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EDEXCEL INTERNATIONAL GCSE (9–1)

HUMAN BIOLOGY

eBook included

Student Book

Phil Bradfield and Steve Potter

Pearson

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GCSE (9–1)

HUMAN BIOLOGY

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UNIT 1

UNIT 2

UNIT 3

UNIT 4

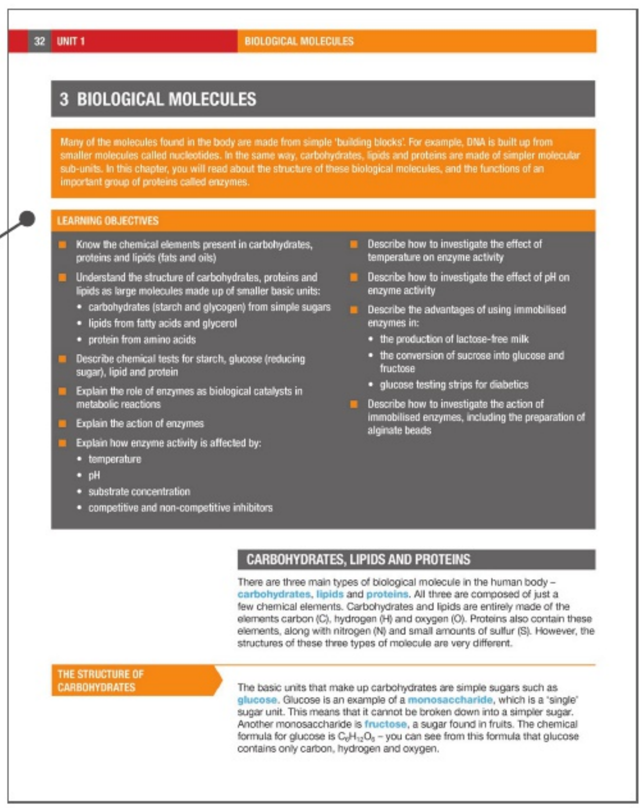
ABOUT THIS BOOK

This book is written for students following the Pearson 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.

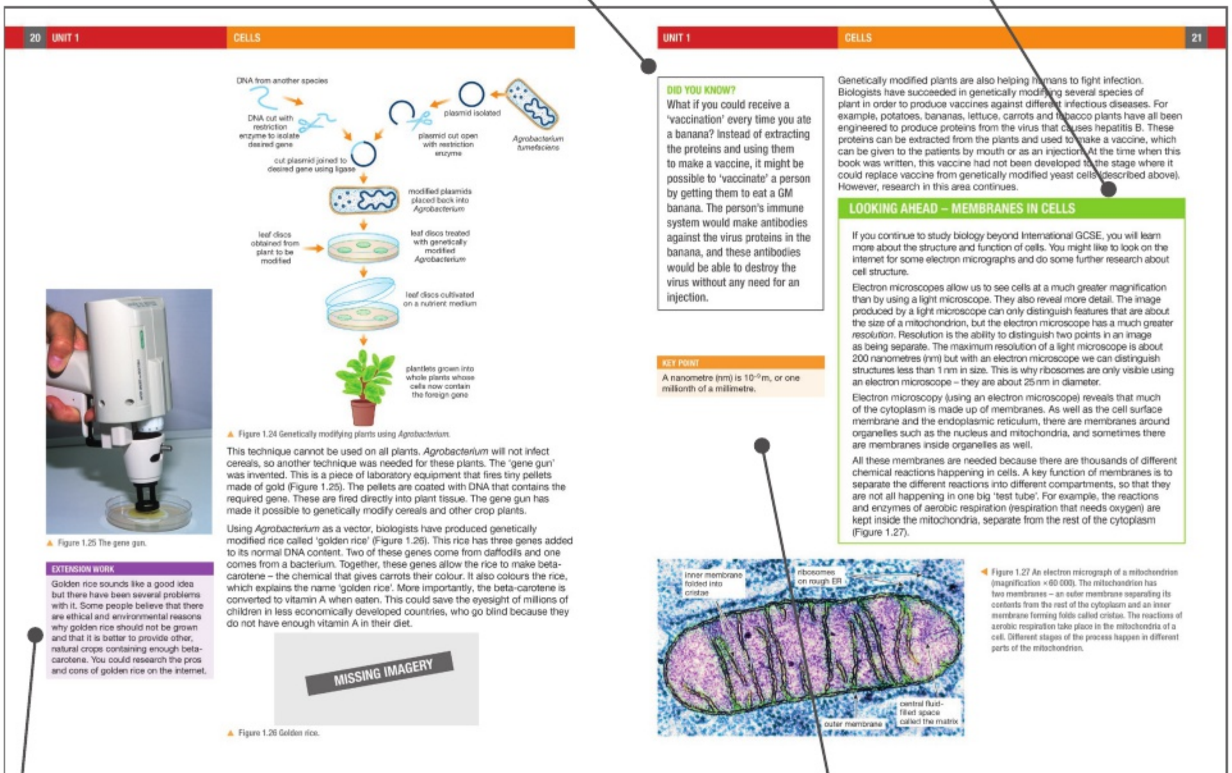
THE STRUCTURE OF CARBOHYDRATES

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.

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

DNA from another species; DNA cut with restriction enzyme to isolate desired gene; plasmid isolated; *Agrobacterium tumefaciens*; plasmid cut open with restriction enzyme; cut plasmid joined to desired gene using ligase; modified plasmids placed back into *Agrobacterium*; leaf discs obtained from plant to be modified; leaf discs treated with genetically modified *Agrobacterium*; leaf discs cultivated on a nutrient medium; plantlets grown into whole plants whose cells now contain the foreign gene

▲ 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' (Figure 1.26). 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.

MISSING IMAGERY

▲ Figure 1.26 Golden rice.

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.

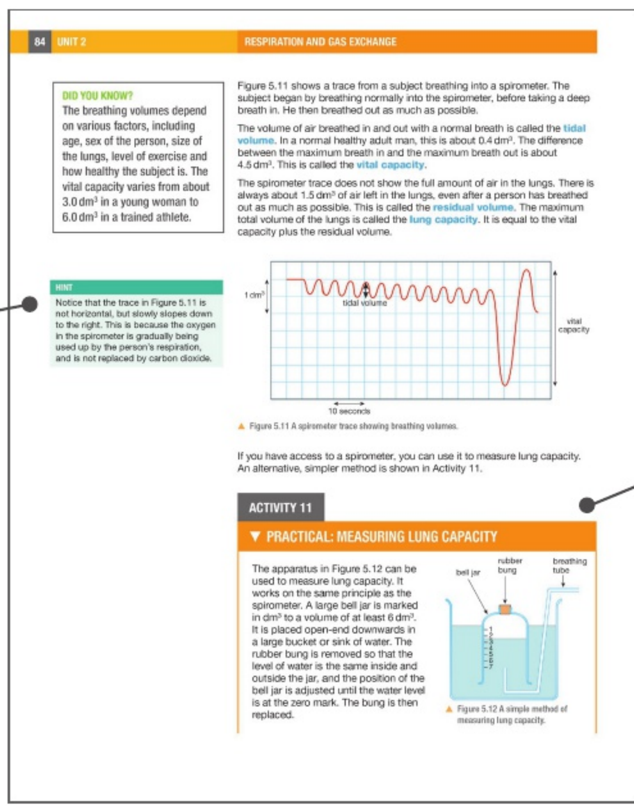
All these membranes are needed because there are thousands of different chemical reactions happening in cells. A key function of membranes is to separate the different reactions into different compartments, so that they are not all happening in one big 'test tube'. For example, the reactions and enzymes of aerobic respiration (respiration that needs oxygen) are kept inside the mitochondria, separate from the rest of the cytoplasm (Figure 1.27).

inner membrane folded into cristae; ribosomes on rough ER; central fluid-filled space called the matrix; outer membrane

◀ Figure 1.27 An electron micrograph of a mitochondrion (magnification ×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.



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 dm^3 in a young woman to 6.0 dm^3 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 dm^3. The difference between the maximum breath in and the maximum breath out is about 4.5 dm^3. 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 dm^3 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.

1 dm^3; tidal volume; vital capacity; 10 seconds

▲ 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

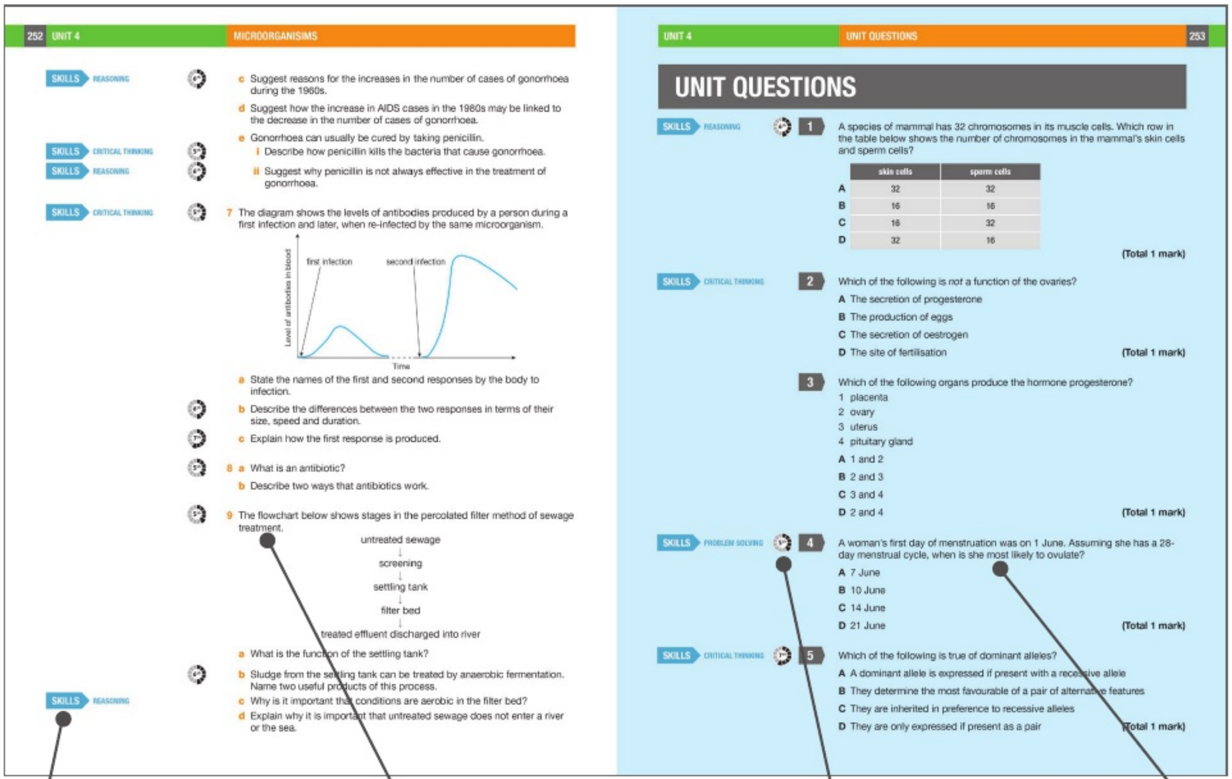
The apparatus in Figure 5.12 can be used to measure lung capacity. It works on the same principle as the spirometer. A large bell jar is marked in dm^3 to a volume of at least 6 dm^3. It is placed open-end downwards in a large bucket or sink of water. The rubber bung is removed so that the level of water 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.

bell jar; rubber bung; breathing tube

▲ 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.


252 UNIT 4 MICROORGANISMS

SKILLS REASONING

c Suggest reasons for the increases in the number of cases of gonorrhoea during the 1960s.

d Suggest how the increase in AIDS cases in the 1980s may be linked to the decrease in the number of cases of gonorrhoea.

e Gonorrhoea can usually be cured by taking penicillin.

SKILLS CRITICAL THINKING

i Describe how penicillin kills the bacteria that cause gonorrhoea.

SKILLS REASONING

ii Suggest why penicillin is not always effective in the treatment of gonorrhoea.

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.

a State the names of the first and second responses by the body to infection.

b Describe the differences between the two responses in terms of their size, speed and duration.

c Explain how the first response is produced.

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.

SKILLS REASONING

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.

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)

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.

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

ABOUT THIS BOOK

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.

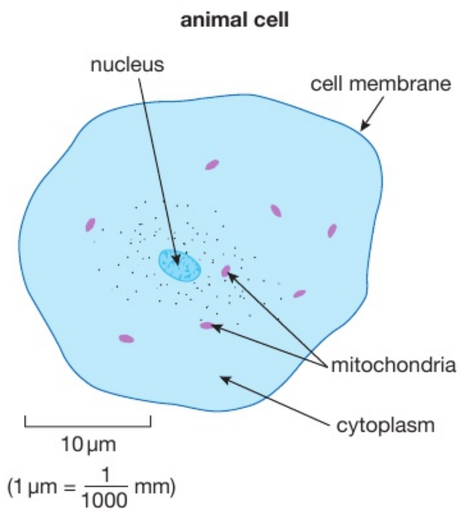


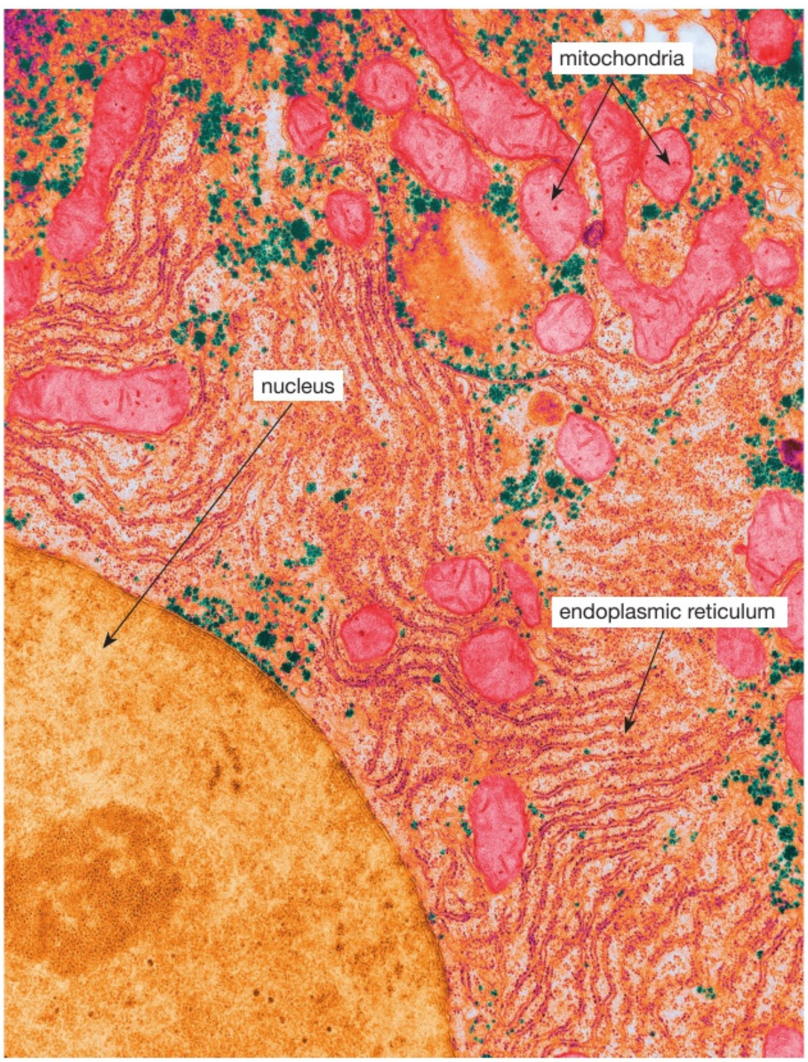
Figure 1.1 The structure of a generalised animal cell, as seen through a light microscope.

CELL STRUCTURE

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).

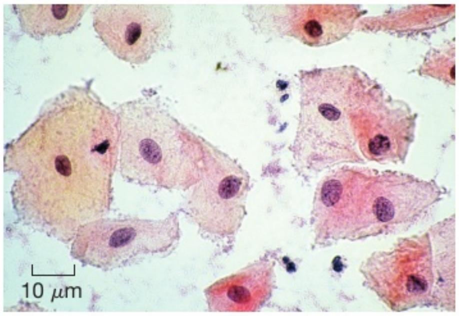
The largest organelle in the cell is the **nucleus**. Nearly all cells have a nucleus, with a few exceptions, such as red blood cells. The nucleus controls the activities of the cell. It contains **chromosomes** (46 in human body cells) which carry the genetic material or **genes**. Genes control the 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.



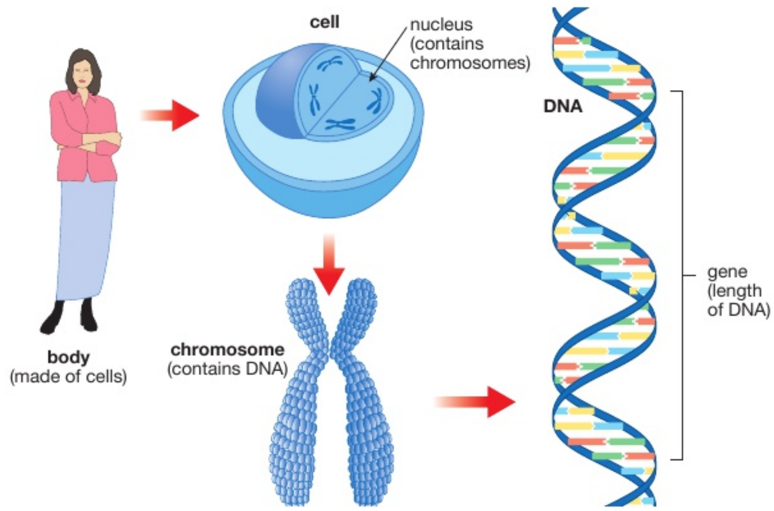
▲ Figure 1.3 Cells from the inside lining of a human cheek. The cells are stained to show up the details of structures such as the nucleus.

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?

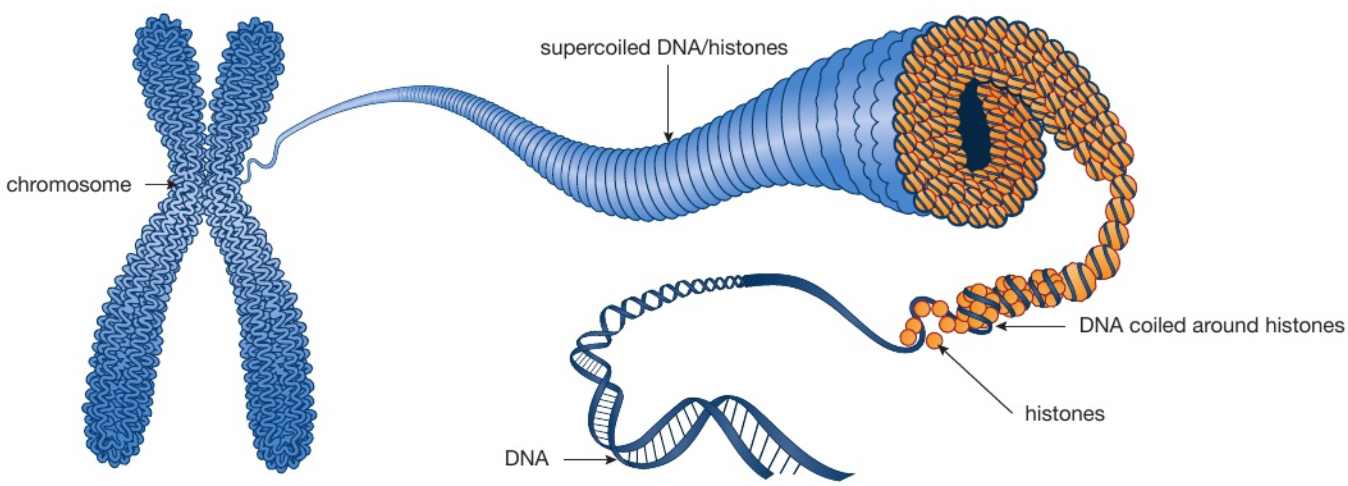
CHROMOSOMES, GENES AND DNA

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.

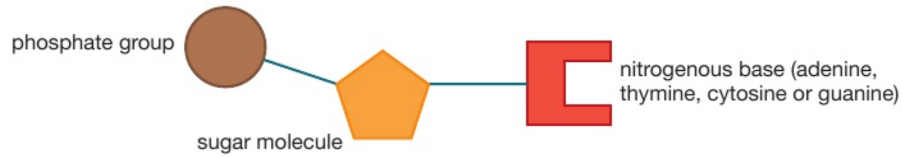
Each chromosome contains one DNA molecule. The DNA is folded and coiled so that it can be packed into a small space. The DNA is coiled around proteins called **histones** (Figure 1.5).



▲ Figure 1.5 The structure of a chromosome.

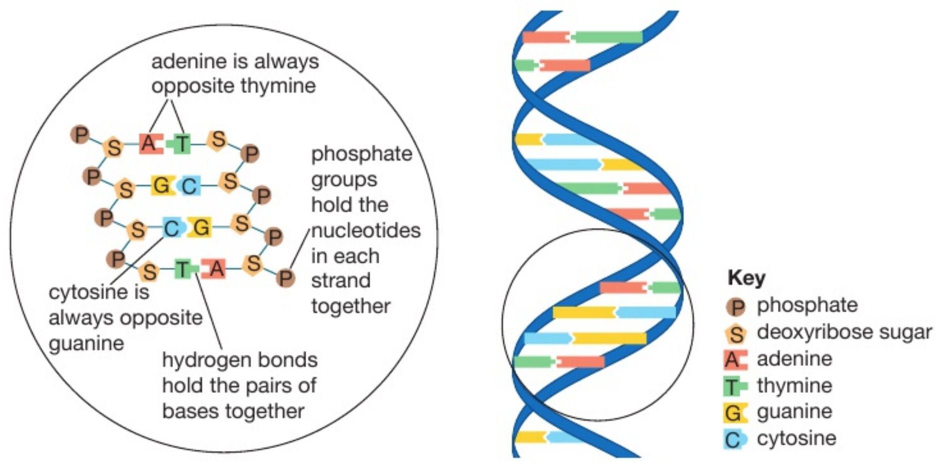
THE STRUCTURE OF DNA

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

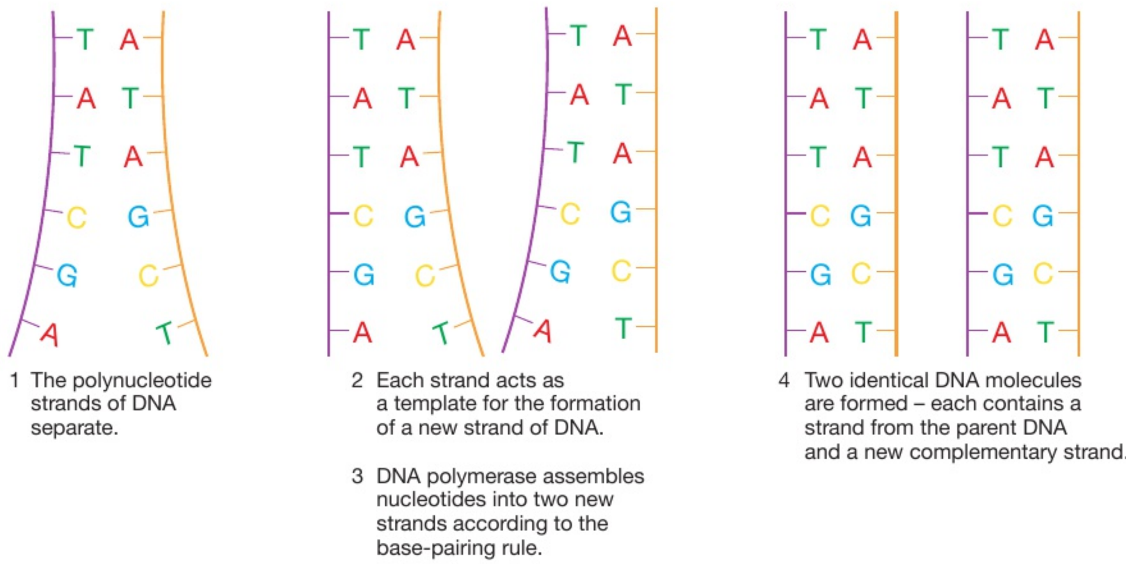
One consequence of the base-pairing rule is that, in each molecule of DNA, the amounts of adenine and thymine are equal, as are the amounts of cytosine and guanine.

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.

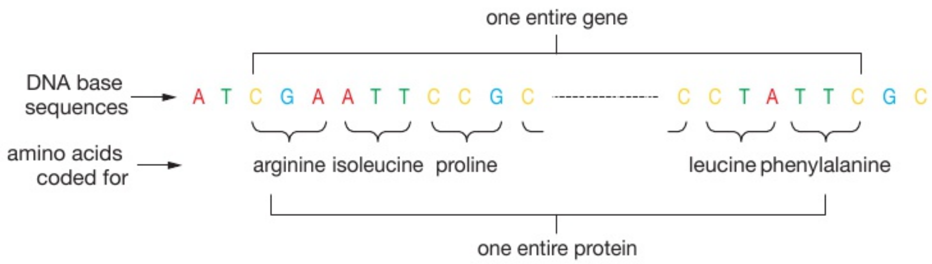
KEY POINT

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).

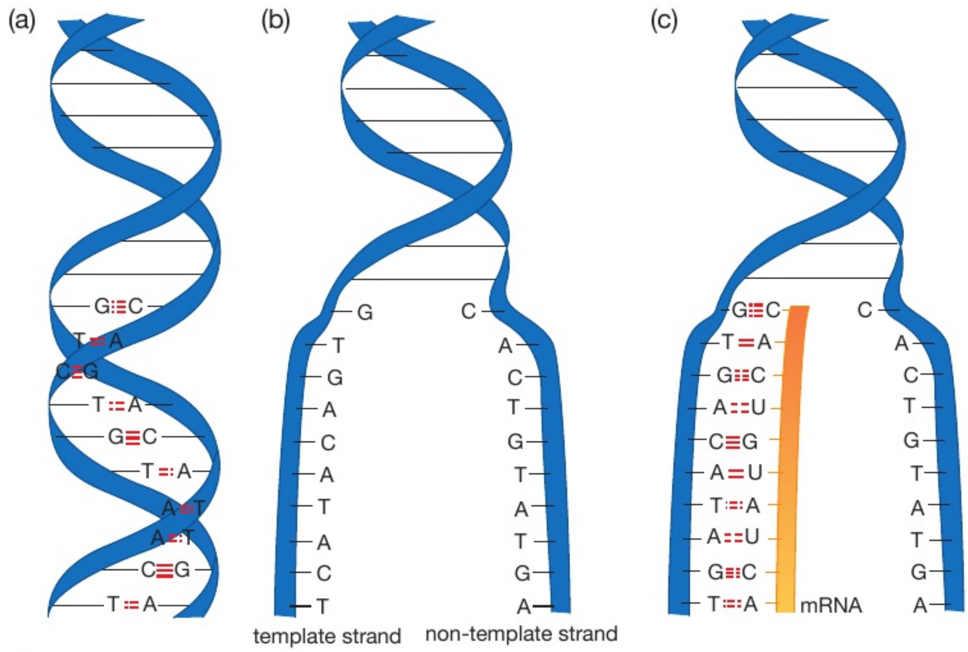
Two types of RNA take part in protein synthesis:

- **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.)

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.

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

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.

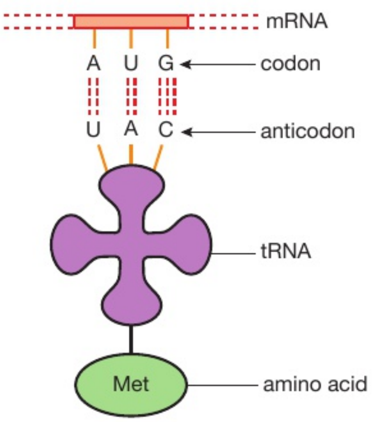


Figure 1.11 A tRNA molecule with the anticodon UAC, carrying the amino acid methionine. The anticodon is complementary to the codon AUG on the mRNA.

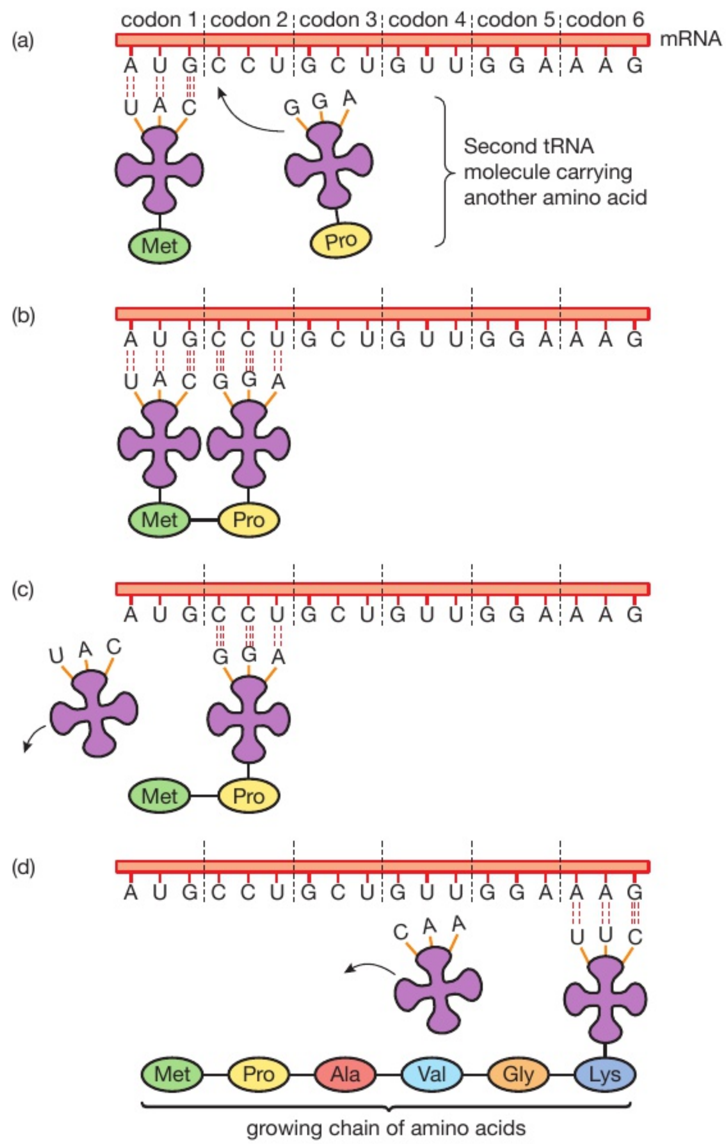


Figure 1.12 Translation. (a) A tRNA molecule carrying the first amino acid is attached to the first codon on the mRNA. A second tRNA is arriving, carrying the second amino acid. (b) Two tRNA molecules are attached to the mRNA. A bond is formed between the two amino acids. (c) The first tRNA molecule 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:

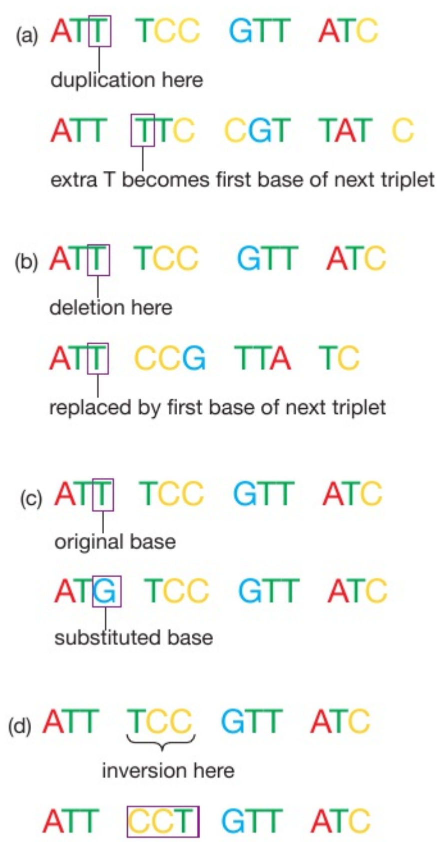
- The first tRNA to bind at the mRNA does so at the 'start codon', which always has the base sequence AUG. This codes for the amino acid methionine.
- Another tRNA brings along a second amino acid. The anticodon of the second tRNA binds to the next codon on the mRNA.
- A bond forms between the methionine 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.

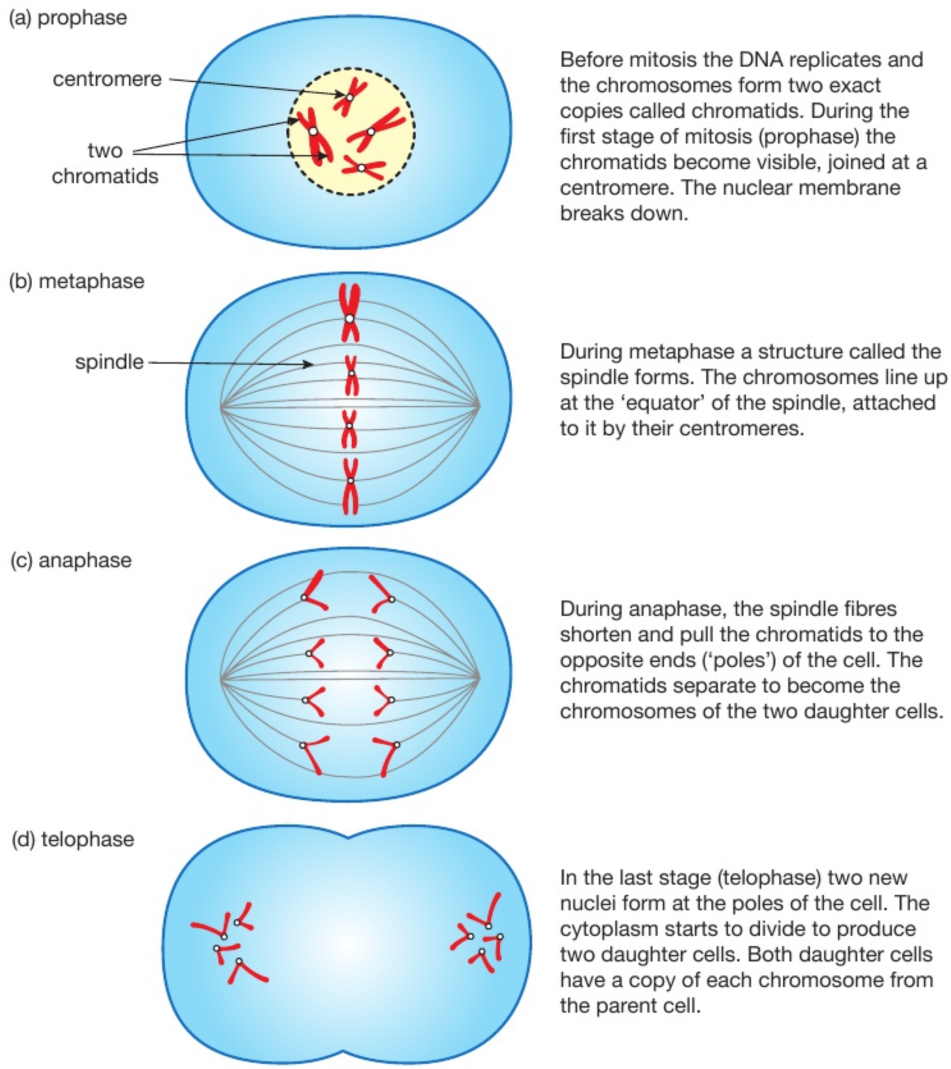
Human body cells have 46 chromosomes in 23 pairs called **homologous pairs**. These body cells are **diploid** cells – they have *two* copies of each chromosome. The sex cells have 23 chromosomes (only one copy of each chromosome); they are **haploid** cells.

MITOSIS

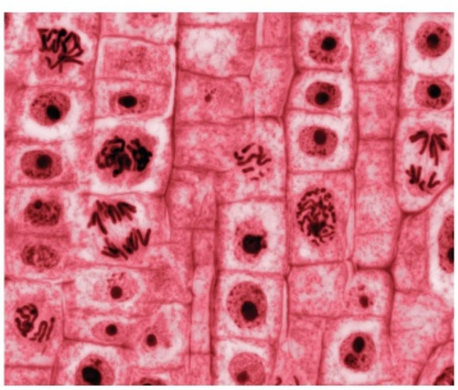
When a ‘parent’ cell divides, it produces *daughter cells*. Mitosis produces two daughter cells that are genetically identical to the parent cell – both daughter cells have the same number and type of chromosomes as the parent cell.

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.



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



▲ 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?

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).

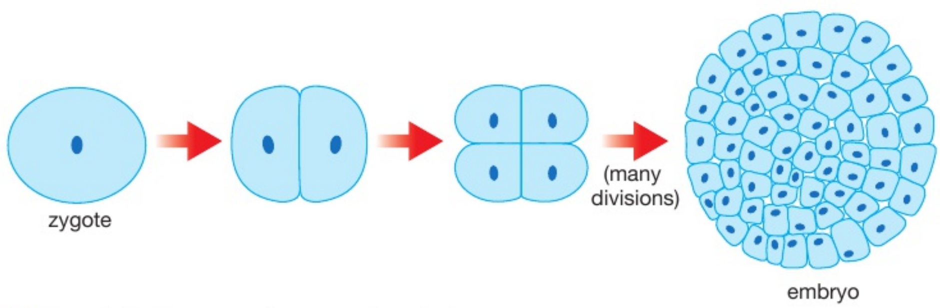
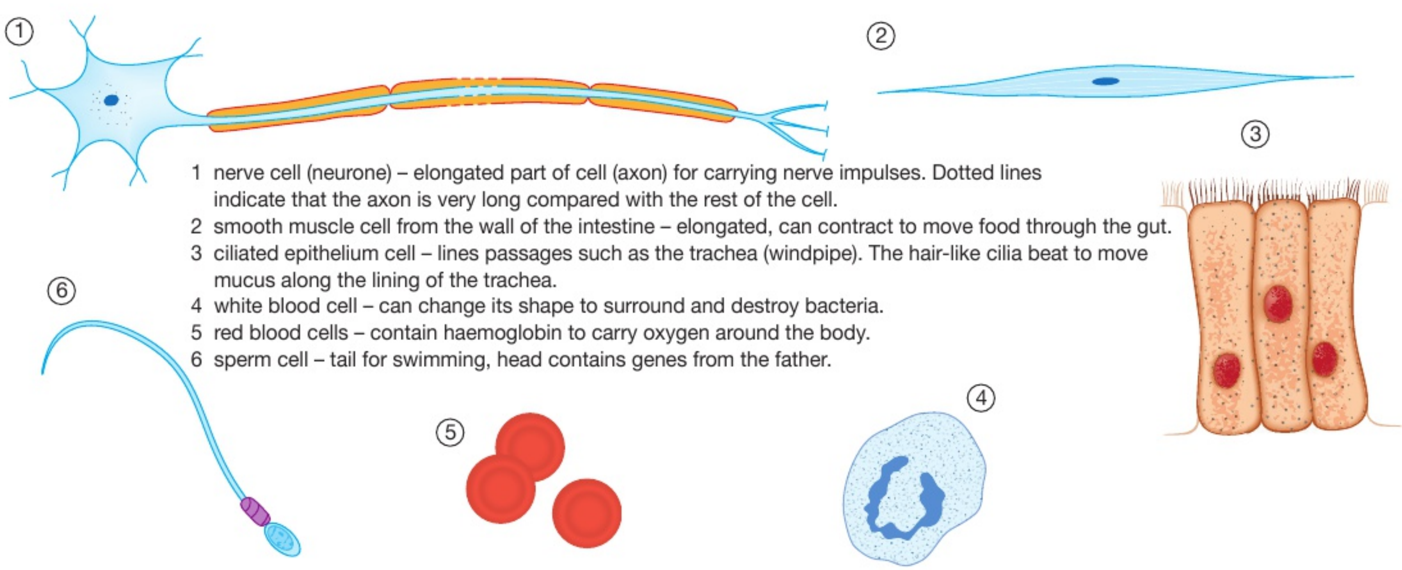


Figure 1.16 A human embryo grows by mitosis.

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 (neurone) – 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.

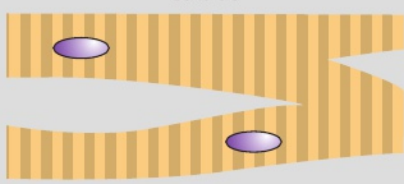
> **DID YOU KNOW?**
> Throughout this book, you will read about *adaptations*. An **adaptation** is a way that the structure of a cell, tissue or organ is suited (adapted) to its function.

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).

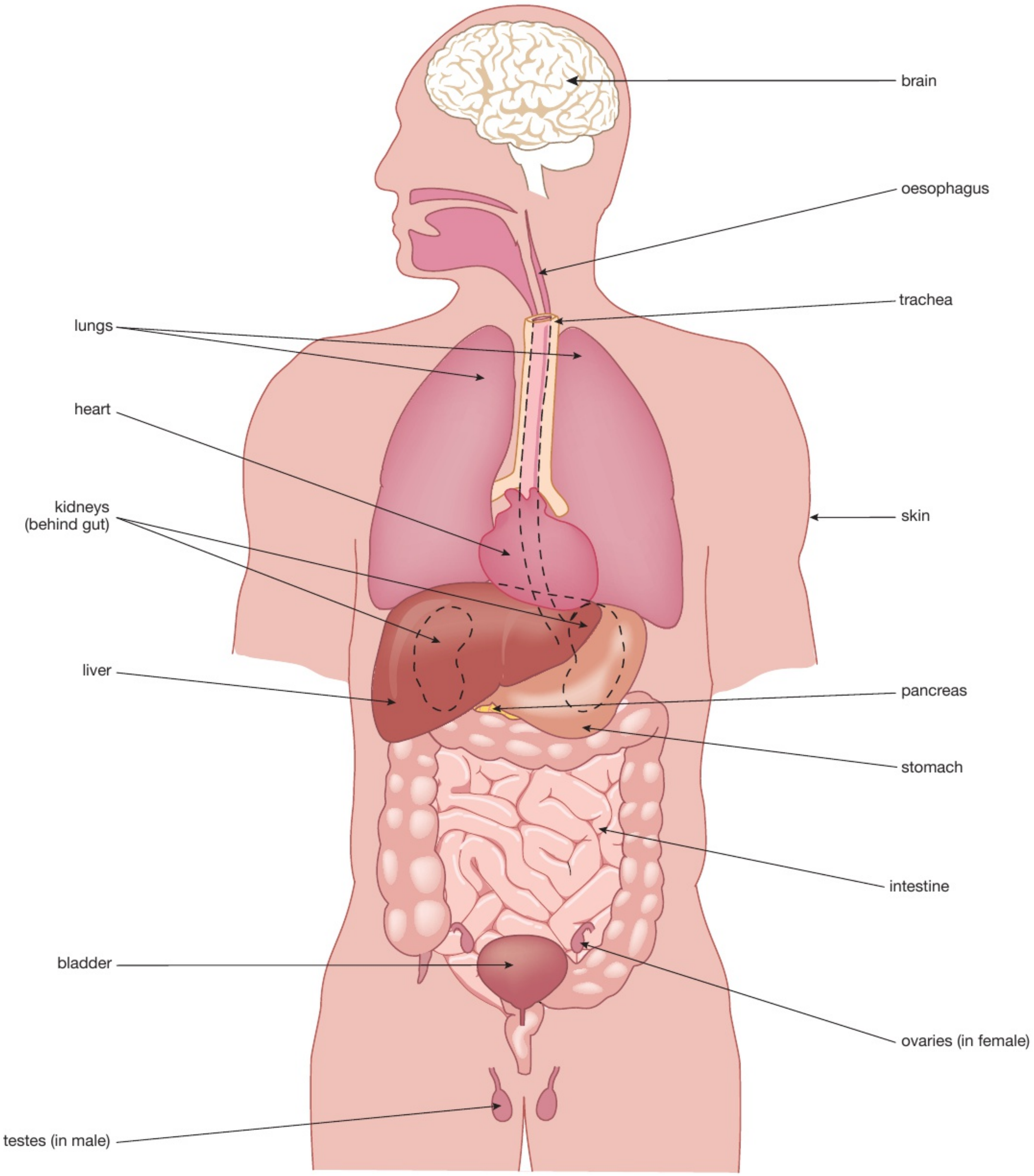
▼ Table 1.2 The three types of muscle cell.

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:

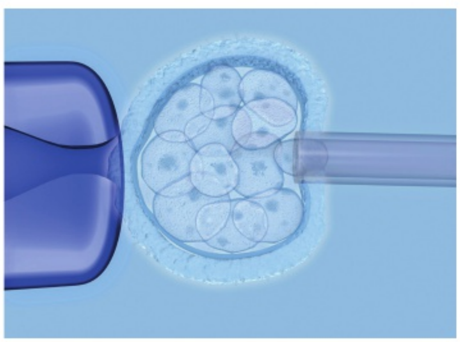
- **Embryonic stem cells** are found in the early stage of development of the embryo. Embryonic stem cells can differentiate into any type of body cell.
- **Adult stem cells** are found in certain adult tissues, such as bone marrow, skin, and the lining of the intestine. They have lost the ability to 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.

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.

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.

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.



▲ 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.

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**.

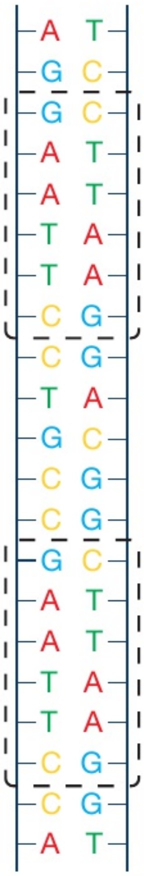


Figure 1.20 Part of a DNA molecule containing the base sequence G-A-A-T-T-C. Notice that the sequence is present on both strands, but running in opposite directions.

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.

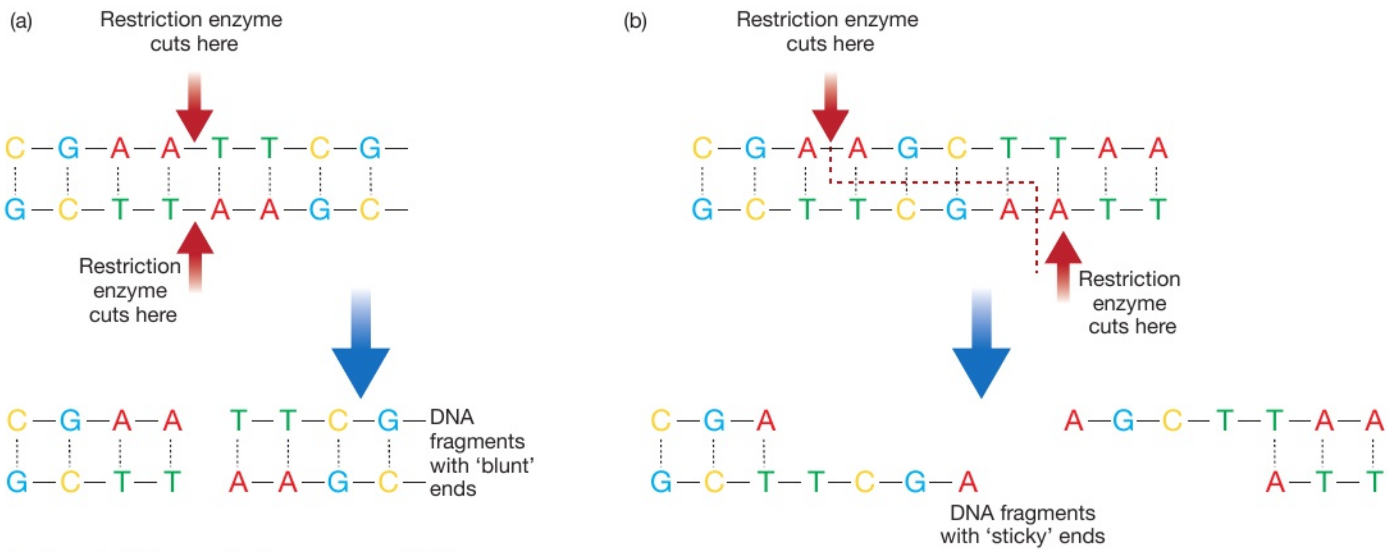
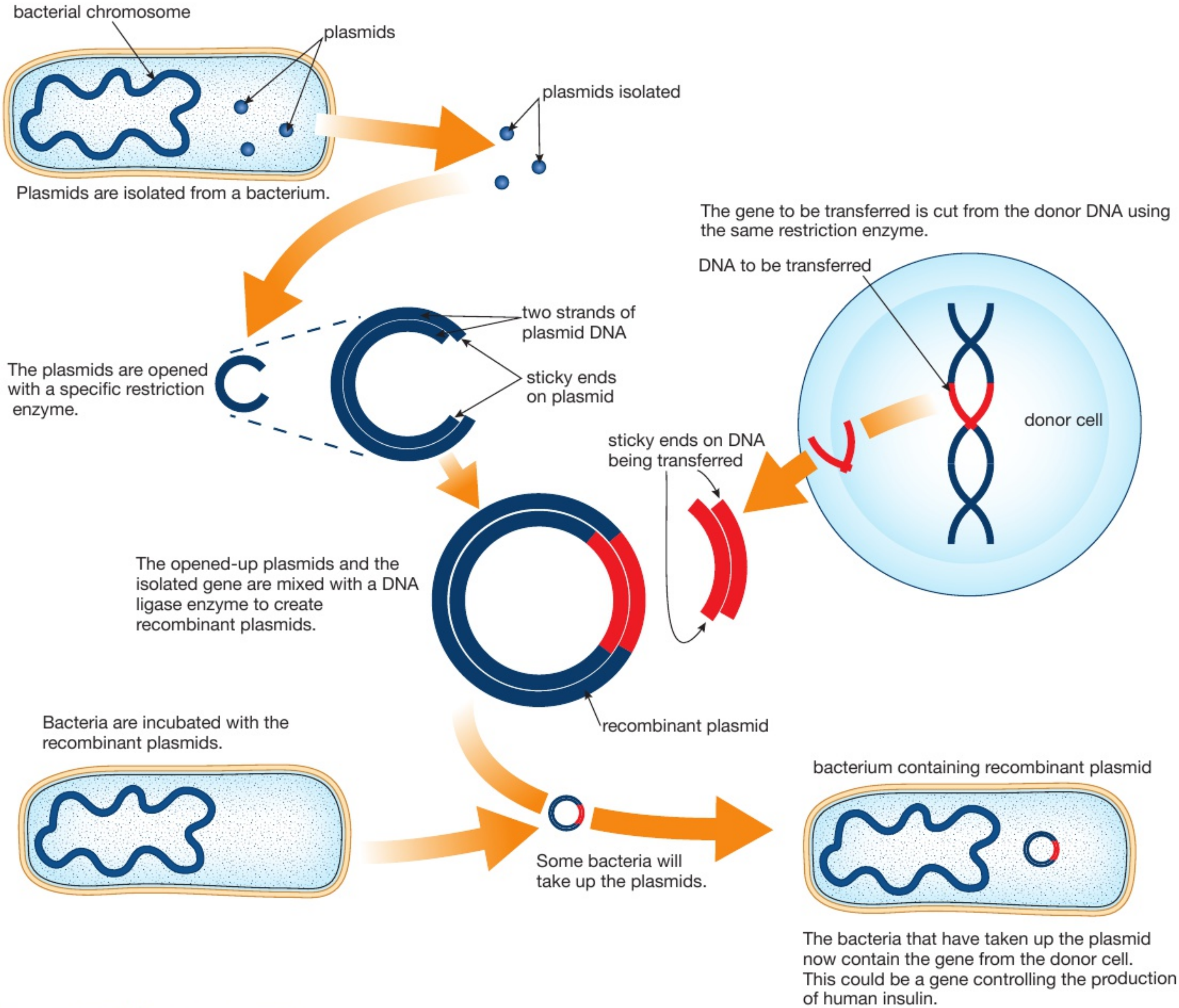


Figure 1.21 How restriction enzymes cut DNA.

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 dm^3 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.

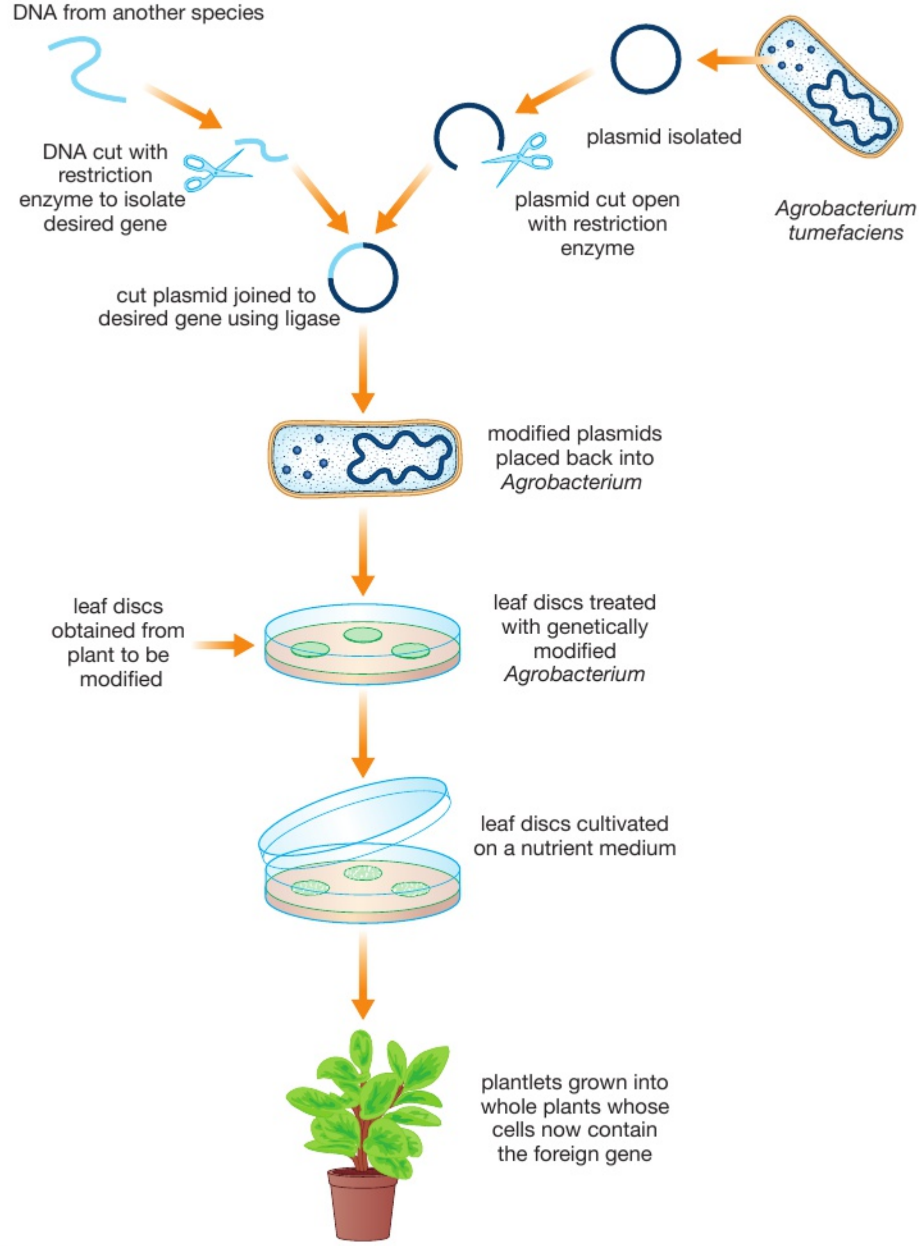
- **Hepatitis B vaccine:** Yeast cells can be genetically modified to produce the surface proteins (**antigens**) of the hepatitis B virus. These proteins are used to make a vaccine against hepatitis B. When the vaccine is injected into a patient, their body makes antibodies against the proteins, so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

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.

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).

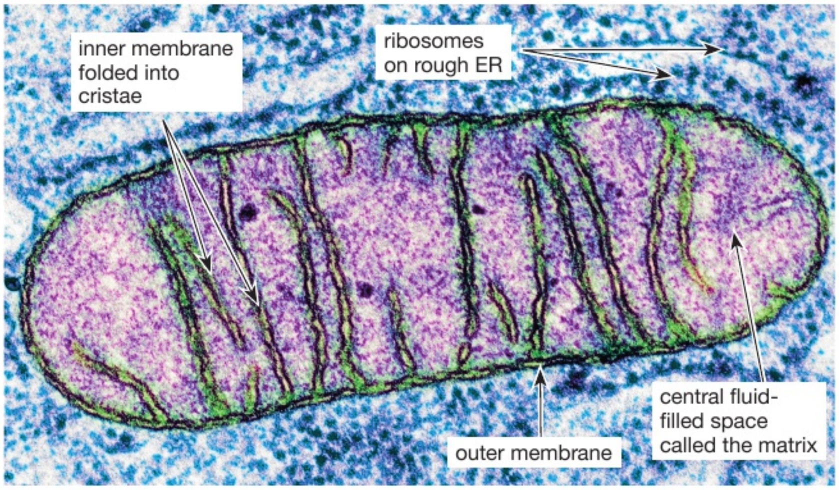


Figure 1.26 An electron micrograph of a mitochondrion (magnification × 60 000). The mitochondrion has two membranes – an outer membrane separating its contents from the rest of the cytoplasm and an inner membrane forming folds called cristae. The reactions of aerobic respiration take place in the mitochondria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