cytoplasm (Figure 1.26).

Figure 1.26 An electron micrograph of a mitochondrion (magnification $\times 60\,000$). The mitochondrion has two membranes – an outer membrane separating its contents from the rest of the cytoplasm and an inner membrane forming folds called cristae. The reactions of aerobic respiration take place in the mitochondria of a cell. Different stages of the process happen in different parts of the mitochondrion.

Extension boxes include content which is not on the specification and which you do not have to learn for your examination. However, it will help to extend your understanding of the topic.

Key Point boxes summarise the essentials.

252 UNIT 4 MICROORGANISMS

SKILLS REASONING

- Suggest reasons for the increases in the number of cases of gonorrhoea during the 1980s.
- Suggest how the increase in AIDS cases in the 1980s may be linked to the decrease in the number of cases of gonorrhoea.
- Gonorrhoea can usually be cured by taking penicillin.
 - Describe how penicillin kills the bacteria that cause gonorrhoea.
 - Suggest why penicillin is not always effective in the treatment of gonorrhoea.

SKILLS CRITICAL THINKING

SKILLS REASONING

SKILLS CRITICAL THINKING

7 The diagram shows the levels of antibodies produced by a person during a first infection and later, when re-infected by the same microorganism.

SKILLS REASONING

8 a What is an antibiotic?
b Describe two ways that antibiotics work.

9 The flowchart below shows stages in the percolated filter method of sewage treatment.

```

    untreated sewage
    |
    screening
    |
    settling tank
    |
    filter bed
    |
    treated effluent discharged into river
    
```

a What is the function of the settling tank?
b Sludge from the settling tank can be treated by anaerobic fermentation. Name two useful products of this process.
c Why is it important that conditions are aerobic in the filter bed?
d Explain why it is important that untreated sewage does not enter a river or the sea.

SKILLS REASONING

UNIT 4 UNIT QUESTIONS 253

UNIT QUESTIONS

SKILLS REASONING

1 A species of mammal has 32 chromosomes in its muscle cells. Which row in the table below shows the number of chromosomes in the mammal's skin cells and sperm cells?

| | skin cells | sperm cells |
|---|------------|-------------|
| A | 32 | 32 |
| B | 16 | 16 |
| C | 16 | 32 |
| D | 32 | 16 |

(Total 1 mark)

SKILLS CRITICAL THINKING

2 Which of the following is not a function of the ovaries?
A The secretion of progesterone
B The production of eggs
C The secretion of oestrogen
D The site of fertilisation

(Total 1 mark)

3 Which of the following organs produce the hormone progesterone?
1 placenta
2 ovary
3 uterus
4 pituitary gland

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

(Total 1 mark)

SKILLS PROBLEM SOLVING

4 A woman's first day of menstruation was on 1 June. Assuming she has a 28-day menstrual cycle, when is she most likely to ovulate?
A 7 June
B 10 June
C 14 June
D 21 June

(Total 1 mark)

SKILLS CRITICAL THINKING

5 Which of the following is true of dominant alleles?
A A dominant allele is expressed if present with a recessive allele
B They determine the most favourable of a pair of alternative features
C They are inherited in preference to recessive alleles
D They are only expressed if present as a pair

(Total 1 mark)

Unit Questions test your knowledge of the whole unit and provide quick, effective feedback on your progress.

Skills tags tell you which skills you are practising in each question.

Chapter Questions test your knowledge of the content in that chapter.

Progression icons show the level of difficulty according to the Pearson International GCSE Science Progression Scale.

ASSESSMENT OVERVIEW

The following tables give an overview of the assessment for this course.

We recommend that you study this information closely to help ensure that you are fully prepared for this course and know exactly what to expect in the assessment.

| PAPER 1 | SPECIFICATION | PERCENTAGE | MARK | TIME | AVAILABILITY |
|---|---------------|------------|------|----------------|---|
| Written examination paper, externally set and assessed by Pearson Paper code 4HB1/01 | Human Biology | 50% | 90 | 1 hour 45 mins | January and June examination series First assessment June 2019 |
| PAPER 2 | SPECIFICATION | PERCENTAGE | MARK | TIME | AVAILABILITY |
| Written examination paper, externally set and assessed by Pearson Paper code 4HB1/02 | Human Biology | 50% | 90 | 1 hour 45 mins | January and June examination series First assessment June 2019 |

ASSESSMENT OBJECTIVES AND WEIGHTINGS

| ASSESSMENT OBJECTIVE | DESCRIPTION | % IN INTERNATIONAL GCSE |
|----------------------|--|-------------------------|
| AO1 | Knowledge and understanding of human biology | 38%–42% |
| AO2 | Application of knowledge and understanding, analysis and evaluation of human biology | 38%–42% |
| AO3 | Experimental skills, analysis and evaluation of data and methods in human biology | 19%–21% |

EXPERIMENTAL SKILLS

In the assessment of experimental skills, students may be tested on their ability to:

- solve problems set in a practical context
- apply scientific knowledge and understanding in questions with a practical context
- devise and plan investigations, using scientific knowledge and understanding when selecting appropriate techniques
- demonstrate or describe appropriate experimental and investigative methods, including safe and skilful practical techniques
- make observations and measurements with appropriate precision, record these methodically and present them in appropriate ways
- identify independent, dependent and control variables
- use scientific knowledge and understanding to analyse and interpret data to draw conclusions from experimental activities that are consistent with the evidence
- communicate the findings from experimental activities, using appropriate technical language, relevant calculations and graphs
- assess the reliability of an experimental activity
- evaluate data and methods taking into account factors that affect accuracy and validity.

CALCULATORS

Students are expected to take a suitable calculator into the examinations. Calculators with QWERTY keyboards or that can retrieve text or formulae will not be permitted.

UNIT 1

Humans are composed of microscopic units known as cells, which are the ‘building blocks’ of life. Cells have a number of features in common, which allow them to grow, reproduce and generate more cells. In Chapter 1, you will start by looking at the structure and function of cells. You will also consider the role of DNA, which contains the genetic instructions for the development and functions of the body.

Cells need a supply of raw materials in order to function, and they produce other materials as waste products. In Chapter 2, you will learn about the ways in which these substances are exchanged between a cell and its surroundings. In Chapter 3, you will study the chemistry of cells – the structure and function of the different molecules that make up the human body.



1 CELLS

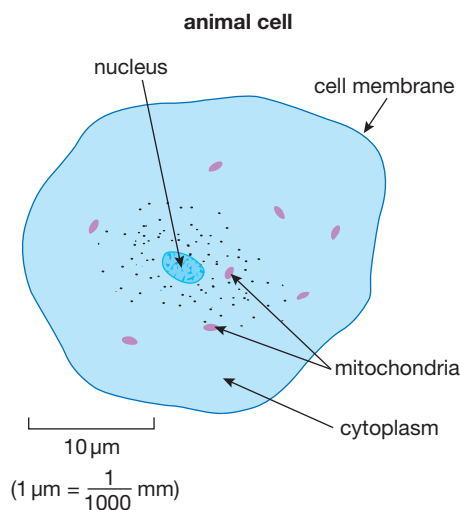
There are structural features that are common to the cells of all living organisms. In this chapter, you will find out about the structure and function of human cells, and how they are organised into tissues and organs. You will also learn about the role of the genetic material in cells – the DNA – and the principles of genetic engineering.

LEARNING OBJECTIVES

- Recognise cell structures as seen with a light microscope and transmission electron microscope, including the nucleus, chromosomes, cell membrane, mitochondria, endoplasmic reticulum and ribosomes
- Describe the functions of the nucleus, chromosomes, cell membrane, mitochondria, endoplasmic reticulum and ribosomes
- Describe the structure of a DNA molecule as two strands coiled to form a double helix, containing nucleotides, strands linked by complementary bases, and bases linked by hydrogen bonds
- Describe the process of DNA replication as the separation of DNA strands and the formation of a new strand by complementary base pairing of nucleotides, including the role of DNA polymerase
- Understand that a gene is a length of DNA containing a sequence of bases coding for a specific protein
- Know that RNA is a second type of nucleic acid that has the following features: single stranded, contains ribose, contains uracil; and that RNA is used to take information from DNA in the nucleus to the ribosomes for the synthesis of proteins
- Describe protein synthesis as:
 - transcription – the formation of mRNA in the nucleus and the transfer of mRNA to ribosomes in the cytoplasm
 - translation of the genetic code by tRNA from mRNA codons; the formation of a polypeptide chain using amino acids
- Understand that a DNA mutation involves a change in the sequence of bases that could lead to a change in the amino acid sequence and thus a change in the phenotype of an individual
- Understand that mitosis occurs during growth, repair, cloning and asexual reproduction
- Know the four main stages of mitosis – prophase, metaphase, anaphase and telophase – which result in the production of two genetically identical diploid daughter cells
- Understand that cells are grouped into tissues and tissues are organised into organs
- Describe the structure of bone, muscle (voluntary, involuntary and cardiac, as observed under a light microscope), blood, nervous tissue, and epithelium (squamous and ciliated, with reference to cells lining the cheek and trachea)*
- Describe the structure of cells specialised for reproduction (egg (ovum) and sperm) and relate their structure to their function*
- Know that there are different types of stem cell, including embryonic and adult stem cells, which have the ability to develop into other body cells
- Describe the advantages, disadvantages and ethics in the research and use of embryonic and adult stem cells
- Outline the principles of genetic engineering, including the production of genetically modified bacteria to produce human insulin, and the production of genetically modified plants to produce vaccines (e.g. hepatitis B) and to improve health (e.g. 'golden rice' to increase vitamin A in the diet)

* These specialised cells and tissues are described in more detail in later chapters.

CELL STRUCTURE

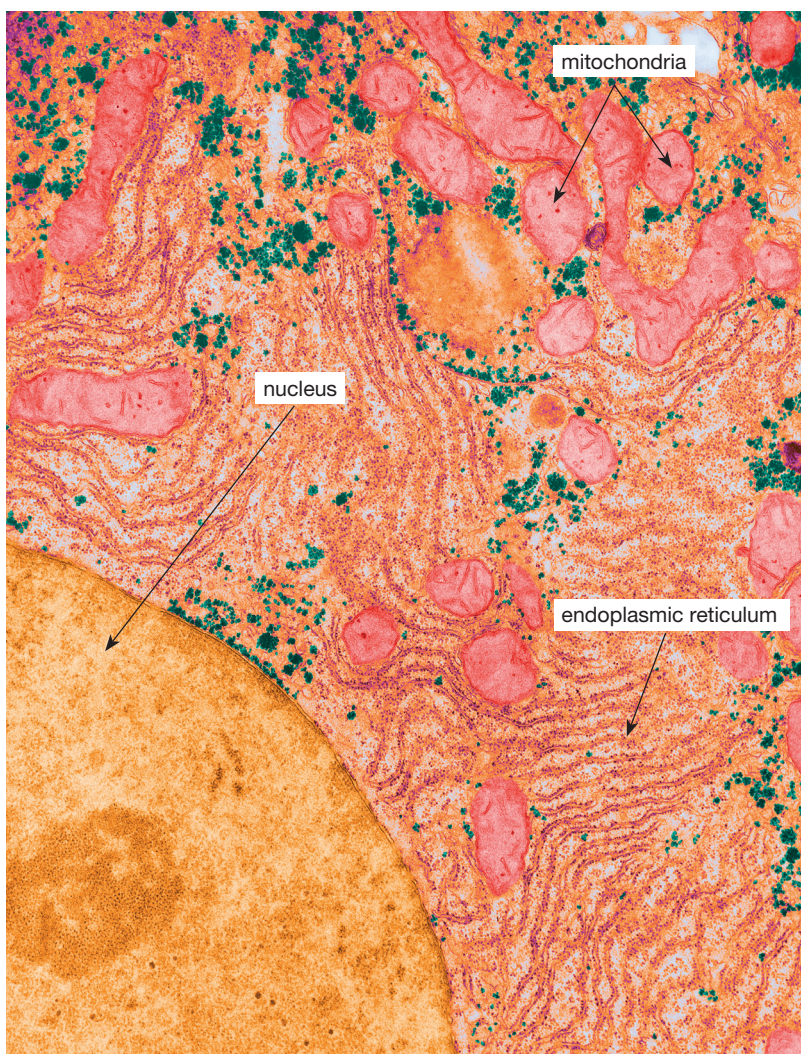


▲ Figure 1.1 The structure of a generalised animal cell, as seen through a light microscope.

The basic building block of living organisms is the **cell**. The human body is composed of countless millions of cells. There are many different types of cell, which are specialised so they can carry out particular functions in the body. Despite these differences, certain features are the same in most cells. Figure 1.1 shows some of the structures present in a typical animal cell.

The living material that makes up a cell is called **cytoplasm**. It has a texture rather like sloppy jelly, in other words, somewhere between a solid and a liquid. Unlike a jelly, it is not made of one substance; rather, it is a complex material that contains many different structures called **organelles**. You cannot see many of these structures under an ordinary light microscope. An electron microscope has a much higher magnification and can show the details of these parts of the cell (Figure 1.2).

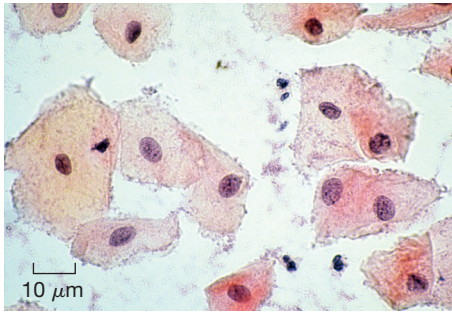
The largest organelle in the cell is the **nucleus**. Nearly all cells have a nucleus, with a few exceptions, such as red blood cells. The nucleus controls the activities of the cell. It contains **chromosomes** (46 in human body cells) which carry the genetic material or **genes**. Genes control the activities in the cell by determining which proteins the cell can make (see below). One very important group of proteins found in cells is **enzymes** (see Chapter 3). Enzymes control chemical reactions that take place in the cytoplasm.



All cells are surrounded by a **cell membrane**, sometimes called the cell *surface* membrane to distinguish it from other membranes inside the cell. This is a thin layer like a 'skin' on the surface of the cell. It forms a boundary between the cytoplasm of the cell and the outside. However, it is not a complete barrier. Some chemicals can pass into the cell and others can pass out of it. We say that the membrane is **partially permeable**. In fact, as you will see, the membrane can actively control the movement of some substances. Because of this, it is also described as **selectively permeable**.

There are many other membranes inside a cell. Throughout the cytoplasm, there is a network of membranes called the **endoplasmic reticulum (ER)**. In places, the endoplasmic reticulum is covered with tiny granules called **ribosomes**. These are the organelles where proteins are made or *synthesised* (see 'The stages of protein synthesis' later in this chapter). The spaces between the membranes of the endoplasmic reticulum act as a transportation system, sending protein to the part of the cell where it is needed.

◀ Figure 1.2 The higher magnification of the electron microscope lets us see more detail in the cell. This photograph shows a small part of a liver cell, with the nucleus in the bottom left-hand corner. The colours are not real – they have been added later to show up the different structures. You can just make out the ribosomes on the endoplasmic reticulum.



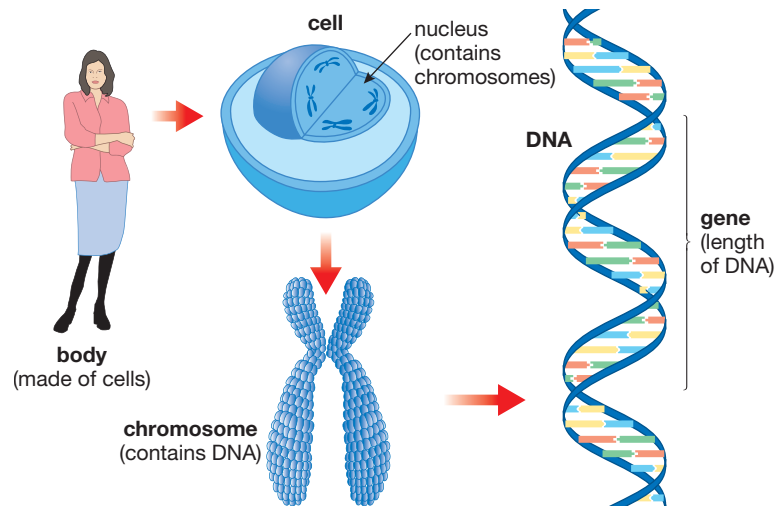
▲ Figure 1.3 Cells from the inside lining of a human cheek. The cells are stained to show up the details of structures such as the nucleus.

One organelle that is found in the cytoplasm of nearly all living cells is the **mitochondrion** (plural mitochondria). In cells that need a lot of energy, such as muscle or nerve cells, there are many mitochondria. This gives us a clue as to their role. They perform some of the reactions of **respiration**, releasing energy that the cell can use (see Chapter 5). Most of the energy from respiration is released in the mitochondria.

Figure 1.3 shows some cells from the lining of a human cheek. They were obtained by gently rubbing a cotton swab on the inside of a person's mouth and transferring the cells to a slide. They are stained with a dye to show them more clearly. How many different organelles can you identify?

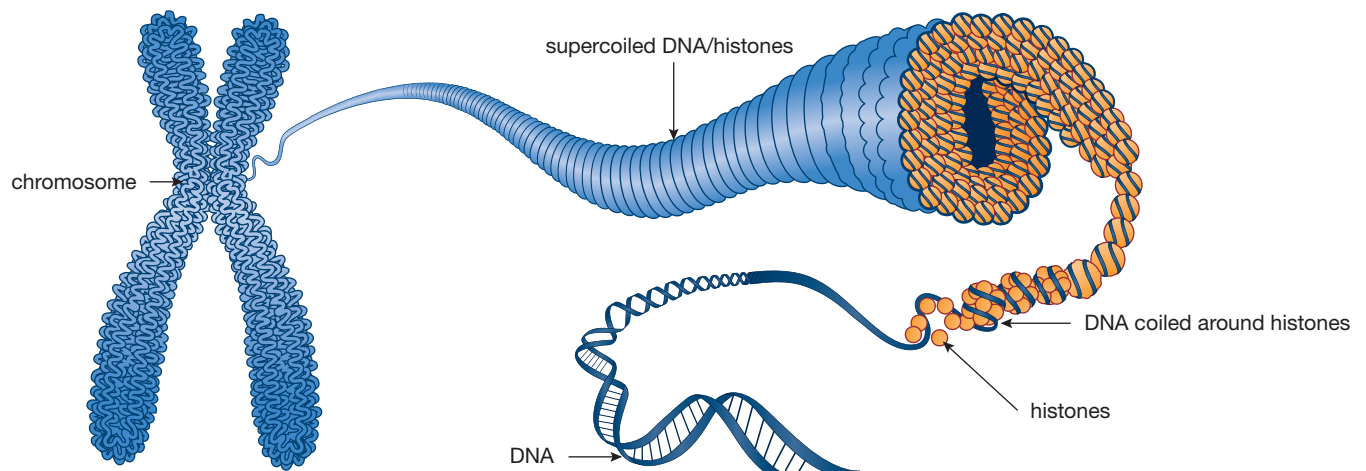
CHROMOSOMES, GENES AND DNA

The chemical that is the basis of inheritance is **deoxyribonucleic acid** or **DNA**. DNA is usually found in the nucleus of a cell, in structures called chromosomes (Figure 1.4). A section of DNA that determines a particular feature is called a gene. Genes determine a person's characteristics by instructing cells to produce particular proteins (see below).



▲ Figure 1.4 Our genetic make-up.

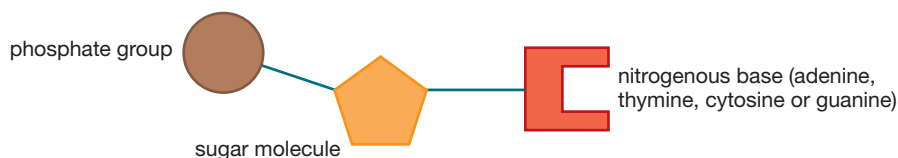
Each chromosome contains one DNA molecule. The DNA is folded and coiled so that it can be packed into a small space. The DNA is coiled around proteins called **histones** (Figure 1.5).



▲ Figure 1.5 The structure of a chromosome.

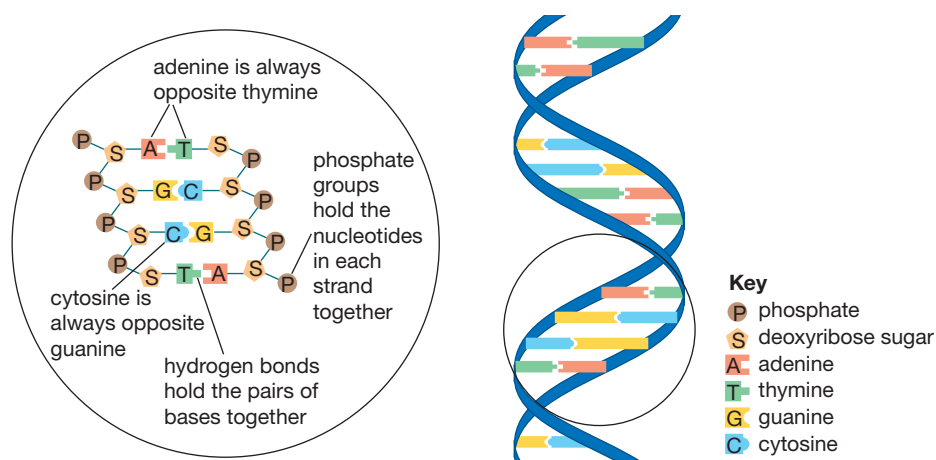
THE STRUCTURE OF DNA

A molecule of DNA is made from two strands of molecular groups called **nucleotides** (Figure 1.6).



▲ Figure 1.6 The structure of a single nucleotide.

Each nucleotide contains a sugar called deoxyribose, a phosphate group, and a nitrogen-containing group called a **base**. There are four bases: adenine (A), thymine (T), cytosine (C) and guanine (G) (Figure 1.7).



▲ Figure 1.7 Part of a molecule of DNA.

KEY POINT

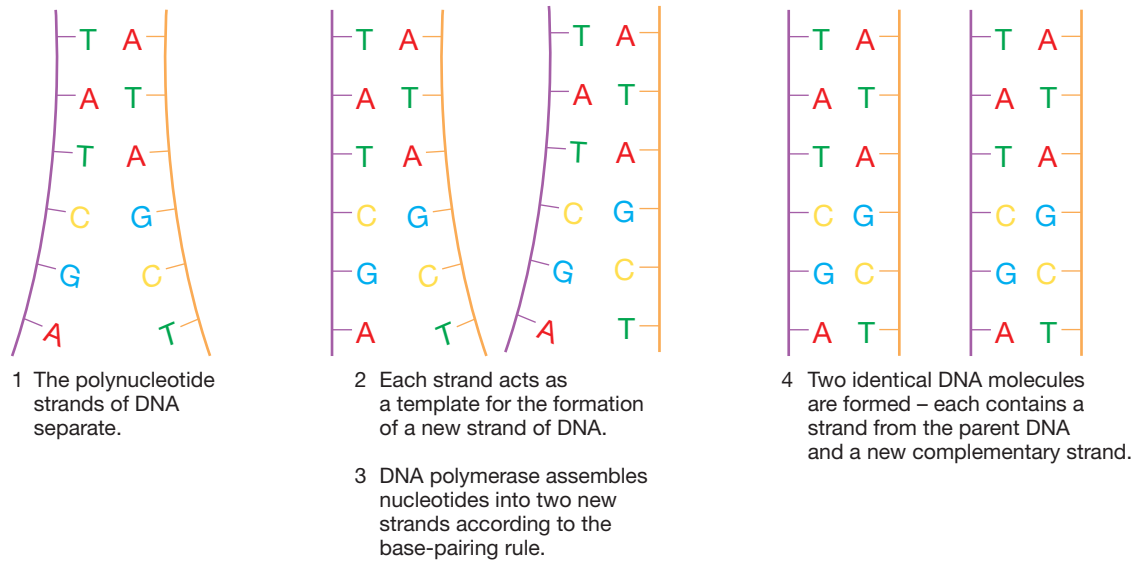
One consequence of the base-pairing rule is that, in each molecule of DNA, the amounts of adenine and thymine are equal, as are the amounts of cytosine and guanine.

Notice that, in the two strands, nucleotides with adenine are always opposite nucleotides with thymine, while cytosine is always opposite guanine. Adenine and thymine are *complementary* bases, as are cytosine and guanine. Complementary bases always bind with each other and never with any other base. This is known as the *base-pairing rule*. The two strands are held together by hydrogen bonds between the complementary base pairs. These are weak bonds between hydrogen atoms on one base and oxygen or nitrogen atoms on another base. They are easily broken, allowing the chains to separate. This property is used when DNA makes a copy of itself.

DNA REPLICATION

DNA is the only chemical that can make exact copies of itself. Because of this, it is able to pass genetic information from one generation to the next as a 'genetic code'.

When a cell is about to divide (see 'Mitosis' later in this chapter) it must first make an exact copy of each DNA molecule in the nucleus. This process is called **replication**. As a result, each 'daughter cell' that is formed receives exactly the same amount and type of DNA. Figure 1.8 summarises this process. The new strands of DNA are assembled from nucleotides under the control of an enzyme called **DNA polymerase**.



▲ Figure 1.8 How DNA replicates itself.

THE GENETIC CODE

DID YOU KNOW?

A ‘template’ is a pattern that can be used to make something. For example, a dress template is a paper pattern for cutting out the material of a dress.

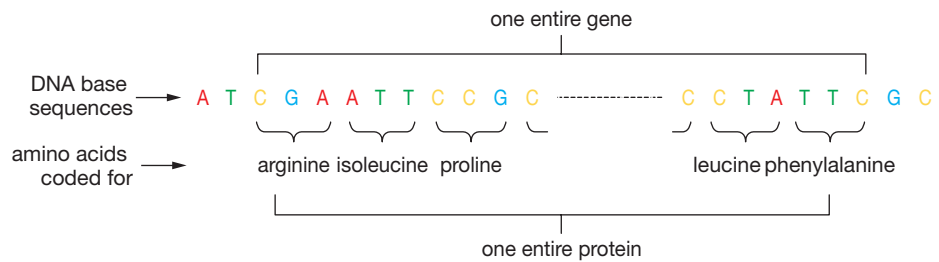
KEY POINT

A gene is a section of a molecule of DNA that codes for a specific protein.

Only one of the strands of a DNA molecule actually codes for the manufacture of proteins in a cell. This strand is called the **template strand**. The other strand is called the non-template strand.

Many of the proteins manufactured are enzymes, which go on to control processes within the cell. Some proteins are structural, for example, keratin in the skin or myosin in muscles. Other proteins have particular functions, such as haemoglobin and some hormones.

Proteins are made of chains of amino acids. A sequence of *three* bases in the template strand of the DNA codes for *one* amino acid. For example, the base sequence TGT codes for the amino acid cysteine. Because three bases are needed to code for one amino acid, the DNA code is a *triplet code*. The sequence of bases that codes for *all* the amino acids in a protein is a gene (Figure 1.9).



▲ Figure 1.9 The triplet code.

The triplets of bases that code for individual amino acids are the same in all organisms. The base sequence TGT codes for the amino acid cysteine in humans, bacteria, bananas, fish, or any other organism you can think of. The DNA code is a *universal code*.

THE STAGES OF PROTEIN SYNTHESIS

DNA stays in the nucleus but protein synthesis takes place in the cytoplasm. This means that, before proteins can be made, the genetic code must be copied and transferred out from the nucleus to the cytoplasm. This is carried out by a different kind of nucleic acid called **ribonucleic acid (RNA)**.

DID YOU KNOW?

Ribose and deoxyribose are very similar in structure. Ribose contains an extra oxygen atom. Similarly, the bases uracil and thymine are very similar in structure.

DID YOU KNOW?

There is a third type of RNA called ribosomal RNA (rRNA). Ribosomes are made of RNA and protein.

There are three main differences between DNA and RNA:

- DNA is a double helix, RNA is a single strand
- DNA contains the sugar deoxyribose, RNA contains ribose
- RNA contains the base uracil (U) instead of thymine (T).

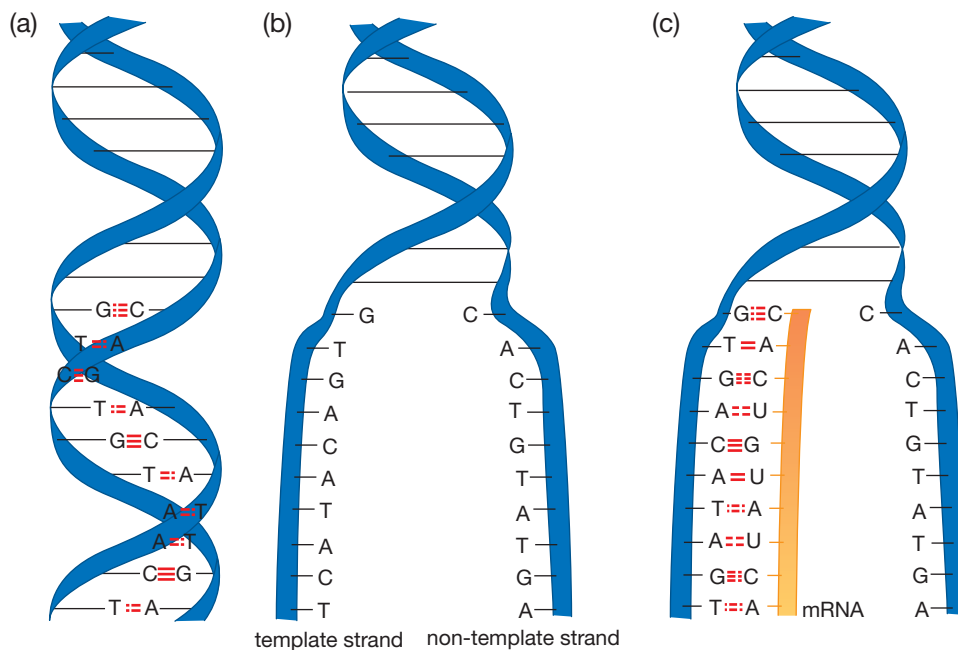
Two types of RNA take part in protein synthesis:

- **messenger RNA (mRNA):** forms a copy of the DNA code
- **transfer RNA (tRNA):** carries amino acids to the ribosomes to make the protein.

Protein synthesis takes place in two stages, called **transcription** and **translation**.

TRANSCRIPTION

Transcription happens in the nucleus. In a chromosome, part of the DNA double helix unwinds and 'unzips', so the two strands separate, exposing the bases along the template strand (Figure 1.10).



▲ Figure 1.10 Transcription. (a) The DNA double helix, showing some base pairs. (b) The two strands of the DNA have separated and unwound. (c) A short length of mRNA has formed. (The mRNA responsible for forming a whole protein would be much longer than this.)

KEY POINT

An RNA nucleotide consists of ribose sugar, a phosphate and one of four bases (C, G, A or U).

▼ Table 1.1 Base-pairing rules in transcription.

| Base on DNA | Base on mRNA |
|-------------|--------------|
| G | C |
| C | G |
| T | A |
| A | U |

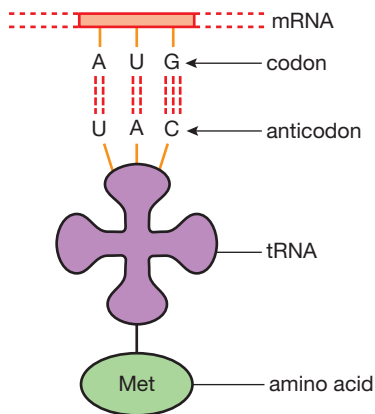
The template strand of the DNA forms a framework upon which a molecule of mRNA is formed. The building blocks of the mRNA are RNA nucleotides. They line up alongside the template strand according to the complementary base-pairing rules (Table 1.1).

The RNA nucleotides link up one at a time to form an mRNA molecule. Bonds form between the ribose and phosphate groups, joining them together to make the sugar-phosphate backbone of the molecule. When a section of DNA corresponding to a protein (a gene) has been transcribed, the mRNA molecule leaves the DNA and passes out of the nucleus to the cytoplasm. It leaves through pores (holes) in the nuclear membrane. The DNA helix then 'zips up' again. Because of complementary base pairing, the triplet code of the DNA is converted into a triplet code in the mRNA.

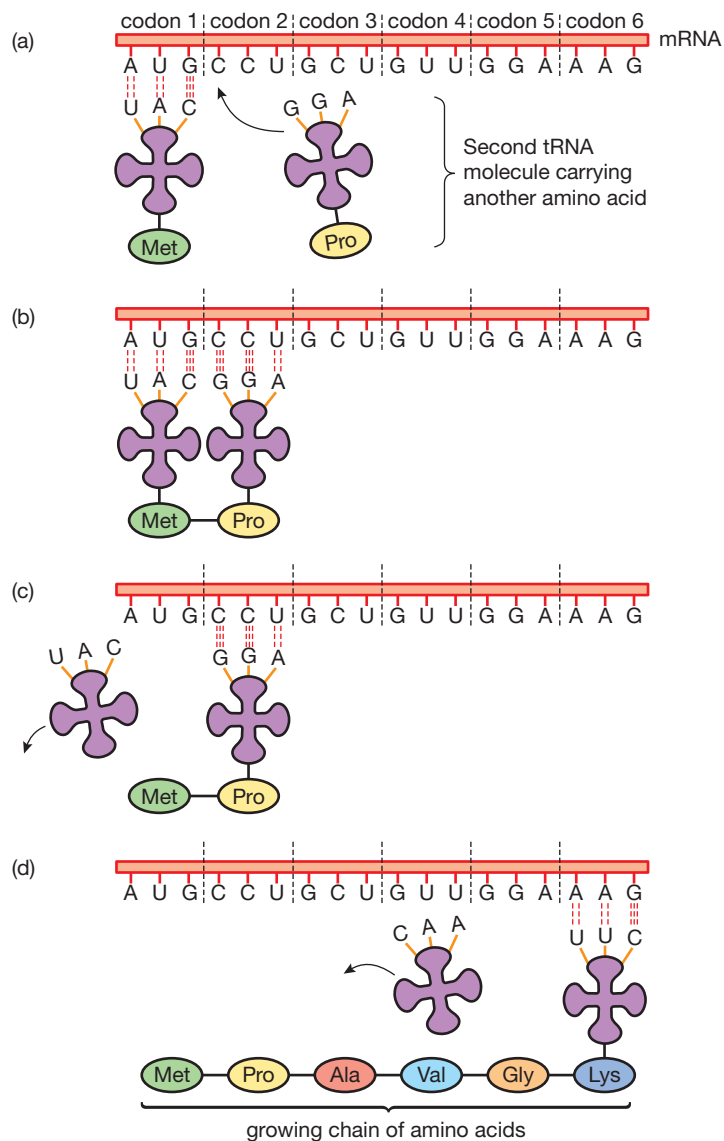
TRANSLATION

Converting the code in the mRNA into a protein is called translation. This takes place at the ribosomes. By this stage, the code consists of sets of three bases in the mRNA (e.g. AUG, CCG, ACA). These triplets of bases are called **codons**. Each codon codes for a particular amino acid; for example, CCU codes for the amino acid proline, and AUG codes for methionine.

The mRNA molecule attaches to a ribosome. Now the tRNA molecules begin their part in the process. Each tRNA molecule has an **anticodon** of three bases at one end of the molecule. This is complementary to a particular codon on the mRNA. At the other end of the tRNA molecule is a site where a specific amino acid can attach (Figure 1.11). This means that there is a particular tRNA molecule for each type of amino acid. The tRNA molecule carries its amino acid to the ribosome, where its specific anticodon links up with the three bases of the corresponding mRNA codon.



▲ Figure 1.11 A tRNA molecule with the anticodon UAC, carrying the amino acid methionine. The anticodon is complementary to the codon AUG on the mRNA.



▲ Figure 1.12 Translation. (a) A tRNA molecule carrying the first amino acid is attached to the first codon on the mRNA. A second tRNA is arriving, carrying the second amino acid. (b) Two tRNA molecules are attached to the mRNA. A bond is formed between the two amino acids. (c) The first tRNA molecule is released. The process continues as more tRNA molecules bring amino acids to the ribosome. (d) The situation after six tRNA molecules have brought amino acids. A chain of amino acids called a polypeptide is starting to form – this is the beginning of a protein molecule.

DID YOU KNOW?

Protein synthesis is a process that uses up a lot of the chemical energy produced in a cell.

KEY POINT

Summary of protein synthesis: The order of bases in the template strand of the DNA forms the genetic code. The code is converted into the sequence of bases in the mRNA. In the cytoplasm, the sequence of mRNA bases is used to determine the position of amino acids in a protein.

This interaction between mRNA and tRNA is the basis of translation. The process is shown in Figure 1.12.

Translation takes place as follows:

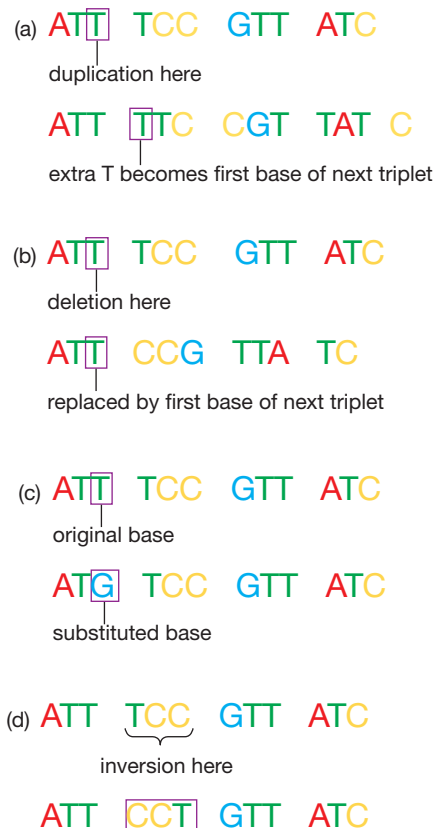
- The first tRNA to bind at the mRNA does so at the 'start codon', which always has the base sequence AUG. This codes for the amino acid methionine.
- Another tRNA brings along a second amino acid. The anticodon of the second tRNA binds to the next codon on the mRNA.
- A bond forms between the methionine and the second amino acid.
- The first tRNA molecule is released and goes off to collect another amino acid.
- More tRNA molecules arrive at the mRNA and add their amino acids to the growing chain, forming a polypeptide.

At the end of the chain, a 'stop codon' tells the 'translation machinery' that the protein is complete, and it is released.

There are 20 different amino acids, so there must be at least 20 different codons (and 20 different anticodons). In fact, there are more than this, because some amino acids use more than one triplet code. For example, the mRNA codons GGU, GGC, GGA and GGG all code for the amino acid glycine.

GENE MUTATIONS – WHEN DNA MAKES MISTAKES

A **mutation** is a random change in the DNA of a cell. Sometimes, when DNA is replicating, mistakes are made and the wrong nucleotide is used. The result is a gene mutation, which can change the sequence of the bases in a gene. In turn, this can lead to the gene coding for the wrong amino acid in a protein. There are several ways in which gene mutations can occur (Figure 1.13).



▲ Figure 1.13 Gene mutations: (a) duplication; (b) deletion; (c) substitution; (d) inversion.

- **Duplication:** In duplication, Figure 1.13(a), the nucleotide is inserted twice instead of once. This means that the entire base sequence is altered, because each triplet after the point where the mutation occurs is changed. The whole gene is different and will code for an entirely different protein.
- **Deletion:** In deletion, Figure 1.13(b), a nucleotide is missed out. Again, the entire base sequence is altered. Each triplet after the mutation is changed and the whole gene is different. As with duplication, the gene will now code for an entirely different protein.
- **Substitution:** In substitution, Figure 1.13(c), a different nucleotide is used. The triplet of bases in which the mutation occurs is changed and it *may* code for a different amino acid. If it does, the structure of the protein molecule will be different. This may be enough to produce a significant change in the functioning of the protein, or it may mean that the protein does not function at all. However, most amino acids have more than one code, so the new triplet may not code for a different amino acid. If this is the case, the protein will have its normal structure and function.
- **Inversion:** In inversion, Figure 1.13(d), the sequence of the bases in a triplet is reversed. The effects are similar to substitution. Only one triplet is affected and this may or may not result in a different amino acid and altered protein structure.

Mutations that occur in body cells, such as those in the heart, intestines or skin, will only affect the particular cell in which they occur. If the mutation is very harmful, the cell will die and the mutation will be lost. If the mutation does not significantly affect the functioning of the cell, the cell may not die. If the cell then divides, a group of cells containing the mutant gene will be formed. When the person dies, however, the mutation will be lost – it will not be passed to their children. Only mutations in the sex cells (**gametes**), or in the cells that divide to form gametes, can be passed on to the next generation. This is how genetic diseases begin.

CELL DIVISION

There are two kinds of cell division – **mitosis** and **meiosis**.

In most parts of the body, cells need to divide so that organisms can grow and replace old or damaged cells. The cells that are produced by this type of cell division should be exactly the same as the cells they are replacing. This is the most common form of cell division and is called mitosis. Mitosis forms all the cells in our bodies except the sex cells.

Only in the sex organs is cell division different. Here, some cells divide to produce sex cells or gametes, which contain only half the original number of chromosomes. When male and female gametes join together at **fertilisation**, the resulting cell (called a **zygote**) will contain the full set of chromosomes and can then divide and grow into a new individual. This type of cell division is called meiosis and is described in Chapter 11.

Human body cells have 46 chromosomes in 23 pairs called **homologous pairs**. These body cells are **diploid** cells – they have *two* copies of each chromosome. The sex cells have 23 chromosomes (only one copy of each chromosome); they are **haploid** cells.

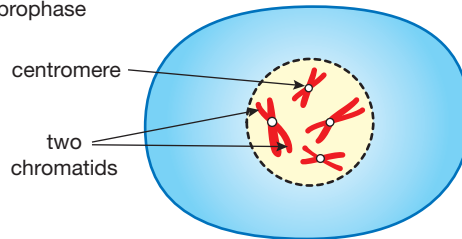
MITOSIS

When a ‘parent’ cell divides, it produces *daughter cells*. Mitosis produces two daughter cells that are genetically identical to the parent cell – both daughter cells have the same number and type of chromosomes as the parent cell.

To achieve this, the dividing cell must copy each chromosome before it divides. The DNA replicates and more proteins are added to the structure. Each daughter cell can then receive a copy of each chromosome (and each molecule of DNA) when the cell divides. If it does not do this, the daughter cells will not contain all the genes.

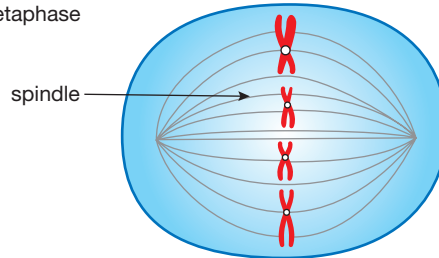
A number of stages occur when a cell divides by mitosis. These are shown in Figure 1.14.

(a) prophase



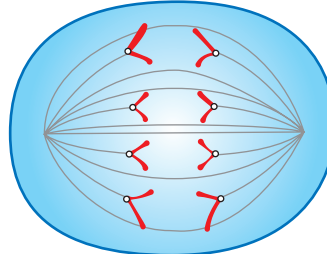
Before mitosis the DNA replicates and the chromosomes form two exact copies called chromatids. During the first stage of mitosis (prophase) the chromatids become visible, joined at a centromere. The nuclear membrane breaks down.

(b) metaphase



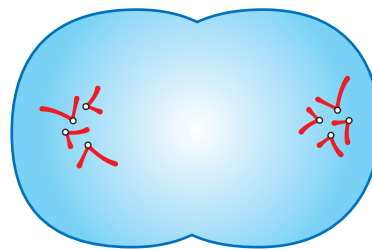
During metaphase a structure called the spindle forms. The chromosomes line up at the 'equator' of the spindle, attached to it by their centromeres.

(c) anaphase

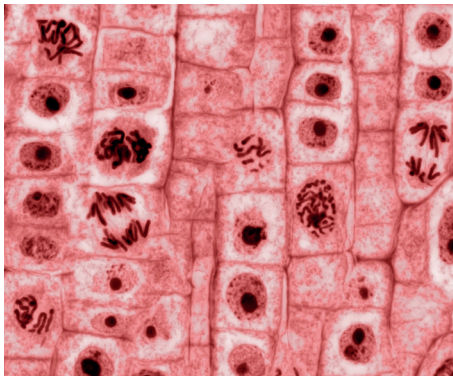


During anaphase, the spindle fibres shorten and pull the chromatids to the opposite ends ('poles') of the cell. The chromatids separate to become the chromosomes of the two daughter cells.

(d) telophase



In the last stage (telophase) two new nuclei form at the poles of the cell. The cytoplasm starts to divide to produce two daughter cells. Both daughter cells have a copy of each chromosome from the parent cell.



▲ Figure 1.15 Cells in the root tip of an onion dividing by mitosis. Can you identify any of the stages shown in Figure 1.14?

▲ Figure 1.14 The stages of mitosis. For simplicity, the cell shown contains only two homologous pairs of chromosomes (one long pair, one short).

It is easiest to see mitosis in plant cells, because these are usually large and well defined by their cell walls. Figure 1.15 is a photograph of some cells from the root tip of an onion. Cells in this region divide by mitosis as the root grows. Although these are plant cells, the process is very similar in human cells.

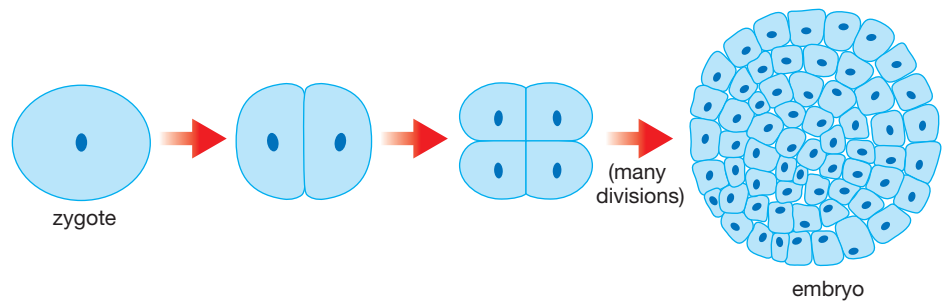
Each daughter cell formed by mitosis is diploid, receiving a copy of every chromosome (and therefore every gene) from the parent cell. Each daughter cell is genetically identical to the others. A group of genetically identical cells produced by mitosis is called a **clone**. Apart from the sex cells, all the cells in our body are clones. They are formed by mitosis and contain copies of all of our chromosomes and genes.

DID YOU KNOW?

You may have heard the words ‘clone’ and ‘cloning’ used to describe the production of entire organisms (animals and plants) from body cells, by mitosis. Many plants reproduce naturally from parts of leaves or roots broken off from the parent plant. This is an example of cloning, and is used commercially to grow plants. Cloning animals is more difficult, but several species have been grown artificially in the laboratory by mitosis from body cells. Since this type of reproduction does not involve sex cells, it is called **asexual reproduction**.

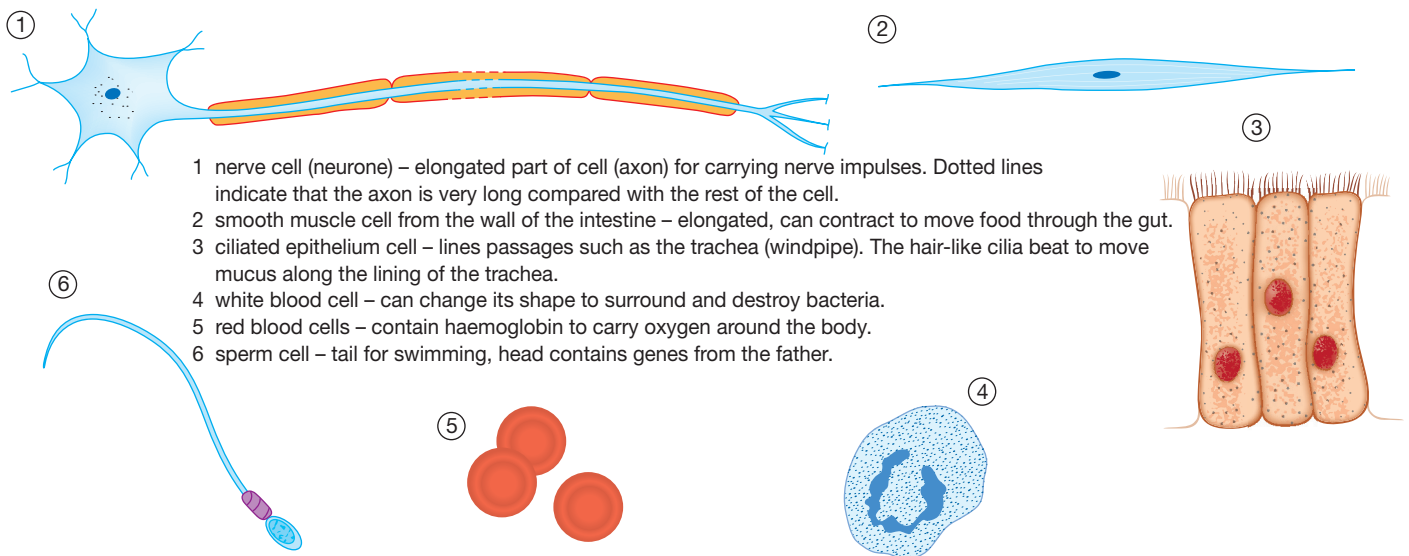
DIFFERENTIATION OF CELLS

A human begins life as a zygote, which divides by mitosis to form two cells, then four, then eight and so on, until an **embryo** is formed, containing many millions of cells (Figure 1.16).



▲ Figure 1.16 A human embryo grows by mitosis.

As the developing embryo grows, cells become specialised to perform particular roles. This specialisation is also under the control of the genes, and is called **differentiation**. Different kinds of cell develop depending on where they are located in the embryo, for example, a nerve cell in the spinal cord, or an epidermal cell in the outer layer of the skin (Figure 1.17).



- 1 nerve cell (neuron) – elongated part of cell (axon) for carrying nerve impulses. Dotted lines indicate that the axon is very long compared with the rest of the cell.
- 2 smooth muscle cell from the wall of the intestine – elongated, can contract to move food through the gut.
- 3 ciliated epithelium cell – lines passages such as the trachea (windpipe). The hair-like cilia beat to move mucus along the lining of the trachea.
- 4 white blood cell – can change its shape to surround and destroy bacteria.
- 5 red blood cells – contain haemoglobin to carry oxygen around the body.
- 6 sperm cell – tail for swimming, head contains genes from the father.

▲ Figure 1.17 Some cells with very specialised functions. They are not drawn to the same scale.

DID YOU KNOW?



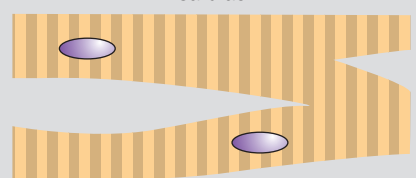
Throughout this book, you will read about *adaptations*. An **adaptation** is a way that the structure of a cell, tissue or organ is suited (adapted) to its function.

What is hard to understand about this process is that, through mitosis, all the cells of the body have the *same* genes. For cells to function differently, they must produce different proteins, and different genes code for the production of these different proteins. How is it that some genes are ‘switched on’ and others are ‘switched off’ to produce different cells? The answer to this question is very complicated, and scientists are only just beginning to understand it.

CELLS, TISSUES AND ORGANS

Cells that have a similar function are grouped together as **tissues**. For example, the muscle of your arm contains millions of muscle cells, all specialised for one function – contracting to move the arm bones (see Chapter 7). This is muscle tissue or, more accurately, **voluntary muscle** tissue. The word ‘voluntary’ refers to the fact that the contraction of muscles like this is under the conscious control of the brain. The smooth muscle cell shown in Figure 1.17 makes up **involuntary muscle** tissue, since the muscles in the gut are not consciously controlled by the brain. Involuntary muscle is present in the walls of organs such as the intestine, bladder and blood vessels. There is a third type of muscle tissue called **cardiac muscle**, which makes up the muscular wall of the heart (see Chapter 6). It is interesting to note that all muscle (voluntary, involuntary and cardiac) contains the same special protein filaments that are able to bring about contraction. However, these filaments are arranged differently in each type of muscle, so the cells have a distinct structure that depends on the type of contraction carried out by the tissue (Table 1.2).

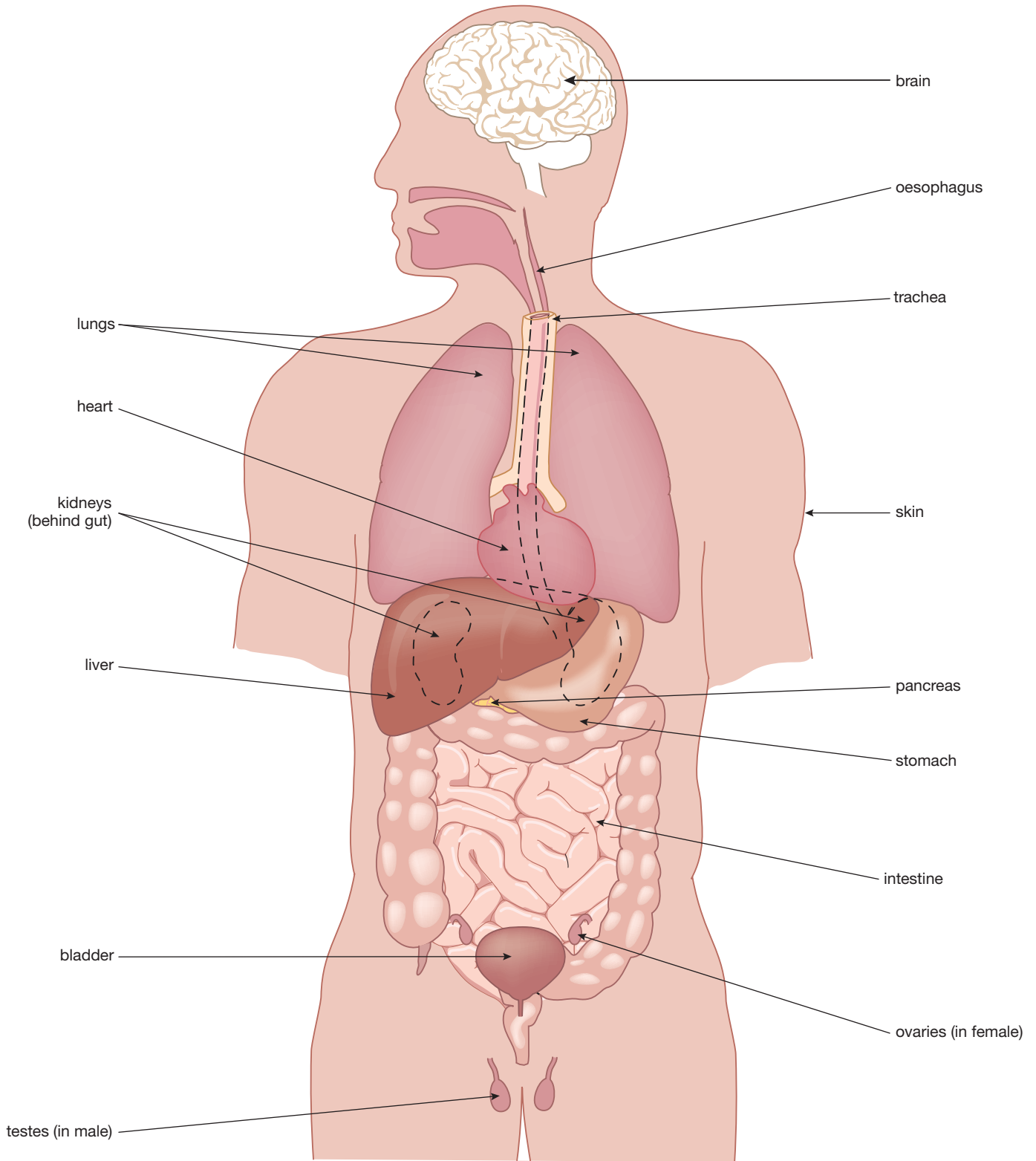
▼ Table 1.2 The three types of muscle cell.

| Type | Structure | Function |
|---|---|---|
| Voluntary  | Striped (striated) due to alignment of protein filaments in the cell. Many nuclei per cell. Not branched. | Rapid contraction to move bones (also called skeletal muscle). Under voluntary control by the brain. |
| Involuntary  | Non-striated because protein filaments are not aligned in the cell (hence also called smooth muscle). One nucleus per cell. Not branched. Cell tapered at ends. | Slow, rhythmic contraction in walls of gut, blood vessels etc. Not under voluntary control by the brain. |
| Cardiac  | Striated. Many nuclei per cell. Branched cells forming a strong mesh-like network. | Only present in the heart. Contracts rhythmically and constantly throughout life without tiring. Not under voluntary control. |

Tissues that line organs are called **epithelia** (singular epithelium). Figure 1.17 shows a **ciliated epithelium** cell, which has tiny hair-like projections called cilia. Cilia are able to beat (wave backwards and forwards) to move liquids along. There are several other types of epithelia, such as the flattened cells lining the human cheek (Figure 1.3). This is called a **squamous epithelium**. You will read about several types of epithelia in this book.

Bone is a tissue made of cells that secrete a hard material made of calcium salts (see Chapter 7). Other tissues include **blood** (Chapter 6), which is made of various types of red and white blood cells in a liquid matrix called plasma, and **nervous tissue** (Chapter 9), which makes up the brain, spinal cord and nerves.

A collection of different tissues carrying out a particular function is called an **organ**. The main organs of the human body are shown in Figure 1.18.



▲ Figure 1.18 Some of the main organs of the human body.

STEM CELLS

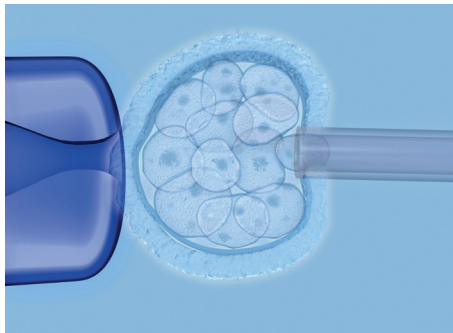
A **stem cell** is a cell that is able to divide many times by mitosis without undergoing differentiation. Later, it can differentiate into specialised cells such as muscle or nerves. In humans, there are two main types of stem cell:

- **Embryonic stem cells** are found in the early stage of development of the embryo. Embryonic stem cells can differentiate into any type of body cell.
- **Adult stem cells** are found in certain adult tissues, such as bone marrow, skin, and the lining of the intestine. They have lost the ability to differentiate into any type of cell but can form a number of specialised tissues. For example, bone marrow cells can divide many times but are only able to produce different types of red and white blood cell.

The use of stem cells to treat or prevent a disease, or to repair damaged tissues, is called **stem cell therapy**. At present, the only widely used types of stem cell therapy are bone marrow transplants. These are used to treat patients with conditions such as leukaemia (a type of blood cancer). Some cancer treatments use chemicals that kill cancer cells (chemotherapy) but this type of treatment also destroys healthy body cells. Bone marrow transplants supply stem cells that can divide and differentiate, replacing cells lost from the body during chemotherapy. Bone marrow transplants are now a routine procedure and have been used successfully for over 30 years. Bone marrow and other adult stem cells are readily available, but they have limited ability to differentiate into other types of cell.

DID YOU KNOW?

Marrow is the soft tissue inside bones that produces blood cells. A bone marrow transplant is a medical operation that replaces unhealthy blood-forming cells with healthy ones.



▲ Figure 1.19 Extracting a stem cell from an embryo at an early stage of its development. The embryo consists of a ball of about 20 cells. A single cell is removed by drawing it into a fine glass capillary tube.

Scientists are able to isolate and culture embryonic stem cells (Figure 1.19). These are obtained from fertility clinics where parents choose to donate their unused embryos for research. In the future, it is hoped that we will be able to use embryonic stem cells to treat many diseases such as diabetes, as well as brain disorders such as Parkinson's disease. Stem cells may also be able to repair nervous tissues damaged in accidents. So far, treatments using embryonic stem cells have not progressed beyond the experimental stage, and there are a number of problems. In particular, many people have moral or ethical objections to using cells from embryos for medical purposes, even though they might one day be used to cure many diseases.

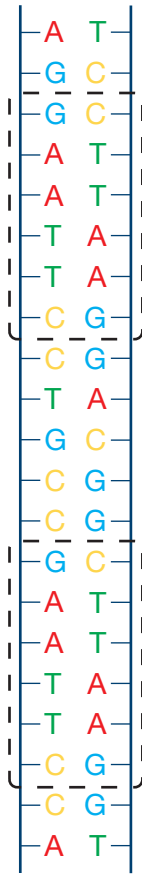
GENETIC ENGINEERING

The basis of genetic engineering is the production of **recombinant DNA**. A section of DNA – a gene – is cut out of the DNA of one species and inserted into the DNA of another. This new DNA is called 'recombinant' because DNA from two different species has been 'recombined'. The organism that receives the gene from a different species is a **transgenic** organism.

The organism that received the new gene now has an added capability. It will manufacture the protein that the new gene codes for. For example, if a bacterium receives the human gene that codes for insulin production, it will make human insulin. If these transgenic bacteria are cultured, they will become a 'factory' for making human insulin.

PRODUCING GENETICALLY MODIFIED (TRANSGENIC) BACTERIA

The breakthrough in being able to transfer DNA from cell to cell came when it was found that bacteria have two sorts of DNA – the DNA found in a bacterial 'chromosome' and much smaller circular pieces of DNA called **plasmids**.



▲ Figure 1.20 Part of a DNA molecule containing the base sequence G-A-A-T-T-C. Notice that the sequence is present on both strands, but running in opposite directions.

DID YOU KNOW?

A bacterial chromosome is not like a human chromosome. It is a continuous loop of DNA rather than a strand. Also, the structure of a bacterial chromosome is simpler and does not contain the histone proteins present in eukaryotic chromosomes. The structure of a bacterial cell is described in Chapter 13.

Bacteria naturally ‘swap’ plasmids, and biologists found ways of transferring plasmids from one bacterium to another. The next stage was to find molecular ‘scissors’ and a molecular ‘glue’ that could cut out genes from one molecule of DNA and stick them back into another. Further research found the following enzymes that were able to do this:

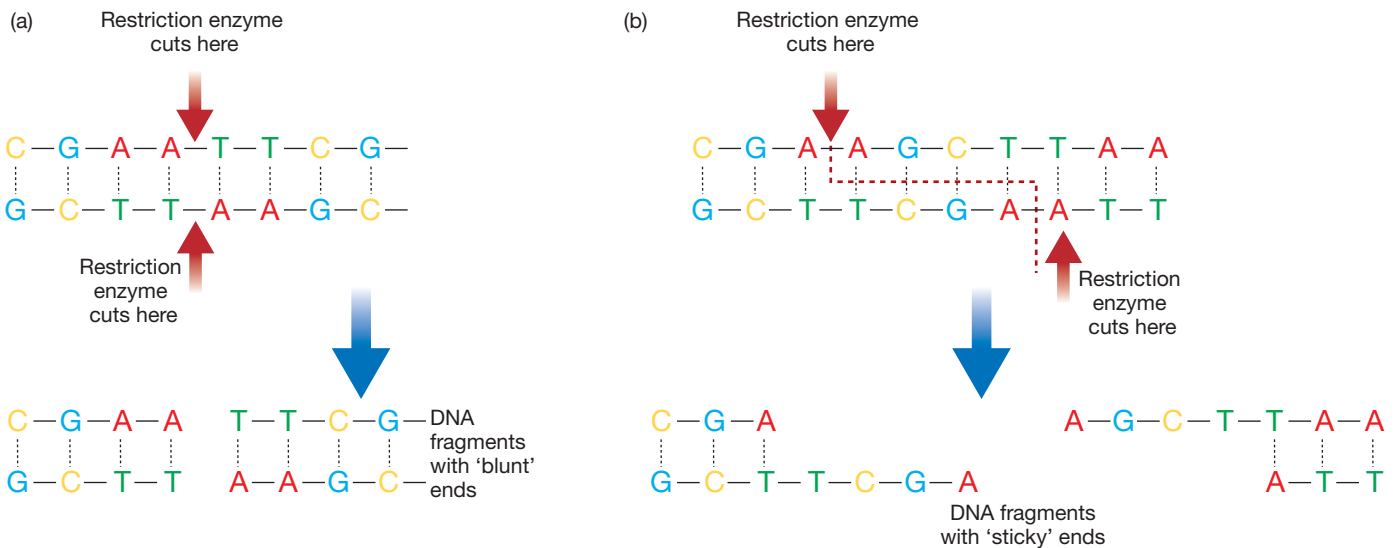
- **Restriction endonucleases** (usually shortened to **restriction enzymes**) are enzymes that cut DNA molecules at specific points. Different restriction enzymes cut DNA at different places. They can be used to cut out specific genes from a molecule of DNA.
- **Ligases** (or DNA ligases) are enzymes that join the cut ends of DNA molecules.

Each restriction enzyme recognises a certain base sequence in a DNA strand. Wherever it encounters that sequence, it will cut the DNA molecule. Suppose a restriction enzyme recognises the base sequence G-A-A-T-T-C. It will only cut the DNA molecule if it can ‘see’ this base sequence on both strands. Figure 1.20 illustrates this.

Some restriction enzymes make a straight cut and the fragments of DNA they produce are said to have ‘blunt ends’ (Figure 1.21(a)). Other restriction enzymes make a staggered (step-shaped) cut. These produce fragments of DNA with overlapping ends with complementary bases (Figure 1.21(b)). These overlapping ends are called ‘sticky ends’ because fragments of DNA with exposed bases are more easily joined by ligase enzymes.

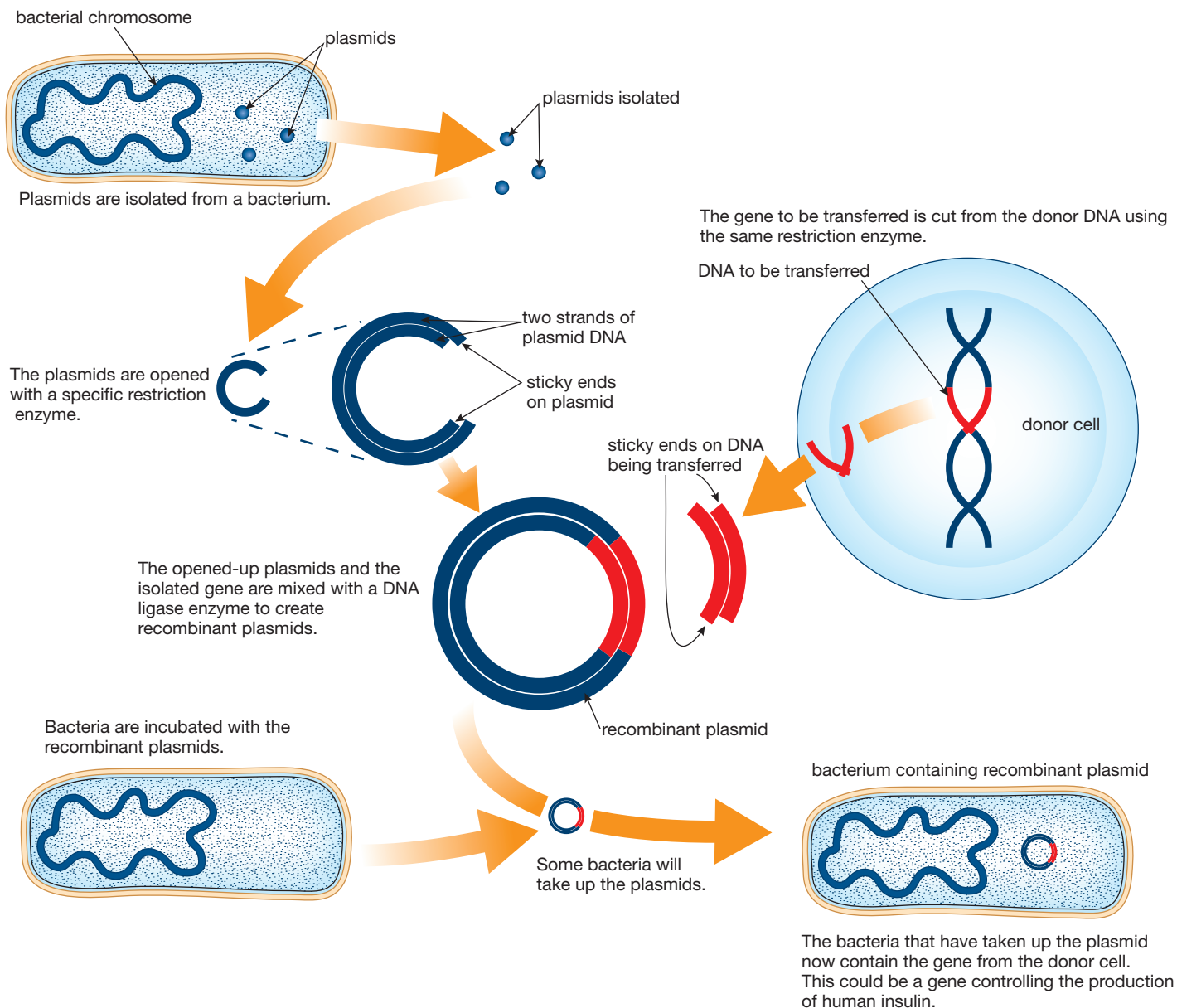
EXTENSION WORK

There is a lot more to producing recombinant DNA and transgenic bacteria than is described here. You could carry out some research to find out more about this subject.



▲ Figure 1.21 How restriction enzymes cut DNA.

Biologists now had a method of transferring a gene from any cell into a bacterium. They could insert the gene into a plasmid and then transfer the plasmid into a bacterium. The plasmid is called a **vector** because it is the means of transferring the gene. The main processes involved in producing a transgenic bacterium are shown in Figure 1.22.



▲ Figure 1.22 The stages in producing a transgenic bacterium.



▲ Figure 1.23 An industrial fermenter holds hundreds of thousands of dm³ of a liquid culture.

Different bacteria have been genetically modified to manufacture a range of products. Once they have been genetically modified, they are grown or 'cultured' in tanks called **fermenters** to produce large amounts of the product (Figure 1.23).

SOME PRODUCTS OF GENETICALLY MODIFIED MICROORGANISMS

Since the basic techniques of transferring genes were developed, many simple single-celled organisms, such as bacteria and yeasts (unicellular fungi), have been genetically modified to produce useful products. Some examples of medical products made using genetically modified microorganisms are:

- **Human insulin:** People suffering from diabetes need a reliable source of the drug **insulin** to treat their condition (see Chapter 9). Before the use of genetic engineering, the only insulin available was extracted from the pancreases of other animals such as cattle or pigs. The chemical structure of insulin from these animals is not quite the same as that of human insulin and does not give the same degree of control of blood glucose levels. Now, however, the human gene for insulin production can be placed in bacteria, which then produce human insulin.

DID YOU KNOW?

More insulin is required every year because the number of diabetics worldwide increases each year, and also because diabetics now have longer life spans.

- **Growth hormone:** In some children, the pituitary gland does not produce enough growth hormone and their growth is restricted. Injections of human growth hormone from genetically modified bacteria can restore normal growth patterns.

DID YOU KNOW?

Before human growth hormone from genetically modified bacteria was available, the only source of the hormone was from human corpses (dead bodies). This was a rather unpleasant procedure and had health risks. A number of children treated in this way developed Creutzfeld–Jacob disease (the human form of ‘mad cow’ disease). When this became known, the treatment was withdrawn.

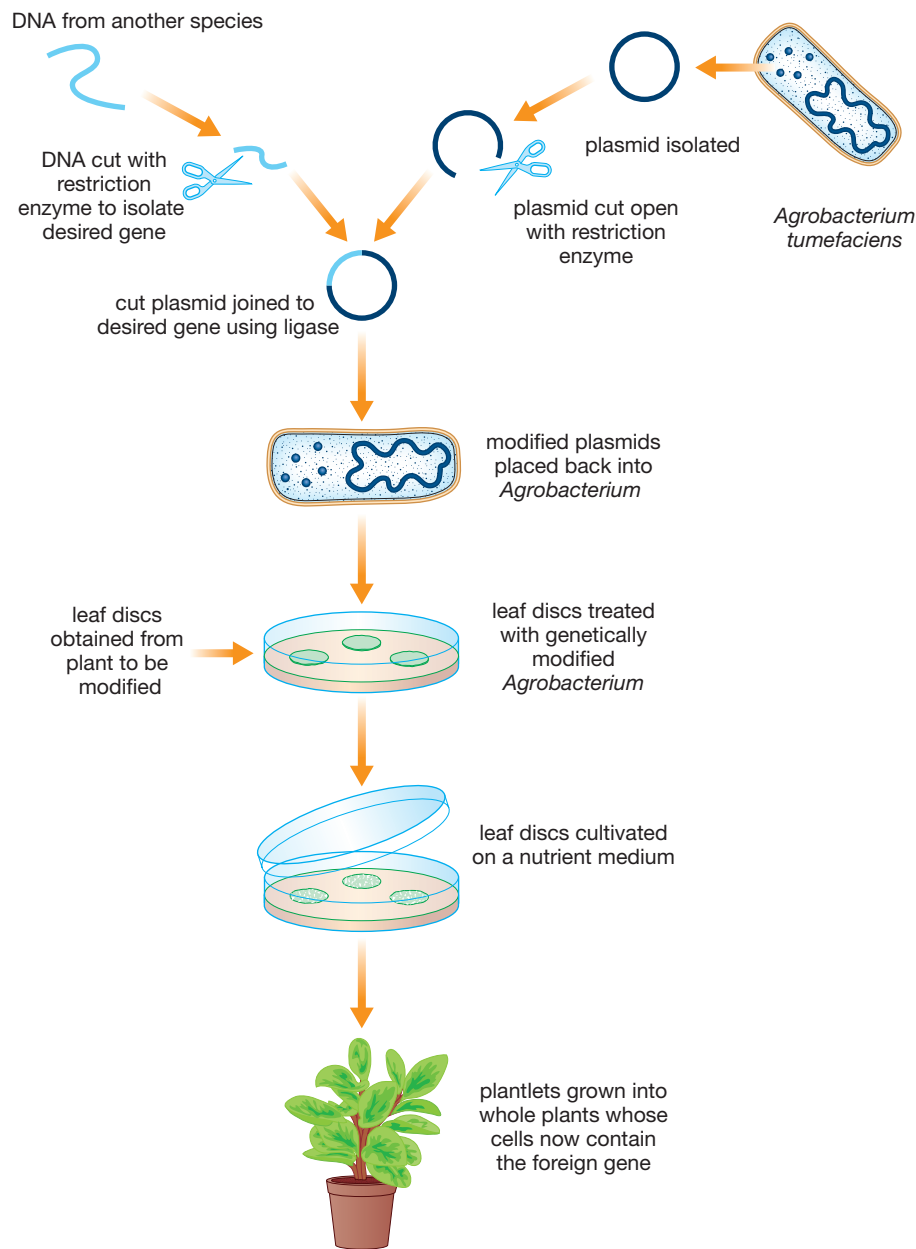
- **Hepatitis B vaccine:** Yeast cells can be genetically modified to produce the surface proteins (**antigens**) of the hepatitis B virus. These proteins are used to make a vaccine against hepatitis B. When the vaccine is injected into a patient, their body makes antibodies against the proteins, so the person becomes immune to the virus.

PRODUCING GENETICALLY MODIFIED PLANTS

The gene technology described so far can transfer DNA from one cell to another cell. In the case of bacteria, this is fine – a bacterium only has one cell. But plants have billions of cells and to genetically modify a plant, each cell must receive the new gene. Any procedure for genetically modifying plants has two main stages:

- introducing the new gene or genes into plant cells
- producing whole plants from just a few cells.

At first, biologists had problems inserting genes into plant cells. Then they discovered a soil bacterium called *Agrobacterium*, which regularly inserts plasmids into plant cells. Now that a vector had been found, the rest became possible. Figure 1.24 outlines one procedure that uses *Agrobacterium* as a vector.



▲ Figure 1.24 Genetically modifying plants using *Agrobacterium*.



▲ Figure 1.25 The gene gun.

EXTENSION WORK

Golden rice sounds like a good idea but there have been several problems with it. Some people believe that there are ethical and environmental reasons why golden rice should not be grown and that it is better to provide other, natural crops containing enough beta-carotene. You could research the pros and cons of golden rice on the internet.

This technique cannot be used on all plants. *Agrobacterium* will not infect cereals, so another technique was needed for these plants. The 'gene gun' was invented. This is a piece of laboratory equipment that fires tiny pellets made of gold (Figure 1.25). The pellets are coated with DNA that contains the required gene. These are fired directly into plant tissue. The gene gun has made it possible to genetically modify cereals and other crop plants.

Using *Agrobacterium* as a vector, biologists have produced genetically modified rice called 'golden rice'. This rice has three genes added to its normal DNA content. Two of these genes come from daffodils and one comes from a bacterium. Together, these genes allow the rice to make beta-carotene – the chemical that gives carrots their colour. It also colours the rice, which explains the name 'golden rice'. More importantly, the beta-carotene is converted to vitamin A when eaten. This could save the eyesight of millions of children in less economically developed countries, who go blind because they do not have enough vitamin A in their diet.

DID YOU KNOW?

What if you could receive a 'vaccination' every time you ate a banana? Instead of extracting the proteins and using them to make a vaccine, it might be possible to 'vaccinate' a person by getting them to eat a GM banana. The person's immune system would make antibodies against the virus proteins in the banana, and these antibodies would be able to destroy the virus without any need for an injection.

KEY POINT

A nanometre (nm) is 10^{-9} m, or one millionth of a millimetre.

Genetically modified plants are also helping humans to fight infection. Biologists have succeeded in genetically modifying several species of plant in order to produce vaccines against different infectious diseases. For example, potatoes, bananas, lettuce, carrots and tobacco plants have all been engineered to produce proteins from the virus that causes hepatitis B. These proteins can be extracted from the plants and used to make a vaccine, which can be given to the patients by mouth or as an injection. At the time when this book was written, this vaccine had not been developed to the stage where it could replace vaccine from genetically modified yeast cells (described above). However, research in this area continues.

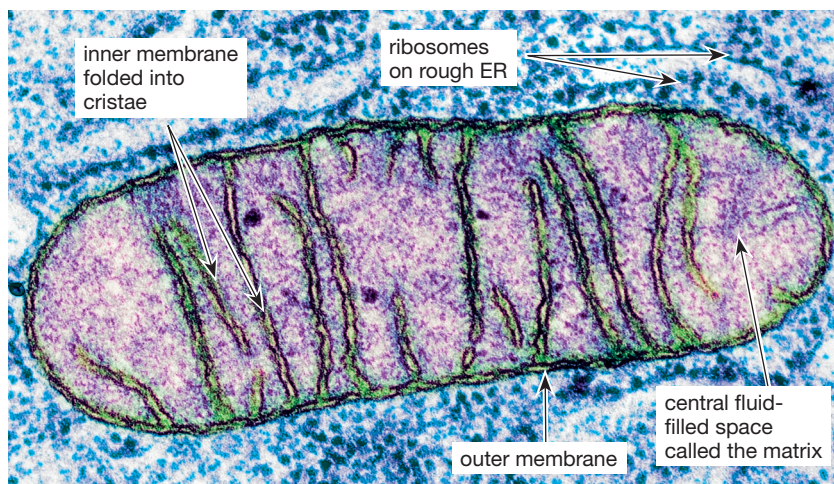
LOOKING AHEAD – MEMBRANES IN CELLS

If you continue to study biology beyond International GCSE, you will learn more about the structure and function of cells. You might like to look on the internet for some electron micrographs and do some further research about cell structure.

Electron microscopes allow us to see cells at a much greater magnification than by using a light microscope. They also reveal more detail. The image produced by a light microscope can only distinguish features that are about the size of a mitochondrion, but the electron microscope has a much greater *resolution*. Resolution is the ability to distinguish two points in an image as being separate. The maximum resolution of a light microscope is about 200 nanometres (nm) but with an electron microscope we can distinguish structures less than 1 nm in size. This is why ribosomes are only visible using an electron microscope – they are about 25 nm in diameter.

Electron microscopy (using an electron microscope) reveals that much of the cytoplasm is made up of membranes. As well as the cell surface membrane and the endoplasmic reticulum, there are membranes around organelles such as the nucleus and mitochondria, and sometimes there are membranes inside organelles as well.

All these membranes are needed because there are thousands of different chemical reactions happening in cells. A key function of membranes is to separate the different reactions into different compartments, so that they are not all happening in one big 'test tube'. For example, the reactions and enzymes of aerobic respiration (respiration that needs oxygen) are kept inside the mitochondria, separate from the rest of the cytoplasm (Figure 1.26).



◀ Figure 1.26 An electron micrograph of a mitochondrion (magnification $\times 60\,000$). The mitochondrion has two membranes – an outer membrane separating its contents from the rest of the cytoplasm and an inner membrane forming folds called cristae. The reactions of aerobic respiration take place in the mitochondria of a cell. Different stages of the process happen in different parts of the mitochondrion.

CHAPTER QUESTIONS

SKILLS INTERPRETATION

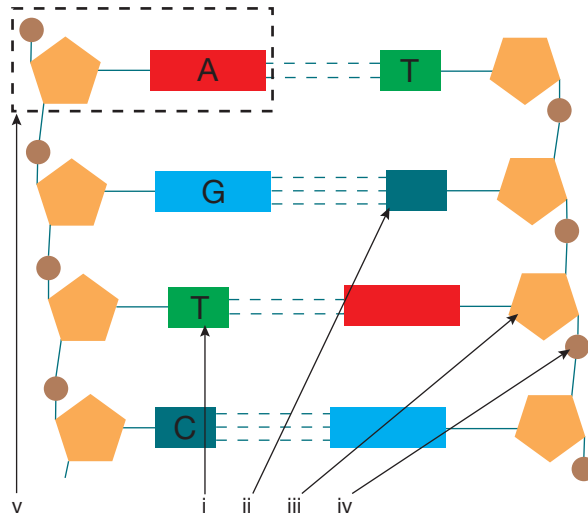


1 Draw a diagram of a generalised animal cell as seen through a light microscope. Label all of the parts. Alongside each label, write the function of that part.

SKILLS REASONING



2 The diagram represents part of a molecule of DNA.



- Name the parts labelled i, ii, iii, iv and v.
- Use the diagram to explain the base-pairing rule.

SKILLS INTERPRETATION



3 DNA is the only molecule capable of replicating itself. Sometimes, mutations occur during replication.

SKILLS REASONING



a Draw a flow diagram to describe the process of DNA replication.



b Explain how a single gene mutation can lead to the formation of a protein in which:

- many of the amino acids are different from those coded for by the non-mutated gene
- only one amino acid is different from those coded for by the non-mutated gene.

SKILLS CRITICAL THINKING



4 Below is a base sequence from part of the coding strand of a DNA molecule.

TAC CTC GGT CAT CCC



a How many amino acids are coded for by this base sequence?

b The sequence of the coding strand was transcribed to form mRNA. Write down the base sequence of this mRNA.

c Write down the corresponding base sequence of the non-coding strand of the DNA.

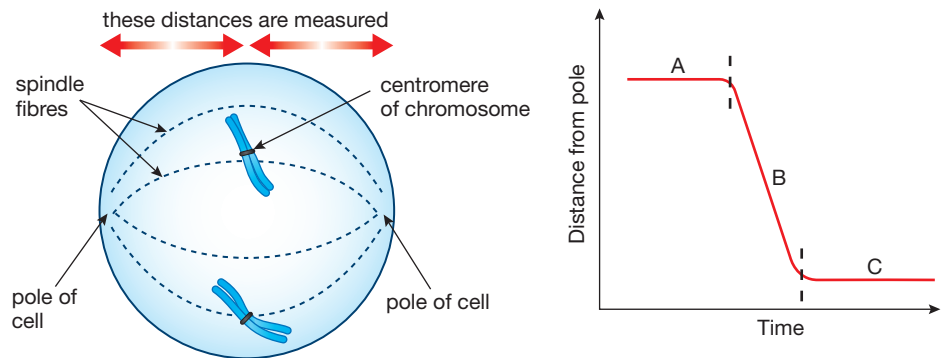
d Copy and complete this description of the next stage in protein synthesis:

The mRNA base sequence is converted into the amino acid sequence of a protein during a process called _____ . The mRNA sequence consists of a triplet code. Each triplet of bases is called a _____ . Reading of the mRNA base sequence begins at a _____ and ends at a _____ . Molecules of tRNA carrying an amino acid bind to the mRNA at an organelle called the _____ .

SKILLS ANALYSIS



5 In an investigation into mitosis, the distance between a chromosome and the pole (end) of a cell was measured. The graph shows the result of the investigation.



- a Describe two events that occur during stage A.
- b Explain what is happening during stage B.
- c Describe two events that occur during stage C.

SKILLS REASONING



6 a What is a stem cell?



b State one difference between an embryonic stem cell and an adult stem cell.

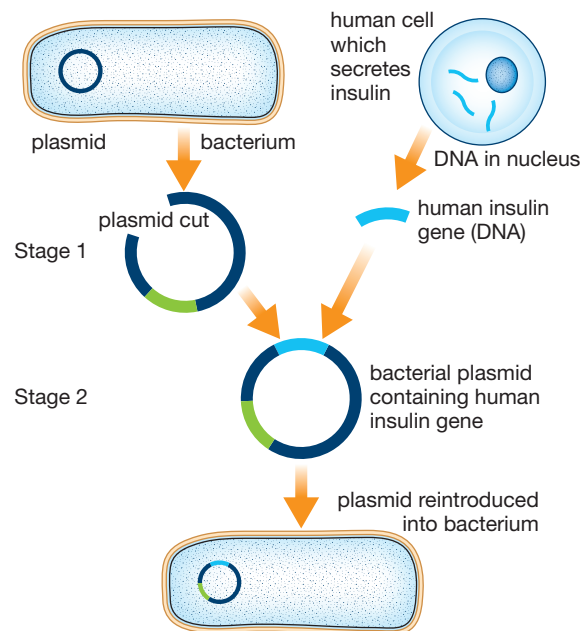


c Suggest how stem cell therapy can be used in the treatment of leukaemia (blood cancer).

SKILLS ANALYSIS



7 The diagram shows the main stages in transferring the human insulin gene to a bacterium.



- a Name the enzymes used at stages 1 and 2.
- b What is the role of the plasmid in this procedure?
- c How would the insulin-producing bacteria be used to produce significant amounts of insulin?
- d Suggest why insulin produced in this way is preferred to insulin extracted from the pancreases of cows.

SKILLS CRITICAL THINKING



SKILLS REASONING



2 MOVEMENT OF SUBSTANCES INTO AND OUT OF CELLS

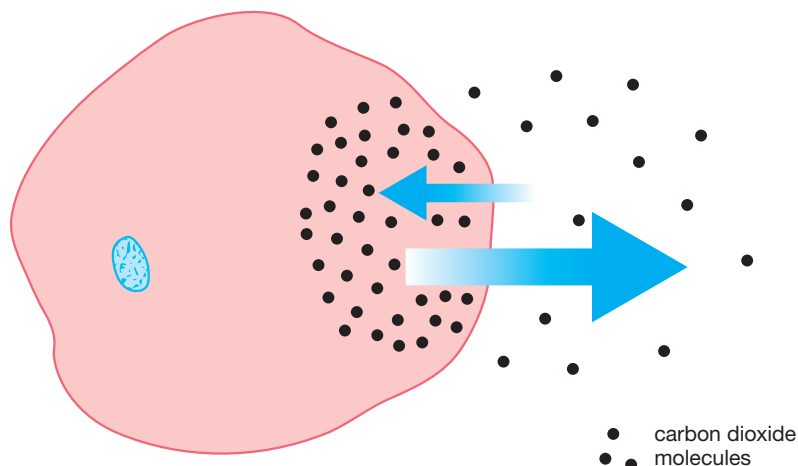
Cells need to take in certain substances (such as oxygen) from their surroundings, and get rid of other substances, such as carbon dioxide. The cell surface membrane is selective about which chemicals can pass through it. Molecules and ions can move through the membrane in three main ways: diffusion, active transport and osmosis.

LEARNING OBJECTIVES

- Know simple definitions of diffusion, osmosis and active transport
- Understand that movement of substances into and out of cells can be by diffusion, osmosis (understanding of water potential is required) and active transport
- Understand the factors that affect the rate of movement of substances into and out of cells, including surface area to volume ratio, temperature and concentration gradient

DIFFUSION

Many substances can pass through the membrane by **diffusion**. Diffusion happens when a substance is more concentrated in one place than another. For example, if a cell is producing carbon dioxide by respiration (see Chapter 5), the concentration of carbon dioxide will be higher inside the cell than outside. This difference in concentration is called a *concentration gradient*. The molecules of carbon dioxide are constantly moving about (they have kinetic energy). The cell membrane is permeable to carbon dioxide, so the molecules can move through it in either direction. Over time, more molecules will move out of the cell than into it, because there is a higher concentration of carbon dioxide molecules inside the cell than outside it. We say there is a *net* movement of molecules out of the cell (Figure 2.1).



▲ Figure 2.1 Respiration produces carbon dioxide, so the concentration of carbon dioxide inside the cell increases. Although the carbon dioxide molecules diffuse in both directions across the cell membrane, the overall (net) movement is out of the cell, down the concentration gradient.

The opposite happens with oxygen. Respiration uses up oxygen, so there is a concentration gradient of oxygen from outside the cell to inside. There is therefore a net movement of oxygen into the cell by diffusion.

KEY TERM

Diffusion is the net movement of particles (molecules or ions) from a region of high concentration to a region of low concentration, i.e. down a concentration gradient.

Various factors affect the rate of diffusion.

- **The concentration gradient:** Diffusion happens more quickly when there is a steep concentration gradient (i.e. a big difference in concentration between two areas).
- **The surface area to volume ratio:** A larger surface area in proportion to the volume will increase the rate of diffusion.
- **The distance:** The greater the distance over which diffusion has to take place, the slower the rate of diffusion.
- **The temperature:** The rate of diffusion is greater at higher temperatures. This is because a high temperature provides the particles with more kinetic energy.



Safety Note: Wear eye protection and avoid skin contact with the permanganate and acid. When cutting the blocks of agar jelly, wear disposable gloves and use a sharp scalpel on a cutting board.

ACTIVITY 1

▼ PRACTICAL: DEMONSTRATING DIFFUSION IN A JELLY

Agar is a jelly that is used for growing cultures of bacteria. It has a consistency similar to the cytoplasm of a cell. Like cytoplasm, it has a high water content. Agar can be used to show how substances diffuse through a cell.

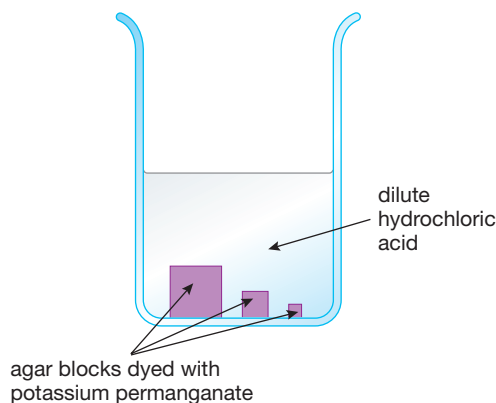
This demonstration uses the reaction between hydrochloric acid and potassium permanganate solution. When hydrochloric acid comes into contact with potassium permanganate, the purple colour of the permanganate disappears.

A Petri dish is prepared which contains a 2 cm deep layer of agar jelly, dyed purple with potassium permanganate. Three cubes of different sizes are cut out of the jelly, with side lengths 2 cm, 1 cm and 0.5 cm. The cubes have different volumes and total surface areas. They also have different surface area to volume ratios, as shown in the table below.

| Length of side of cube / cm | Volume of cube / cm ³ (length × width × height) | Surface area of cube / cm ² (length × width of one side) × 6 | Ratio of surface area to volume of cube (surface area / volume) |
|-----------------------------|---|--|--|
| 2 | (2 × 2 × 2) = 8 | (2 × 2) × 6 = 24 | 24/8 = 3 |
| 1 | (1 × 1 × 1) = 1 | (1 × 1) × 6 = 6 | 6/1 = 6 |
| 0.5 | (0.5 × 0.5 × 0.5) = 0.125 | (0.5 × 0.5) × 6 = 1.5 | 1.5/0.125 = 12 |

Notice that the smallest cube has the largest surface area to volume ratio. The same is true of cells – a small cell has a larger surface area to volume ratio than a large cell.

The cubes are dropped, carefully and at the same time, into a beaker of dilute hydrochloric acid (Figure 2.2).



▲ Figure 2.2 Investigating diffusion in a jelly.

The time taken for each cube to turn colourless is noted.

Which cube would be the first to turn colourless and which the last? Explain the reasoning behind your prediction.

If the three cubes represented cells of different sizes, which cell would have the most difficulty in obtaining substances by diffusion?

It may be possible for you to try this experiment, using similar apparatus.

ACTIVE TRANSPORT

Diffusion happens because of the kinetic energy of the particles. It does not need any extra energy from respiration. Sometimes, however, a cell needs to take in a substance *against* the concentration gradient – when there is less of the substance outside the cell than inside it. It can do this by another process, called **active transport**.

During active transport, a cell uses energy from respiration to take up substances, rather like a pump uses energy to move a liquid from one place to another. In fact, biologists speak of the cell ‘pumping’ ions and molecules in or out. The pumps are large protein molecules located in the cell membrane. An example of a place where this happens is in the human small intestine, where epithelial cells lining the intestine absorb glucose by active transport.

Cells use active transport to control the uptake of many substances. A definition of active transport is given in the key term box.

KEY TERM

Active transport is the movement of particles against a concentration gradient, using energy from respiration.

OSMOSIS

Water moves across cell membranes by a special sort of diffusion, called **osmosis**. Osmosis happens when the total concentrations of all dissolved substances inside and outside the cell are different. Water will move across the membrane from the more dilute solution to the more concentrated one. Notice that this is still obeying the rules of diffusion – the water moves from where there is a higher concentration of water molecules to a lower concentration of

KEY POINT

The cell membrane is both selectively permeable and partially permeable. 'Selectively permeable' means that the membrane has control over which molecules it lets through (by active transport). 'Partially permeable' means that small molecules such as water and gases can pass through it, while larger molecules cannot.

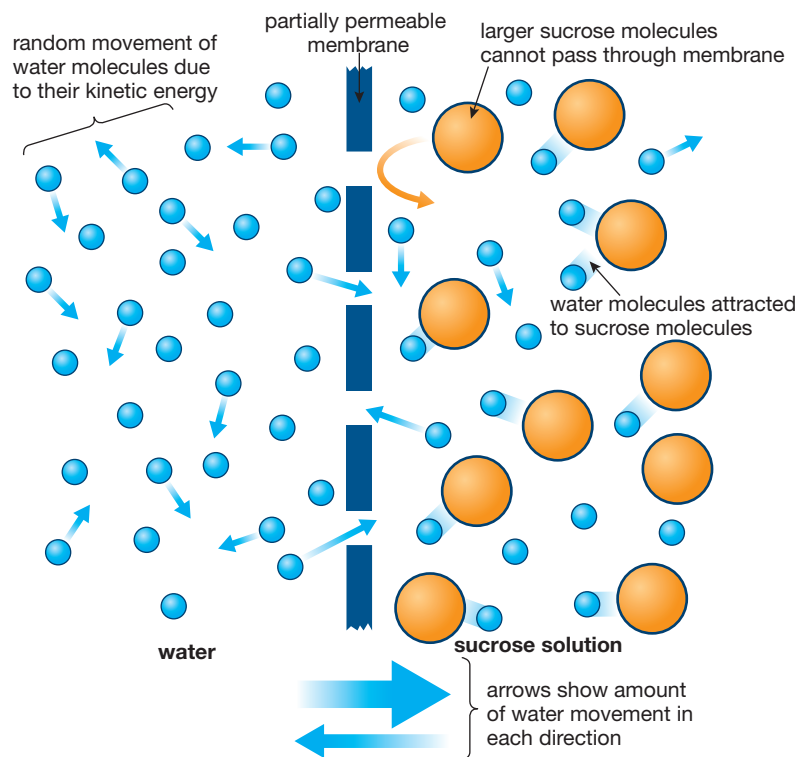


▲ Figure 2.3 Water enters the Visking tubing 'sausage' by osmosis. This causes the level of liquid in the capillary tube to rise. In the photograph, the contents of the Visking tubing have had a red dye added to them to make it easier to see the movement of the liquid.

water molecules. Osmosis can only happen if the membrane is permeable to water but not to some other solutes. We say that it is partially permeable.

One artificial partially permeable membrane is called **Visking tubing**. This is used in kidney dialysis machines (Chapter 10). Visking tubing has microscopic holes in it, which let small molecules such as water pass through (it is permeable to them). However, it is not permeable to some larger molecules, such as the sugar, sucrose. This is why it is called 'partially' permeable. You can show the effects of osmosis by filling a Visking tubing 'sausage' with concentrated sucrose solution, attaching it to a capillary tube and placing the Visking tubing in a beaker of water (Figure 2.3).

The level in the capillary tube rises as water moves from the beaker into the Visking tubing. This movement is due to osmosis. You can understand what is happening if you imagine a highly magnified view of the Visking tubing separating the two liquids (Figure 2.4).



▲ Figure 2.4 In this model of osmosis, more water molecules diffuse from left to right than from right to left.

The sucrose molecules are too big to pass through the holes in the partially permeable membrane. The water molecules can pass through the membrane in either direction, but those on the right are attracted to the sugar molecules. This slows them down and means that they are less free to move – they have less kinetic energy. As a result of this, more water molecules diffuse from left to right than from right to left. In other words, there is a greater diffusion of water molecules from the more dilute solution (in this case pure water) to the more concentrated solution. This leads us to a simple definition of osmosis, as shown in the key term box.

KEY TERM

Osmosis is the net diffusion of water across a partially permeable membrane, from a dilute solution to a more concentrated solution.

KEY POINT

It is important to realise that neither of the two solutions has to be pure water. As long as there is a difference in their concentrations (and their water potentials), and they are separated by a partially permeable membrane, osmosis can still take place.

There is an alternative way of describing osmosis, which uses the idea of **water potential**. The water potential of a solution is a measure of how 'free' the water molecules are to move. The molecules in pure water can move most freely, so pure water has the highest water potential. The more concentrated a solution is, the lower its water potential. In the model in Figure 2.4, water moves from a higher to a lower water potential. This is a law that applies whenever water moves by osmosis. We can bring these ideas together in a 'water potential' definition of osmosis, as shown in the key term box.

KEY TERM

Osmosis is the net diffusion of water across a partially permeable membrane, from a solution with a higher water potential to one with a lower water potential.

In the demonstration of osmosis using Visking tubing (Figure 2.3), the water in the beaker has a higher water potential than the sucrose solution inside the Visking tubing. Osmosis takes place, and water enters the tubing, moving from a high to a lower water potential. The movement of water produces pressure, which pushes the coloured solution up the capillary tube. The movement does not go on forever – eventually the column of water will rise up in the tube to a point where its downward pressure equals the upward pressure due to osmosis. At this point, there will be no further net movement of water and the column will stop rising.

All cells are surrounded by a partially permeable cell membrane. In the human body, osmosis is important in moving water from cell to cell, and from the blood to the tissues (Chapter 6). It is important that the cells of the body are bathed in a solution with the right concentration of solutes; otherwise they could be damaged by osmotic movements of water. For example, if red blood cells are put into water, they will swell up and burst. If the same cells are put into a concentrated salt solution, they lose water by osmosis and shrink, producing cells with crinkly edges (Figure 2.5).



Safety Note: Wear eye protection and avoid skin contact with the blood and solutions.

ACTIVITY 2

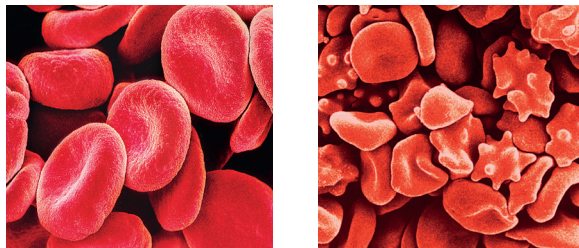
▼ PRACTICAL: DEMONSTRATING THE EFFECTS OF OSMOSIS ON RED BLOOD CELLS

Blood plasma has a concentration equivalent to a 0.85% salt solution. If fresh blood is placed into salt solutions with different concentrations, the blood cells will gain or lose water by osmosis. This can be demonstrated using sterile animal blood (available from suppliers of biological materials).

Three test tubes are set up, containing the following solutions:

- A: 10 cm³ of distilled water
- B: 10 cm³ of 0.85% salt solution
- C: 10 cm³ of 3% salt solution

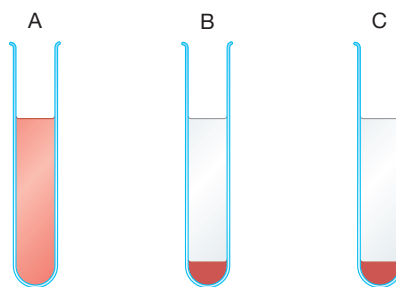
1 cm³ of blood is added to each tube and the tubes are shaken. A sample from each tube is examined under the microscope. The sample from tube A is found to contain no intact cells. Figure 2.5 shows cells from tubes B and C. The cells from tube B look normal, but those from tube C are shrunken, with crinkly edges.



▲ Figure 2.5 Compare the blood cells on the right, which were placed in a 3% salt solution, with the normal blood cells on the left, from a 0.85% salt solution.

Using your knowledge of osmosis, can you explain what has happened to the red blood cells in each tube?

The three tubes are now placed in a centrifuge and spun around at high speed to separate any solid particles from solution. The results are shown in Figure 2.6.



▲ Figure 2.6 The three tubes after centrifugation.

Tube A contains a clear red solution and no solid material at the bottom of the tube. Tubes B and C both contain a colourless liquid and a red precipitate at the bottom.

Can you explain these results?

Activity 2 shows how important it is that animal cells are surrounded by a solution containing the correct concentration of dissolved solutes. If the surrounding solution does not have the right concentration, cells can be damaged by the effects of osmosis. The red blood cells placed in pure water absorb the water by osmosis, swell up and burst, leaving a red solution of haemoglobin in the test tube. When placed in 3% salt solution, the red blood cells lose water by osmosis and shrink.

We will return to the idea that cells need a correct constant 'environment' in Chapter 10.

EXCHANGE SURFACES IN THE BODY

All cells exchange substances with their surroundings, but some parts of the body are specially adapted for the exchange of materials because they have a very large surface area in proportion to their volume. Two examples are the air sacs of the lungs (Chapter 5) and the lining of the small intestine (Chapter 4). Diffusion is a slow process, and organs that rely on diffusion need a large surface over which it can take place. The air sacs of the lungs have a very large surface area that allows oxygen and carbon dioxide to move between the air and the blood, during breathing. The lining of the small intestine is covered with tiny projections called villi, which provide a large surface area for the absorption of digested food. This takes place partly by diffusion and partly by active transport.

CHAPTER QUESTIONS

SKILLS REASONING



SKILLS CRITICAL THINKING



SKILLS PROBLEM SOLVING

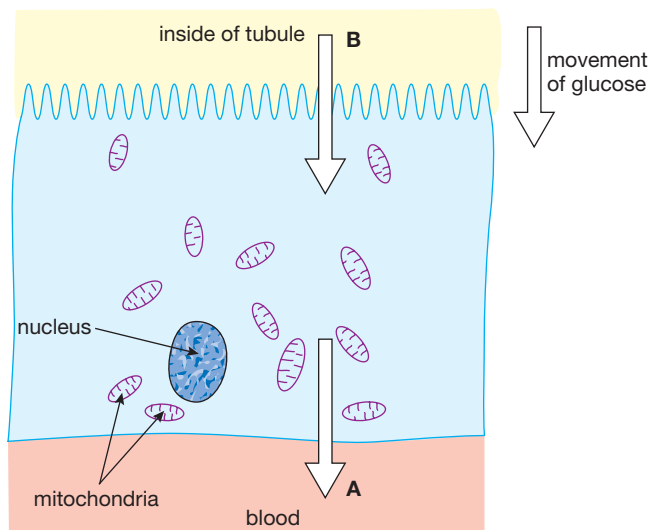


SKILLS REASONING

SKILLS CRITICAL THINKING



- 1 a Explain the differences between diffusion and active transport.
- b State three factors that affect the rate of diffusion.
- c Calculate the ratio of surface area to volume ($\frac{\text{surface area}}{\text{volume}}$) of a cube with a side length of:
- 2 cm
 - 3 cm.
- d From your answer to c, describe what happens to the surface area to volume ratio when the size of the cube is increased. What is the significance of this observation for the diffusion of substances into and out of cells?
- 2 The diagram shows a cell from the lining of a human kidney tubule. One role of this cell is to absorb glucose from the fluid passing along the tubule and pass it into the blood, as shown by the arrows on the diagram.



- a What is the function of the mitochondria?
- b The tubule cell contains a large number of mitochondria. They are needed for the cell to transport glucose across the cell membrane into the blood at 'A'. Suggest the method that the cell uses to do this and explain your answer.
- c The mitochondria are not needed to transport glucose into the cell from the tubule at 'B'. Name the process by which the glucose molecules move across the membrane at 'B' and explain your answer.
- d The surface membrane of the tubule cell at 'B' is greatly folded. Explain how this adaptation helps the cell to carry out its function.
- 3 An experiment was carried out to find the effects of osmosis on blood cells. Three test tubes were filled with different solutions. 10 cm³ of water was placed in tube A, 10 cm³ of 0.85% salt solution in tube B, and 10 cm³ of 3% salt solution in tube C. 1 cm³ of fresh blood was added to each tube. The tubes were shaken and a sample from each tube was observed under the microscope at a high magnification.



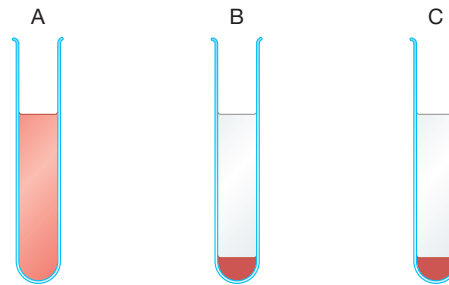
SKILLS REASONING



SKILLS CRITICAL THINKING



The tubes were then placed in a centrifuge and spun around at high speed to separate any solid particles from solution. The results are shown in the diagram below.



SKILLS REASONING



SKILLS ANALYSIS

SKILLS REASONING

- Which solution had a salt concentration that was similar to that of blood?
- Describe what you would expect to see when viewing the samples from tubes A, B and C through the microscope.
- Explain the results shown in the diagram.
- When a patient has suffered severe burns, damage to the skin results in a loss of water from the body. This condition can be treated by giving the patient a saline drip. This is a 0.85% salt solution, which is fed into the patient's blood through a needle inserted into a vein. Explain why 0.85% salt solution is used, and not water.

3 BIOLOGICAL MOLECULES

Many of the molecules found in the body are made from simple 'building blocks'. For example, DNA is built up from smaller molecules called nucleotides. In the same way, carbohydrates, lipids and proteins are made of simpler molecular sub-units. In this chapter, you will read about the structure of these biological molecules, and the functions of an important group of proteins called enzymes.

LEARNING OBJECTIVES

- Know the chemical elements present in carbohydrates, proteins and lipids (fats and oils)
- Understand the structure of carbohydrates, proteins and lipids as large molecules made up of smaller basic units:
 - carbohydrates (starch and glycogen) from simple sugars
 - lipids from fatty acids and glycerol
 - protein from amino acids
- Describe chemical tests for starch, glucose (reducing sugar), lipid and protein
- Explain the role of enzymes as biological catalysts in metabolic reactions
- Explain the action of enzymes
- Explain how enzyme activity is affected by:
 - temperature
 - pH
 - substrate concentration
 - competitive and non-competitive inhibitors
- Describe how to investigate the effect of temperature on enzyme activity
- Describe how to investigate the effect of pH on enzyme activity
- Describe the advantages of using immobilised enzymes in:
 - the production of lactose-free milk
 - the conversion of sucrose into glucose and fructose
 - glucose testing strips for diabetics
- Describe how to investigate the action of immobilised enzymes, including the preparation of alginate beads

CARBOHYDRATES, LIPIDS AND PROTEINS

There are three main types of biological molecule in the human body – **carbohydrates**, **lipids** and **proteins**. All three are composed of just a few chemical elements. Carbohydrates and lipids are entirely made of the elements carbon (C), hydrogen (H) and oxygen (O). Proteins also contain these elements, along with nitrogen (N) and small amounts of sulfur (S). However, the structures of these three types of molecule are very different.

THE STRUCTURE OF CARBOHYDRATES

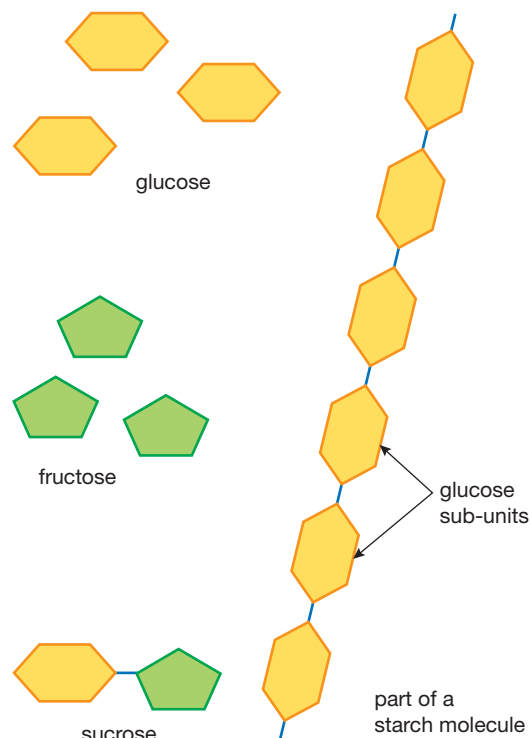
The basic units that make up carbohydrates are simple sugars such as **glucose**. Glucose is an example of a **monosaccharide**, which is a 'single' sugar unit. This means that it cannot be broken down into a simpler sugar. Another monosaccharide is **fructose**, a sugar found in fruits. The chemical formula for glucose is $C_6H_{12}O_6$ – you can see from this formula that glucose contains only carbon, hydrogen and oxygen.

DID YOU KNOW?

In the word 'carbohydrates', the 'carbo' part refers to carbon and the 'hydrate' part refers to the fact that the hydrogen and oxygen atoms in a carbohydrate are often in the ratio 2 : 1, the same as in water (H₂O).

When two monosaccharides are joined together, they form a 'double sugar' or **disaccharide**. For example, ordinary table sugar (**sucrose**) is a disaccharide of glucose and fructose. The sugar found in milk (**lactose**) is a disaccharide made of glucose and galactose.

Monosaccharides can also join together in long chains to produce a **polysaccharide**. One important polysaccharide is **starch**. The 'staple diets' of people from around the world are foods containing starch, such as rice, potatoes, bread and pasta. Starch is made up of long chains of hundreds of glucose molecules joined together. In chemistry terms, it is a *polymer* of glucose (Figure 3.1).



▲ Figure 3.1 Glucose and fructose are 'single sugar' molecules or monosaccharides. A molecule of glucose joined to a molecule of fructose forms the 'double sugar' or disaccharide called sucrose. Starch is a polysaccharide of many glucose sugars.

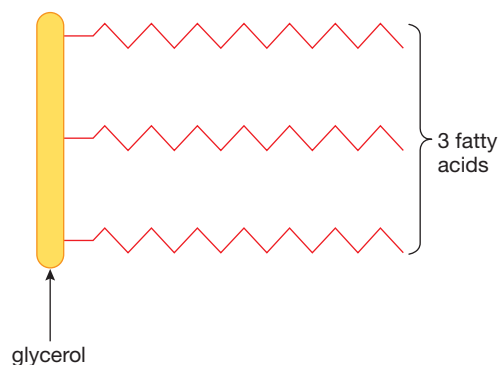
Starch is only found in plant tissues, but some animal cells contain a very similar carbohydrate called **glycogen**. This is also a polysaccharide of glucose, and is found in tissues such as liver and muscle, where it acts as an energy store.

THE STRUCTURE OF LIPIDS

Lipids are fats and oils. The difference between the two is that a fat is solid at room temperature, whereas an oil is liquid. Fats are more common in animal tissues, while oils are mainly found in plants.

Lipids contain the same three elements as carbohydrates – carbon, hydrogen and oxygen – but the proportion of oxygen in a lipid is much lower than in a carbohydrate. For example, meat contains a fat called tristearin, which has the formula C₅₁H₉₈O₆.

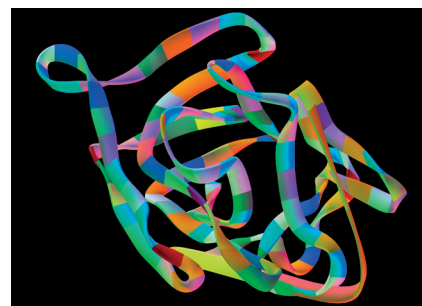
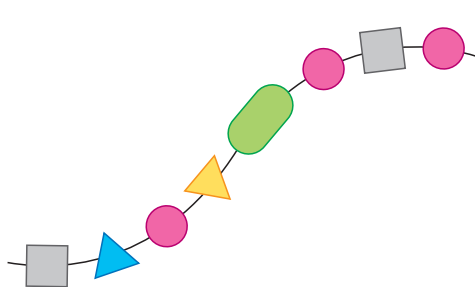
The chemical 'building blocks' of lipids are two types of molecule called **glycerol** and **fatty acids**. Glycerol is an oily liquid, also known as glycerine. It is used in making some cosmetics. In lipids, a molecule of glycerol is joined to three fatty acid molecules. There are many different fatty acid molecules, which result in the wide variety of lipids found in food (Figure 3.2).



▲ Figure 3.2 Lipids are made up of a molecule of glycerol joined to three fatty acids. The many different fatty acids form the variable part of the molecule.

THE STRUCTURE OF PROTEINS

Whereas starch is a polymer made from a single 'building block' (glucose), proteins are made from 20 different sub-units called **amino acids**. All amino acids contain four chemical elements: carbon, hydrogen, oxygen and nitrogen. Two amino acids also contain sulfur. The amino acids are linked together in long chains, which are usually folded up or twisted into spirals. Cross-links hold the chains together (Figure 3.3).



▲ Figure 3.3 (a) A chain of amino acids forming part of a protein molecule. Each shape represents a different amino acid. (b) A computer model of a protein in the blood that is involved in forming a blood clot. The coloured bands represent different amino acids in a chain.

The shape of a protein is very important in allowing it to perform its function. The shape depends on the order of amino acids in the protein. Because there are 20 different amino acids, and they can be arranged in any order, the number of different protein structures that can be made is enormous. There are thousands of different kinds of protein in organisms, from structural proteins such as collagen and keratin in skin and nails, to proteins with more specific functions, such as enzymes and haemoglobin.

TESTS FOR BIOLOGICAL SUBSTANCES

You can carry out simple chemical tests for starch, glucose, protein or lipid. Activity 3 uses pure substances for the tests, but it is possible to do them on normal foods too. Unless the food is a liquid like milk, it needs to be cut up into small pieces and ground with a pestle and mortar, then shaken with some water in a test tube. This is done to extract the components of the food and dissolve any soluble substances, such as sugars.



Safety Note: Wear eye protection and avoid skin contact with all the reactants. Always use a water bath for the glucose test – never use a Bunsen burner to heat the test tube directly.



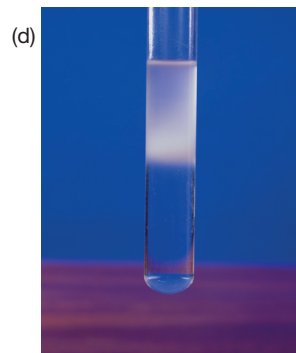
(a)



(b)



(c)



(d)

▲ Figure 3.4 (a) Testing for starch using iodine; (b) testing for glucose using Benedict's solution; (c) testing for protein using biuret; and (d) testing for lipid.

ACTIVITY 3

▼ PRACTICAL: TESTING FOR SOME BIOLOGICAL SUBSTANCES

Test for starch

A little starch is placed on a spotting tile. A drop of yellow-brown iodine solution is added to the starch. The iodine reacts with the starch, forming a very dark blue, or 'blue-black', colour (Figure 3.4(a)). Starch is insoluble but this test will work on a solid sample of food, such as potato, or a suspension of starch in water

Test for glucose

Glucose is called a **reducing sugar**. This is because the test for glucose involves reducing an alkaline solution of copper (II) sulfate to copper (I) oxide.

A small spatula measure of glucose is placed in a test tube and a little distilled water is added (about 2 cm deep). The tube is shaken to dissolve the glucose. Several drops of *Benedict's solution* are added to the tube, enough to colour the mixture blue.

A water bath is prepared by half-filling a beaker with water and heating it on a tripod and gauze. The test tube is placed in the beaker and the water is allowed to boil (using a water bath is safer than heating the tube directly with the Bunsen burner). After a few seconds, the clear blue solution will gradually change colour, forming a cloudy orange or 'brick red' precipitate of copper (I) oxide (Figure 3.4(b)).

All other single sugars (monosaccharides), such as fructose, are reducing sugars, and so are some double sugars (disaccharides), such as the milk sugar, lactose. However, ordinary table sugar (sucrose) is not. If sucrose is boiled with Benedict's solution it will stay a clear blue colour.

Test for protein

The test for protein is sometimes called the 'biuret' test, after the coloured compound that is formed.

A little protein, such as powdered egg white (albumen), is placed in a test tube and about 2 cm depth of water is added. The tube is shaken to mix the powder with the water. An equal volume of dilute (5%) potassium hydroxide solution is added and the tube is shaken again. Finally, two drops of 1% copper sulfate solution are added. A pale purple colour will develop (Figure 3.4(c)). (Sometimes these two solutions are supplied already mixed together as 'biuret solution'.)

Test for lipid

Fats and oils are insoluble in water but will dissolve in ethanol (alcohol). The test for lipid uses this fact.

A pipette is used to place one drop of olive oil in the bottom of a test tube. About 2 cm depth of ethanol is added and the tube is shaken to dissolve the oil. The solution is poured into a test tube that is about three-quarters full with cold water. A white cloudy layer will form on the top of the water (Figure 3.4(d)). The white layer forms as the ethanol dissolves in the water and leaves the lipid behind as a suspension of tiny droplets, called an emulsion.

KEY POINT

The chemical reactions taking place in a cell are known as metabolic reactions. The sum of all the metabolic reactions is known as the **metabolism** of the cell. The function of enzymes is to catalyse metabolic reactions.

ENZYMES: CONTROLLING REACTIONS IN THE CELL

The chemical reactions that take place in a cell are controlled by a group of proteins called enzymes. Enzymes are biological **catalysts**. A catalyst is a chemical that speeds up a reaction without being used up itself. It takes part in the reaction but afterwards it is unchanged and free to catalyse more reactions. Cells contain hundreds of different enzymes, each catalysing a different reaction. This is how the activities of a cell are controlled – the nucleus contains the genes, the genes control the production of enzymes, and the enzymes catalyse reactions in the cytoplasm:

genes → proteins (enzymes) → catalyse reactions

Everything a cell does depends on which enzymes it can make. This in turn depends on which of the genes in its nucleus are working.

Enzymes are needed because the temperatures inside organisms are low (e.g. the human body temperature is about 37 °C). Without catalysts, most of the reactions that happen in cells would be far too slow to allow life to go on. The reactions can only take place quickly enough when enzymes are present to speed them up.

There are thousands of different sorts of enzyme because enzymes are proteins, and protein molecules have an enormous range of structures and shapes.

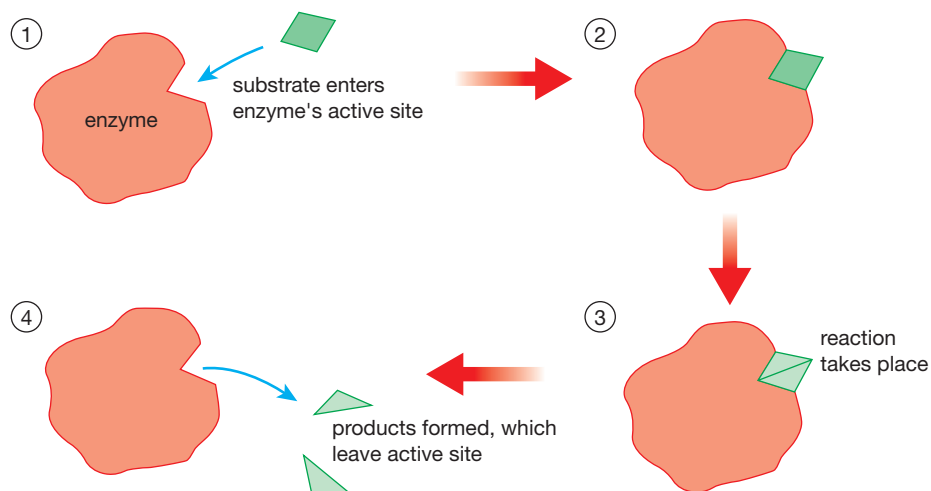
The molecule that an enzyme acts on is called its **substrate**. Each enzyme has a small area on its surface called the **active site**. The substrate attaches to the active site of the enzyme. The reaction then takes place and products are formed. When the substrate joins up with the active site, less energy is needed for the reaction to start and the products can be formed more easily.

Enzymes also catalyse reactions where large molecules are built up from smaller ones. In this case, several substrate molecules attach to the active site, the reaction takes place and the larger product molecule is formed. The product then leaves the active site.

The substrate fits into the active site of the enzyme rather like a key fitting into a lock. Just as a key will only fit one lock, a substrate will only fit into the active site of a particular enzyme. This is known as the **lock and key model** of enzyme action (Figure 3.5). It is the reason why enzymes are *specific*, i.e. an enzyme will only catalyse one reaction.

DID YOU KNOW?

You have probably heard of enzymes being involved in the digestion of food. In the intestine, enzymes are secreted onto the food to break it down. These are called *extracellular* enzymes, which means they function outside cells. However, most enzymes are *intracellular* – they stay inside cells and carry out their function there. You will find out about digestive enzymes in Chapter 4.



▲ Figure 3.5 Enzymes catalyse reactions at their active site. The active site acts like a 'lock' to the substrate 'key'. The substrate fits into the active site and products are formed. This happens more easily than without the enzyme – enzymes act as catalysts.

After an enzyme molecule has catalysed a reaction, the product is released from the active site and the enzyme is free to act on more substrate molecules.

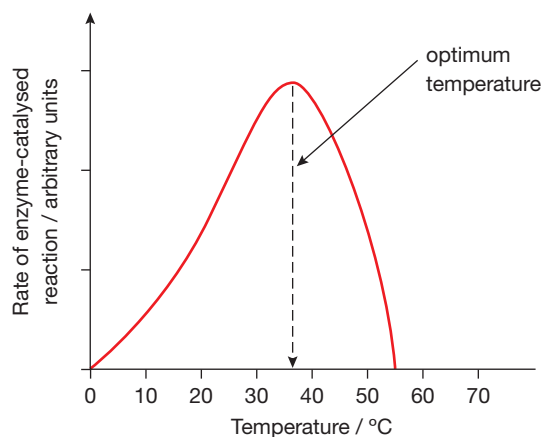
FACTORS AFFECTING ENZYMES

A number of factors affect the activity of enzymes, including:

- temperature
- pH
- substrate concentration
- the presence of **inhibitors**.

TEMPERATURE

The effect of temperature on the action of an enzyme is easiest to see as a graph, where we plot the rate of reaction against temperature (Figure 3.6).



▲ Figure 3.6 Effect of temperature on the action of an enzyme.

KEY TERM

The 'optimum' temperature is the 'best' temperature, in other words the temperature at which the reaction takes place most rapidly.

KEY TERM

Kinetic energy is the energy an object has because of its movement. The molecules of enzyme and substrate are moving faster, so they have more kinetic energy.

DID YOU KNOW?

Not all enzymes have an optimum temperature near 37 °C, only those of animals such as mammals and birds, which have body temperatures close to this value. Enzymes have evolved to work best at the normal body temperature of the organism. Bacteria that always live at an average temperature of 10 °C will probably have enzymes with an optimum temperature near 10 °C.

Enzymes in the human body have evolved (changed over time) to work best at body temperature (37 °C). The graph in Figure 3.6 shows a peak on the curve at this temperature, which is called the *optimum temperature* for the enzyme.

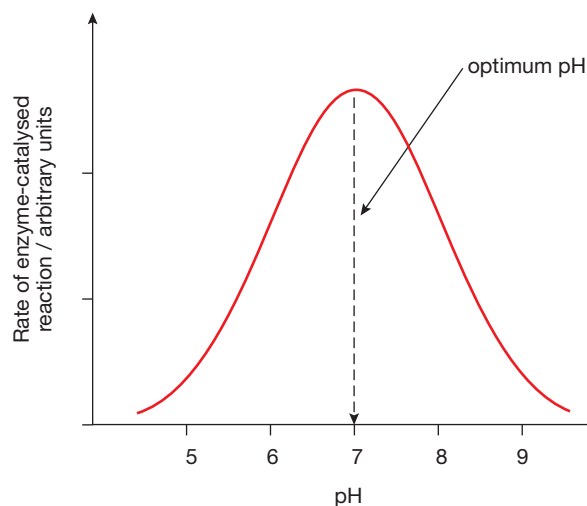
As the enzyme is heated up to the optimum temperature, the rate of reaction increases. This is because higher temperatures give the molecules of the enzyme and the substrate more kinetic energy, so they collide more often. More collisions mean that the reaction will take place more frequently.

However, if the enzyme is heated too much, the rate of reaction decreases again. This is because enzymes are made of protein, and proteins are broken down by heat. At temperatures above 40 °C, the heat destroys the enzyme – we say that the enzyme is **denatured**. You can see the effect of denaturing when you boil an egg. The egg white is made of protein and turns from a clear runny liquid into a white solid as the heat denatures the protein. Denaturing changes the shape of the active site, so the substrate will no longer fit into it. Denaturing is permanent – the enzyme molecules will no longer catalyse the reaction.

pH

The pH around the enzyme is also important. The pH inside cells is usually around 7 (neutral) and most enzymes have evolved to work best at this pH. At extremes of pH, the enzyme activity decreases, as shown in Figure 3.7. The pH at which the enzyme works best is called its *optimum pH*. Either side of the

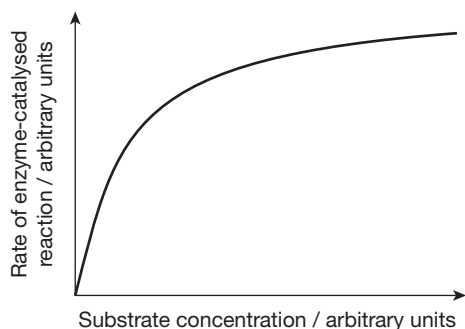
optimum, the pH affects the structure of the enzyme molecule and changes the shape of its active site, so the substrate will not fit into it so well.



▲ Figure 3.7 Most enzymes work best at a neutral pH.

KEY POINT

Although most enzymes work best at a neutral pH, a few have an optimum below or above pH 7. The stomach produces hydrochloric acid, which makes its contents very acidic (see Chapter 4). Most enzymes stop working at a low pH, but the stomach makes an enzyme called pepsin which has an optimum pH of about 2. Pepsin is adapted to work well in these unusually acidic surroundings.



▲ Figure 3.8 The effect of substrate concentration on the action of an enzyme.

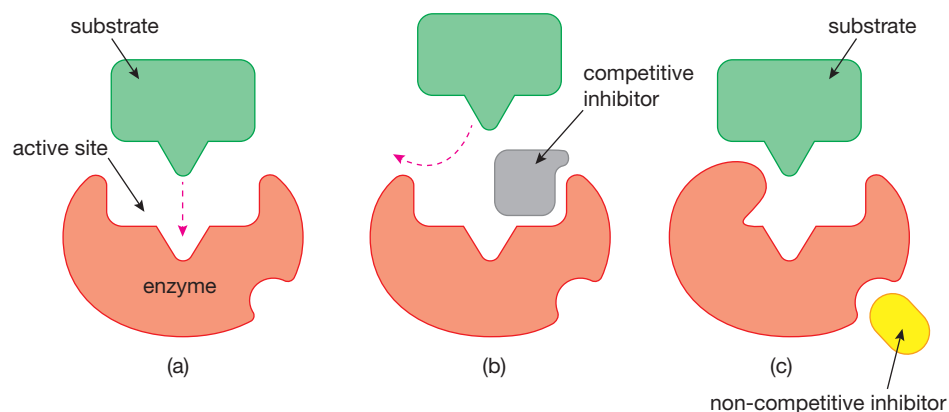
SUBSTRATE CONCENTRATION

When there is a low concentration of substrate, the active sites of some enzyme molecules will be empty, so the rate of reaction will be low. If the concentration of substrate is increased, there will be more collisions between enzyme and substrate molecules and more active sites will be filled. As a result, the rate of reaction will increase. This can be shown by a graph (Figure 3.8).

Notice that the curve becomes flatter or ‘levels off’ at high concentrations of substrate. This is because all the active sites become filled with substrate (we say they are *saturated*), so the rate of reaction reaches a maximum. It is as if each substrate molecule has to ‘wait’ for an empty active site to become available. The enzyme concentration is limiting the rate at which the reaction can take place – enzyme concentration is now the limiting factor.

THE PRESENCE OF INHIBITORS

Inhibitors are substances that reduce the rate of an enzyme-catalysed reaction. Two types are called competitive and non-competitive inhibitors (Figure 3.9).



▲ Figure 3.9 The actions of enzyme inhibitors. (a) Normal enzyme–substrate reaction. (b) The effect of a competitive inhibitor. (c) The effect of a non-competitive inhibitor.

DID YOU KNOW?

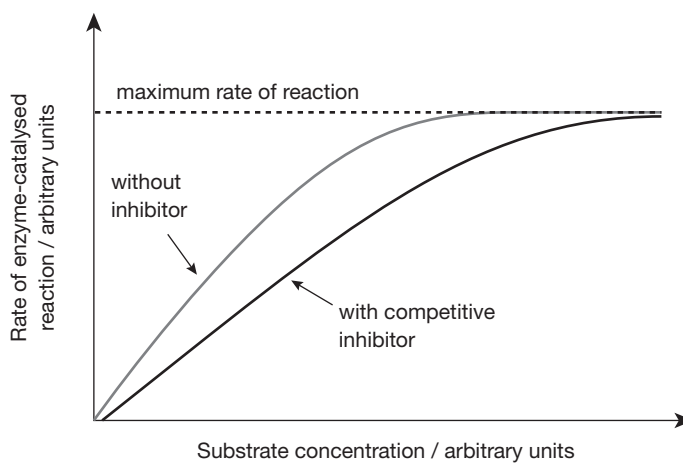
Methanol (methyl alcohol) is a highly poisonous (toxic) chemical. If a person drinks methanol, an enzyme in the body oxidises it to formaldehyde and formic acid. These chemicals attack the optic nerve leading from the eye to the brain, causing blindness. Doctors give ethanol (ethyl alcohol) as an antidote for methanol poisoning, because ethanol competitively inhibits the oxidation of methanol. The enzyme oxidises ethanol in preference to methanol, so the toxic by-products do not build up and cause nerve damage.

DID YOU KNOW?

The ions of 'heavy metals' such as silver (Ag^+), mercury (Hg^{2+}) and lead (Pb^{2+}) are highly poisonous (toxic). This is because they bind irreversibly to proteins and act as non-competitive inhibitors of enzymes.

Competitive inhibitors are molecules with a similar shape to the substrate (Figure 3.9(b)). They fit into the active site, stopping the substrate from entering. However, this is *temporary* – the inhibitor can leave and the substrate can take its place. This is why these inhibitors are called competitive – the inhibitor and the substrate are *competing* for the active site.

The presence of the inhibitor slows the rate of reaction. The greater the concentration of inhibitor (relative to substrate) the more effect it will have on the rate of reaction. Figure 3.10 shows how a competitive inhibitor affects enzyme activity at different concentrations of substrate. Notice that at high concentrations of substrate, the inhibitor has no effect on the activity of the enzyme.



▲ Figure 3.10 The effect of a competitive inhibitor at different concentrations of substrate.

Non-competitive inhibitors do not have a shape like that of the substrate (Figure 3.9(c)). They do not attach to the active site, but to other parts of the enzyme. When they attach, they change the shape of the whole enzyme molecule, including the active site. The active site can no longer receive the substrate, so the reaction slows down.

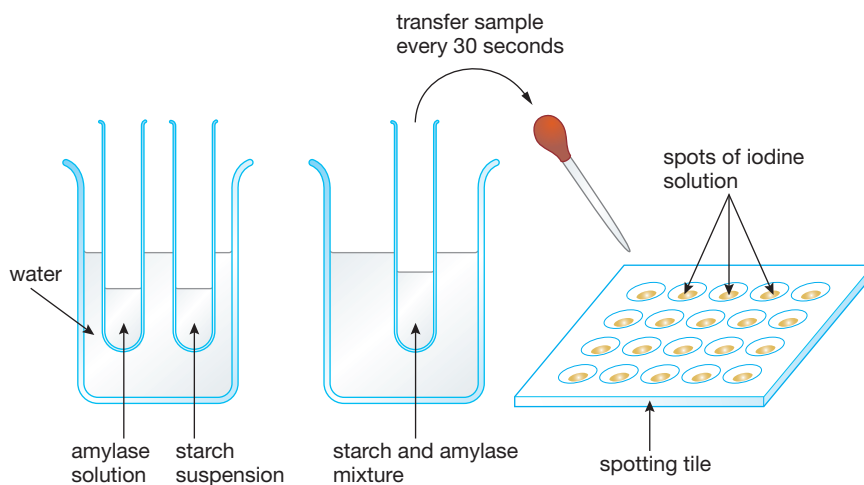
This time, the enzyme will not be able to catalyse the reaction even if the concentration of substrate is increased, because the substrate cannot fit into the active site. The relative concentrations of inhibitor and substrate do not affect the rate of reaction.

ACTIVITY 4

▼ PRACTICAL: INVESTIGATING THE EFFECT OF TEMPERATURE ON THE ACTIVITY OF AMYLASE

The digestive enzyme amylase breaks down starch into the sugar maltose. The activity of the amylase can be measured by recording the speed at which the starch disappears.

Figure 3.11 shows apparatus which can be used to record how quickly the starch is used up.



▲ Figure 3.11 Apparatus used to find the effect of temperature on the activity of amylase.

Spots of iodine solution are placed in the dips on the spotting tile. A syringe is used to place 5 cm³ of starch suspension in one boiling tube. A different syringe is used to place 5 cm³ of amylase solution in another tube. The beaker is filled with water at 20 °C. Both boiling tubes are placed in the beaker of water for 5 minutes, and the temperature of the water bath is recorded.

The amylase solution is then poured into the starch suspension, and the tube containing the mixture is left in the water bath. Immediately, a pipette is used to remove a small sample of the mixture from the tube and add it to the first drop of iodine solution on the spotting tile. The colour of the iodine solution is recorded.

A sample of the mixture is taken every 30 seconds for 10 minutes and tested for starch as above, until the iodine solution remains yellow, showing that all the starch has been used up.

The experiment is repeated, with the water bath at different temperatures between 20 °C and 60 °C. A set of results showing the colour changes at each temperature is given in the table opposite.

Safety note: Wear eye protection and avoid skin contact with the reactants.

| Time / min | Temperature / °C | | | | |
|------------|------------------|------------|------------|------------|------------|
| | 20 | 30 | 40 | 50 | 60 |
| 0.0 | blue-black | blue-black | blue-black | blue-black | blue-black |
| 0.5 | blue-black | blue-black | brown | blue-black | blue-black |
| 1.0 | blue-black | blue-black | yellow | blue-black | blue-black |
| 1.5 | blue-black | blue-black | yellow | blue-black | blue-black |
| 2.0 | blue-black | blue-black | yellow | brown | blue-black |
| 2.5 | blue-black | blue-black | yellow | brown | blue-black |
| 3.0 | blue-black | blue-black | yellow | brown | blue-black |
| 3.5 | blue-black | blue-black | yellow | yellow | blue-black |
| 4.0 | blue-black | blue-black | yellow | yellow | blue-black |
| 4.5 | blue-black | blue-black | yellow | yellow | blue-black |
| 5.0 | blue-black | blue-black | yellow | yellow | blue-black |
| 5.5 | blue-black | blue-black | yellow | yellow | blue-black |
| 6.0 | blue-black | brown | yellow | yellow | blue-black |
| 6.5 | blue-black | brown | yellow | yellow | blue-black |
| 7.0 | blue-black | yellow | yellow | yellow | blue-black |
| 7.5 | blue-black | yellow | yellow | yellow | brown |
| 8.0 | blue-black | yellow | yellow | yellow | brown |
| 8.5 | brown | yellow | yellow | yellow | yellow |
| 9.0 | brown | yellow | yellow | yellow | yellow |
| 9.5 | yellow | yellow | yellow | yellow | yellow |
| 10.0 | yellow | yellow | yellow | yellow | yellow |

The rate of reaction can be calculated from the time taken for the starch to be broken down fully, as shown by the colour change from blue-black to yellow. For example, at 50 °C the starch had all been digested after 3.5 minutes. The rate is found by dividing the volume of starch (5 cm³) by the time:

$$\text{Rate} = \frac{5.0 \text{ cm}^3}{3.5 \text{ min}} = 1.4 \text{ cm}^3 \text{ per min}$$

Plotting a graph of rate against temperature should produce a curve similar to the one shown in Figure 3.6. Try this, using the results in the table. Better still, you may be able to do this experiment and provide your own results.

If your curve is not exactly the same as the one in Figure 3.6, can you suggest reasons for this? How could you improve the experiment to get more reliable results?



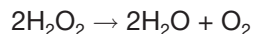
Safety note: Wear eye protection and avoid skin contact with the reactants. Wash hands after chopping the potato. Take care with the blender – the blades are very sharp.

ACTIVITY 5

▼ PRACTICAL: INVESTIGATING THE EFFECT OF pH ON THE ACTIVITY OF CATALASE

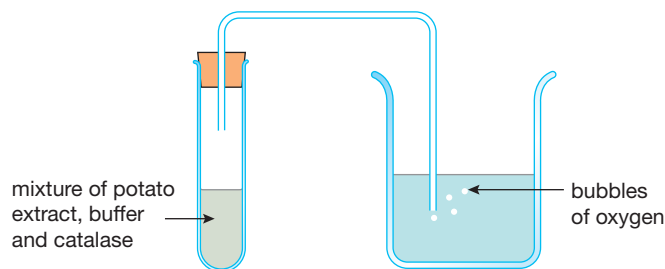
Buffer solutions are solutions of salts that resist changes in pH. Different buffer solutions can be prepared to maintain different values of pH. Buffer solutions are useful for finding the effect of pH on enzyme activity.

Hydrogen peroxide (H_2O_2) is a product of metabolism. Hydrogen peroxide is toxic (poisonous), so it must not be allowed to build up in cells. The enzyme catalase protects cells by breaking down hydrogen peroxide into the harmless products water and oxygen:



Potato cells contain a high concentration of catalase. A large potato is chopped into small pieces and placed in a blender with an equal volume of distilled water. The blender is switched on to mince up the potato tissue and release the catalase from the cells. The remains of the potato tissue are allowed to settle to the bottom and the liquid extract above the debris is removed.

The extract is tested for catalase activity at different values of pH. A graduated syringe is used to place 5 cm^3 of extract in a boiling tube. Another syringe is used to add 5 cm^3 of pH 7 buffer solution to the same boiling tube. The tube is shaken gently to mix the buffer with the potato extract. The mixture is left for 5 minutes, then 5 cm^3 of 5% hydrogen peroxide solution is added to the tube from a third syringe. A bung and delivery tube are quickly inserted into the boiling tube and the end of the delivery tube is placed in a beaker of water (Figure 3.12).



▲ Figure 3.12 Apparatus to investigate the effect of pH on catalase activity.

The bubbles of oxygen gas produced in the first minute after the hydrogen peroxide is added are counted. The number of bubbles per minute is a measure of the initial reaction rate.

The experiment is repeated, using different buffers. Some results are shown in the table below.

| pH | Rate of reaction / bubbles per minute |
|----|---------------------------------------|
| 5 | 6 |
| 6 | 39 |
| 7 | 47 |
| 8 | 14 |

Plot a bar chart of the results.

- Which pH gives the fastest rate of reaction?
- How could you modify this experiment to find a more accurate value for the optimum pH for the enzyme catalase? (Think – are four values of pH enough?)
- Is there a better way to measure the rate of reaction than counting bubbles of gas?
- How could you control the temperature during the experiment?
- How could you modify the experiment to make the results more reliable? (Think – is one set of results enough?)

IMMOBILISED ENZYMES

Enzymes can be extracted from cells or tissues and used for industrial or medical purposes. For example, the amylase used in Activity 4 is usually obtained from a fungus. Preparations of enzymes have a wide range of uses, for example:

- stain removers in biological detergents
- conversion of starch to glucose in the food industry
- preservatives in food and drinks
- clarification (clearing) of fruit juices
- making cheese
- manufacture of paper
- detection of blood glucose levels in people with diabetes
- measuring the level of the waste product called urea in the blood.

Some of these examples use enzymes dissolved in water ('in solution'). However, some enzymes are more useful if they are not in solution, but are instead *immobilised* by being attached to, or trapped within, an insoluble material. Using an **immobilised enzyme** has several advantages over the use of a dissolved enzyme:

- The enzymes are much more stable at high temperatures and are less likely to denature.
- The enzymes are more resistant to changes in pH.
- The enzymes are less likely to be broken down by organic solvents.
- The products are uncontaminated by enzyme and can be collected more easily.
- The enzyme can be kept and re-used.
- An industrial process can use columns of immobilised enzyme, allowing large-scale production.

Enzymes can be immobilised in a number of different ways. Some methods involve attaching the enzyme molecules to the surface of a material such as porous glass or cellulose. Other methods involve trapping the enzyme molecules in a permeable membrane, such as nylon, or in a polymer such as **alginate** (see Activity 6).

DID YOU KNOW?

It has been estimated that three-quarters of the adult population of the world is lactose-intolerant to some degree.

DID YOU KNOW?

Despite their liking for milk and cream, many cats are lactose-intolerant. Dairy products can give cats problems similar to those in lactose-intolerant humans.

Three uses of immobilised enzymes are described below.

LACTOSE-FREE MILK

Milk contains a disaccharide sugar called lactose (see the section on carbohydrates earlier in this chapter). Babies get their nutrition from milk, and they produce an enzyme called **lactase**, which breaks down lactose into glucose and galactose.

Many adults also drink milk and eat milk products such as butter and cheese. However, many adults are unable to produce lactase, so they cannot digest lactose. This is called 'lactose intolerance'. If a lactose-intolerant person drinks milk, the lactose is instead broken down by bacteria in their gut, producing waste gases. The person suffers from painful stomach cramps, nausea and diarrhoea.

Immobilised lactase can be used to produce lactose-free milk and milk products for lactose-intolerant people (see Activity 6).

The lactase is immobilised in porous beads and held in a column. Milk is passed through the column, where the lactase breaks down the lactose. Lactase is an expensive enzyme, and this method means it can be kept and re-used, lowering the cost.

BREAKDOWN OF SUCROSE

Sucrose is a disaccharide of glucose and fructose (see Figure 3.1). The enzyme **invertase** is produced by yeast cells, and breaks down sucrose into its component monosaccharides.

Invertase is used commercially to break down sucrose to produce a mixture of glucose and fructose, called 'invert syrup'. Invert syrup is widely used for sweetening products in the food and drinks industry.

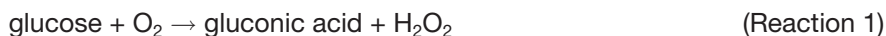
Commercial invertase is extracted from yeast and trapped in alginate beads (like the lactase in Activity 6). It is then used in this immobilised form.

TESTING FOR GLUCOSE IN BLOOD OR URINE

The disease called **diabetes** can result in higher than normal levels of glucose in the blood and the appearance of glucose in the urine (see Chapter 9).

People with diabetes have to test their blood and urine for glucose at regular intervals. This can be done in two ways – using test strips or with biosensors.

Test strips use two immobilised enzymes. An enzyme called glucose oxidase catalyses the oxidation of glucose to gluconic acid and hydrogen peroxide:



The hydrogen peroxide produced in Reaction 1 oxidises a colourless organic substance (XH_2) to its coloured form, X, by removing hydrogen:



(*'X' represents the organic substance, which is colourless when reduced and coloured when oxidised.*)

Reaction 2 is catalysed by another enzyme called peroxidase. The amount of the coloured substance X produced is a direct measure of the concentration of glucose present in the sample of blood or urine. This method is very specific for glucose – the reactions will not be affected by other sugars in the sample. The glucose oxidase, peroxidase and XH_2 are attached to a cellulose pad on a test strip, which is dipped in the blood or urine sample. The colour change of the test strip gives an approximate measure of the concentration of glucose (Figure 3.13).



▲ Figure 3.13 Coloured test strips are used to detect glucose in urine.



Safety note: Wear eye protection and avoid skin contact with the lactase, alginate solution and gel. Do not taste the whole milk or the lactose-free milk.

ACTIVITY 6

▼ PRACTICAL: USING IMMOBILISED LACTASE TO PRODUCE LACTOSE-FREE MILK

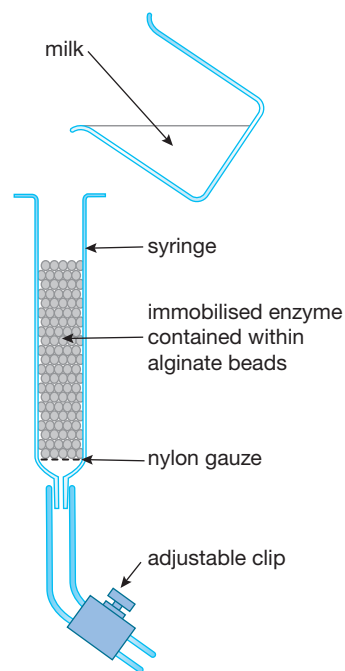
Lactase catalyses the breakdown of lactose into glucose and galactose. This is used to make lactose-free milk for people who are lactose-intolerant. The lactase is immobilised in beads of calcium alginate gel.

A small syringe is used to add 2 cm³ of lactase solution to a beaker containing 8 cm³ of 2% sodium alginate solution. The two are mixed thoroughly using a stirring rod. Using the same syringe, some of the mixture is removed from the beaker and added drop by drop to another beaker, containing 100 cm³ of a solution of 1.5% calcium chloride.

As the mixture drops into the solution, the sodium alginate is converted into insoluble calcium alginate, forming gelatinous (jelly-like) beads. The beads contain the enzyme immobilised in the calcium alginate gel. (At this stage, it is important that the tip of the syringe does not touch the calcium chloride solution, or it will block with gel.)

The beads are left to set for five minutes. Then the mixture is poured through a sieve to separate the beads from the solution. The beads are washed with distilled water.

The beads are packed into the barrel of a 10 cm³ syringe, which has its outlet covered by a small piece of nylon gauze. The syringe is clamped upright, with the outlet tube closed by an adjustable clip. Fresh milk (not UHT) is poured into the open end of the syringe barrel (Figure 3.14).



▲ Figure 3.14 Using lactase immobilised in alginate beads to produce lactose-free milk.

The milk leaving the syringe is tested using glucose test strips. After a while, glucose will be present in the milk that has passed through the column of beads. As a Control, the milk is tested before treatment – it will not contain any glucose.

LOOKING AHEAD – BIOSENSORS

Another way of measuring blood glucose is to use a **biosensor**. This is an instrument that quickly and easily measures the concentration of glucose, and gives a more accurate reading than using test strips. A drop of the person's blood is placed onto the probe of the biosensor (Figure 3.15).



▲ Figure 3.15 A biosensor for measuring blood glucose levels. A drop of blood has been placed onto the probe of the biosensor.

The biosensor uses the enzyme glucose oxidase described above. At the end of the probe, the enzyme is immobilised in a gel attached to an instrument called an oxygen electrode. This measures the concentration of oxygen dissolved in a solution. When the drop of blood is placed on the probe, glucose in the blood diffuses into the gel. The enzyme breaks down this glucose (see Reaction 1 on page 44), using up oxygen. The electrode measures the oxygen level and changes it into an electrical signal, which is converted into a reading of blood glucose concentration on a meter.

Biosensors using immobilised enzymes are used in medicine to measure a number of other substances in the blood, including alcohol and other drugs.

CHAPTER QUESTIONS

SKILLS INTERPRETATION



1 Copy and complete the following table.

| Biological molecule | 'Building blocks' of the molecule | Chemical elements in the molecule |
|---------------------|-----------------------------------|-----------------------------------|
| carbohydrate | simple sugars (monosaccharides) | |
| lipid | | carbon, hydrogen, oxygen |
| protein | | |

SKILLS EXECUTIVE FUNCTION

2 Describe how to carry out a chemical test for the following substances. State the result if the test is positive.

- a starch
- b glucose

SKILLS CRITICAL THINKING

SKILLS INTERPRETATION

SKILLS REASONING

SKILLS EXECUTIVE FUNCTION



3 a What is an enzyme?



b Draw a labelled diagram to explain the 'lock and key' model of enzyme action.



c 'The lock and key model helps us to understand the effect of a competitive inhibitor on an enzyme-controlled reaction'. Explain the meaning of this statement.



d From your knowledge of inhibitors, suggest how you could find out if an enzyme-catalysed reaction was being inhibited by a competitive or non-competitive inhibitor.

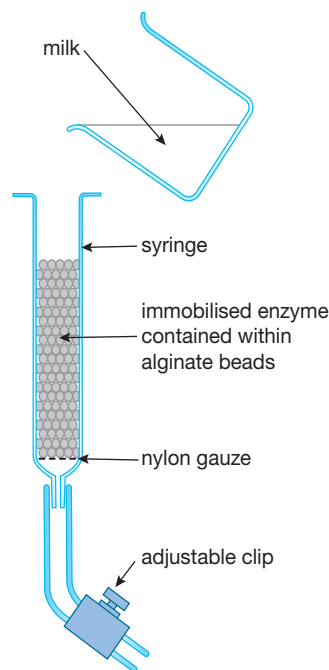


4 The enzyme lactase catalyses the breakdown of lactose into glucose and galactose:



One of the products of the reaction (galactose) acts as a competitive inhibitor of lactase.

The apparatus below uses immobilised lactase to produce lactose-free milk.



The speed of flow of the milk through the column of alginate beads affects the rate of the enzyme-catalysed reaction. If the flow is too fast, there is not enough time for the reaction to take place. If the flow is too slow, galactose builds up in the syringe and inhibits the reaction.

a Using this apparatus, how could you investigate the effect of the speed of flow of the milk on the rate of breakdown of lactose?

b Name the independent variable and the dependent variable in this investigation.

c State three advantages of using immobilised enzymes to make useful products.

SKILLS CRITICAL THINKING



UNIT QUESTIONS

SKILLS CRITICAL THINKING**1**

Which of the following is the best definition of 'differentiation'?

- A The organisation of the body into cells, tissues and organs
- B A type of cell division resulting in the growth of an embryo
- C The adaptation of a cell for its function
- D The process by which the structure of a cell becomes specialised for its function

(Total 1 mark)**2**

Which of the following are components of DNA?

- A Deoxyribose, uracil and phosphate
- B Ribose, adenine and guanine
- C Deoxyribose, phosphate and adenine
- D Ribose, thymine and cytosine

(Total 1 mark)**3**

Which of the following is the function of transfer RNA (tRNA)?

- A Transporting amino acids to a ribosome
- B Coding for the order of amino acids
- C Transcription of the DNA
- D Translation of the DNA

(Total 1 mark)**4**

The base sequence for the same length of DNA before and after a gene mutation was as follows:

Before mutation: ATT TCC GTT ATC CGG

After mutation: ATT CCG TTA TCC GGA

Which type of mutation took place?

- A duplication
- B deletion
- C substitution
- D inversion

(Total 1 mark)**5**

The statements below show some of the stages in the production of human insulin from genetically modified bacteria.

1. DNA for insulin inserted into plasmids
2. Bacteria cloned
3. Plasmids inserted into bacteria
4. DNA for insulin cut out using restriction enzyme

Which of the following shows the correct sequence of steps in the process?

- A 2 → 1 → 4 → 3
- B 4 → 2 → 3 → 1
- C 4 → 1 → 3 → 2
- D 2 → 3 → 4 → 1

(Total 1 mark)

SKILLS CRITICAL THINKING



6

Which of the following enzymes is used to join together pieces of DNA?

- A ligase
- B DNA polymerase
- C protease
- D restriction enzyme

(Total 1 mark)



7

Which of the following cell processes needs a source of metabolic energy?

- A diffusion
- B osmosis
- C respiration
- D active transport

(Total 1 mark)

SKILLS REASONING



8

A bag made of Visking tubing contains a 5% solution of sucrose. It is placed in a beaker containing a 10% solution of sucrose. Which of the following will take place?

- A More water will enter the Visking tubing than leaves it and the volume of the tubing will increase
- B More water will leave the Visking tubing than enters it and the volume of the tubing will decrease
- C There will be no net movement of water and the volume will not change
- D At first the volume of the Visking tubing will increase, but it will then decrease as pressure builds up in the bag

(Total 1 mark)

SKILLS CRITICAL THINKING



9

Biuret solution is used to test for which of the following substances?

- A starch
- B glucose
- C protein
- D lipid

(Total 1 mark)

SKILLS REASONING



10

How does denaturing by heat prevent an enzyme from working?

- A By providing kinetic energy to the substrate molecules
- B By preventing the substrate from binding with the active site
- C By preventing the products from leaving the active site
- D By increasing the optimum temperature for the enzyme

(Total 1 mark)

SKILLS CRITICAL THINKING



11

Enzymes increase the rate of a reaction. Consider the following statements about the 'lock and key' model of enzyme action:

- 1 The reaction can only take place in the active site.
- 2 The active site is the 'key' to the substrate 'lock'.
- 3 The enzyme is unable to take part in further reactions after the substrate has left the active site.
- 4 When the substrate enters the active site, the energy needed to start the reaction is reduced.

Which of the statements is/are true?

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

(Total 1 mark)



12

Which of the following is *not* an advantage of using an immobilised enzyme?

- A The enzyme can be collected with the products.
- B The enzyme is less affected by changes in pH.
- C The enzyme is more stable at high temperatures.
- D The enzyme can be re-used.

(Total 1 mark)

13

Copy and complete the following passage about genes:

A gene is a section of a molecule called _____.
 The molecule is found within the _____ of a
 cell, within thread-like structures called _____.
 The strands of the molecule form a double helix joined by paired
 bases. The base adenine is always paired with its complementary base
 _____, and the base cytosine is paired with
 _____. During the process of transcription,
 the order of bases in one strand of the molecule is used to form
 _____, which carries the code for making proteins
 out to the cytoplasm.

(Total 6 marks)

SKILLS PROBLEM SOLVING



14

In a section of double-stranded DNA there are 100 bases, of which 30 are cytosine (C).

Calculate the total number of each of the following in this section of DNA:

- a complementary base pairs (1)
- b guanine (G) bases (1)
- c thymine (T) bases (1)
- d adenine (A) bases (1)
- e deoxyribose sugar groups. (1)

(Total 5 marks)

SKILLS INTERPRETATION



15

Different particles (molecules or ions) move across cell membranes using different processes. The table below shows some ways in which active transport, osmosis and diffusion are similar and some ways in which they are different. Copy and complete the table, using a tick (✓) if the feature applies to a process or a cross (✗) if it does not apply.

| Feature | Active transport | Osmosis | Diffusion |
|--|------------------|---------|-----------|
| particles must have kinetic energy | | | |
| requires energy from respiration | | | |
| particles move down a concentration gradient | | | |

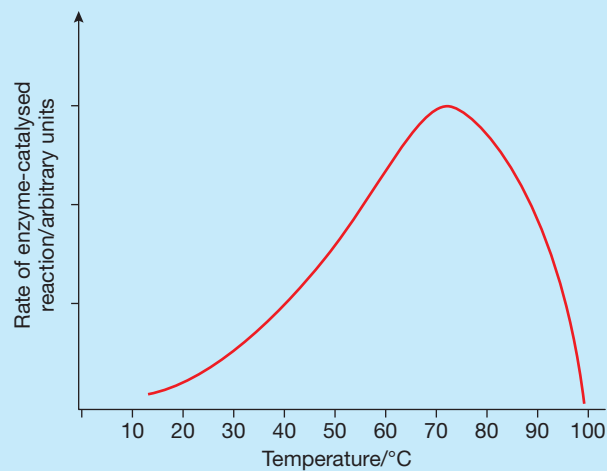
(Total 3 marks)

SKILLS ANALYSIS



16

The graph shows the effect of temperature on an enzyme. The enzyme was extracted from a microorganism that lives in hot mineral springs near a volcano.



- What is the optimum temperature of this enzyme? (1)
- Explain why the activity of the enzyme is greater at 60 °C than at 30 °C. (3)
- The optimum temperature of enzymes in the human body is about 37 °C. Explain why this enzyme is different. (2)
- Describe what happens to the enzyme at 90 °C. (2)

(Total 8 marks)

SKILLS REASONING



UNIT 2

The human body is a very complex machine. It needs food for growth and repair of tissues, and as a supply of energy. In Chapter 4, you will learn how the digestive system obtains the nutrients we need from the food we eat.

In Chapter 5, you will learn how we obtain energy from our food, through the process of respiration. Aerobic respiration needs a supply of oxygen from the air, and produces carbon dioxide as a waste product. These gases are exchanged in the lungs, which are also described in Chapter 5.

In Chapter 6, you will find out about the structure and function of the blood and circulatory system.



4 NUTRITION AND ENERGY

Food is essential for life – the nutrients obtained from it are used in many different ways by the body. In this chapter, you will look at the different classes of food substance and how they are broken down by the digestive system and absorbed. You will also find out about some of the problems that happen when we do not eat a balanced diet.

LEARNING OBJECTIVES

- Explain the importance of a balanced diet and the recommended dietary intake of carbohydrates, lipids, proteins, vitamins A and C, calcium, iron, and fibre
- Know the sources and functions of carbohydrates, lipids, proteins, vitamins A, C and D, and the mineral ions calcium and iron
- Describe the causes and symptoms of deficiency diseases – kwashiorkor (due to lack of protein), anaemia (lack of iron), scurvy (lack of vitamin C) and blindness (lack of vitamin A)
- Describe how to investigate the vitamin C content of a sample of food
- Understand differences in dietary needs related to age, pregnancy, climate and occupation
- Describe how to investigate the energy content of a sample of food
- Know the structure of the human alimentary canal
- Know the types, structure and functions of teeth, the factors affecting their growth, and how to care for teeth and gums
- Explain how food is moved through the gut by peristalsis and the role of dietary fibre in the process
- Describe the functions of the mouth, oesophagus, stomach, small intestine, large intestine and pancreas in digestion
- Understand the role of digestive enzymes, including:
 - their site of production and action
 - the digestion of starch to glucose by amylase and maltase
 - the digestion of proteins to amino acids by proteases (pepsin, trypsin)
 - the digestion of lipids to fatty acids and glycerol by lipases
- Know that bile is produced by the liver and stored in the gall bladder, and understand the role of bile in neutralising stomach acid and emulsifying lipids
- Understand how the structure of the villi helps absorption of the products of digestion in the small intestine
- Understand the meaning of Body Mass Index (BMI) and how to calculate it, the role of obesity as a risk factor in early onset of diabetes and the significance of high cholesterol levels in atherosclerosis*
- Explain the importance of hygienic methods of food preparation, cooking, storage and preservation

*These topics are discussed in more detail in Chapter 6 and Chapter 9.

A BALANCED DIET

We need food for three main reasons:

- to supply us with a ‘fuel’ for energy
- to provide materials for growth and repair of tissues
- to help prevent disease and keep our bodies healthy.

The food that we eat is called our diet. No matter what you like to eat, if your body is to work properly and stay healthy, your diet must include carbohydrates, lipids, proteins, **minerals** and **vitamins**, as well as **dietary fibre** and water. Food should provide you with all of these things, but it is important to ensure your diet includes the *right amount* of each substance. A diet that provides enough of these substances and in the correct proportions to keep you healthy is called a **balanced diet** (Figure 4.1). We will look at each type of food in turn, to find out about its chemistry and the role it plays in the body.



▲ Figure 4.1 A balanced diet contains all the types of food the body needs, in just the right amounts.

CARBOHYDRATES

Carbohydrates only make up about 1% of the mass of the human body, but they have a very important role. They are the body’s main ‘fuel’ for supplying cells with energy. Cells release this energy by breaking down the sugar glucose, in the process called cell respiration (see Chapter 5).

Glucose is found naturally in many sweet-tasting foods, such as fruits and vegetables. Other foods contain different sugars, such as the fruit sugar called fructose, and the milk sugar, lactose. Ordinary table sugar, the sort some people put in their tea or coffee, is called sucrose. Sucrose is the main sugar that is transported through plant stems. This is why we can extract it from sugar cane, which is the stem of a large grass-like plant. Sugars have two physical properties that you will probably know: they all taste sweet, and they are all soluble in water.

We can get all the sugar we need from natural foods such as fruits and vegetables, and from the digestion of starch. Many processed foods contain large amounts of *added* sugar. For example, a typical can of cola can contain up to seven teaspoons (27 g) of sugar! There is hidden sugar in many other foods. A tin of baked beans contains about 10 g of added sugar. This is on top of all the food that we eat with a more obvious sugar content, such as cakes, biscuits and sweets.

In fact, we get most of the carbohydrate in our diet not from sugars, but from starch, which is a polysaccharide of glucose (see Chapter 3). Starch is a large, *insoluble* molecule. Because it does not dissolve, it is found as a storage carbohydrate in many plants, such as potato, rice, wheat and millet, and in foods made from these plants, such as bread and pasta.

Another polysaccharide of glucose is glycogen, which is found in animal tissues such as liver and muscle. Polysaccharides are broken down into simple sugars during digestion, so that the sugars they contain can be absorbed into the blood.

Another carbohydrate that is a polymer of glucose is **cellulose**, a material that makes up plant cell walls. Humans are not able to digest cellulose, because the human gut does not make the enzyme needed to break down the cellulose molecule. This means that we are not able to use cellulose as a source of energy. However, it still has a vitally important function in our diet. It forms dietary fibre or 'roughage', which gives the muscles of the gut something to push against as food is moved through the intestine. This keeps the gut contents moving, avoiding constipation and helping to prevent serious diseases of the intestine, such as colitis and bowel cancer.

How much carbohydrate is there in a balanced diet? It is difficult to give one value for this, because different people need different amounts of food for energy. However, the recommended total carbohydrate in a healthy diet should supply about 50% of the body's daily energy needs, with less than 5% coming from sugars. Total daily carbohydrate for an adult should include about 30 g of dietary fibre.

LIPIDS (FATS AND OILS)

Lipids are fats and oils. Fats are solid at room temperature and oils are liquid. They are made of fatty acids and glycerol (see Chapter 3). Meat, butter, cheese, milk, eggs and oily fish are all rich in animal fats; so are foods fried in animal fat. Vegetable oils include many types used for cooking, such as olive oil, corn oil and rapeseed oil, as well as products made from oils, such as margarine (Figure 4.2).



▲ Figure 4.2 These foods are all rich in lipids.

Lipids make up about 10% of our body's mass. They form an essential part of the structure of all cells, and fat is also deposited in certain parts of the body as a long-term store of energy (for example, under the skin and around the heart and kidneys). The fat layer under the skin acts as insulation, reducing heat loss through the surface of the body. Fat around organs such as the kidneys helps to protect them from mechanical damage.

Although lipids are an essential part of our diet, too much lipid is unhealthy. In particular, you must make sure your diet does not contain too much **cholesterol** (a lipid compound) or saturated fat. Cholesterol is a substance that the body gets from food such as eggs and meat, but we also make cholesterol in our liver. It is an essential part of all cells, but too much cholesterol is linked to heart disease (see Chapter 6).

The recommended total lipid in a healthy diet should supply less than 35% of the body's daily energy needs, with less than a third of this coming from saturated fat.

DID YOU KNOW?

Saturated lipids (saturated fats) are more common in food from animal sources, such as meat and dairy products. 'Saturated' is a word used in chemistry, which means that the fatty acids of the lipids contain no double bonds. Other lipids are **unsaturated**, which means that their fatty acids contain double bonds. These are more common in plant oils. There is evidence that unsaturated lipids are healthier for us than saturated ones.

PROTEINS



▲ Figure 4.3 This child is suffering from a lack of protein in his diet, a disease called kwashiorkor. His swollen belly is not due to a full stomach, but is caused by fluid collecting in the tissues. Other symptoms include loss of weight, poor muscle growth, general weakness and flaky skin.

DID YOU KNOW?

A disease that is caused by a lack of a particular nutrient is called a **nutrient deficiency disease**. Later in this chapter you will learn about other deficiency diseases caused by a lack of certain vitamins and minerals.

Proteins are large molecules made of long chains of amino acids (see Chapter 3). They make up about 18% of the mass of the body. This is the second largest fraction after water. All cells contain protein, so we need it for growth and repair of tissues. Many compounds in the body are made from protein, including enzymes.

Most foods contain some protein, but certain foods such as meat, fish, cheese and eggs are particularly rich in it. You will notice that these foods are animal products. Plant material generally contains less protein, but some foods, especially beans, peas and nuts, are richer in protein than others.

DID YOU KNOW?

Humans need 20 different amino acids. They can make 10 of them, but the other 10 have to be taken in as part of the diet. These 10 are called **essential amino acids**. There are higher amounts of essential amino acids in meat, fish, eggs and dairy products. If you are a vegetarian, you can still get all the essential amino acids you need, as long as you eat a varied diet that includes a range of different plant materials.

However, we do not need much protein in our diet to stay healthy. Nutrition experts recommend a daily intake of 0.75 grams of protein per kilogram bodyweight per day for healthy adults. For example:

- if an adult weighs 60 kg, they need: $(60 \times 0.75) = 45$ g of protein per day
- if an adult weighs 75 kg, they need: $(75 \times 0.75) = 56$ g of protein per day

In more economically developed countries, people often eat far more protein than they need. In many poorer countries, a disease called **kwashiorkor** – caused by a lack of protein – is common (Figure 4.3).

MINERALS

All the foods you have read about so far are made from just five chemical elements: carbon, hydrogen, oxygen, nitrogen and sulfur. Our bodies contain many other elements which we get from our food as minerals or mineral ions. Some are present in large amounts in the body, for example calcium, which is used for making teeth and bones. Others are present in much smaller amounts, but still have essential jobs to do. For instance, our bodies contain about 3 g of iron. This may not sound like much, but without it our blood would not be able to carry oxygen. Table 4.1 shows just a few of these minerals and the reasons they are needed.

▼ Table 4.1 Some examples of minerals needed by the body.

| Mineral | Approximate mass in an adult body / g | Location or role in body | Examples of foods rich in minerals |
|------------|---------------------------------------|--|--|
| calcium | 1000 | making teeth and bones | dairy products, fish, bread, vegetables |
| phosphorus | 650 | making teeth and bones; part of many chemicals, e.g. DNA | most foods |
| sodium | 100 | in body fluids, e.g. blood | common salt, most foods |
| chlorine | 100 | in body fluids, e.g. blood | common salt, most foods |
| magnesium | 30 | making bones; found inside cells | green vegetables |
| iron | 3 | part of haemoglobin in red blood cells, helps carry oxygen | red meat, liver, eggs, some vegetables, e.g. spinach |



▲ Figure 4.4 The legs of this child show the symptoms of rickets. This is due to lack of calcium or a lack of vitamin D in the diet, leading to poor bone growth. The bones stay soft and cannot support the weight of the body, so they become deformed.

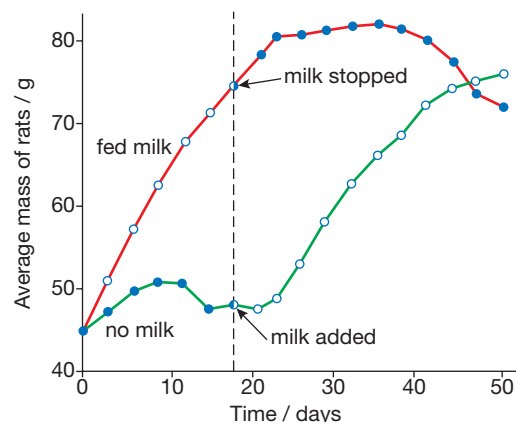
If a person does not get enough of a particular mineral from their diet, they will show the symptoms of a mineral deficiency disease. For example, a one-year-old child needs to consume about 0.6 g (600 mg) of calcium every day, to make the bones grow properly and harden. Anything less than this over a prolonged period could result in poor bone development. The bones become deformed, a disease called rickets (Figure 4.4). Rickets can also be caused by a lack of vitamin D in the diet (see below).

Similarly, 16-year-olds need about 12 mg of iron in their daily food intake. If they do not get this amount, they cannot make enough haemoglobin for their red blood cells (see Chapter 6). This causes a condition called anaemia. People of any age can become anaemic; a person suffering from anaemia becomes tired and lacks energy, because their blood does not carry enough oxygen.

VITAMINS

During the early part of the twentieth century, experiments were carried out that identified another class of food substances. When young laboratory rats were fed a diet of pure carbohydrate, lipid and protein, they all became ill and died. If they were fed on the same pure foods with a little added milk, they grew normally. The milk contained chemicals that the rats needed in small amounts to stay healthy. These chemicals are called vitamins. The results of one of these experiments are shown in Figure 4.5.

At first, the chemical nature of vitamins was not known, and they were given letters to distinguish between them, such as vitamin A, vitamin B and so on. Each vitamin was identified by the effect on the body of a lack of that vitamin (vitamin deficiency). For example, vitamin D is needed for growing bones to take up calcium salts. A deficiency of this vitamin can result in rickets (Figure 4.4), just as a lack of calcium can.



▲ Figure 4.5 Rats were fed on a diet of pure carbohydrate, lipid and protein, with and without added milk. Vitamins in the milk had a dramatic effect on their growth.

We now know the chemical structure of the vitamins and the exact ways in which they work in the body. Vitamin A is needed to make a light-sensitive chemical in the retina of the eye (see Chapter 8). One of the first signs of vitamin A deficiency is night blindness, where the person finds it difficult to see in dim light. Long-term deficiency of vitamin A results in complete blindness. This is especially common in children in poorer countries. It is estimated that between 250 000 and 500 000 badly nourished children in developing countries go blind each year as a result of vitamin A deficiency. About half of these children die within a year of becoming blind. This is because lack of vitamin A has other effects in the body, so the children are more likely to develop a severe illness from childhood infections such as measles.

Vitamin C is needed to make fibres of a material called connective tissue. This acts as a 'glue', binding cells together in a tissue and supporting internal organs. Connective tissue is found in the walls of blood vessels, in the skin and in many other tissues such as cartilage, tendons and ligaments. Vitamin C deficiency leads to a disease called scurvy, where wounds fail to heal, and bleeding occurs in various places in the body. This is especially noticeable in the gums (Figure 4.6).



▲ Figure 4.6 Vitamin C helps lining cells, such as those in the mouth and gums, stick to each other. Lack of vitamin C causes scurvy, where the mouth and gums become damaged and bleed.

DID YOU KNOW?

The cure for scurvy was discovered as long ago as 1753. Sailors on long voyages often got scurvy because they ate very little fresh fruit and vegetables (the main source of vitamin C). A ship's doctor called James Lind wrote an account of how the disease could quickly be cured by eating fresh oranges and lemons. A British explorer called Captain Cook, on his world voyages in 1772 and 1775, kept his sailors healthy by making sure that they ate fresh fruit. By 1804, all British sailors were made to drink lime juice to prevent scurvy.

Vitamin B is not a single substance, but a collection of many different substances called the vitamin B group. It includes vitamins B1 (thiamine), B2 (riboflavin) and B3 (niacin). These compounds are involved in the process of cell respiration. Different deficiency diseases result if any of them are missing from the diet. For example, lack of vitamin B1 results in the weakening of the muscles and paralysis, a disease called beri-beri.

The main vitamins, their roles in the body and some foods which are good sources of them, are summarised in Table 4.2. Notice that we only need very small amounts of vitamins but we cannot stay healthy without them.