Unit
2A

Chapter 3
Cells exchange materials

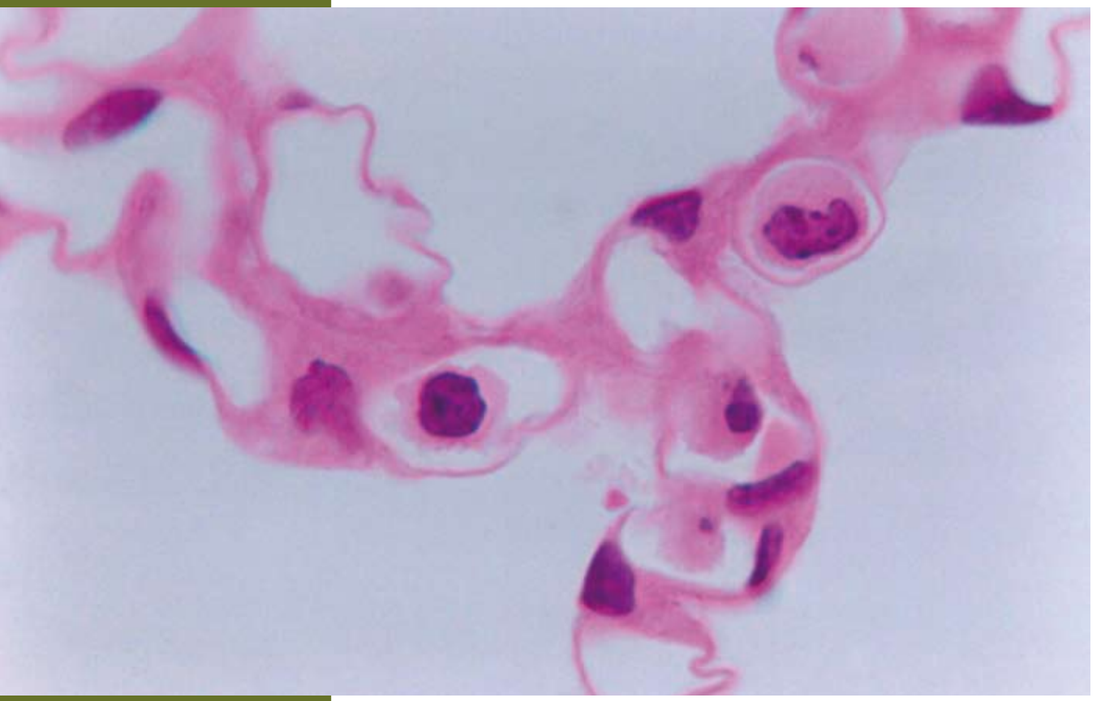


Figure 3.1 Cells come in a variety of shapes and sizes, such as these striated muscle fibres

Outcome

Students understand how the structure and function of the human body maintain life processes.

In achieving this outcome, students:

- understand relationships between structure and function in the body
- understand the mechanisms of life processes
- understand how the body maintains balance.

Essential content

Cells carry out life functions including exchange of materials. Collect and use simple mathematical calculations on data.

All living organisms, including humans, are made up of cells and materials produced by cells. This is a basic principle of biology and is known as the **cell theory**.

The structure of an organism and the way in which it functions results from the activities of all of its cells. There are trillions of cells in the human body and everything we do results from the combined and coordinated actions of our cells. Each cell, however, is an individual unit with requirements that must be satisfied if it is to function normally.

Cell requirements

For normal functioning, cells in the human body need to be in a stable environment—they must have a continual supply of the materials they need and continual removal of materials they produce.

The immediate environment of a cell is the fluid that surrounds it, known as the **tissue fluid** or **extracellular fluid**. Even cells that appear to be very close together when observed under a microscope will have a thin layer of fluid between them. There is continual exchange of materials between cells and the tissue fluid.

Body systems work together to make sure that the cellular environment is kept constant. This is called **homeostasis**. The cells are maintained at a constant temperature and the concentration of fluids around the cell is kept constant.

To carry out their functions cells need certain substances that must be taken in from the tissue fluid. As substances are processed within the cell, materials are then produced which must be removed from the cell. Different cells will have different requirements and different products depending on the particular role of the cell. There are, however, certain substances that all cells require and which all cells produce.

All cells need oxygen for respiration. It is the process of respiration that releases the energy needed for the cell's activities. Also needed for respiration is glucose, the substance that is broken down to release energy. Respiration produces carbon dioxide and water, substances that cannot be allowed to accumulate in the cell.

Many cells produce substances that will be used elsewhere in the body, such as hormones and enzymes. Many other wastes are produced in addition to carbon dioxide. All of these products must be released into the tissue fluid.

How substances get into and out of cells

Each cell is surrounded by a **cell membrane** (see Fig. 3.8), also called a **plasma membrane**. The cell membrane separates the cell contents from the external environment. It is very thin—too thin to be seen clearly with a light microscope. The cell membrane represents a barrier between the cell and its surroundings. Substances that enter or leave the cell must pass through the cell membrane, so the membrane is very important in determining which substances will get into or out of a cell.

Cell membranes are described as being **differentially permeable**. They allow certain ions and molecules to pass through, but restrict the movement of others. (Differentially permeable membranes may also be called semipermeable or selectively permeable membranes.)

Materials may pass through a cell membrane in a number of different ways. Some transfer mechanisms are **passive processes** which means that the cell's energy, which comes from respiration, does not have to be used. **Active processes** require the cell's energy for the transfer to occur.

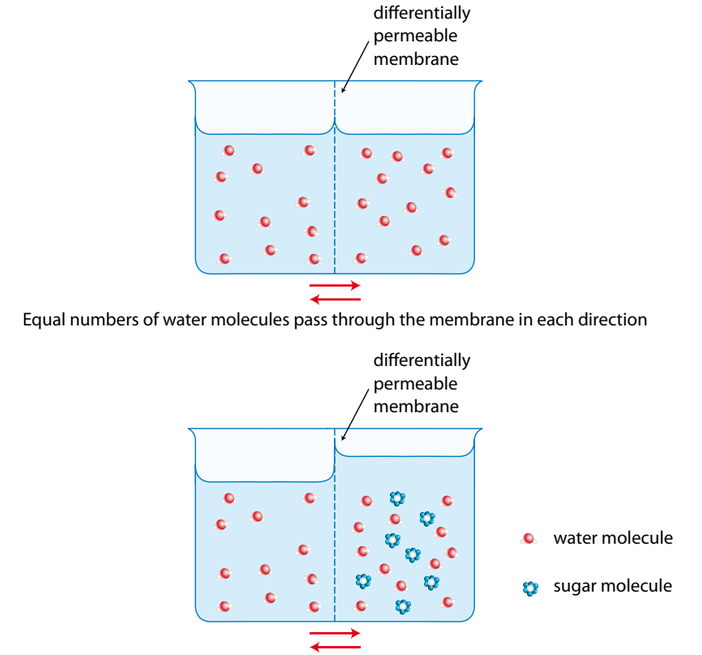


Figure 3.4 Process of osmosis

Water moves into, or out of, a cell depending on the water concentration on each side of the cell membrane.

Carrier-mediated transport

In **carrier-mediated transport** there are special proteins in the cell membrane that bind to an ion or molecule and help it to move across the membrane. The carrier proteins are specific; they usually only work with one particular ion or molecule.

Facilitated diffusion

Many substances that a cell needs, such as glucose and amino acids, are too large to fit through the cell membrane by simple diffusion. Such substances can be moved through the membrane by carrier proteins in a process called **facilitated diffusion**. Facilitated diffusion is a passive process that moves substances from a higher concentration on one side of the membrane to a lower concentration on the opposite side.

The transported substance binds to a carrier protein, which then changes shape, moving the molecule to the opposite side of the cell membrane where it is released (Fig. 3.5). Facilitated diffusion is different from simple diffusion because once all the carrier molecules are in use the process cannot go any faster. With simple diffusion there is no such limitation; the greater the concentration difference, the faster the rate of diffusion.

All cells transport glucose through their membranes by facilitated diffusion.

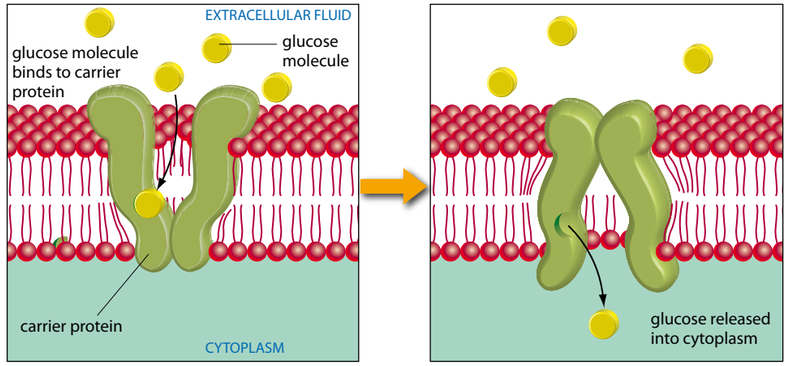


Figure 3.5 Process of facilitated diffusion

Active transport

As its name states, active transport is an active process requiring cellular energy. Although energy expenditure is a disadvantage for the cell, the big advantage of active transport is that it can move substances across the membrane against the concentration gradient; that is, from lower concentration to higher concentration. **Active transport** is therefore the movement of substances across the cell membrane against the concentration gradient using cellular energy. Carrier proteins are involved in a similar way to facilitated diffusion. Substances such as amino acids and certain ions that are already more concentrated inside the cell can still be absorbed. In the same way some less concentrated materials can be exported from the cell.

EXTENSION

A mechanism called the sodium–potassium pump is an example of active transport that occurs in the plasma membrane of all cells. The sodium–potassium pump uses about half of the energy that you consume each day.

Investigate:

- how the sodium–potassium pump works
- the functions of the sodium–potassium pump.

Vesicular transport

Vesicular transport is an active process in which materials move into or out of the cell enclosed as vesicles. **Vesicles** are bubble-like structures surrounded by a membrane. They can form at the cell membrane or can fuse with the membrane. Solid particles, droplets of fluid or many molecules at a time can be moved across the membrane in vesicles. Vesicular transport is also known as **bulk transport** because large quantities of materials can be transported in this way.

There are two basic types of vesicular transport—endocytosis and exocytosis.

Endocytosis

Endocytosis is when a cell surrounds some extracellular material with a fold of the cell membrane. The enfolding membrane then breaks away, and the material is enclosed within the cell in the form of a small membrane-bound vesicle (Fig. 3.6).

Although cells differ greatly in size, shape and the particular function they perform, they all carry out chemical processes that keep the organism alive.

All the chemical reactions that take place in cells, and therefore in the organism of which the cells are a part, are referred to as **metabolism**. Metabolism is made up of two different types of chemical reaction: reactions in which large molecules are broken down to smaller ones are known as **catabolism**; reactions in which small molecules are built up into larger ones are referred to as **anabolism**. Catabolic reactions release energy whereas anabolic reactions require energy. Thus, metabolism is concerned with maintaining a balance between energy release and energy utilisation.

Enzymes and metabolism

Enzymes are proteins that allow chemical reactions to take place at normal body temperature. Without enzymes these reactions would be too slow to be of any use to the body. Most chemical reactions require energy to get started. For example, when striking a match the friction between the match head and the striking surface of the box releases enough energy to begin the process of combustion and the match catches alight. The heat energy from the match can then be used to start other chemical reactions such as burning a candle.

The energy needed to get a chemical reaction started is called **activation energy**. Enzymes reduce the activation energy needed to begin a reaction. Thus, when our cells 'burn' glucose in respiration the reaction can occur at body temperature instead of at the normally higher temperature of combustion. Not only do enzymes decrease the activation energy but they also allow the reactions to proceed at a rate that suits the body's requirements.

Enzymes are specific. Each enzyme will combine with only one particular substrate and is involved in only one specific reaction. This occurs because the enzyme and its substrate have characteristics that are complementary to one another; that is, the enzyme and substrate have a shape and structure that allow them to fit together. The situation has been likened to a lock and key: the key (enzyme) is shaped to fit the lock (substrate), and only the correct key will open the lock (Fig. 4.2). The part of the enzyme molecule that combines with the substrate is called the **active site**.

Figure 4.2 Enzyme action: the lock and key model

Factors affecting enzyme activity

A number of factors influence the activity of enzymes and the rates of chemical reactions in which they are involved.

- The higher the concentration of enzyme, the faster the rate of a chemical reaction. By regulating the type and amount of enzymes present, the body is able to control which reactions occur and the rate at which they proceed.
- Temperature influences enzyme activity. The rate of most chemical reactions increases as temperature increases. This is true of most enzyme reactions but only within a limited temperature range. Because they are proteins, the structure of enzymes changes beyond about 45–50°C and the enzyme is inactivated. The temperature at which an enzyme works best is called the *optimum temperature*. For most enzymes in the human body this is between 30°C and 40°C.
- Enzymes are very sensitive to the pH of the medium in which a reaction is taking place. Each enzyme has an optimum pH at which it will work most effectively.
- Many enzymes require the presence of certain ions or non-protein molecules before they will catalyse a reaction. Such substances are called **co-factors**.

Cellular respiration

Cellular respiration is one of the most important metabolic processes in any cell. It is the process by which organic molecules, taken in as food, are broken down in the cells to release energy for the cell's activities—activities such as movement of the cell, uptake of materials from the surroundings, or production and secretion of new chemical compounds.

The term 'respiration' is often used loosely to mean breathing, and so the chemical process of respiration is referred to as cellular respiration (or sometimes *tissue respiration* or *internal respiration*). The process goes on in every cell in the body, to supply each cell with the energy it needs.

Glucose formed from the breakdown of complex carbohydrates, amino acids formed from protein breakdown, and fatty acids and glycerol from lipids (Fig. 4.3 on pages 40–41) can all be broken down in cellular respiration to release energy. However, the main food material utilised is glucose and discussion here will therefore be confined to the respiration of glucose.

Respiration can be summarised as an equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

This summary makes respiration look like a simple reaction. However, the breakdown of glucose to carbon dioxide and water actually involves over 20 separate reactions, which occur in a series, one after the other. At each step an intermediate compound is formed, and each step is catalysed by a different enzyme. Small amounts of energy are released as the reactions proceed. In this way release of energy is controlled rather than happening all at once.

Energy from cellular respiration

In the complete breakdown of glucose to carbon dioxide and water, about 60% of the available energy is released as heat. Cells cannot utilise heat energy, but it is important in keeping the body temperature constant. Heat is continually lost to the environment, so a continual supply of heat is necessary in order to maintain body temperature.

The remaining energy from cellular respiration is used to form a compound called **adenosine triphosphate**, or **ATP** (Fig. 4.4 on page 42). ATP is formed when an inorganic phosphate group is joined to a molecule of **adenosine diphosphate (ADP)**. The phosphate groups in ATP are joined by high-energy chemical bonds (Fig. 4.5). Some of the energy from cellular respiration is stored in the bond between the ADP molecule and the third phosphate group. This bond is more easily broken than the bond between the first and second phosphate groups.

To complete the breakdown of glucose, the two pyruvic acid molecules produced in glycolysis must enter a mitochondrion, where enzymes are available to allow two more series of reactions to occur. The first of these, known as the Krebs cycle (or citric acid cycle), results in the formation of two more ATP molecules from the two pyruvic acid molecules. The second series of reactions, known as the electron transport system, can produce up to 34 molecules of ATP from the products of one molecule of glucose. Thus, aerobic respiration of one molecule of glucose has the potential to generate 38 molecules of ATP—two from glycolysis, two from the Krebs cycle and up to 34 from the electron transfer mechanism. This can be represented as:

$$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O$$

$$38\ ADP + 38\ P \rightarrow 38\ ATP$$

A summary of the processes of anaerobic and aerobic respiration is given in Figure 4.7.

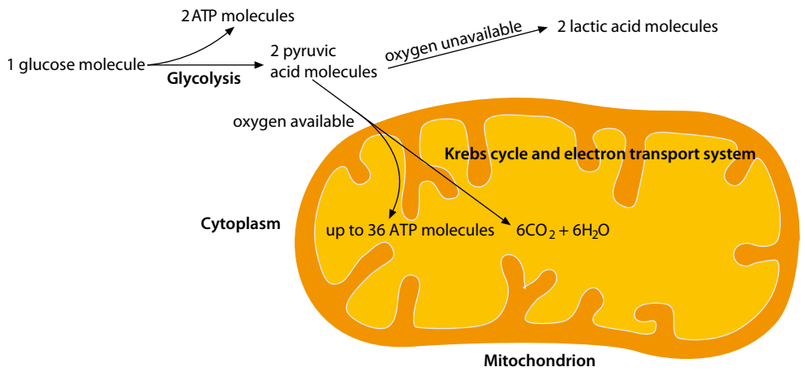


Figure 4.7 A summary of the processes of anaerobic and aerobic respiration in a cell

A yield of 38 ATP molecules from the energy contained in one molecule of glucose is the theoretical maximum. The actual ATP yield is often lower than this. Since the reactions of aerobic respiration take place in the mitochondria, and because aerobic respiration releases about 95% of the energy needed to keep a cell alive, the mitochondria are often known as the powerhouses of the cell.

Energy use by the cell

Cells need the energy that is temporarily stored in the ATP molecule for a variety of processes. These are summarised in Figure 4.8.

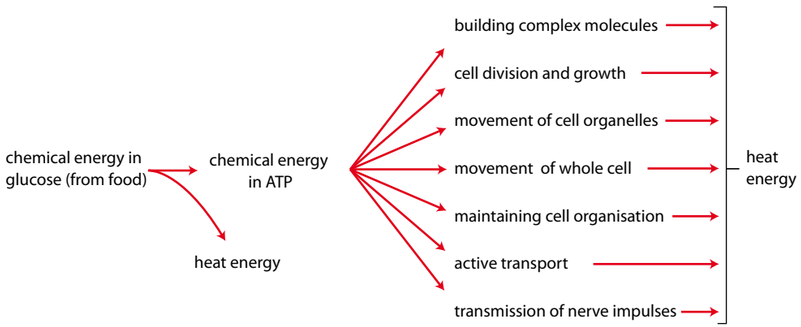


Figure 4.8 Uses of energy in the cell

From each of the chemical reactions involved in cellular processes, a certain amount of heat is produced. Only about 40% of the energy released in respiration is incorporated into ATP; the other 60% is lost as heat. Therefore, energy must be continually consumed in the form of food to replace that lost as heat and that utilised for other purposes.

As mentioned previously, ATP may be used to transfer energy from cellular respiration to reactions involving the build-up of large molecules. Such reactions require energy to form the chemical bonds that hold the parts of the molecule together. For example, when lactic acid is recombined with oxygen in the liver to form glucose, or when glucose molecules are joined to form glycogen, the energy required comes from the breakdown of ATP to ADP. Similarly, energy for the build-up of proteins, lipids and other molecules is transferred from cellular respiration by ATP (Fig. 4.9).

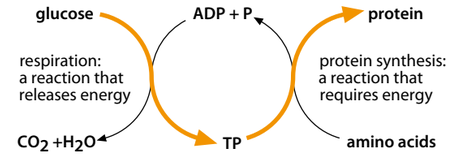


Figure 4.9 ATP transfers energy from reactions that release energy to reactions that require energy

Synthesis

Synthesis is the combining of small molecules to make larger molecules (it means the same as anabolism). In the example of energy transfer by ATP, shown in Figure 4.9, protein is synthesised from amino acids. In a similar way, glycogen molecules can be synthesised by joining glucose units together and glucose can be synthesised from lactic acid and oxygen. Synthesis requires both matter and energy—matter in the form of small molecules to be joined, and energy to form the chemical bonds that hold the smaller units together.

Protein synthesis

The synthesis of proteins is a very important part of cell metabolism. Proteins make up much of the structural material of cells, and chemical reactions are controlled by special proteins called enzymes.

The types of proteins a cell can make are determined by **genes**, which are parts of the DNA molecules in the nucleus. Each DNA molecule contains thousands of genes and therefore holds the information needed to make thousands of different proteins.

DNA molecules consist of two chains of alternating sugar and phosphate groups linked by pairs of nitrogen bases (Fig. 4.10). There are four different bases: adenine (A), thymine (T), cytosine (C) and guanine (G). It is the order in which these four bases occur in a DNA molecule that makes up the genetic code. Each sequence of three bases is the code for a particular amino acid. For example, the sequence CAG (cytosine-adenine-guanine) is a DNA code for the amino acid valine; CGA is a code for alanine; and TTC is a code for lysine. Thus, if the bases in part of a DNA molecule occurred in the order CAG-CGA-TTC, then the amino acids valine, alanine and lysine would be assembled in that order in any protein made using instructions from that part of the DNA molecule.

Although the DNA is in the nucleus, the amino acids are actually joined together at the ribosomes in the cytoplasm of the cell (Fig. 4.11). The code for each amino acid is taken from the DNA in the nucleus to the ribosomes in the cytoplasm by a special messenger molecule called RNA (ribonucleic acid). RNA differs from DNA in that it is usually only a single strand of sugars and phosphates, and the bases thus occur singly.

4. Adolf Hitler and a number of high-ranking Nazi leaders committed suicide by taking cyanide. Find out what effect cyanide has on cells. Why is cyanide a lethal poison?
5. Vitamin C is essential for the production of the hormone collagen in the body. A deficiency of vitamin C leads to scurvy, a disease that causes loss of teeth and easy bruising, especially around the joints. Suggest why an inability to make sufficient collagen results in the symptoms of scurvy.
6. Figure 4.14 is a model showing how an enzyme is involved in a chemical reaction. Which letter corresponds to the enzyme, substrate, active site, enzyme–substrate complex and product?

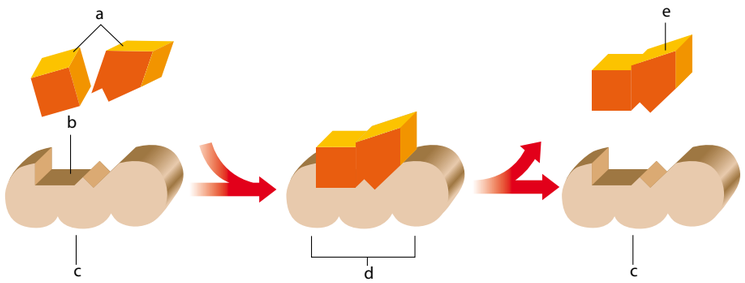


Figure 4.14

Chapter 5
New cells

Unit
2A

Outcome

Students understand how the structure and function of the human body maintain life processes.

In achieving this outcome, students:

- understand relationships between structure and function in the body
- understand the mechanisms of life processes
- understand how the body maintains balance.

Students understand the mechanisms of reproduction and inheritance and their relationship with human variability and evolution.

In achieving this outcome, students:

- understand the mechanisms of reproduction

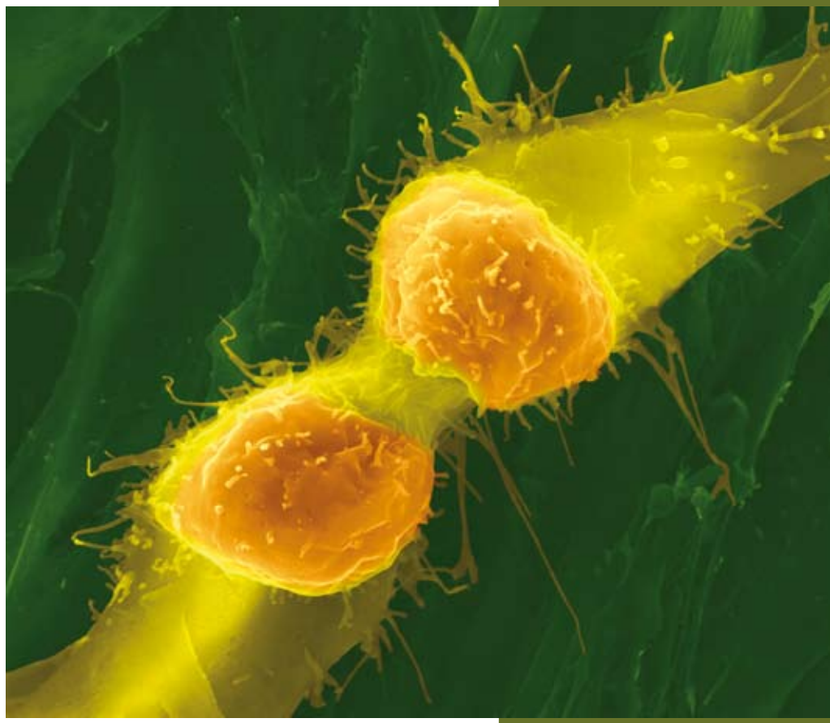


Figure 5.1 New cells can be formed by dividing in two, like these muscle cells

Essential content

Cells carry out essential functions including … cell division (mitosis and meiosis).

New cells are produced from existing cells. In this chapter we examine the process by which cells are produced for growth, maintenance and repair of the body—**mitosis**. We also look at the process by which cells are produced for sexual reproduction—**meiosis**.

Mitosis

Cells reproduce so that organs can grow larger, but even in a mature person cells are constantly reproducing. Cells that are damaged, worn out or diseased must be replaced. Some human cells have a very short life span. Those lining the intestines live for less than two days; on the other hand, many nerve cells in the brain last for the lifetime of the person. Generally, the more wear and tear on a cell, the shorter the life span. Table 5.1 shows the life span of a number of different types of human cells.

Table 5.1 Average life span of human cells

Cell type	Average life span (days)
Intestinal lining	1.3
Stomach lining	2.9
Tongue surface	3.5
Cervix (neck of the uterus)	5.7
Cornea of the eye	7
Epidermis of the abdomen	7
Epidermis of the cheek	10
Alveolus (air sac in the lung)	21
White blood cell	depending on type and activity, from hours to years
Red blood cell	120
Kidney	170
Bladder lining	330
Liver	450
Nerve cell in brain	29 200+ (80+ years)

The cell cycle

Cell division provides replacements for the dying cells and also new cells in parts of the body where growth is occurring. The **cell cycle** is the cycle of events from one cell division to the next.

The phases of the cell cycle (Fig. 5.2) are:

- **G_1 phase** or first growth phase. This is the phase between cell division and the duplication of the cell's DNA. During this phase the cell produces new proteins, grows and carries out its normal tasks for the body.
- **S phase** or synthesis phase. During this phase the cell's DNA replicates so that two identical sets of DNA molecules are produced.
- **G_2** phase or second growth phase. This relatively short phase involves preparation for cell division. The enzymes that control cell division are synthesised and replication of the centrioles (see Fig. 3.8) is completed.
- **M phase** or mitotic phase. During this phase the cell divides into two daughter cells.

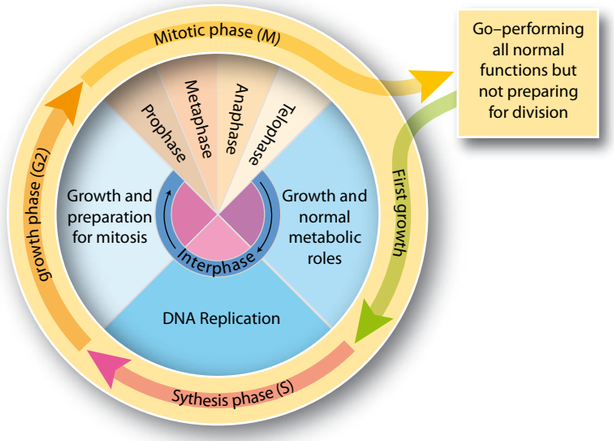


Figure 5.2 The cell cycle

After cell division cells may continue the cycle and enter the G_1 phase again. Some cells leave the cell cycle and stop dividing for days, years or even for the rest of the person's life. These cells are in the **G_0 phase**.

The phases of mitosis

As we saw in Chapter 4, the DNA in the nucleus of a cell determines the types of protein that the cell can make. Since proteins are the structural materials of a cell, the DNA determines the structure of a cell, and since the body is made up of cells, the DNA therefore determines the structure of the whole body. DNA not only determines the structure of each cell, and of the body, but also the way each cell functions and the way in which the body functions. Enzymes are proteins so the DNA determines which enzymes a cell will make. In this way the DNA determines the chemical reactions that go on inside and outside the body cells. Thus, it is vital that when a cell reproduces each new cell gets *exactly* the same DNA as the parent cell. In other words, each new cell must contain the same genetic information as the parent cell. This is achieved by division of the nucleus known as **mitosis**. Mitosis ensures that each body cell receives exactly the same hereditary material (DNA) as that possessed by its parent cell.

For convenience, biologists describe mitosis in four stages (Table 5.2): prophase, metaphase, anaphase and telophase. However, the process is continuous; it does not occur in steps.

Table 5.2 A summary of cell division

Stage	Events occurring
Interphase	DNA molecules duplicate.
Prophase	Nucleoli disappear; nuclear membrane breaks down; centrioles migrate to opposite poles; chromosomes appear as pairs of chromatids; spindle forms.
Metaphase	Chromosomes line up on the spindle at the equator of the cell.
Anaphase	Centromeres divide; chromosomes move to opposite ends of the spindle.
Telophase	Spindle disappears; nuclear membranes and nucleoli form; centrioles divide; chromosomes uncoil and disappear; during this phase cytokinesis occurs.
Cytokinesis	Cytoplasm of the cell divides into two, each with a nucleus

Diploid cells are designated *2n*, where *n* stands for the number of different types of chromosomes. The diploid number for humans is 46. In gametes, only *one* of each type of chromosome is present, and these cells are described as **haploid**. Haploid cells have half the usual number of chromosomes and are designated *n*. The haploid number for humans is therefore 23.

Figure 5.5 illustrates the stages of meiosis using a cell with the diploid number of eight. This is for convenience, as the diagram would be very complicated if all 46 chromosomes were shown. The first division of meiosis involves the reduction of the chromosome number and includes similar stages to those discussed for mitosis earlier in this chapter.

The first meiotic division: a reduction in the chromosome number

During the **prophase** of the first division of meiosis, the chromosomes become visible as long threads. Each has already duplicated and consists of a pair of chromatids. These chromosomes gradually move, so that the members of a pair of homologous chromosomes come to lie alongside each other throughout their entire length (see Fig. 5.5). The chromosomes then shrink and thicken as the DNA becomes more tightly coiled. As each chromosome consists of two chromatids, each chromosome pair appears as *four* strands, frequently all twisted together.

While the chromosomes are shortening and thickening, a spindle forms, stretching between the poles of the cell. The paired chromosomes move towards the spindle fibres until, at **metaphase**, they are arranged on the spindle fibres across the centre, or equator, of the cell (see Fig. 5.5). At **anaphase**, the pairs of homologous chromosomes move apart, with *one* member of each *pair* (consisting of two chromatids) moving to one pole of the cell while the other member of the pair moves to the opposite pole. During this stage the centromeres do not divide and the pairs of chromatids remain intact. Instead, the members of each *pair* of homologous chromosomes separate, resulting in 23 chromosomes moving to each pole of the cell. Thus, in the first division of meiosis, the number of chromosomes assembling at each pole of the cell is half the number present in the original cell. This is a major difference from the events occurring in mitosis. In mitosis, the centromeres divide so that each chromatid becomes a chromosome. Forty-six chromosomes then migrate to each pole of the cell.

During **telophase**, the cytoplasm may divide into two parts.

The second division: the separation of chromatids

At the beginning of the second division the two cells are haploid, each containing half the number of parental chromosomes. Each daughter cell with its 23 chromosomes undergoes the same sequence of events, in which the chromatids separate and migrate to either end of the cell. This results in four haploid cells being formed (see Fig. 5.5).

During the **second prophase**, a new spindle forms at each end of the original spindle and usually at right angles to the original. The chromosomes in each cell gradually move towards the equator, so that at **metaphase** they are arranged on the new spindle. The centromeres then divide, so that each chromatid is now a separate chromosome. These new chromosomes migrate to opposite poles of the cell (**anaphase**). Nuclear membranes begin to form and the cytoplasm starts to divide (**telophase**). By the end of the second division four new cells have been formed, each with half the number of chromosomes of the original cell.

Table 5.3 summarises the differences between the two types of cell division—mitosis and meiosis.

Table 5.3 A comparison of mitosis and meiosis

Mitosis	Meiosis
One duplication of chromosomes and one nuclear division	One duplication of chromosomes and two nuclear divisions
Produces two diploid cells	Produces four haploid cells
Homologous chromosomes do not pair	Homologous chromosomes pair off
Chromatids separate so that each new cell gets a complete set of daughter chromosomes	At first meiotic division members of homologous pairs separate so that new cells get a haploid set of chromosomes. At second division chromatids separate giving four haploid cells
Chromosomes do not change their genetic make-up	Genetic make-up of chromosomes can be changed through crossing over
Produces new cells for growth and repair	Produces haploid gametes for sexual reproduction

An important feature of meiosis occurs during the prophase of the first meiotic division. When the homologous chromosomes are paired the chromatids may break and exchange segments. This is called **crossing over** (see Fig. 5.7). Crossing over creates new combinations of genes so that the chromosomes passed on to the offspring are not the same as those inherited from the parents.

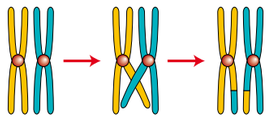


Figure 5.7 Crossing over

Working scientifically

Activity 5.1 Modelling mitosis and cytokinesis

Simulate the sequence of events that occurs in mitosis and division of the cytoplasm.

You could draw a cell in pencil on a large sheet of paper, or you could draw on a laminated board or benchtop with a whiteboard marker. Items such as strings of beads could be used for chromosomes/chromatids. Use different lengths to represent different chromosomes. The centromeres holding the chromatids together could be paperclips or elastic bands. (Have only three chromosomes in your cell so that the process does not become too complicated.)

Work through the phases of mitosis. As changes occur in the cell, lines on your paper or board can be erased and replaced.

Activity 5.2 Modelling meiosis

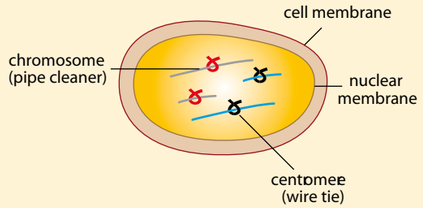
You will need

For each pair: A large sheet of paper or laminated board or benchtop to write on; 8 pipe cleaners (4 each of two different colours); wire ties; pencil or whiteboard marker; eraser

What to do

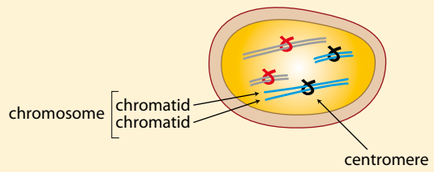
1. Draw a large outline on your paper to represent one cell from an organism produced by sexual reproduction.
2. Inside the cell draw a smaller circle representing the nucleus.
3. Your cell is to have a chromosome number of 4 ($2n = 4$). Since the cell has resulted from sexual reproduction, two of the chromosomes will have come from the female parent and two from the male.
4. The pipe cleaners will be your chromosomes. To model the chromosomes have two pipe cleaners of one colour to represent those from one parent and two of another colour for chromosomes from the other parent.
5. Make the chromosomes that are the same colour different lengths so that you can distinguish them.
6. Place a wire tie around each chromosome to represent the centromere.
7. Place the four chromosomes in the nucleus of your cell. Your cell should now look like Figure 5.8.

Figure 5.8 The model cell



8. At some time before meiosis begins the chromosomes form duplicates of themselves. When the chromosomes become visible at the start of meiosis they are already duplicated. Duplicate your chromosomes by adding an extra pipe cleaner to each. The duplicates are joined at the centromere (the wire tie). Your cell will now look like Figure 5.9.

Figure 5.9 The model cell with duplicated chromosomes



9. When meiosis begins the nuclear membrane breaks down. Erase the line in your cell that represents the nucleus.
10. The chromosomes now pair off. Arrange your 'chromosomes' in pairs. The members of each pair will be of equal length but of a different colour.
11. A spindle now forms stretching from one end of the cell to the other. Draw the spindle in your cell.
12. The pairs of chromosomes arrange themselves on the equator of the spindle attached to the spindle fibres by their centromeres. Arrange your chromosomes.
13. The pairs of chromosomes now separate, with one member of each pair going to each end of the cell. Separate your chromosomes.

14. Complete the first division of meiosis by erasing the spindle and drawing nuclear membranes around each of your groups of chromosomes. Now divide your cell into two.
15. For the second meiotic division the nuclear membranes break down and a new spindle forms in each cell at right angles to the first. Erase the nuclear membranes and draw the spindles.
16. The chromosomes arrange themselves on the equator of each spindle. Arrange the chromosomes.
17. The centromeres divide and the chromatids have now become chromosomes. Separate your chromatids (which are now daughter chromosomes).
18. The daughter chromosomes separate to opposite ends of each cell.
19. Nuclear membranes form around each group of chromosomes. Draw the nuclear membranes.
20. The cytoplasm of each cell divides into two. Draw in the new cell membranes.
21. You should now have four gametes each with the haploid number of chromosomes. Redraw your original cell and place four chromosomes in the nucleus. Model the process of meiosis again but do so without looking at any of the instructions given above.

Studying your results

1. What is meant by a *model* in science?
2. With respect to the colours of the chromosomes, how many different types of gametes did your model produce? How many colour combinations are possible?
3. Suppose the chromosome number of your cell was six. How many combinations of chromosomes would now be possible?
4. Humans have a chromosome number of 46. What can you say about the number of possible chromosome combinations in human eggs and sperm?
5. Why is it that children of the same parents do not inherit identical chromosomes (except for identical twins)?

REVIEW QUESTIONS

1. **(a)** What is the cell cycle?
   (b) Describe the four phases of the cell cycle.
2. Explain the difference between a chromatid and a chromosome.
3. What are homologous chromosomes?
4. Draw up a table (similar to Table 5.2) to summarise, in your own words, the events of mitosis. Include in your table a column with a drawing showing the changes taking place at each stage.
5. Name three places where mitosis would be occurring in the body of a healthy adult human. Explain why cell reproduction is necessary in these places.
6. How does mitosis ensure that each daughter cell has exactly the same genetic information as the parent cell?
7. **(a)** Using a series of diagrams to illustrate your answer, describe the events that take place during the process of meiosis.
   (b) Why is meiosis essential in sexually reproducing organisms?
   (c) Distinguish between haploid and diploid cells.
8. Explain how crossing over can change the combination of genes on a chromosome.

APPLY YOUR KNOWLEDGE

1. Skeletal muscle cells and most nerve cells remain in phase G_0 of the cell cycle. What does this tell you about the likelihood of such cells dividing?
2. What do you think would happen if the spindle fibres did not form in a cell that was undergoing mitosis?
3. Explain the major differences between the processes of mitosis and meiosis. Relate the differences to the type of cells produced by each process.
4. How many chromosomes are present in a cell in a human ovary during each of the following stages of meiosis?
   (a) prophase of the first meiotic division
   (b) at the end of telophase of the first division
   (c) prophase of the second meiotic division
   (d) at the end of telophase of the second division