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Student Book

Edexcel International GCSE Human Biology

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Contents

About this book

This book has several features to help you with International GCSE Human Biology.

Introduction
Each chapter has a short introduction to help you start thinking about the topic and let you know what is in the chapter.

End of Chapter Checklists
These lists summarise the material in the chapter. They could also help you to make revision notes because they form a list of things that you need to revise. (You need to check your specification to find out exactly what you need to know.)

Chapter 3: Food and Digestion

We need food for three main reasons:

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

Food is essential for life. The nutrients obtained from it are used in many different ways by the body. This chapter looks at the different kinds of food, and how the food is broken down by the digestive system and absorbed into the blood, so that it can be carried to all the tissues of the body.

A balanced diet

The food that we eat is called our **diet**. No matter what you like to eat, if your body is to work properly and stay healthy, your diet must include five groups of food substances – **carbohydrates, lipids, proteins, minerals** and **vitamins** – as well as **water** and **fibre**. Food should provide you with all of these substances, but they must also be present in the *right* amounts. A diet that provides enough of these substances and in the correct proportions to keep you healthy is called a **balanced diet** (Figure 3.1). We will deal with each type of food in turn, to find out about its chemistry and the role that it plays in the body.

Figure 3.1 *A balanced diet contains all the types of food the body needs, in just the right amounts*

Carbohydrates

Carbohydrates only make up about 5% of the mass of the human body, but they have a very important role. They are the body's main 'fuel' for supplying cells with energy. Cells release this energy by oxidising a sugar called **glucose**, in the process called cell respiration (see Chapter 1). Glucose and other sugars are one sort of carbohydrate.

Glucose is found naturally in many sweet-tasting foods, such as fruits and vegetables. Other foods contain different sugars, such as the fruit sugar called **fructose**, and the milk sugar, **lactose**. Ordinary table sugar, the sort some people put in their tea or coffee, is called **sucrose**. Sucrose is the main sugar that is

The chemical formula for glucose is $C_6H_{12}O_6$. Like all carbohydrates, glucose contains only the elements carbon, hydrogen and oxygen. The 'carbo' part of the name refers to carbon, and the 'hydrate' part refers to the fact that the hydrogen and oxygen atoms are in the ratio two to one, as in water (H_2O).

Margin Boxes
The boxes in the margin give you extra help or information. They might explain something in a little more detail or guide you to linked topics in other parts of the book.

End of Chapter Checklist

You should now be able to:

- understand that division of a diploid cell by mitosis produces two cells that contain identical sets of chromosomes
- understand a simple outline description of the four stages of mitosis
- recall that the diploid number of chromosomes in humans is 46 and the haploid number is 23
- understand that division of a cell by meiosis produces four cells, each with half the number of chromosomes, and that this results in the formation of genetically different haploid gametes
- understand that mitosis occurs during growth, repair, asexual reproduction and cloning
- understand that variation within a species can be genetic, environmental or a combination of both

Questions

1 Cells can divide by mitosis or by meiosis
   a) Give one similarity and two differences between the two processes
   b) Do cancer cells divide by mitosis or meiosis? Explain your answer.
   c) Why is meiosis sometimes called reduction division?

2 Some cells divide by mitosis, others divide by meiosis. For each of the following examples, say whether mitosis or meiosis is involved. In each case, give a reason for your answers
   a) Cells in the testes dividing to form sperm
   b) Cells in the lining of the small intestine dividing to replace cells that have been lost
   c) Cells in the bone marrow dividing to form red blood cells and white blood cells
   d) A zygote dividing to form an embryo

3 Variation in organisms can be caused by the environment as well as by the genes they inherit. For each of the following examples, state whether the variation described is likely to be genetic, environmental or both. In each case, give a reason for your answers.

   a) Humans have brown, blue or green eyes
   b) Half the human population is male, half is female
   c) Cuttings of hydrangea plants grown in soils with different pH values develop flowers with slightly different colours
   d) People in some families are more at risk of heart disease than people in other families. However, not every member of the 'high risk' families has a heart attack and some members of the 'low risk' families do

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

Questions
There are short questions at the end of each chapter. These help you to test your understanding of the material from the chapter.

Chapter 1: Life Processes

The human body is composed of countless millions of units called **cells**. In an animal like a human there are many different types of cells, with different structures. They are specialised so that they can carry out particular functions in the body. Despite all the differences, there are basic features that are the same in most cells.

The cells of humans and other organisms share common features. In this chapter you will read about these features and look at some of the processes that keep cells alive.

Cell structure

For over 160 years scientists have known that animals and plants are made from cells. All cells contain some common parts, such as the nucleus, cytoplasm and cell membrane. Some cells have structures missing, for instance red blood cells lack a nucleus, which is unusual. The first chapter in a biology textbook usually shows diagrams of 'typical' plant and animal cells. In fact, there is really no such thing as a 'typical' cell. Humans, for example, are composed of hundreds of different kinds of cells from nerve cells to blood cells, skin cells to liver cells. What we really mean by a 'typical' cell is a general diagram that shows all the features that you might find in most cells, without them being too specialised. Figure 1.1 shows the features you would expect to see in many animal and plant cells. However, not all these are present in all cells – the parts of a plant which are not green do not have chloroplasts, for example.
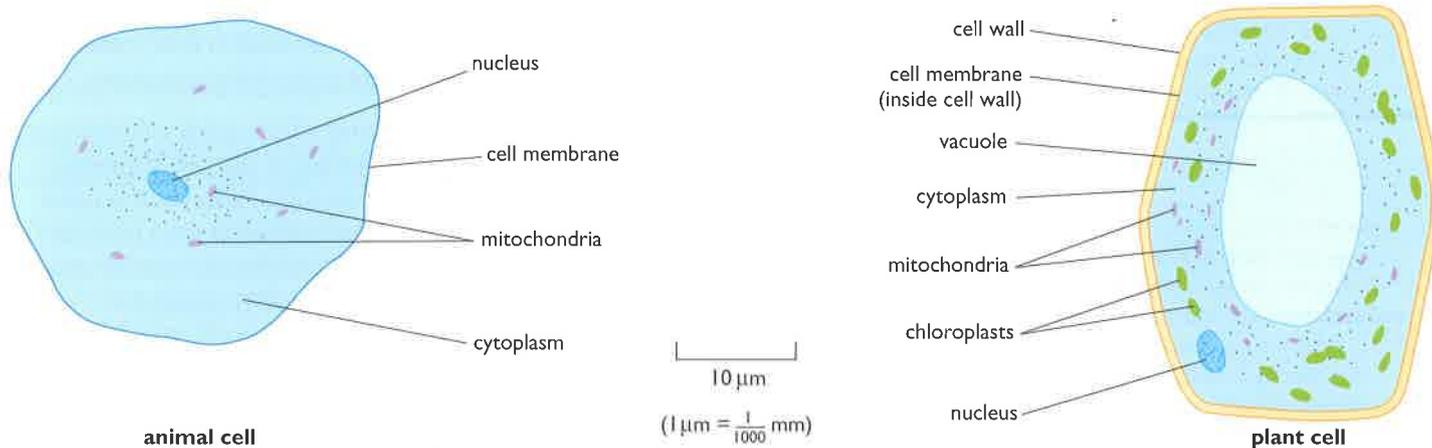
Figure 1.1 *The structure of a 'typical' animal and plant cell.*

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 but is a complex material made of many different structures. You can't 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 structures, which are called **organelles** (Figure 1.2).
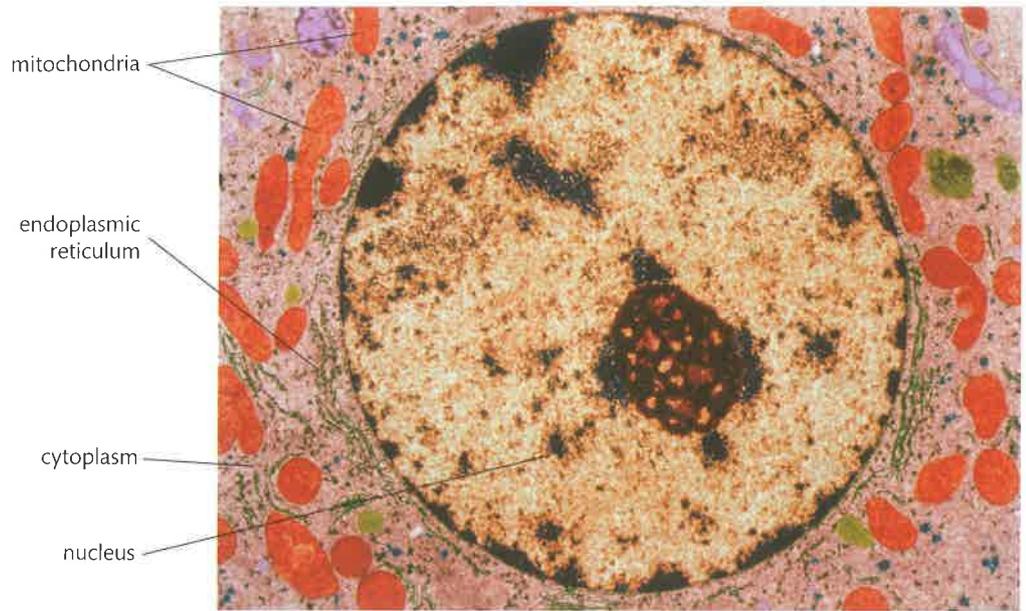
Figure 1.2 *The organelles in a cell can be seen using an electron microscope.*

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 cells) which carry the genetic material, or **genes**. You will find out much more about genes and inheritance later in the book. Genes control the activities in the cell by determining which proteins the cell can make. One very important group of proteins found in cells is **enzymes** (see below). Enzymes control chemical reactions that go on in the cytoplasm.

All cells are surrounded by a **cell surface membrane** (often simply called the cell membrane). 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 (the membrane is **permeable** to them). In fact, the cell membrane *controls* which substances pass in either direction. We say that it is **selectively** permeable.

There are other membranes inside a cell. Throughout the cytoplasm is a network of membranes called the **endoplasmic reticulum**. In places the endoplasmic reticulum is covered with minute granules called **ribosomes**. These are the organelles where proteins are assembled.

One organelle that is found in the cytoplasm of all living cells is the **mitochondrion** (plural **mitochondria**). There are many mitochondria in cells that need a lot of energy, such as muscle or nerve cells. This gives us a clue to the role of mitochondria. They carry out some of the reactions of **respiration** (see page 6) to release energy that the cell can use. In fact, most of the energy from respiration is released in the mitochondria.

All of the structures we have seen so far are found in both animal and plant cells. However, some structures are only ever found in plant cells. There are three in particular – the cell wall, a permanent vacuole and chloroplasts.

The **cell wall** is a layer of non-living material that is found outside the cell membrane of plant cells. It is made mainly of a carbohydrate called **cellulose**, although other chemicals may be added to the wall in some cells. Cellulose is a tough material that helps the cell keep its shape. This is why plant cells have a fairly fixed shape. Animal cells, which lack a cell wall, tend to be more variable in shape.

Plant cells often have a large central space surrounded by a membrane, called a **vacuole**. This vacuole is a permanent feature of the cell. It is filled with a watery liquid called **cell sap**, a store of dissolved sugars, mineral ions and other solutes. Animal cells can have small vacuoles, but they are only temporary structures.

Cells of the green parts of plants, especially the leaves, have another very important organelle, the **chloroplast**. Chloroplasts absorb light energy to make food in the process of photosynthesis. The chloroplasts are green because they contain a green pigment called **chlorophyll**.

Figure 1.3 shows some animal and plant cells seen through the light microscope.

Enzymes: controlling reactions in the cell

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

genes → proteins (enzymes) → catalyse reactions

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

What hasn't been mentioned is why enzymes are needed at all. This is because the temperatures inside organisms are low (e.g. the human body temperature is about 37 °C) and without catalysts, most of the reactions that happen in cells would be far too slow to allow life to go on. Only when enzymes are present to speed them up do the reactions take place quickly enough.

It is possible for there to be thousands of different sorts of enzymes because they are made of proteins, and protein molecules have an enormous range of structures and shapes (see Chapter 4). The molecule that an enzyme acts on is called its **substrate**. Each enzyme has a small area on its surface called the **active site**. The substrate attaches to the active site of the enzyme. The reaction then takes place and products are formed. When the substrate joins up with the active site, it lowers the energy needed for the reaction to start, allowing the products to be formed more easily.

The substrate fits into the active site of the enzyme rather like a key fitting into a lock. That is why this is called the 'lock and key' model of enzyme action (Figure 1.4).
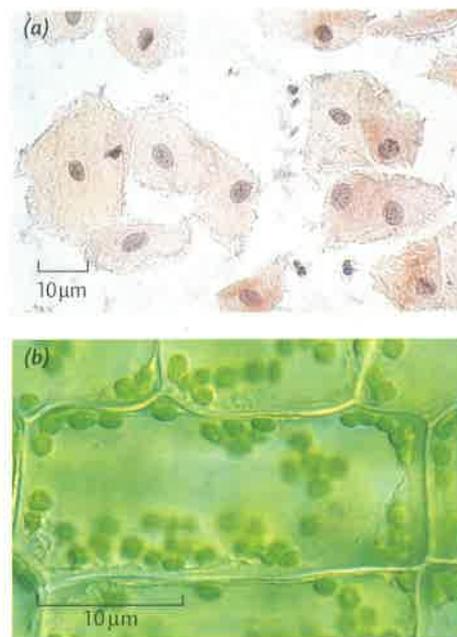
Figure 1.3 *(a) Cells from the lining of a human cheek. (b) Cells from the photosynthetic tissue of a leaf.*

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

You have probably heard of the enzymes involved in digestion of food. They are secreted by the intestine onto the food to break it down. They are called **extracellular** enzymes, which means 'outside cells'. However, most enzymes stay *inside* cells – they are **intracellular**. You will read about digestive enzymes in Chapter 3.
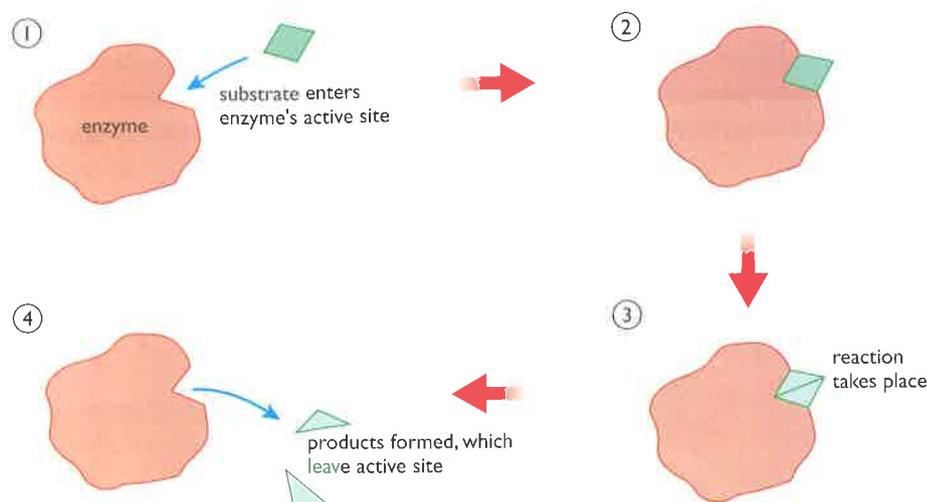
Figure 1.4 *Enzymes catalyse reactions at their active site. This acts like a 'lock' to the substrate 'key'. The substrate fits into the active site, and products are formed. This happens more easily than without the enzyme – so enzymes act as catalysts.*

Notice how, after it has catalysed the reaction once, the enzyme is free to act on more substrate molecules.

Factors affecting enzymes

Temperature affects the action of enzymes. This is easiest to see as a graph, where we plot the rate of the reaction controlled by an enzyme against the temperature (Figure 1.5).

Enzymes in the human body have evolved to work best at about body temperature (37 °C). The graph (Figure 1.5) shows this, because the peak on the curve happens at about this temperature. In this case 37 °C is called the **optimum temperature** for the enzyme.

As the enzyme is heated up to the optimum temperature, increasing temperature speeds up the rate of reaction. This is because higher temperatures give the molecules of enzyme and substrate more energy, so they collide more often. More collisions mean that the reaction will take place more frequently. However, above the optimum temperature another factor comes into play. Enzymes are made of protein, and proteins are broken down by heat. From 40 °C upwards, the heat destroys the enzyme. We say that it is **denatured**. You can see the effect of denaturing when you boil an egg. The egg white is made of protein, and turns from a clear runny liquid into a white solid as the heat denatures the protein.

Temperature is not the only factor that affects an enzyme's activity. The rate of reaction may also be increased by raising the concentration of the enzyme or the substrate. The pH of the surroundings is also important. The pH inside cells is around neutral (pH 7) and not surprisingly, most enzymes have evolved to work best at this pH. At extremes of pH either side of neutral, the enzyme activity decreases, as shown by Figure 1.6. The pH at which the enzyme works best is called the **optimum pH** for that enzyme. Either side of the optimum, the pH affects the structure of the enzyme molecule, and changes the shape of its active site so that the substrate will not fit into it so well.
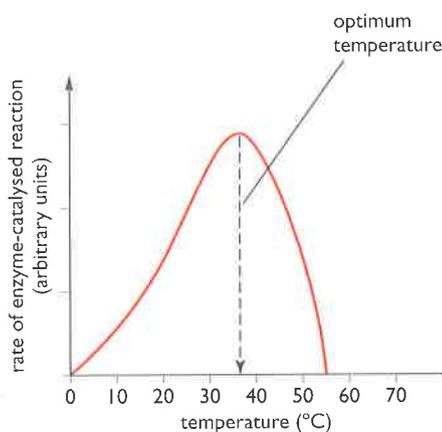
Figure 1.5 *Effect of temperature on the action of an enzyme.*

'Optimum' temperature means the 'best' temperature, in other words the temperature at which the reaction takes place most rapidly.

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

Although most enzymes work best at a neutral pH, a few have an optimum below or above pH 7. The stomach produces hydrochloric acid, which makes its contents very acidic (see Chapter 4). Most enzymes stop working at a low pH like this, but the stomach makes an enzyme called pepsin which has an optimum pH of about 2, so that it is adapted to work well in these unusually acidic surroundings.
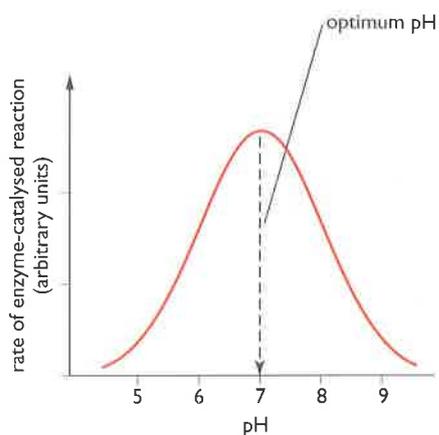
Figure 1.6 *Most enzymes work best at a neutral pH.*

An investigation into the effect of temperature on the activity of amylase

The digestive enzyme amylase breaks down starch into the sugar maltose. If the speed at which the starch disappears is recorded, this is a measure of the activity of the amylase.

Figure 1.7 shows apparatus which can be used to record how quickly the starch is used up.
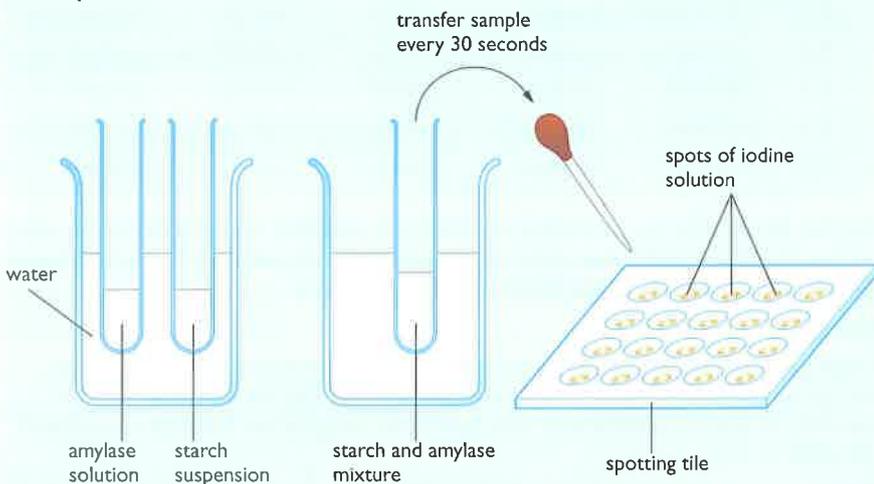
Figure 1.7 *Steps 1–6.*

Spots of iodine are placed into the depressions on the spotting tile. 5 cm³ of starch suspension is placed in one boiling tube, using a syringe, and 5 cm³ of amylase solution in another tube, using a different syringe. The beaker is filled with water at room temperature. Both boiling tubes are placed in the beaker of water for 5 minutes, and the temperature recorded.

The amylase solution is then poured into the starch suspension, leaving the tube containing the mixture in the water bath. Immediately, a small sample of the mixture is removed from the tube with a pipette and added to the first drop of iodine on the spotting tile. The colour of the iodine is recorded.

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

The experiment is repeated, maintaining the water bath at different temperatures between 20 °C and 60 °C. A set of results is shown in the table below.

| Time (min) | Colour of mixture at different temperatures | | | | |
	20 °C	30 °C	40 °C	50 °C	60 °C
0	blue-black	blue-black	blue-black	blue-black	blue-black
0.5	blue-black	blue-black	brown	blue-black	blue-black
1.0	blue-black	blue-black	yellow	blue-black	blue-black
1.5	blue-black	blue-black	yellow	blue-black	blue-black
2.0	blue-black	blue-black	yellow	brown	blue-black
2.5	blue-black	blue-black	yellow	brown	blue-black
3.0	blue-black	blue-black	yellow	brown	blue-black
3.5	blue-black	blue-black	yellow	yellow	blue-black
4.0	blue-black	blue-black	yellow	yellow	blue-black
5.5	blue-black	blue-black	yellow	yellow	blue-black
6.0	blue-black	brown	yellow	yellow	blue-black
6.5	blue-black	brown	yellow	yellow	blue-black
7.0	blue-black	yellow	yellow	yellow	blue-black
7.5	blue-black	yellow	yellow	yellow	brown
8.0	blue-black	yellow	yellow	yellow	brown
8.5	brown	yellow	yellow	yellow	yellow
9.0	brown	yellow	yellow	yellow	yellow
9.5	yellow	yellow	yellow	yellow	yellow
10.0	yellow	yellow	yellow	yellow	yellow

The rate of reaction can be calculated from the time taken for the starch to be used up. For example, at 50 °C the starch was all gone after 3.5 minutes. The rate is found by dividing the volume of the starch (5 cm³) by the time:

Rate = 5/3.5 = 1.4 cm³/min

Plotting a graph of rate against temperature should produce a curve something like the one shown in Figure 1.6. Try this, either using the results in the table, or you may be able to provide your own results, by carrying out a similar experiment yourself.

If the curve doesn't turn out quite like the one in Figure 1.6, can you explain why this may be? How could you improve the experiment to get more reliable results?

How the cell gets its energy

To be able to carry out all the processes needed for life, a cell needs a source of energy. It gets this by breaking down food molecules to release the stored chemical energy that they contain. This process is called **cell respiration**. Many people think of respiration as meaning 'breathing', but although there are links between the two processes, the biological meaning of respiration is very different.

The process of respiration happens in all the cells of our body. Oxygen is used to oxidise food, and carbon dioxide (and water) are released as waste products. The

main food oxidised is glucose (a sugar). Glucose contains stored chemical energy that can be converted into other forms of energy that the cell can use. It is rather like burning a fuel to get the energy out of it, except that burning releases all its energy as heat, whereas respiration releases some heat energy, but most is trapped as energy in other chemicals. This chemical energy can be used for a variety of purposes, such as:

- contraction of muscle cells, producing movement
- active transport of molecules and ions (see page 9)
- building large molecules, such as proteins
- cell division.

The overall reaction for respiration is:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} \quad (\text{+ energy})$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad (\text{+ energy})$$
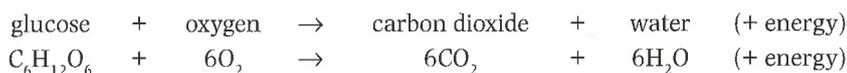
This is called **aerobic** respiration, because it uses oxygen. It is not just carried out by human cells, but by all animals and plants and many other organisms. It is important to realise that the equation above is just a *summary* of the process. It actually takes place gradually, as a sequence of small steps that release the energy of the glucose in small amounts. Each step in the process is catalysed by a different enzyme. The later steps in the process are the aerobic ones, and these release the most energy. They happen in the cell's mitochondria.

ATP: the energy 'currency' of the cell

You have seen that respiration gives out energy, while other processes such as protein synthesis and active transport use it up. Cells must have a way of passing the energy from respiration across to these other processes that need it. The way that they do this is through a substance called **adenosine triphosphate**, or **ATP**, which is present in all cells.

ATP is made up from an organic molecule (adenosine) attached to three inorganic phosphate groups (hence triphosphate). ATP can be broken down in the cell, losing a phosphate and producing a similar molecule called adenosine diphosphate, or ADP (Figure 1.8a).

When this reaction happens, energy is released, and is available for the processes that demand energy.

(a) When energy is needed ATP is broken down into ADP and phosphate ( ):
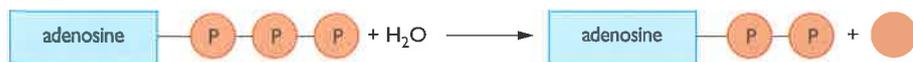
(b) During respiration ATP is made from ADP and phosphate:

Figure 1.8 *ATP is the energy 'currency' of the cell.*

More ATP is made during the reactions of respiration, using the energy from the oxidised glucose to add a phosphate back onto ADP.

Because of its role, ATP is described as the energy 'currency' of a cell. It exchanges chemical energy between the process that produces the energy (respiration) and the processes that use it up.

The reactions of respiration are not 100% efficient, and some energy is not used to make ATP, but instead is lost as heat. Animals such as mammals and birds use this heat to keep their bodies warm, maintaining a constant body temperature (see Chapter 8).
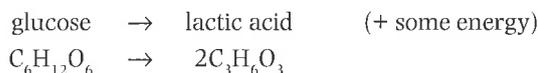
Yeasts can also respire anaerobically. Yeasts are single-celled fungi. When they are deprived of oxygen, they break down sugars into ethanol (alcohol) and carbon dioxide. This is used in commercial processes such as making wine and beer, and baking bread.

There are some situations where cells can respire *without* using oxygen. This is called **anaerobic** respiration. In anaerobic respiration, glucose is not completely broken down, and less energy is released. However, the advantage of anaerobic respiration is that it can occur in situations where oxygen is in short supply, for example in contracting muscle cells.

If muscles are overworked, the blood cannot reach them fast enough to deliver enough oxygen for aerobic respiration. This happens when a person does a 'burst' activity, such as a sprint, or quickly lifting a heavy weight. The glucose is broken down into a substance called **lactic acid**:

$$\text{glucose} \quad \rightarrow \quad \text{lactic acid} \qquad (+ \text{ some energy})$$
$$C_6H_{12}O_6 \quad \rightarrow \quad 2C_3H_6O_3$$

It used to be thought that lactic acid was a cause of cramps in overused muscles. It is now known that this is not true. Muscle cramp may happen, but it is caused by various other factors resulting from the intense exercise, and is not due to the lactic acid.

Anaerobic respiration provides enough energy to keep the overworked muscles going for a short period, but continuing the 'burst' activity makes lactic acid build up in the bloodstream. When the period of exercise is over, the lactic acid is oxidised aerobically. This uses oxygen. It takes about 30 minutes of rest for all the lactic acid to be used up (see Chapter 4, page 66). The volume of oxygen needed to completely oxidise the lactic acid that builds up in the body during anaerobic respiration is called the **oxygen debt**.

Movements of materials in and out of cells

Cell respiration shows the need for cells to be able to take in certain substances from their surroundings, such as glucose and oxygen, and get rid of others, such as carbon dioxide and water. As you have seen, the cell surface membrane is selective about which chemicals can pass in and out. There are three main ways that molecules and ions can move through the membrane. They are diffusion, active transport and osmosis.

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

Many substances can pass through the membrane by **diffusion**. Diffusion happens when a substance is more concentrated in one place than another. For example, if the cell is making carbon dioxide by respiration, the concentration of carbon dioxide inside the cell will be higher than outside. This difference in concentration is called a **concentration gradient**. The molecules of carbon dioxide are constantly moving about because of their kinetic energy. The cell membrane is permeable to carbon dioxide, so they can move in either direction through it.

Because there is a higher concentration of carbon dioxide molecules inside the cell than outside, over time more molecules will move from inside the cell to outside than move in the other direction. We say that there is a *net* movement of the molecules from inside to outside (Figure 1.9).

carbon dioxide molecules
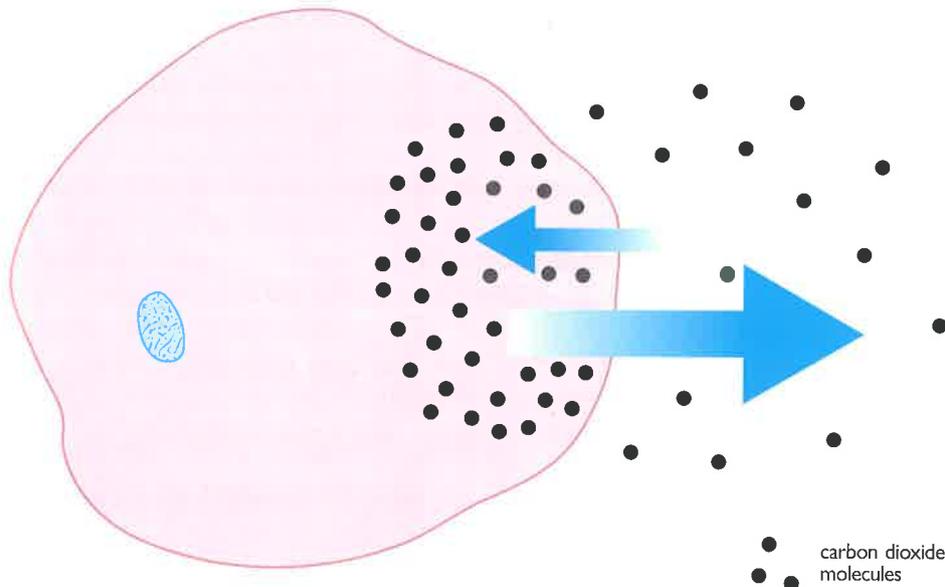
Figure 1.9 *Carbon dioxide is produced by respiration, so its concentration builds up inside the cell. Although the carbon dioxide molecules diffuse in both directions across the cell membrane, the overall (net) movement is out of the cell, down the concentration gradient.*

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

Diffusion happens because of the kinetic energy of the particles. It does not need an 'extra' source of energy from respiration. However, sometimes a cell needs to take in a substance when there is very little of that substance outside the cell, in other words *against* a concentration gradient. It can do this by another process, called **active transport**. The cell uses energy from respiration to take up the particles, rather like a pump uses energy to move a liquid from one place to another. In fact, biologists usually speak of the cell 'pumping' ions or molecules in or out. The pumps are large protein molecules located in the cell membrane. An example of a place where this happens is in the human small intestine, where some glucose in the gut is absorbed into the cells lining the intestine by active transport.

The rate of diffusion of a substance is greater at higher temperatures. The reason for this is that a higher temperature will give the diffusing particles more kinetic energy.

The rate of diffusion of a substance is increased by:
- a steep concentration gradient
- high temperatures
- a large surface area to volume ratio.

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

Demonstration of diffusion in a jelly

Agar jelly has a consistency similar to the cytoplasm of a cell. Like cytoplasm, it has a high water content. Agar can be used to show how substances diffuse through a cell.

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

A Petri dish is prepared which contains a 2 cm deep layer of agar jelly, dyed purple with potassium permanganate. Three cubes of different sizes are cut out of the jelly, with side lengths 2 cm, 1 cm and 0.5 cm.

The cubes are carefully dropped, at the same time, into a beaker of dilute hydrochloric acid (Figure 1.10)

The time is taken for each cube to turn colourless.

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

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

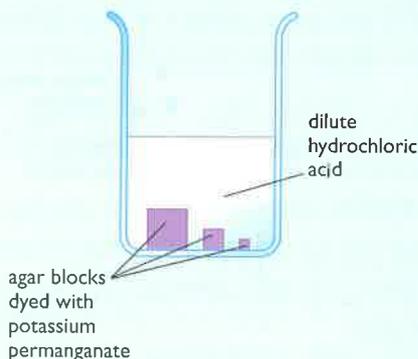It may be possible for you to try this experiment, using similar apparatus.

Figure 1.10 *Investigating diffusion in a jelly.*

Earlier in this chapter we called the cell membrane 'selectively' permeable. This term is sometimes used when describing osmosis. It means that the membrane has control over which molecules it lets through (e.g. by active transport). 'Partially' permeable just means that small molecules such as water and gases can pass through, while larger molecules cannot. Strictly, the two words are not interchangeable, but they are often used this way in biology books.

Osmosis in cells is the net movement of water from a dilute solution to a more concentrated solution across the partially permeable cell membrane.

Water moves across cell membranes by a special sort of diffusion, called **osmosis**. Osmosis happens when the total concentrations of all dissolved substances inside and outside the cell are different. Water will move across the membrane from the more dilute solution to the more concentrated one. Notice that this is still obeying the rules of diffusion – the water moves from where there is a higher concentration of *water* molecules to a lower concentration of *water* molecules. Osmosis can only happen if the membrane is permeable to water but not to some other solutes. We say that it is **partially** permeable.

One artificial partially permeable membrane is called Visking tubing. This is used in kidney dialysis machines. Visking tubing has microscopic holes in it, which let small molecules like water pass through (it is *permeable* to them) but is not permeable to some larger molecules, such as the sugar sucrose. This is why it is called 'partially' permeable. You can show the effects of osmosis by filling a Visking tubing 'sausage' with concentrated sucrose solution, attaching it to a capillary tube and placing the Visking tubing in a beaker of water (Figure 1.11).

The level in the capillary tube rises as water moves from the beaker to the inside of the Visking tubing. This movement is due to osmosis. You can understand what's happening if you imagine a highly magnified view of the Visking tubing separating the two liquids (Figure 1.12).
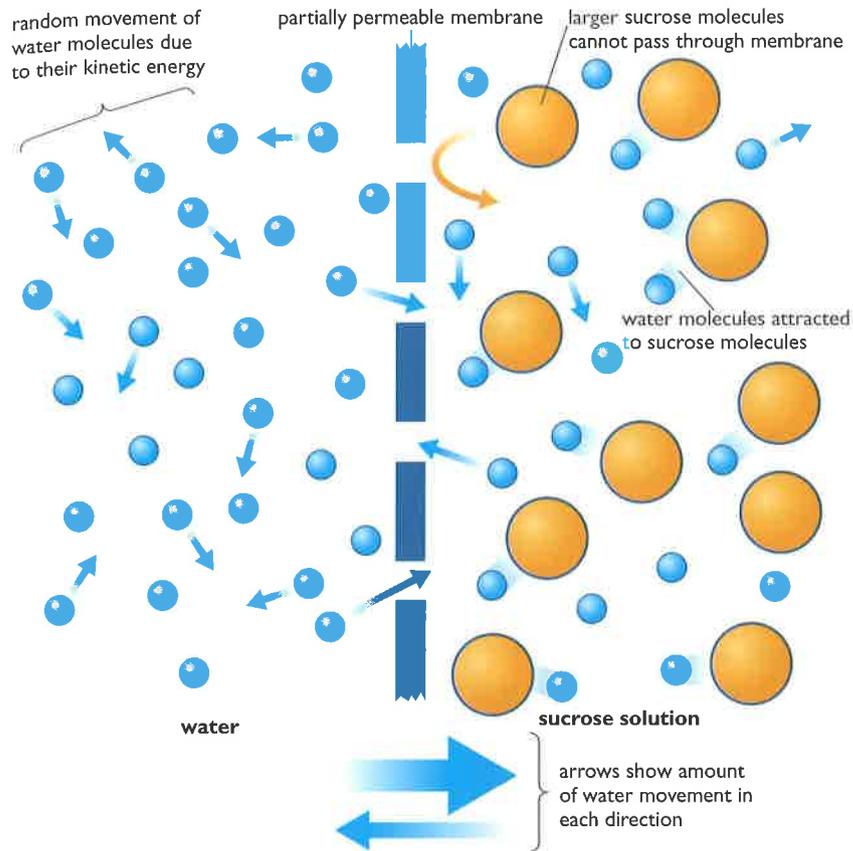

Figure 1.12 *In this model of osmosis, more water molecules diffuse from left to right than from right to left.*

Figure 1.11 *Water enters the Visking tubing 'sausage' by osmosis. This causes the level of liquid in the capillary tube to rise. In the photograph, the contents of the Visking tubing have had a red dye added to make it easier to see the movement of the liquid.*

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

How 'free' the water molecules are to move is called the **water potential**. The molecules in pure water can move most freely, so pure water has the highest water potential. The more concentrated a solution is, the lower is its water potential. In the model in Figure 1.12, water moves from a high to a low water potential. This is a law that applies whenever water moves by osmosis. We can bring these ideas together in an alternative definition of osmosis.

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

Osmosis is the net diffusion of water across a partially permeable membrane, from a solution with a high water potential to one with a lower water potential.
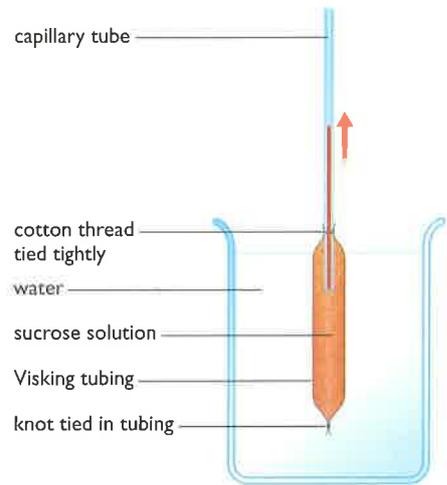
All cells are surrounded by a partially permeable cell membrane. In the human body, osmosis is important in moving water from cell to cell, and from the blood to the tissues (see Chapter 4, page 60). It is important that the cells of the body are bathed in a solution with the right concentration of solutes; otherwise they could be damaged by osmotic movements of water. For example, if red blood cells are put into water, they will swell up and burst. If the same cells are put into a concentrated salt solution, they lose water by osmosis and shrink, producing cells with crinkly edges.

Experiment 3

Demonstration of the effects of osmosis on red blood cells

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

Three test tubes are set up, containing these solutions:

- A $10 cm^3$ of distilled water
- B $10 cm^3$ of 0.85% salt solution
- C $10 cm^3$ of 3% salt solution

$1 cm^3$ of blood is added to each tube, and the tubes are shaken. A sample from each tube is examined under the microscope. The sample from tube A is found to contain no intact cells. Figure 1.13 shows cells from tubes B and C. The cells from tube B look normal, but those from tube C are shrunken, with crinkly edges.
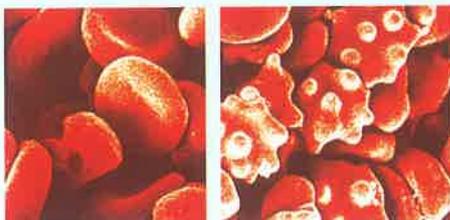

Figure 1.13 *Compare the blood cells on the right, which were placed in a 3% salt solution, with the normal blood cells on the left, from a 0.85% salt solution.*

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

The three tubes are now placed in a centrifuge and spun around at high speed to separate any solid particles from solution. The results are shown in Figure 1.14.
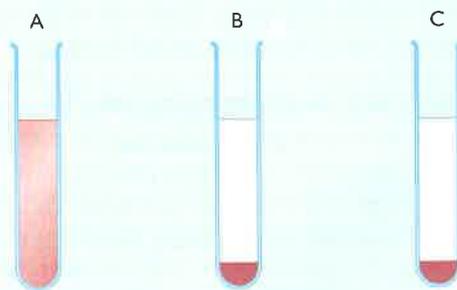

Figure 1.14 *The three tubes after centrifugation.*

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

Can you explain these results?

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

We will return to the idea that cells need a correct constant 'environment' in Chapter 8.

All cells exchange substances with their surroundings, but some parts of the body are specially adapted for the exchange of materials because they have a very large surface area in proportion to their volume. Two examples are the alveoli of the lungs (Chapter 2) and the villi of the small intestine (Chapter 3). Diffusion is a slow process, and organs that rely on diffusion need a large surface over which it can take place. The alveoli (air sacs) allow exchange of oxygen and carbon dioxide to take place between the air and the blood, during breathing. The villi of the small intestine provide a large surface area for the absorption of digested food.

Cell division and differentiation

Humans begin life as a single fertilised egg cell, called a **zygote**. This divides into two cells, then four, then eight and so on, until the adult body contains countless millions of cells (Figure 1.15).

This type of cell division is called **mitosis** and is under the control of the genes. You can read a full account of mitosis in Chapter 11, but it is worthwhile considering an outline of the process now. First of all the chromosomes in the nucleus are copied, then the nucleus splits into two, so that the genetic information is shared equally between the two 'daughter' cells. The cytoplasm then divides, forming two smaller cells. These then take in food substances to supply energy and building materials so that they can grow to full size. The process is repeated, but as the developing **embryo** grows, cells become specialised to carry out particular roles. This specialisation is also under the control of the genes, and is called **differentiation**. Different kinds of cells 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 1.16). Throughout this book you will read about cells that have a structure adapted for a particular function.
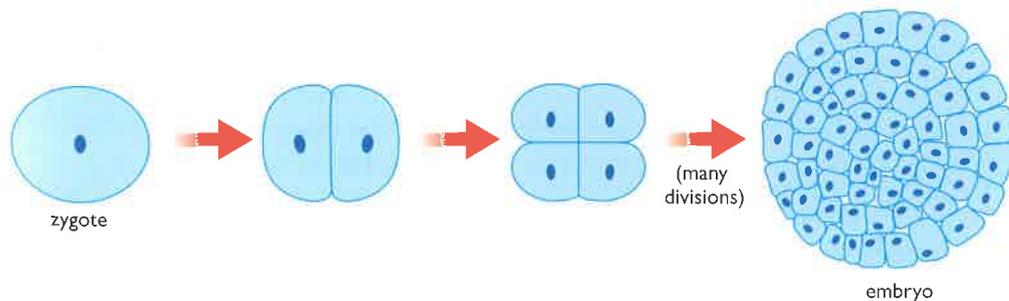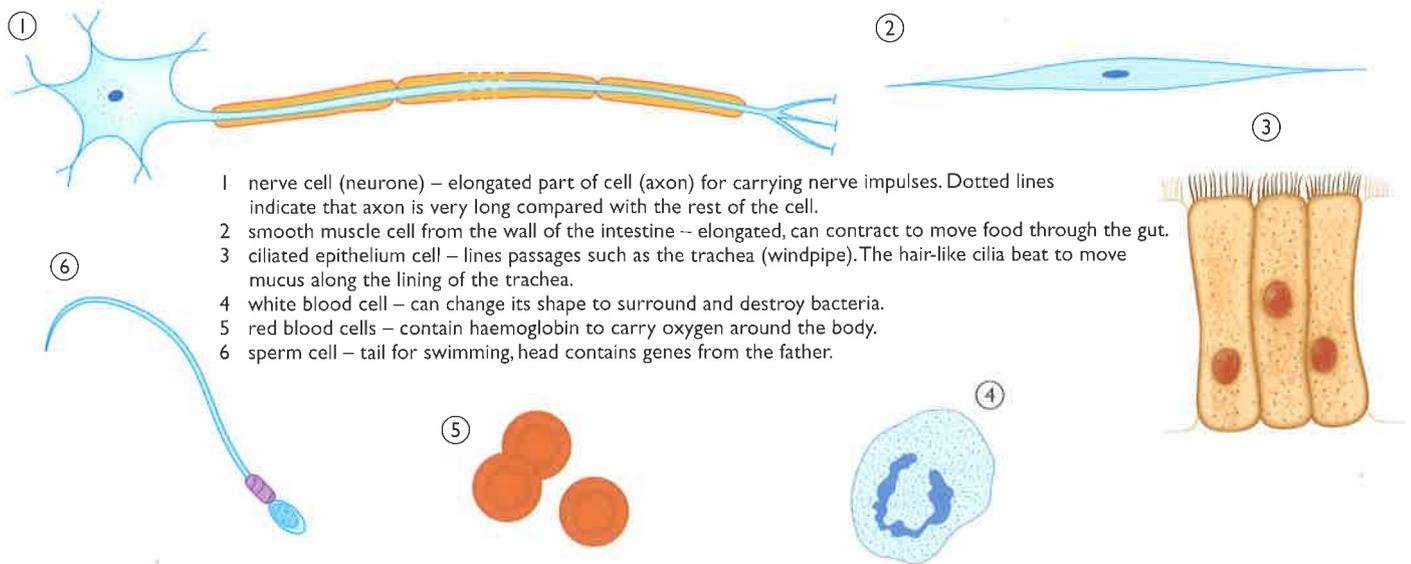

zygote   (many divisions)   embryo

Figure 1.15 *Animals and plants grow by cell division.*

1   nerve cell (neurone) – elongated part of cell (axon) for carrying nerve impulses. Dotted lines
    indicate that 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 1.16 *Some cells with very specialised functions. They are not drawn to the same scale.*

What is hard to understand about this process is that through mitosis all the cells of the body have the *same* genes. 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 work it out.

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 – contraction to move the arm bones (Chapter 7). This is muscle tissue, or more accurately **voluntary muscle** tissue. The 'voluntary' refers to the fact that contraction of muscles like this is under conscious control of the brain. The smooth muscle cell shown in Figure 1.16 above makes up **involuntary muscle**, since the gut muscles are not under voluntary control by your 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.

Tissues that line organs are called **epithelia** (singular 'epithelium'). Figure 1.16 shows a **ciliated** epithelium cell, which has minute hair-like projections called cilia, able to beat to move materials 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 throughout this book.

Bone is a tissue made of cells that secrete a hard matrix made of calcium salts (Chapter 7). Other tissues include **blood** (Chapter 4) which is made of various types of red and white blood cells in a liquid matrix called plasma, and **nervous tissue** (Chapter 5), 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 1.17.
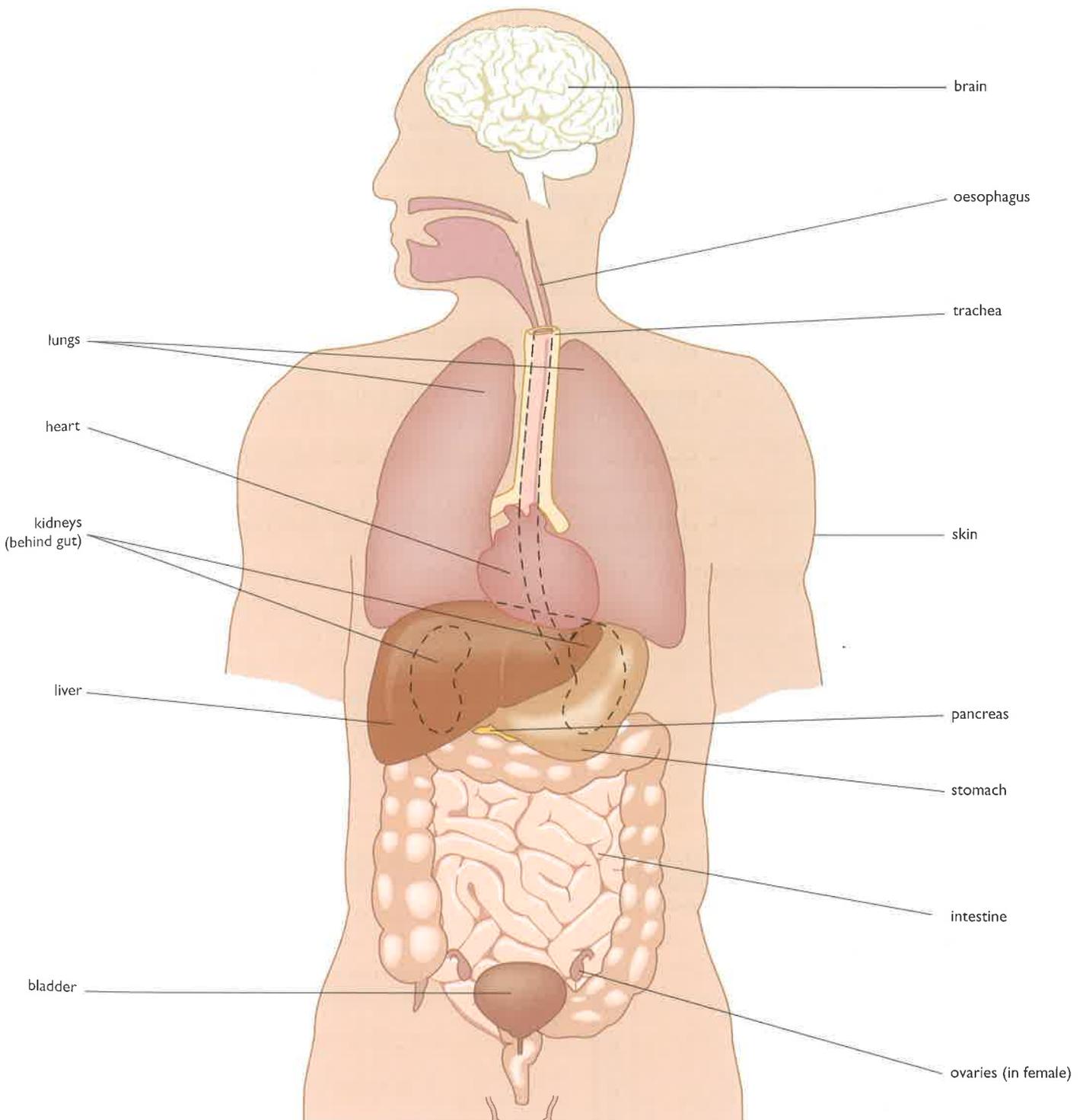
Figure 1.17 *Some of the main organs of the human body.*

In humans, jobs are usually carried out by several different organs working together. This is called an **organ system**. For example, the digestive system consists of the gut, along with glands such as the pancreas and gall bladder. The function of the whole system is to digest food and absorb the digested products into the blood. There are seven main systems in the human body, these are the:

- **digestive** system

- **respiratory** system – including the lungs, which exchange oxygen and carbon dioxide

- **circulatory** system – including the heart and blood vessels, which transport materials around the body

- **excretory** system – including the kidneys, which filter toxic waste materials from the blood

- **nervous** system – consisting of the brain, spinal cord and nerves, which coordinate the body's actions

- **endocrine** system – glands secreting hormones, which act as chemical messengers

- **reproductive** system – producing sperm in males and eggs in females, and allowing the development of the embryo.

End of Chapter Checklist

You should now be able to:

✓ recognise cell structures and describe the functions of the nucleus, cytoplasm, cell membrane, mitochondria, endoplasmic reticulum and ribosomes

✓ explain the role and functioning of enzymes as biological catalysts in metabolic reactions

✓ explain how enzymes can be affected by changes in temperature and pH

✓ describe how to carry out simple controlled experiments to show how enzyme activity can be affected by changes in temperature

✓ understand the process of aerobic respiration and recall the word equation and chemical symbol equation for aerobic respiration

✓ explain the significance of the breakdown and regeneration of ATP

✓ explain the differences between aerobic and anaerobic respiration and the formation of lactic acid in anaerobic respiration

✓ understand the movement of substances into and out of cells by diffusion, osmosis and active transport, and the factors that can affect the rate of movement

✓ describe how to carry out simple experiments on diffusion and osmosis using living and non-living systems

✓ understand the grouping of cells into tissues, including: voluntary, involuntary and cardiac muscle; bone, blood, nervous tissue and squamous and ciliated epithelia

✓ recall the organisation of cells into organs.

Questions

1 **a)** Draw a diagram of an animal cell. Label all of the parts. Alongside each label write the function of that part.

b) Write down three differences between the cell you have drawn and a 'typical' plant cell.

2 Write a short description of the nature and function of enzymes. It would be easier if you worked on a computer. Include in your description:

- a definition of an enzyme

- a description of the 'lock and key' model of enzyme action

- an explanation of the difference between intracellular and extracellular enzymes.

Your description should be about a page in length, including a labelled diagram.

3 The graph shows the effect of temperature on an enzyme. The enzyme was extracted from a microorganism that lives in hot mineral springs near a volcano.
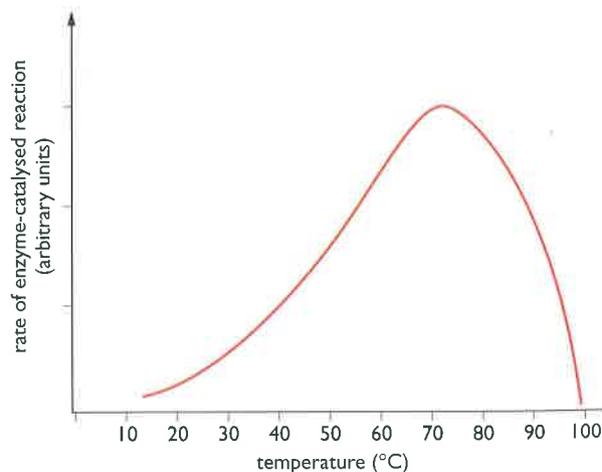
a) What is the optimum temperature of this enzyme?

b) Explain why the activity of the enzyme is greater at 60 °C than at 30 °C.

c) The optimum temperature of enzymes in the human body is about 37 °C. Explain why this enzyme is different.

d) What happens to the enzyme at 90 °C?

4 Explain the differences between diffusion and active transport.

5 The nerve cell called a **motor neurone** (page 14) and a **red blood cell** (page 14) are both very specialised cells. Look up each of these cells in this book and explain very briefly (three or four lines) how each is adapted to its function.

6 The diagram shows a cell from the lining of a human kidney tubule. A major role of the cell is to absorb glucose from the fluid passing along the tubule and pass it into the blood, as shown by the arrows on the diagram.
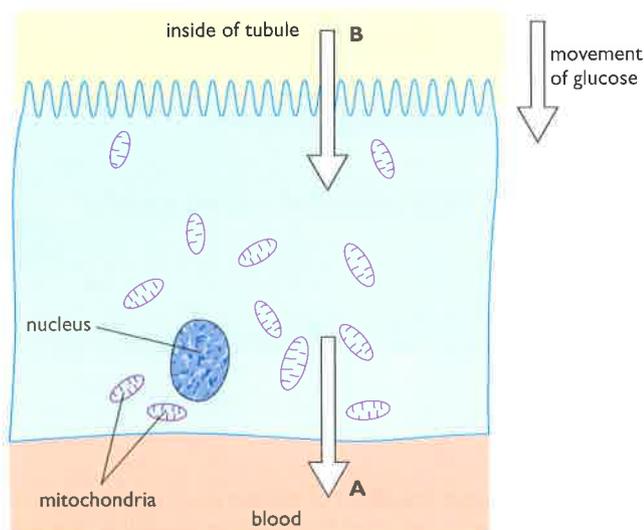
a) What is the function of the mitochondria?

b) The tubule cell contains a large number of mitochondria. They are needed for the cell to transport glucose across the cell membrane into the blood at 'A'. Suggest the method that the cell uses to do this and explain your answer.

c) The mitochondria are not needed to transport the glucose into the cell from the tubule at 'B'. Name the process by which the ions move across the membrane at 'B' and explain your answer.

d) The surface membrane of the tubule cell at 'B' is greatly folded. Explain how this adaptation helps the cell to carry out its function.

7 An experiment was carried out to find the effects of osmosis on blood cells. Three test tubes were filled with different solutions. 10 cm³ of water was placed in tube A, 10 cm³ of 0.85% salt solution in tube B, and 10 cm³ of 3% salt solution

in tube C. 1 cm³ of fresh blood was added to each tube. The tubes were shaken, and then a sample from each was observed under the microscope under high power.

The tubes were then placed in a centrifuge and spun around at high speed to separate any solid particles from solution. The results are shown in the diagram below.
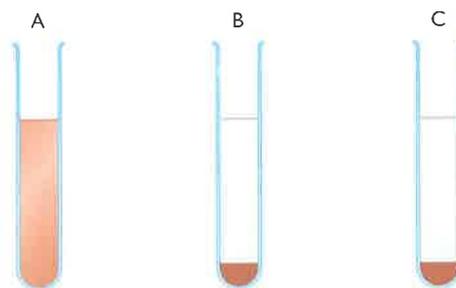
a) Which solution had a similar salt concentration to blood?

b) Describe what you would expect to see when viewing the samples from tubes A to C through the microscope.

c) Explain the results shown in the diagram.

d) When a patient has suffered severe burns, damage to the skin results in a loss of water from the body. This condition can be treated by giving the patient a saline drip. This is a 0.85% salt solution which is fed into the patient's blood through a needle inserted into a vein. Explain why 0.85% salt solution is used, and not water.

8 In multicellular organisms, cells are organised into tissues, organs and organ systems.

a) The diagram shows a section through an artery and a capillary.
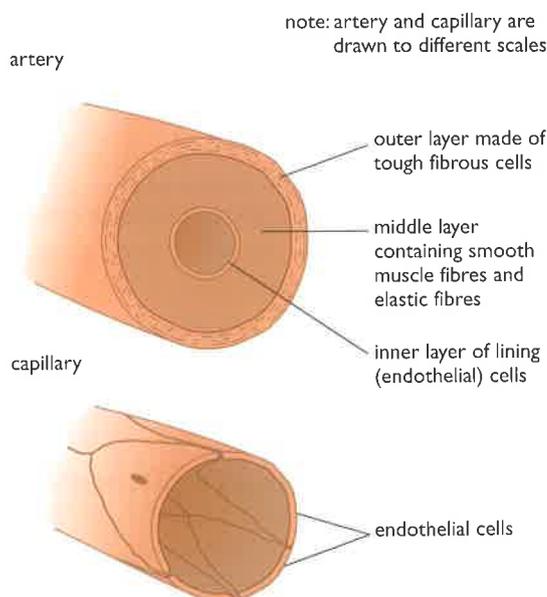
Explain why an artery can be considered to be an organ whereas a capillary cannot.

b) Organ systems contain two or more organs whose functions are linked. The digestive system is one human organ system. (See Chapter 3.)

   i) What does the digestive system do?

   ii) Name three organs in the human digestive system. Explain what each organ does as part of the digestive system.

   iii) Name two other human organ systems and, for each system, name two organs that are part of the system.

9 Different particles move across cell membranes using different processes. The table below shows some ways in which active transport, osmosis and diffusion are similar and some ways in which they are different. Copy and complete the table with ticks and crosses.

Feature	Active transport	Osmosis	Diffusion
particles must have kinetic energy			
requires energy from respiration			
particles move down a concentration gradient			
process needs special carriers in the membrane			

10 Cells in the wall of the small intestine divide by mitosis to replace cells lost as food passes through.

a) Chromosomes contain DNA. The graph shows the changes in the DNA content of a cell in the wall of the small intestine as it divides by mitosis.
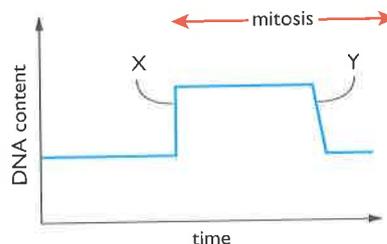
   i) Why is it essential that the DNA content is doubled (X) before mitosis commences?

   ii) What do you think happens to the cell at point Y?

b) The diagram shows a cell in the wall of a villus in the small intestine (see Chapter 3, page 47). The cell absorbs glucose from the intestine and passes it into the blood.
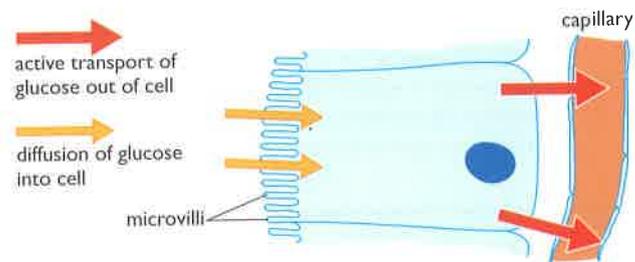
   i) Suggest how the microvilli adapt this cell to its function of absorbing glucose.

   ii) Suggest how the active transport of glucose out of the cell and into the bloodstream helps with the absorption of glucose from the small intestine.