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Adrian Schmit, Jeremy Pollard

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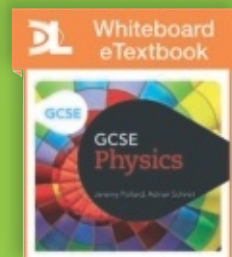
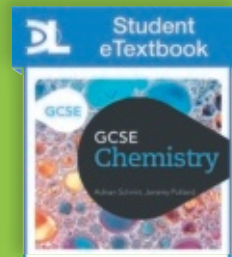
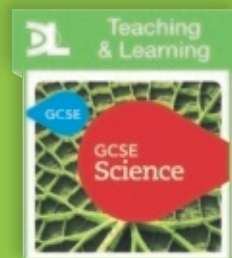
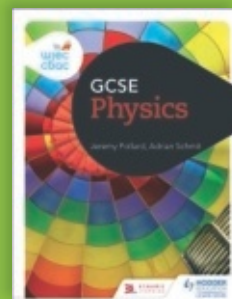
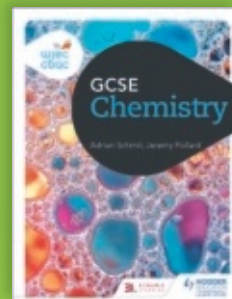
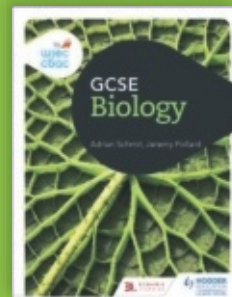
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# 1

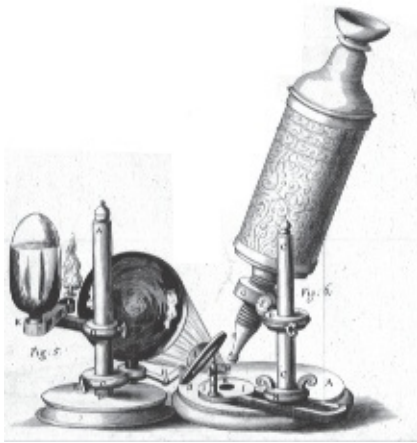
## Cells and movement across cell membranes



### Specification coverage

This chapter covers specification **Unit 1, topic 1.1** and is called **Cells and movement across cell membranes**.

It covers the structure and function of cells, how they transport materials and some metabolic processes that occur within them.



**Figure 1.1** An early microscope used by Robert Hooke to discover cells.

### What are cells?

Cells are now known to be the basic ‘unit’ of all living things. Cells were first described by the famous scientist Robert Hooke in 1665 (Figure 1.1), but at that time he had no idea that cells were found in all living things. That idea, which formed part of what is known as the cell theory, was first suggested by German scientists Theodor Schwann (working on animals) and Matthias Schleiden (who worked on plants) in the 1830s.

The cell theory that Schwann and Schleiden proposed is still the basis of cell theory today, although it has been developed as we have come to know more about cells.

Today’s cell theory states that:

- ▶ All living organisms are composed of cells. They may be **unicellular** (one celled) or **multicellular** (many celled).
- ▶ The cell is the basic ‘unit’ of life.
- ▶ Cells are formed from pre-existing cells during cell division.
- ▶ Energy flow occurs within cells (enabling the chemical reactions that make up life to take place).
- ▶ Hereditary information (**deoxyribonucleic acid, DNA**) is passed on from cell to cell when cell division occurs.
- ▶ All cells have the same basic chemical composition.

Although all cells have features in common, there are also differences between different types of cell. Some of those differences allow scientists to classify cells as either animal cells or plant cells.

### Plant and animal cells

All cells in both plants and animals have certain features in common:

- ▶ They all have **cytoplasm**, a sort of ‘living jelly’, where most of the chemical reactions that make up life go on.
- ▶ The cytoplasm is always surrounded by a **cell membrane**, which controls what enters and leaves the cell.

- ▶ They have a **nucleus**, which contains DNA, the chemical which controls the cell's activities.
- ▶ They contain **mitochondria** (singular: mitochondrion), which are the structures that carry out aerobic respiration, supplying cells with energy.

Plant cells can be distinguished from animal cells, because they have some features that are not seen in animal cells. These are:

- ▶ a **cell wall**, made of **cellulose**, which surrounds all plant cells
- ▶ a large, permanent central **vacuole**, which is a space filled with liquid cell sap
- ▶ **chloroplasts**, which absorb the light plants need to make their food by photosynthesis – chloroplasts are not found in *all* plant cells, but they are never found in animal cells.

Figure 1.2 shows examples of plant and animal cells, showing the differences.

**Figure 1.2** Animal cell (left) and plant cell (right) showing differences in structure.

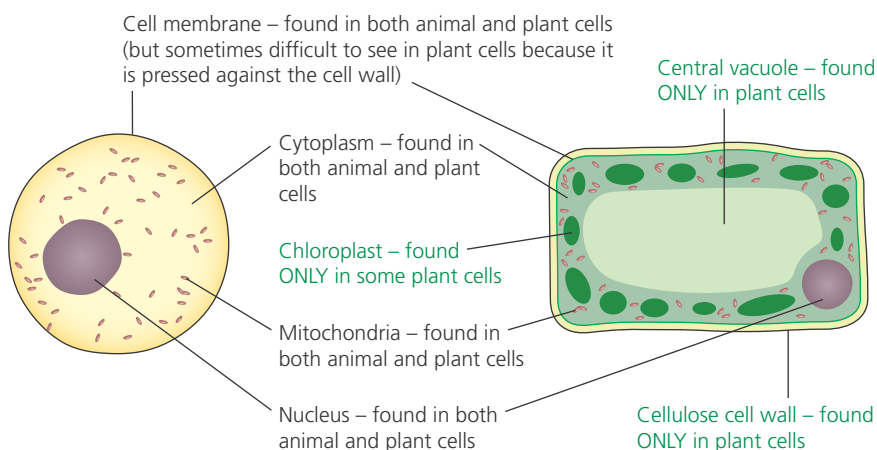


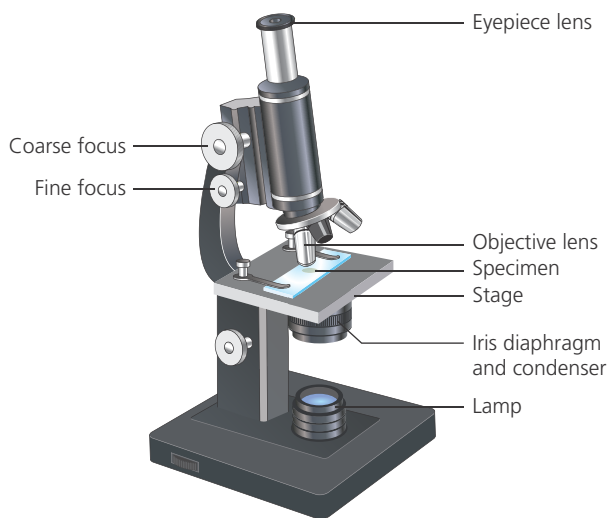
Table 1.1 summarises the information you need to know about the structure of cells.

**Table 1.1** A summary of cell structure.

Organelle	Where found	Function
Nucleus	All cells	Contains DNA, which controls the cell's activities
Cell membrane	All cells	Controls what enters and leaves the cell
Cytoplasm	All cells	Forms the bulk of the cell and is where most of the chemical reactions occur
Mitochondria	All cells	Provide energy by carrying out aerobic respiration
Chloroplasts	Some plant cells	Absorb light for photosynthesis
Cell wall	Plant cells	Supports the cell
Vacuole	Plant cells	Filled with a solution of nutrients including glucose, amino acids and salts

## ▶ Observing cells with a microscope

Throughout history since the time of Robert Hooke, scientists have used light microscopes to observe cells. There are now more powerful types of microscope available (for example, electron microscopes), which have allowed us to see the detailed structure of cell organelles,



**Figure 1.3** Parts of a light microscope.

but these are complex and expensive and the light microscope is still by far the most widely used type of microscope. The parts of a typical light microscope are shown in Figure 1.3.

The functions of the parts of a light microscope are as follows:

- ▶ The **eyepiece lens** is of fixed magnification, although it is possible to exchange it with a lens of a different magnification.
- ▶ The **objective lenses** are of different magnifying power and are interchangeable. They are the ones used to adjust the magnification of the image that you see down the microscope.
- ▶ The **stage** is where the microscope slide you are observing is placed, with clips to hold it in place.
- ▶ Below the stage is a part that is usually made up of two components – an **iris diaphragm**, which can be opened or closed to adjust the amount of light entering the objective lens, and (sometimes) a **condenser**, which concentrates the light into a beam directed precisely into the objective lens.
- ▶ At the base of the microscope is a **lamp**, although some older microscopes may have a mirror, which is used in conjunction with a separate lamp to shine light through the condenser and iris diaphragm.
- ▶ The microscope is focused using two focus controls. The **coarse focus** control is used to get the image roughly into focus using the lowest-power objective, and then the **fine focus** control is used to fine tune the image and make it as clear as possible.
- ▶ Microscope **slides** hold thin specimens or sections, which may be stained using a variety of dyes so that structures can be seen more clearly.

### ✓ Test yourself

- 1 State three features that are found in both animal and plant cells.
- 2 State three features that are found in plant cells but not in animal cells.
- 3 Muscle cells have a lot of mitochondria. Suggest a reason for this.
- 4 What is the function of the cell wall in plant cells?
- 5 Suggest a reason why many plant cells do not contain chloroplasts.

### Microscope drawings

The purpose of a scientific drawing of a microscope specimen is to show it accurately (correct shapes and proportions) and as clearly as possible. You do not have to be a wonderful artist to produce a good scientific drawing, but you do have to be observant and neat. There are certain ‘rules’ about producing scientific diagrams:

- 1 Always use a sharp pencil.
- 2 Make sure lines are thin, clear and do not overlap where they join.
- 3 Do not shade parts of your drawing, unless it is absolutely essential in order to clearly distinguish structures.
- 4 Always use a ruler for labelling lines. The lines should never cross each other.
- 5 Do not label on the drawing itself – keep the labels outside the drawing.
- 6 Make sure the proportions of the drawing are correct. If a structure is twice as wide as it is long, then the drawing of it should be, too.



## Required practical

### Examination of animal and plant cells using a microscope, and production of scientific labelled diagrams

In this practical you will look at animal cells from your own body and plant cells from an onion. As onions are formed underground and are not exposed to light, their cells do not have chloroplasts. It is also unlikely that the microscope you use will be powerful enough to see mitochondria.

#### Animal cells

##### Apparatus

- > cotton wool buds
- > microscope slide
- > cover slip
- > microscope
- > methylene blue stain
- > filter paper

##### Procedure

- 1 Gently scrape the inside of your cheek with a cotton wool bud (see Figure 1.4).
- 2 Smear the saliva from the bud gently onto your microscope slide.
- 3 Add a drop or two of water to the part of the slide you smeared.
- 4 Place the cover slip onto the slide. Place one edge on the slide and then gently lower the cover slip down.
- 5 Add a drop of methylene blue dye near one edge of the cover slip, on the microscope slide.
- 6 Draw the dye under the cover slip by putting the filter paper next to the opposite edge of the cover slip to the dye.
- 7 Leave a few minutes for the dye to stain the cells, then observe the slide under the microscope.
- 8 Make a drawing of three cells.



Figure 1.4 Sampling cheek cells.

#### Plant cells

##### Apparatus

- > onion
- > scalpel
- > forceps
- > microscope slide
- > cover slip
- > methylene blue stain
- > microscope

##### Procedure

- 1 Split and pull the onion apart into layers.
- 2 With the scalpel, make a square cut part way through an onion segment. Make sure that this is on the side of the segment that was towards the inside of the onion, and that the square cut is smaller than the cover slip.
- 3 Using the forceps, carefully peel the inner epidermal cell layer away from the onion (Figure 1.5). The epidermal layer (or epidermis) is a 'skin' one cell thick on the inside and outside of each of the layers of the onion. Use the inner side of the onion layer for this procedure.
- 4 Place a drop of methylene blue stain onto the centre of the slide.
- 5 Gently lay the sheet of epidermis onto the drop of dye. Try to avoid trapping air bubbles underneath the tissue.
- 6 Lay a cover slip over the tissue.
- 7 Leave a few minutes for the dye to stain the cells, then observe the slide under the microscope.
- 8 Make a drawing of a group of no more than four cells.



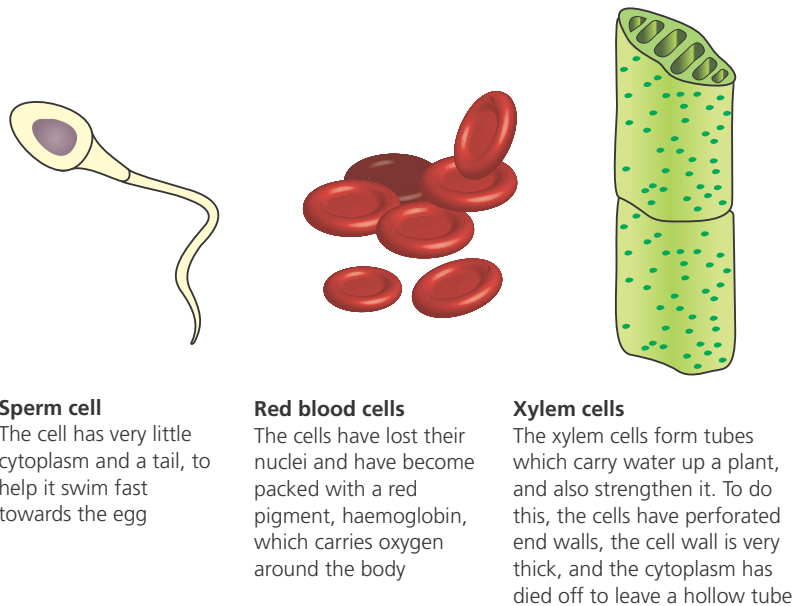
Figure 1.5 Removing the epidermis from an onion.

## Specialised cells

Just like whole organisms, cells have evolved over time to become specialised for their particular 'jobs' (Figure 1.6). This can sometimes result in cells that look very different from the examples in Figure 1.2.

Newly formed cells in different tissues look very similar to one another, no matter what tissue they come from. As they grow and mature, however, they gradually develop the specialisations that suit their function. This process of change is called **differentiation**. Let's take a red blood cell as an example. The cell is formed as a basic animal cell, very similar to that shown in Figure 1.2. Over a period of about two days, the cell gradually loses its nucleus and organelles, forms haemoglobin (which is the pigment needed to carry oxygen) and acquires its characteristic biconcave shape to become a fully formed red blood cell.

**Figure 1.6** Specialised cells.



## ► How are cells organised into a whole body?

During the development of an animal or plant, the cells organise themselves into groups called **tissues**. Different tissues are grouped together to form **organs**, and the organs may link up to form **organ systems** (the organs may not be physically linked – they may just have linked functions). All of the organ systems working together form a whole animal or plant – which is known as an **organism**. Definitions and examples of the different levels of organisation are shown in Table 1.2. Note that the term 'organism' does not actually imply that organ systems are present – some living organisms consist of only one cell.



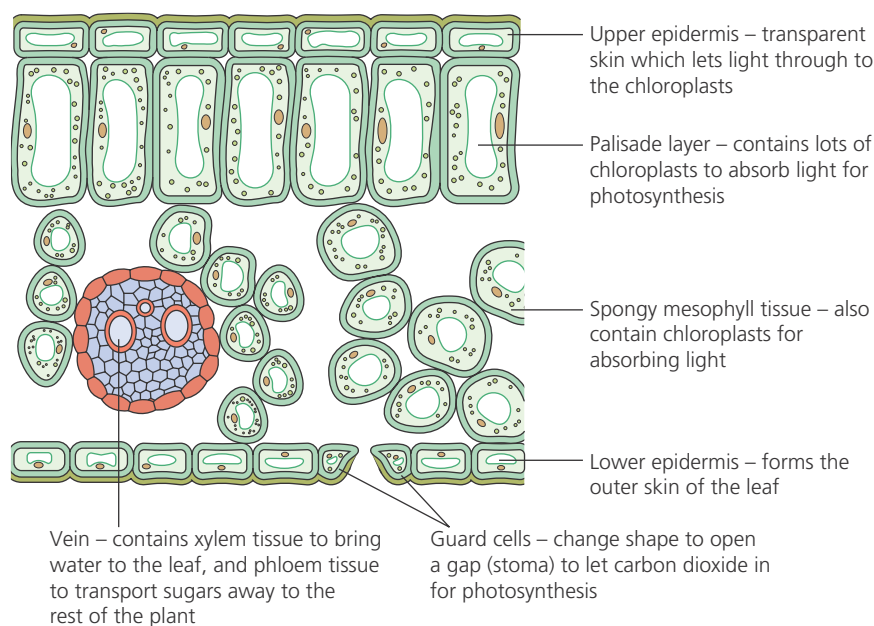
**Table 1.2** Levels of organisation in the structure of living things.

Level of organisation	Definition	Examples
Tissue	A group of similar cells with similar functions	Bone, muscle, blood, xylem, epidermis
Organ	A collection of two or more tissues that perform specific functions	Kidney, brain, heart, leaf, flower
Organ system	A collection of several organs that work together	Digestive system, nervous system, respiratory system, shoot system, root system
Organism	A whole animal or plant	Cat, elephant, human, rose bush, oak tree

Bone is an example of a tissue. It is made up of two types of similar cells, osteoclasts and osteoblasts, which together form and maintain bones. Note that ‘a bone’ is an organ, as it consists of both bone tissue and blood.

A leaf is another example of an organ. It has several different types of cell which perform different functions, all linked to the production of food by photosynthesis (Figure 1.7).

**Figure 1.7** The tissues in a leaf.



The digestive system is an example of an organ system. It consists of a number of organs (including the stomach, small intestine, liver and pancreas) that work together to digest and absorb nutrients.

## ► Movement into and out of cells

In order to get into and out of cells, substances have to get through the cell membrane. The cell membrane is selectively permeable, which means it lets some molecules through but not others. Sometimes, you see the cell membrane referred to as ‘partially permeable’ rather than ‘selectively permeable’. Don’t worry – it’s the same thing. In general, large molecules cannot get through the membrane, but smaller molecules can. Whether they actually do get through, which way they travel, and how quickly, depends upon

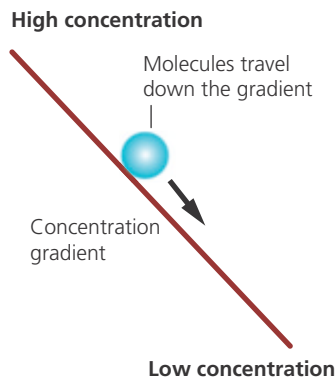


Figure 1.8 Concentration gradient.

a number of factors, as we shall see. There are three processes by which substances move through membranes:

- ▶ **diffusion**, when molecules sort of ‘drift’ through the membrane
- ▶ **osmosis**, which is a special case of diffusion, involving water only
- ▶ **active transport**, when molecules are actively ‘pumped’ through the membrane in a particular direction.

The statements in the list above are not full definitions. Those will be given later, as we consider each of these processes in detail.

## Diffusion

Diffusion is the spreading of molecules from an area of higher concentration to an area of lower concentration, as a result of random movement. We say the molecules move down a **concentration gradient** (Figure 1.8).

Diffusion is a natural process that results from the fact that all molecules are constantly in motion. It is called a **passive process**, because it does not require an input of energy. The movement is random – there is nothing pushing them and the molecules cannot possibly ‘know’ in which direction they are heading. The molecules will move in all directions, yet the *overall* (net) movement is always from an area of high concentration to an area of low concentration.

Two of the most important substances that enter and leave cells by diffusion are oxygen, which is needed for respiration, and carbon dioxide, which is a waste product of that process. The speed of diffusion can be increased by increasing the temperature, because that makes the molecules move faster, or by increasing the concentration gradient (the difference between the high and low concentrations).



## Practical

### Modelling diffusion

#### Procedure

- 1 Place about 10 marbles in a group on the laboratory bench. Ensure that they stay in a group and do not roll apart. These represent molecules in a high concentration. The surrounding area, with no marbles, represents a low concentration.
- 2 Bring your fists down firmly on the bench on either side of the group of marbles. This will provide the marbles with energy and they should move.
- 3 Observe how they travel.
- 4 You should find that the marbles spread out from the group. In other words, they move from an area of high concentration to an area of low concentration.

#### Questions

- 1 The marbles never remain in a group, they always spread out. Explain why this happens.
- 2 In what way(s) is this model an inaccurate way of representing the movement of molecules?



## Practical

### How does the membrane affect diffusion?

Small molecules can get through the cell membrane, but large molecules cannot. In this experiment, you will be using starch (a large molecule), iodine (a small molecule) and Visking tubing, which is a sort of cellophane with similar properties to a cell membrane. It has pores in it that let only small molecules through. Iodine stains starch blue-black when it comes into contact with it.

#### Risk assessment

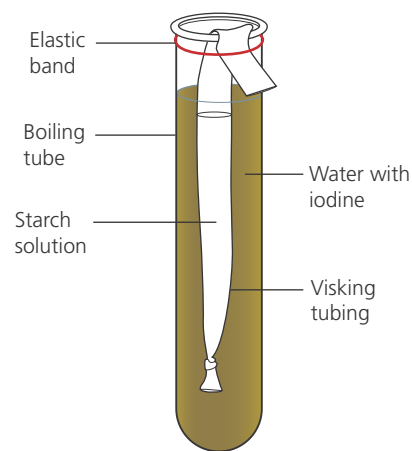
Your teacher will provide you with a risk assessment for this experiment.

#### Apparatus

- > boiling tube
- > length of Visking tubing, knotted at one end
- > dropping pipette
- > elastic band
- > iodine in potassium iodide solution
- > 1% starch solution
- > test-tube rack

#### Procedure

- 1 Set up the apparatus as shown in Figure 1.9. Fill the Visking tubing with starch solution using the dropping pipette. Be careful that no starch drips down the outside of the tubing.
- 2 Place the boiling tube in a test-tube rack and leave for about 10 minutes.
- 3 Observe the result.
- 4 Explain the colours that you see after 10 minutes inside and outside the Visking tubing.

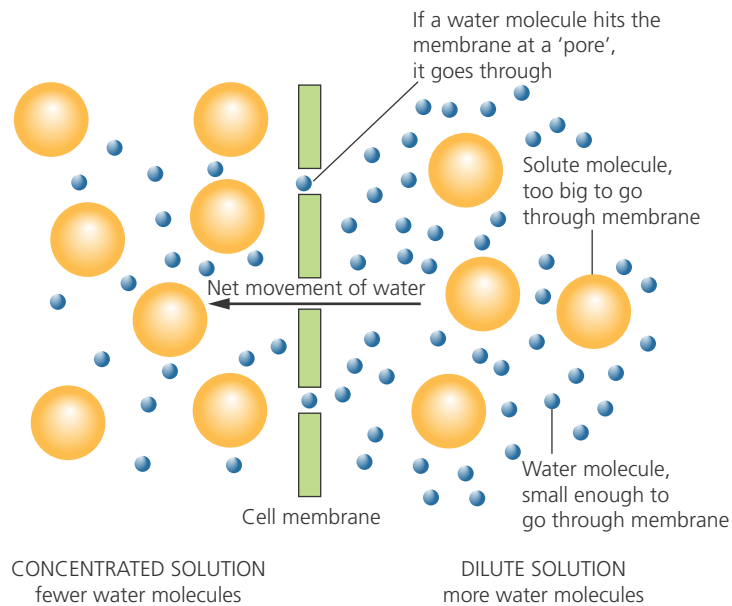


**Figure 1.9** Apparatus for an experiment investigating how a membrane affects diffusion.

## Osmosis

Osmosis is a specific type of diffusion. It is the diffusion of **water molecules** through a **selectively permeable membrane**. Diffusion of any other substance through a selectively permeable membrane is just called diffusion. Diffusion of water, but *not* through a membrane, is just diffusion. To be called osmosis, the process has to involve *both* water *and* a membrane. In osmosis, we say that water moves from a solution of low solute concentration (which has more water) to a solution of high solute concentration (which has less water), through a selectively permeable membrane. Notice that the substance (water) that is diffusing is still going down a concentration gradient. A concentrated solution of salt, for instance, would have a low 'concentration' of water, whereas a dilute solution would have a high 'concentration' of water. The movement of water happens because the membrane is permeable to water (that is, it lets it through), but not to the solute. The process of osmosis is shown in Figure 1.10, on the next page.

**Figure 1.10** The process of osmosis.



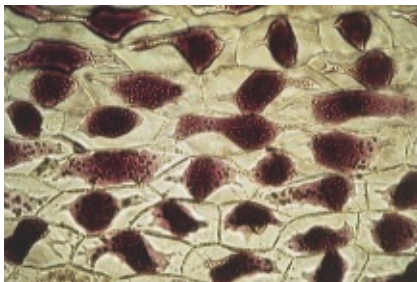
All the molecules on both sides of the membrane are moving. Occasionally, a molecule hits a membrane 'pore'. Water molecules will go through but solute molecules will not. Because there is a higher proportion of water molecules in the dilute solution, more will travel from the dilute solution to the concentrated solution than the other way. Although water molecules move in both directions, there is **net movement** from the dilute to the more concentrated solution.

If the concentrations of the solutions on either side of the membrane are the same, then overall an equal number of water molecules travel in each direction – we say that such solutions are **in equilibrium**.

### Why is osmosis important?

Osmosis is important because too much or too little water inside cells can have disastrous effects. If an animal cell is put into a solution that is more dilute than its cytoplasm, water will go in by osmosis and the cell will burst. If a patient in hospital needs extra fluid, they are often put on to a 'saline drip'. Saline is a solution of salts at the same concentration as the blood. If just water was given, the blood would become too dilute and osmosis would make the blood cells burst.

Plant cells are not damaged by being put into water. They swell as water enters, but their cell wall stops them bursting. However, they can be damaged (as can animal cells) by being put into a concentrated solution. In this case, water leaves the cell by osmosis, and the cytoplasm collapses and shrinks. In plant cells, the cytoplasm pulls away from the cell wall, a condition known as **plasmolysis** (Figure 1.11). Plasmolysis can result in the death of the cell.



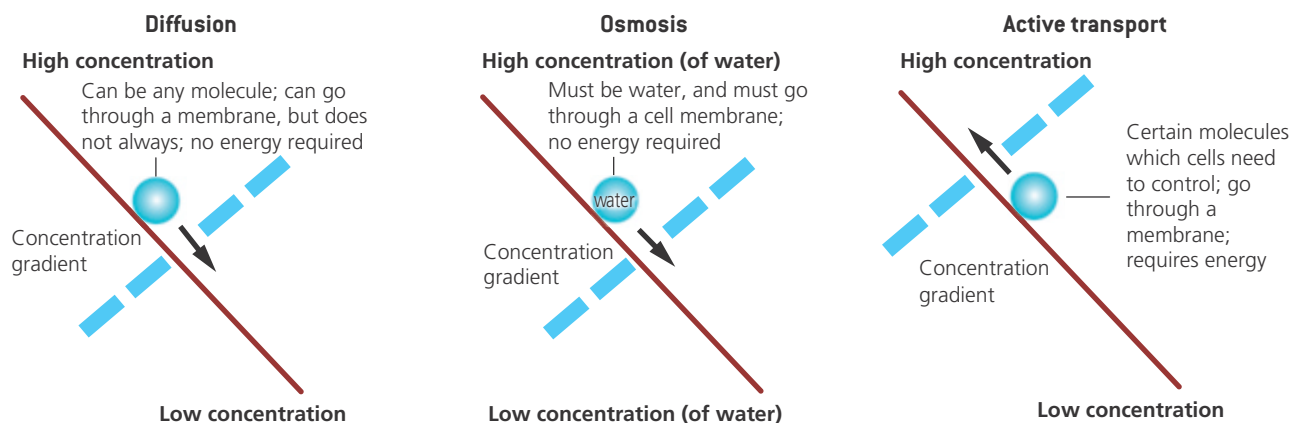
**Figure 1.11** The plant cells have plasmolysed. Water has left the cells by osmosis and the cytoplasm has shrunk and pulled away from the cell wall.



gradient. In other words, they have to be moved from an area of lower concentration to an area of higher concentration. This will not happen by diffusion, and in order to move the molecules, the cell has to use energy to 'pump' the molecules in the direction they need to go. As this type of transport requires an input of energy, it is called **active transport**.

### Comparing active transport, diffusion and osmosis

Figure 1.12 shows the similarities and differences between the three cell transport processes.



**Figure 1.12** Comparison of diffusion, osmosis and active transport.



#### Test yourself

- 6 Why is diffusion described as a passive process?
- 7 Why is active transport necessary?
- 8 When water evaporates, it spreads through the air by diffusion. Why would it be incorrect to call this osmosis?
- 9 What conditions cause plasmolysis in plant cells?
- 10 Why is it important that any fluid put into the bloodstream has the same concentration as the blood?

### ► How are the activities of a cell controlled?

All of the activities of a cell depend on chemical reactions. It has been estimated that 10 million reactions occur in a typical cell every second. These reactions are controlled by special molecules called **enzymes**. Which enzymes are produced in cells is controlled by another molecule, **deoxyribonucleic acid (DNA)**, which is found in the cell nucleus.

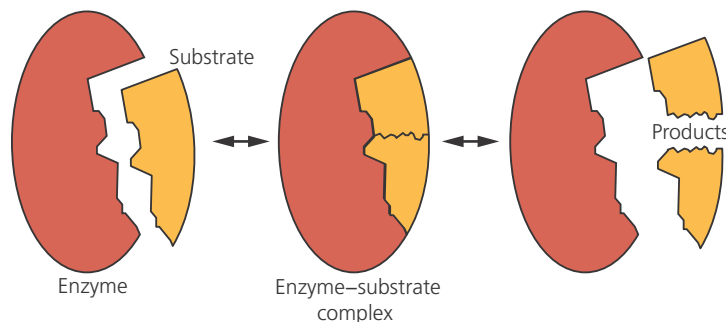
#### Enzymes

Enzymes are protein molecules that act as **catalysts**. A catalyst is something that speeds up a chemical reaction. It doesn't react itself, it simply causes the reaction it catalyses to go faster. Here are some important facts about enzymes:

- Enzymes act as catalysts, speeding up chemical reactions.
- The enzyme is unchanged by the reaction it catalyses.

- ▶ Enzymes are specific, which means that a certain enzyme will only catalyse one reaction or one type of reaction.
- ▶ Enzymes work better as temperature increases, but if the temperature gets too high they are destroyed (denatured).
- ▶ Different enzymes are denatured at different temperatures.
- ▶ Enzymes work best at a particular 'optimum pH' value, which is different for different enzymes.
- ▶ The chemicals on which enzymes work are called **substrates**. In order to catalyse a reaction, the enzyme has to 'lock together' with its substrate. The shapes of the enzyme and substrate must match, so that they fit together like a lock and key. That is why enzymes are specific – they can only work with substances that fit with their particular shape.

The action of this 'lock and key' model is shown in Figure 1.13.



**Figure 1.13** The 'lock and key' model of enzyme action. Note that in some reactions an enzyme catalyses the breakdown of a substrate into two or more products, while in others an enzyme causes two or more substrate molecules to join to make one product molecule.

### The effect of temperature and pH on enzymes

Warming an enzyme actually makes it work faster at first, because the enzyme and substrate molecules move around faster and so meet and join together more often. But at higher temperatures the enzyme stops working altogether.

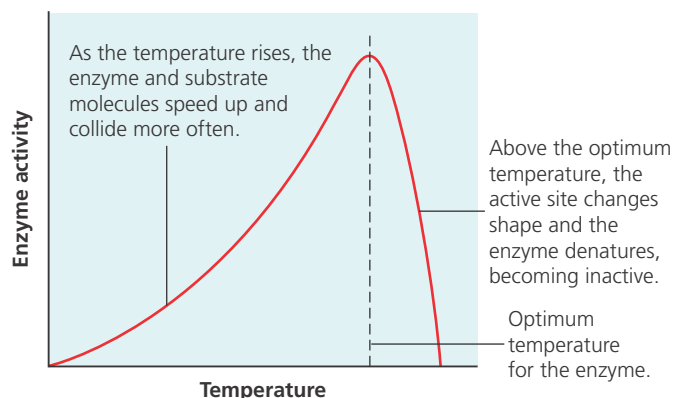
You can see from the 'lock and key' model that the shape of the enzyme molecule is important if it is to work. The reason that enzymes won't work if they are at too high a temperature or at the wrong pH is because in these conditions their shape is altered, so that they no longer fit the substrate.

The part of an enzyme which binds to a substrate is called the **active site** and it is held in shape by chemical bonds. High temperatures and unsuitable pH conditions can break these bonds. This changes the shape of the active site so that the substrate molecule will no longer fit. The enzyme no longer works, and is said to be **denatured**. The actual temperature that denatures enzymes is different for different enzymes. Some enzymes start to denature at about 40 °C, most denature at around 60 °C, and boiling is fairly certain to denature an enzyme. A very small number of enzymes, mostly found in bacteria, have been found to tolerate temperatures as high as 110 °C.

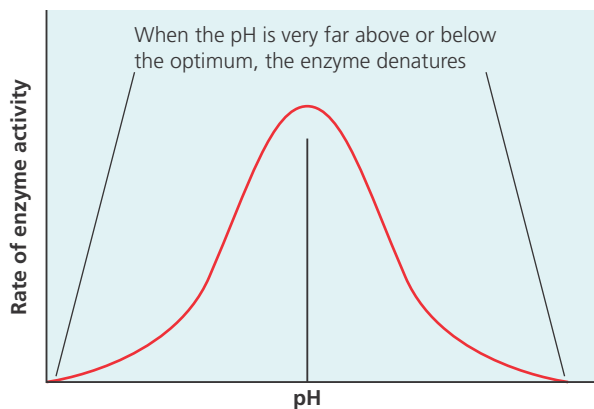
When scientists want to test if a certain substance is acting as an enzyme, they do a controlled experiment in which a boiled sample

of the substance is used in place of an un-boiled sample. If the reaction does not then occur, it is assumed that the substance acts as an enzyme.

The effect of temperature on enzyme action is shown in Figure 1.14, and the effect of pH is shown in Figure 1.15.



**Figure 1.14** The effect of temperature on enzymes.



**Figure 1.15** The effect of pH on enzymes.



## Required practical

### Investigation into factors affecting enzymes

#### What is the best temperature at which to wash your clothes?

Enzymes are used for many commercial and industrial purposes, including 'biological' washing detergents. Many of the hardest stains to remove are mainly lipid (such as oils and butter) or protein (for example, blood and grass). The inclusion of enzymes that break down lipids (lipases) and proteins (proteases) in biological washing detergents helps to remove these stains (Figure 1.16). The enzymes used are more resistant to high temperatures than most, but can still be denatured.

Egg yolk is a good stain to test because egg yolk consists mostly of protein with a small amount of lipid. Design and carry out an experiment to test what temperature is best to use with a given brand of biological detergent (in any form). When designing the experiment, consider the following:

- > How are you going to 'measure' how successful the detergent has been?
- > How are you going to make the test fair?
- > How are you going to make sure that you are measuring the effect of the detergent, rather than just the temperature of the water it is in?
- > The experiment will not be valid unless the detergent is maintained at approximately its designated temperature throughout the experiment.
- > You need to do a risk assessment of your experiment.



**Figure 1.16** Biological detergents contain a mixture of enzymes to break down stains.

#### Analysing and evaluating your experiment

- 1 What is your conclusion from the experiment?
- 2 How strong is the evidence for your conclusion? Explain your answer.
- 3 If you could re-design your experiment, is there anything you would now change?
- 4 What other factors, apart from the effectiveness of stain removal, might influence a decision about what temperature to use for your wash?
- 5 Explain why enzymes allow washing at a lower temperature than non-biological detergents.

**Test yourself**

- 11 Define the term 'catalyst'.
- 12 Why would it be incorrect to say that an enzyme reacts with a substrate?
- 13 Enzymes are specific – that is, they will only work with one type of substrate. Explain this using the 'lock and key' theory.
- 14 One way of preserving food is to pickle it in acid, as this kills bacteria. Suggest a reason why most bacteria cannot survive in a low pH.

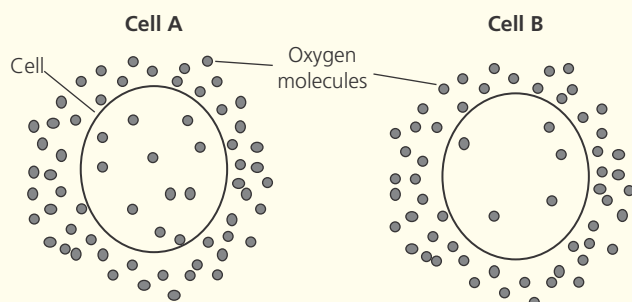
**Chapter summary**

- Animal and plant cells have the following parts: cell membrane, cytoplasm, nucleus, mitochondria; in addition, plants cells have a cell wall, vacuole and sometimes chloroplasts.
- Cells differentiate in multicellular organisms to become specialised cells, adapted for specific functions.
- Tissues are groups of similar cells with a similar function; organs may comprise several tissues performing specific functions; organs are organised into organ systems, which work together in organisms.
- Diffusion is the passive movement of substances, down a concentration gradient.
- The cell membrane forms a selectively permeable barrier, allowing only certain substances to pass through by diffusion, most importantly oxygen and carbon dioxide.
- Visking tubing can be used as a model of a cell membrane.
- Osmosis is the diffusion of water through a selectively permeable membrane from a region of high water (low solute) concentration to a region of low water (high solute) concentration.
- *Active transport is an active process by which substances can enter cells against a concentration gradient.*
- Enzymes control the chemical reactions in cells; they are proteins made by living cells, which speed up – or catalyse – the rate of chemical reactions.
- The specific shape of an enzyme enables it to function, the shape of the active site allowing it to bind to its appropriate substrate.
- Enzyme activity requires molecular collisions between the substrate and the enzyme's active site.
- Increasing temperature increases the rate of enzyme activity, up to an optimum level, after which any further increase results in the enzyme being denatured. Boiling denatures most enzymes.
- Enzyme activity varies with pH. For each enzyme, there is an optimum pH, which is different for different enzymes.



## Chapter review questions

- 1 a) State the function of the cell membrane. [1]
- b) The diagrams below show two cells that are carrying out respiration. Oxygen molecules are shown inside and outside both cells.



Copy and complete the following statements by choosing the correct answer. [2]

- i) In cell A:
- the oxygen molecules move into the cell
  - the oxygen molecules move out of the cell
  - there is no net movement.
- ii) In cell B:
- the oxygen molecules move into the cell
  - the oxygen molecules move out of the cell
  - there is no net movement.

Now answer the following questions. [2]

- iii) In which cell would there be greater net movement of oxygen? [1]
- iv) Name the process by which the oxygen molecules are moving. [1]

(from WJEC Paper B2(H), Summer 2014, question 1)

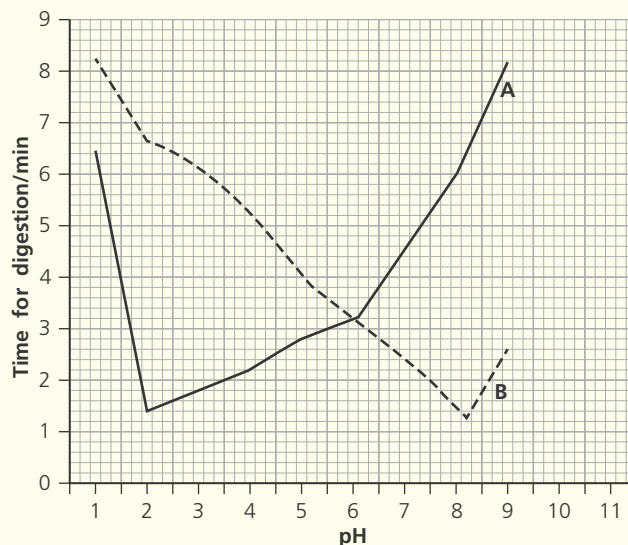
- 2 A student used red blood cells to carry out an investigation into cell membranes. Red blood cells were placed in salt solutions at three different concentrations. A sample of red blood cells was then removed from each concentration and placed on a microscope slide. The cells were viewed using a microscope for a period of time. The observations were recorded in a table.

Concentration of salt solution, %	Observation of rd blood cells
0.0	Swell and burst
0.9	Remain the same size
3.0	Smaller and shrivelled

Explain the observations shown in the table. [6]

(from WJEC Paper B2(H), Summer 2014, question 9)

- 3 The graph below shows the result of an investigation into the effect of pH on the action of two digestive enzymes labelled A and B.



- a) From the graph, state the time taken for enzyme B to complete its digestion at pH4.5. [1]
- b) At what pH is the rate of reaction the same for both enzymes? [1]
- c) From the graph, describe and explain the effect of pH on enzyme A. [4]

(from WJEC Paper B2(H), January 2013, question 1)

- 4 *Valonia ventricosa* is an unusual single-celled organism which lives in the seas of tropical and subtropical areas. It lives in shallow depths (80 m or less). The single cell is large, up to around 5 cm. The cell has a cellulose cell wall, a vacuole and many nuclei and chloroplasts. It attaches to rocks by small hair-like structures called rhizoids. Its large size makes it easy to study and scientists have measured the concentrations of ions in the vacuole and the surrounding sea water. The results for some ions are shown below.

Ion	Concentration	
	Cell vacuole	Sea water
Potassium	0.5	0.01
Calcium	0.002	0.01
Sodium	0.1	0.5

- a) State three features of *Valonia* that are found in plant cells. [3]
- b) State two features of *Valonia* that are different from a normal plant cell. [2]
- c) Look at the concentration data. Suggest, with reasons, how each of the ions enters the cell (by diffusion or by active transport). [4]
- d) What is the ratio of potassium in the cell vacuole compared to the sea water? [1]

# 12

## The kidney and homeostasis



### Specification coverage

This chapter covers specification **Unit 2, Topic 2.6** and is called **The kidney and homeostasis**.

It covers the structure and function of the kidney and its role in the regulation of the water content of the blood. The detail of the nephron is required along with the role of ADH. The treatment for kidney failure is also considered.

### Key terms

**Homeostasis** The maintenance of a constant internal environment regardless of changing environmental conditions.

**Aqueous solution** A solution that has water as the solvent.

**Dehydration** A reduction in the normal water content of the body.

### ► What is the function of the kidneys?

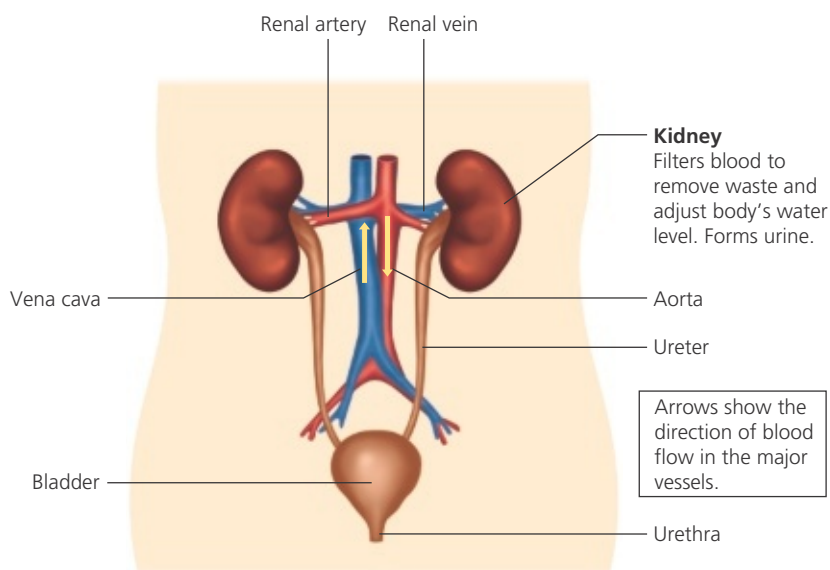
We saw in the Chapter 11 that the body controls various factors like blood glucose and temperature within a restricted range, which allows the optimum working of living processes. The general term for such control is **homeostasis**. Another major factor that needs to be controlled is the water content of the body. All the chemical reactions that make up life take place in an **aqueous solution**. Differences in water content in body tissues affect concentrations and therefore rates of reaction, as well as determining the direction of water movement into and out of cells by osmosis. If water content of the body gets too high or low it can have serious consequences. **Dehydration**, for instance, can be fatal.

The water content of the blood, and therefore of the body's cells, is regulated by the kidneys. These organs are responsible for the removal of waste products from the body. The wastes the kidneys remove are water soluble, and so their removal involves the loss of water, in urine. The kidneys control the water loss so that the concentration of the blood remains more or less constant, provided enough water is taken in via food and drink to replace the small amount of water that must always be lost in urine.

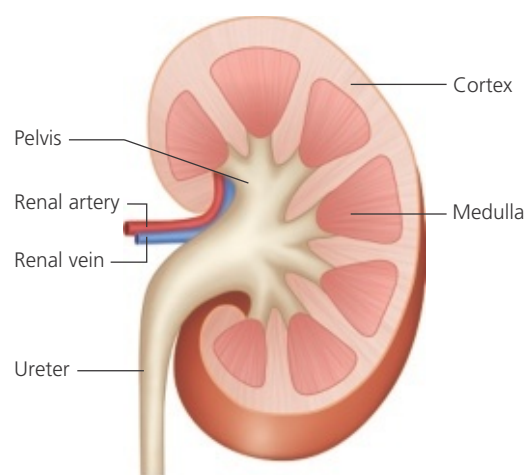
Urine contains the waste product urea, which is made in the liver by the breakdown of proteins that are not needed by the body. Urea is a poisonous substance and so cannot be allowed to build up and is removed from the blood by the kidneys.

### The excretory system

The human excretory system is shown in Figure 12.1. Urine is formed in the **kidneys** and then drains down the **ureters** to be temporarily stored in the bladder, before exiting via the **urethra**. The blood is brought to the kidneys from the heart via the **aorta** and then the **renal arteries**, and then returns via the **renal veins** and the **vena cava**.



**Figure 12.1** The human excretory system.



**Figure 12.2** Internal structure of the kidney.

The internal structure of a kidney is shown in Figure 12.2. There are three main areas, the outer **cortex**, inner **medulla** and (in the centre) the **pelvis**, which is where the urine drains before leaving via the ureter.



## Practical

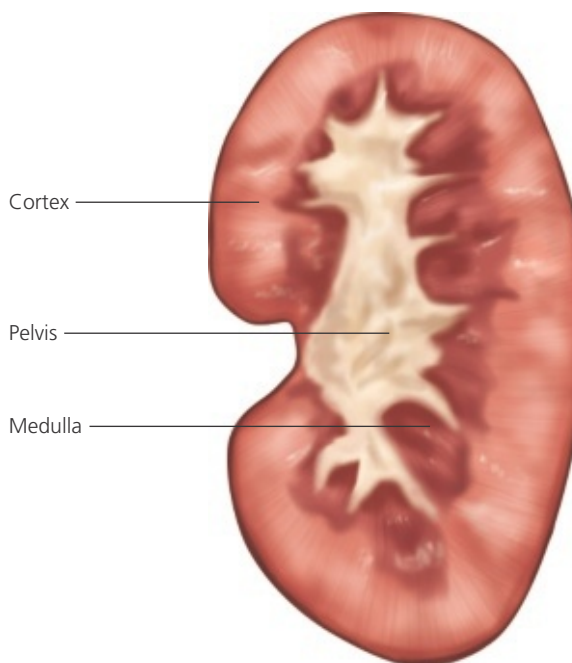
### Dissecting a kidney

#### Apparatus

- > kidney
- > scalpel
- > 2 mounted needles
- > Petri dish

#### Procedure

- 1 Cut the kidney in half from top to bottom, using the scalpel.
- 2 Draw one half of the kidney to accurately show the location and proportions of the medulla, cortex and pelvis (Figure 12.3).
- 3 Cut a small piece of tissue (about 1 cm square) from the cortex.
- 4 Using the mounted needles, pull the tissue apart. Between the pieces, you should be able to see tubes of various diameters, some very thin. These are the nephrons that make up the kidney.
- 5 If available, use a stereo microscope to look at the kidney tubes.



**Figure 12.3** The appearance of a half kidney during dissection.

You are unlikely to have the ureter, renal artery and renal vein attached if the kidney has been bought from a butcher.

### ✓ Test yourself

- 1 What is the main waste product in urine?
- 2 Which organ manufactures this waste material?
- 3 Which blood vessel supplies the kidney with blood?
- 4 What tube connects the bladder and the kidney?

## ► How do the kidneys work?

A kidney is made up of millions of small tubes called **nephrons**, which extract wastes from the blood to produce urine, a waste solution containing urea and excess salts. The structure of a nephron is shown in Figure 12.4.

The walls of the **capillary knot** and the **Bowman's capsule** are leaky, and as blood flows through the capillary knot the blood pressure forces fluid through into the Bowman's capsule. The arteriole leading into the capillary knot is wider than the one leading away from it, so pressure builds up in the capillary knot. Only small molecules can get through the walls, so the walls act like a filter. Blood cells and larger molecules like proteins remain in the blood. (The presence of blood in the urine can indicate kidney disease, although there are other causes, as well.)

The materials that go through the filter into the nephron are water, glucose, urea and salts. Some of these substances are useful, however, and the body does not want to lose them. Urea is a waste product so it is a good thing to let that pass out in the urine, but glucose is a useful substance, and that is reabsorbed from the tubule into the blood. Some salts and most of the water are also reabsorbed into the blood, but how much is reabsorbed varies according to the body's needs.

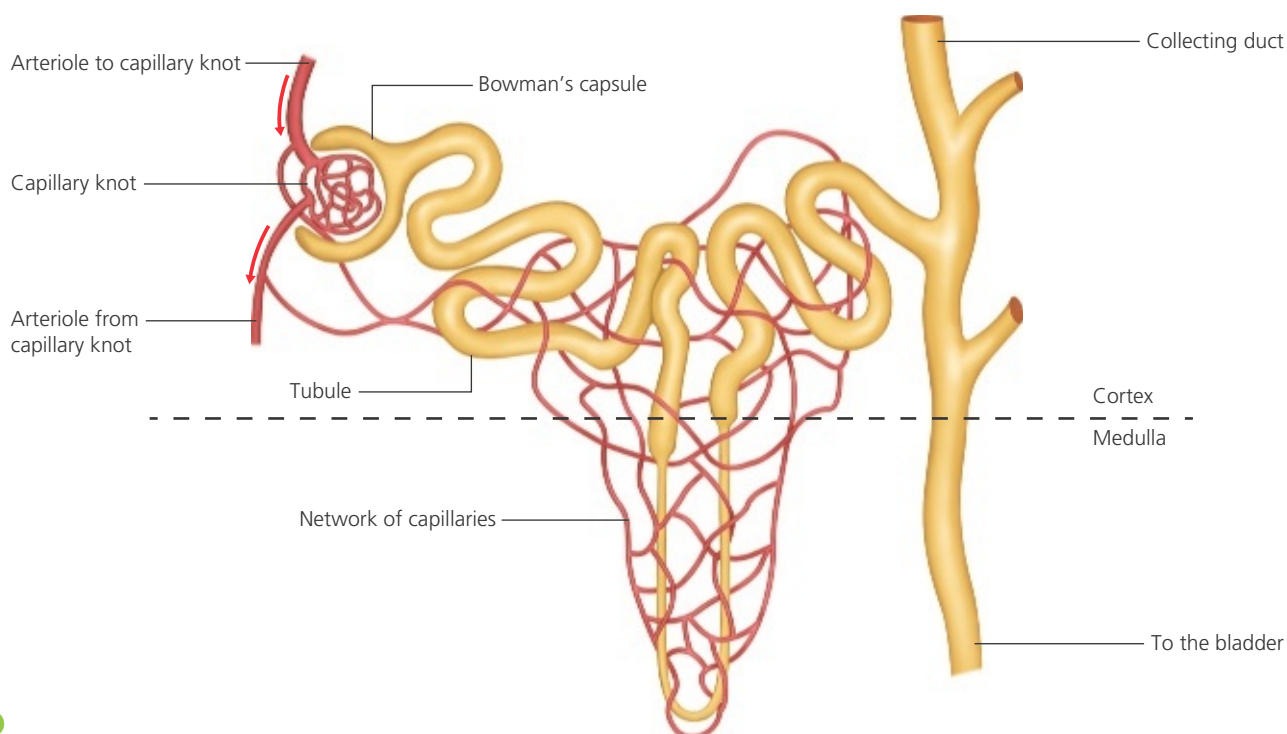


Figure 12.4 The structure of a nephron.



The process by which some things are reabsorbed and others are not is called **selective reabsorption**. Due to this reabsorption, the composition of the filtrate varies as it travels along the nephron tubule. By the time it reaches the end, the filtrate has changed into the liquid we call urine.

The amount of water reabsorbed in the nephron varies according to whether water is plentiful in the body, or in short supply. If the blood is too dilute, which can happen if the person has drunk a lot of liquid, less water is reabsorbed and the urine is pale and dilute. If the blood is too concentrated, then reabsorption is increased and the urine is darker and more concentrated. Normally, urine is most concentrated first thing in the morning, as you do not drink during the night while you are asleep.

The amount of water reabsorbed is controlled by a hormone, called **anti-diuretic hormone (ADH)**. Areas in the brain detect the concentration of the blood and, if the concentration is too high, ADH is produced by the pituitary gland (a hormone-producing gland just beneath, but attached to, the brain). ADH causes the kidney to reabsorb more water and produce a more concentrated urine. Once the blood concentration returns to normal, ADH production stops and less water is reabsorbed.



### Specified practical

#### Testing artificial urine samples for the presence of protein and sugar

Urine should not contain either sugar or protein. The presence of sugar is an indication that the patient has diabetes, and the presence of protein can indicate kidney disease (although in pregnancy a small protein is present in the urine – this is the basis for pregnancy tests).

You will be provided with artificial urine samples to test for protein and glucose, which is the sugar that would be present in diabetic urine.

The Biuret test for proteins and the Benedict's test for reducing sugars (glucose is a reducing sugar) are described in Chapter 3. Carry out each test on the artificial urine samples you are given. Note that the colours observed will be affected by the colour of the artificial urine sample. This will have little effect on the Benedict's test but may make it slightly more difficult to see the violet colour that indicates the presence of protein in the Biuret test.

## ► How can we treat kidney failure?

Most people have two kidneys, and if something happens to one – for example, if it has to be removed as a result of an accident or cancer – we can live a full and healthy life with only one working kidney. Indeed, some people are born with just one kidney, and live a normal life. If a patient has kidney disease, however, it is likely to lead to failure of both kidneys, and this is a life-threatening condition. There are two types of treatment for kidney failure:

- **Kidney dialysis** – The patient has to spend regular sessions attached to an artificial kidney machine, which removes wastes and restores the balance of salts and water in the blood.
- **Kidney transplant** – A new kidney can be placed in the body, so that kidney function is restored.

Each of these treatments has advantages and disadvantages, which we will look at below.

### Kidney dialysis

When a patient is hooked up to a kidney dialysis machine, the blood is taken out of a blood vessel in the arm and pumped through the machine (Figure 12.5). A special dialysis fluid containing salts, called the **dialysate**, is also put through the machine. The dialysate is separated from the blood by a selectively permeable membrane, which lets small molecules through, much like the kidney's natural filter. The concentration of the dialysate is carefully controlled to ensure that only excess salts and water pass into it. It has less water and salts in it than the patient's blood has, and so salts diffuse into the dialysate down a concentration gradient, and water moves out of the blood by osmosis. The dialysate is constantly renewed so that the blood continually loses the salts and water that have built up without a properly functioning kidney.

Once the excess salts and water have been removed, the blood is returned to the body.

The problems with dialysis as a treatment for kidney disease are as follows:

- ▶ The patient normally needs to have dialysis sessions on three days each week, and each session lasts about 4 hours. Some patients have dialysis machines at their homes and do their dialysis while they sleep. However, there are not enough machines to go around, so many patients have to visit hospital three days a week for a session. This is inconvenient and may mean that patients cannot work full-time.
- ▶ In between sessions, patients have to be very careful about what they eat and drink. They have to restrict fluid and salt intake so that the levels do not build up to dangerous levels, or to an extent where more than four hours of dialysis would be needed.

### Kidney transplantation

A kidney transplant is a cure for kidney disease, and patients can live a normal life without having to repeatedly undergo dialysis. However, there are some disadvantages:

- ▶ The process involves surgery, which always carries some risk.
- ▶ The 'foreign' kidney transplanted will be recognised by the body's immune system, which will then attack it. To avoid this rejection, kidney transplant patients have to take drugs that suppress their immune system (often for the rest of their lives). These drugs are called immunosuppressants. Their use can make patients more likely to get infections.
- ▶ Transplanted kidneys have a limited lifespan. Only about 40–50% of transplanted kidneys last longer than 15 years. A young patient may therefore need several transplants during their lifetime.

- ▶ A person needs to be reasonably strong and healthy (other than suffering from kidney disease) in order to have a transplant. Patients who are very sick are not able to have the operation as the risks are too great.
- ▶ A person can only receive a kidney from someone who has a similar 'tissue type'. Some patients have to wait many years for a suitable donor.

### ✓ Test yourself

- 5 What name is given to the kidney tubules?
- 6 What causes the pressure build-up that filters the blood in the kidney?
- 7 Which hormone controls the amount of water reabsorbed in the kidney?
- 8 What will happen to the concentration of urea in the filtrate liquid as it travels through the kidney tubule? Explain your answer.
- 9 Why do kidney transplant patients have to take immunosuppressant drugs after their transplant?

### ↓ Chapter summary

- The kidneys regulate the water content of the blood and remove waste products such as urea from the blood. This is necessary because urea is a poisonous waste, and if the blood is too concentrated or too dilute it can disrupt processes in the body.
- The human excretory system contains the following structures: kidneys, renal arteries, renal veins, aorta, vena cava, ureters, bladder and urethra.
- A kidney has the following parts: cortex, medulla, pelvis and ureter.
- A nephron consists of the following structures: capillary knot, Bowman's capsule, tubule, collecting duct, capillary network, and arterioles to and from the capillary knot.
- Blood is filtered under pressure in the capillary knot. The pressure results from the arteriole leaving the knot being smaller than the one entering.
- Glucose, some salts and much of the water are selectively reabsorbed as the fluid moves through the kidney tubule.
- Urine – containing urea, water and excess salts – passes from the kidneys in the ureters to the bladder, where it is stored before being passed out of the body.
- The presence of blood or cells in the urine indicates disease in the kidney.
- The kidneys produce dilute urine if there is too much water in the blood or concentrated urine if there is a shortage of water in the blood.
- *The regulation of water absorption in the kidney is controlled by anti-diuretic hormone (ADH).*
- Dialysis and transplantation can be used to treat kidney failure.
- *In a dialysis machine excess salts and water pass from the blood into a fluid called the dialysate by diffusion and osmosis. The concentration of the dialysate is carefully controlled to regulate this.*
- Kidney transplants require a donor with a similar 'tissue type' to the recipient.
- The donor kidney may be rejected by the body and attacked by the immune system, unless drugs are taken that suppress the immune response.
- Dialysis and transplantation each have advantages and disadvantages.

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