

# Membranes, chemicals and movement in and out of cells

*Membranes around cells provide separation from and links with the external environment*

## 2.1

### Chemicals in cells

Studies of the ultrastructure of cells reveal a variety of organelles in the cytoplasm that function together so that a cell can carry out life processes such as respiration, growth and many

others. Our studies now proceed to a chemical level—looking at what chemical substances make up these cell organelles.

#### ■ *identify the major groups of substances found in living cells and their uses in cell activities*

The chemical substances found in cells fit into two main groups: *organic* substances and *inorganic* substances.

**Organic compounds** are chemical substances that are synthesised by *living* things and contain atoms of carbon and hydrogen. Carbon atoms bond very strongly with other carbon atoms and form long chains—the basis of the large organic molecules made by cells. (*Note:* The term ‘organic’, used to refer to chemical compounds (as above) should not be mixed up with the modern day use of the term ‘organic’ meaning a product of a farming method that avoids the use of pesticides, artificial fertilisers and herbicides.)

Examples of organic compounds are:

- *carbohydrates* such as sugars and starch
- *lipids* such as fats and oils
- *proteins*
- *nucleic acids* (DNA and RNA)
- *vitamins*.

**Inorganic compounds** are part of the inanimate, *non-living* world. These substances do not contain the element carbon combined with hydrogen and do not have long chains. Examples of inorganic compounds are:

- *mineral salts* such as calcium salts, sodium chloride (ordinary table salt) and phosphates
- *water* (H<sub>2</sub>O)
- some *gases* such as carbon dioxide (CO<sub>2</sub>) and oxygen (O<sub>2</sub>)—although carbon dioxide contains the atom carbon, it has no hydrogen and so it is inorganic.

Organic and inorganic compounds are important both in forming structural parts of cells and in cell functioning.

**Table 2.1** Inorganic compounds in cells

## Inorganic compounds

Inorganic compound	Position in cells	Uses in cell activities
Water: <ul style="list-style-type: none"> <li>chemical elements: carbon and hydrogen</li> <li>chemical formula: <math>H_2O</math>.</li> </ul>	90% of the protoplasm (cytoplasm and nucleus) is water	<ul style="list-style-type: none"> <li>Water is the <b>transport medium</b> in cells and in organisms</li> <li>Water is an important <b>solvent</b> for many molecules (gases, sugars, some amino acids and organic acids) inside cells. (<i>Note:</i> Molecules in cells that are <i>insoluble</i> in water are starch granules, lipids and some parts of proteins)</li> <li>Water is the medium in which all <b>chemical reactions</b> in cells take place; water may be used in the reactions (e.g. it is a reactant in photosynthesis, the food-making process in plant cells)</li> <li>Water is used to <i>regulate temperature</i> in organisms, as it needs to be heated to change to water vapour. This heat energy comes from the body, cooling it down.</li> </ul>
Mineral salts: chlorides, nitrates, phosphates and carbonates of sodium, magnesium, calcium, potassium and ammonium (e.g. sodium chloride, NaCl; and calcium carbonate, $CaCO_3$ ).	Dissolved as ions in the cytoplasm and in vacuoles in plant cells	Generally: <ul style="list-style-type: none"> <li>mineral salts assist all chemical reactions in cells by helping enzymes to function (they are then called <i>co-enzymes</i>)</li> <li>mineral salts are used in the synthesis of many macromolecules and body tissues (e.g. calcium for bones and teeth, and iron in blood cells)</li> <li>sodium ions (<math>Na^+</math>) and chloride ions (<math>Cl^-</math>) assist in water balance in cells and are essential for cell membrane functioning and the function of nerve and muscle cells.</li> </ul>
Gases: <ul style="list-style-type: none"> <li>carbon dioxide (<math>CO_2</math>)</li> <li>oxygen (<math>O_2</math>).</li> </ul>	Dissolved in the protoplasm; used and/or produced in chloroplasts and mitochondria	Carbon dioxide: <ul style="list-style-type: none"> <li>used by plant cells within chloroplasts during the process of photosynthesis (food production)</li> <li>released as a product of aerobic respiration (plants and animals)</li> <li>can react with water to form bicarbonates, a buffer limiting changes in acidity or alkalinity in cells.</li> </ul> Oxygen: <ul style="list-style-type: none"> <li>used by all living organisms during aerobic cellular respiration to release energy for cells to function</li> <li>released as a product of photosynthesis.</li> </ul>

## Organic compounds

Most organic compounds are very large molecules, termed **macromolecules** or **polymers**. These include carbohydrates, lipids, proteins and nucleic acids as well as vitamins. Macromolecules are built up from

smaller organic molecules called **monomers**, which are joined together in a repetitive manner (see Table 2.2). Macromolecules are assembled into a variety of structures and make up the components of cells and their organelles.

**Table 2.2** Organic compounds in cells

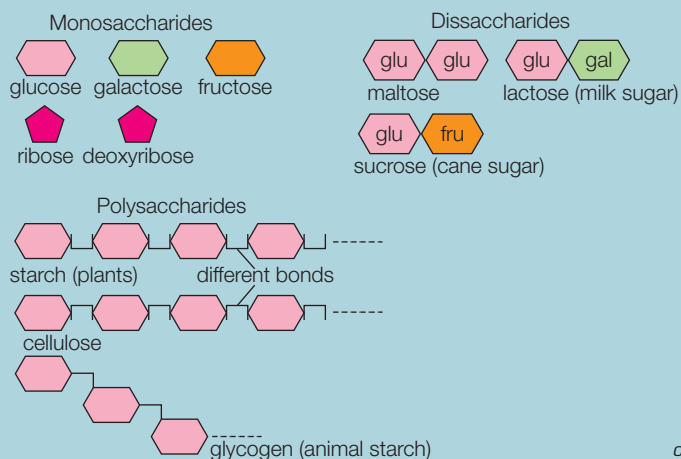
### Polymer

Carbohydrates:

- monosaccharides**—simple sugars consisting of single units
- disaccharides**—complex sugars consisting of two units
- polysaccharides**—complex polymers consisting of more than five (up to hundreds) of units.

*Note:* monomers = simple sugars

### Diagrams



*continued . . .*

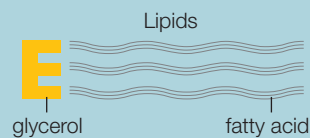
**Polymer**

**Lipids:**

- glycerol
- fatty acids.

*Note:* Three fatty acids attach to one glycerol molecule to form a lipid molecule.

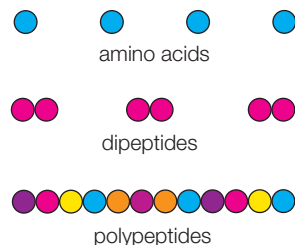
**Diagrams**



**Proteins:**

- amino acids
- dipeptides
- polypeptides.

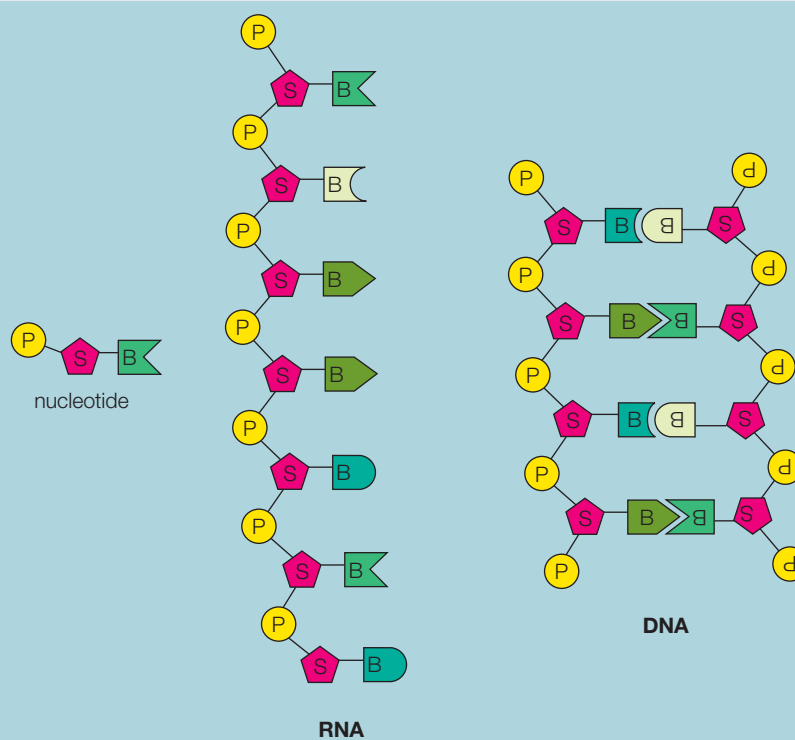
*Note:* monomers = amino acids



**Nucleic acids:**

- DNA
- RNA.

*Note:* monomers = nucleotides: sugar – phosphate – base

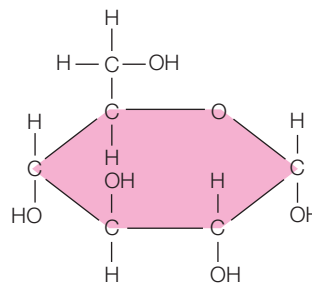


**Carbohydrates**

**Structure**

Carbohydrates are a group of organic molecules made up of carbon, hydrogen and oxygen atoms. They have a high proportion of oxygen atoms, having a ratio of one oxygen atom for every two hydrogen atoms. The general chemical formula for a carbohydrate is  $C_x(H_2O)_y$  where  $x$  is equal or approximately equal to  $y$ . For example the sugar glucose has the formula  $C_6H_{12}O_6$ ; the sugar ribose is

$C_5H_{10}O_5$ ; and sucrose is  $C_{12}H_{22}O_{11}$  or  $C_{12}(H_2O)_{11}$ . In all of these, the ratio of H:O is 2:1.



**Figure 2.1** Structural formula of carbohydrate (e.g. glucose)

### Uses of carbohydrates in cells

■ **Sugars** are a source of *quick energy* in both plant and animal cells. Mitochondria use sugars, together with oxygen, to make a form of chemical energy called ATP (adenosine triphosphate) during chemical respiration. ATP is the form of energy that a cell needs in order to carry out its life functions. In some plant cells sugars may be stored dissolved in the vacuole, but most carbohydrates are stored in cells as polysaccharides.

There are three main types of polysaccharides found in cells:

1. **cellulose**, which forms a *structural part of cell walls* in plant cells, giving them strength and support
  2. **starch**, a form of *stored energy* in plant cells. It is most commonly stored as starch grains in the chloroplasts or in the cytoplasm
  3. **glycogen**, a form of *energy stored* as granules in the cytoplasm of animal cells.
- Starch and glycogen are too large to dissolve in water and so these polysaccharides are a useful form of *stored energy* in cells, as they do not affect the water balance of a cell.
- Plants *manufacture carbohydrates* in a process called photosynthesis. The carbohydrates made are an energy source that can be used by the plant

itself and it can also be passed on in food chains to animals.

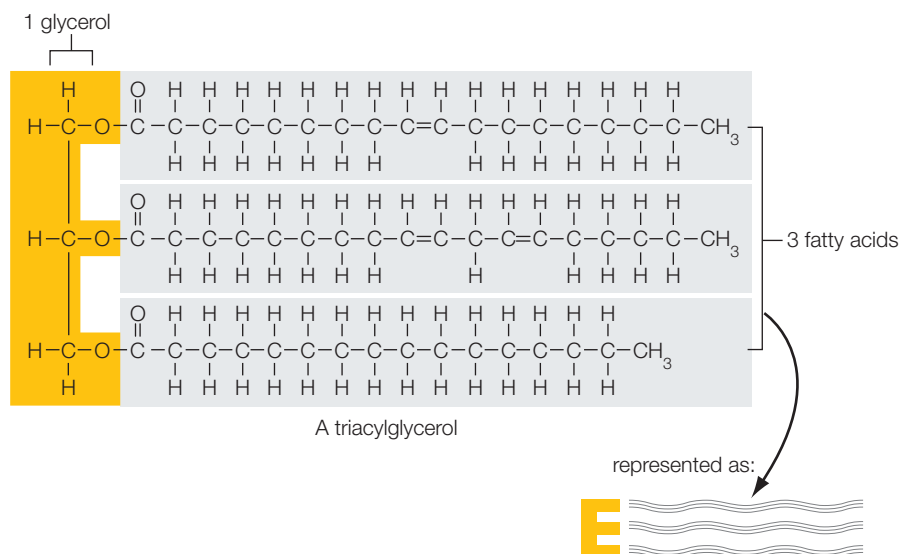
- Animals *consume plants* or other animals to obtain carbohydrates in their diet, gaining both energy (from starch and glycogen) and fibre or roughage (from cellulose).
- Cellulose in cell walls is often associated with a non-carbohydrate substance called **lignin**, an organic compound that helps walls of plant cells to bind. It also makes cell walls strong, rigid and impermeable to water. It is commonly found in the wood of trees.

### Lipids

#### Structure

**Lipids** are macromolecules that contain many carbon and hydrogen atoms, but few oxygen atoms. Lipids are organic compounds that have an oily, greasy, or waxy consistency. They are relatively insoluble in water and tend to be water-repellent (e.g. have a waxy cuticle on leaf surfaces). Most lipids are made of a glycerol molecule to which fatty acids attach. Triglycerides have three fatty acids attached to each glycerol.

Lipids may be *fats* (solid at room temperature, e.g. butter) or *oils* (liquid at room temperature, e.g. olive oil). Most *fats* are *animal products* and *oils* are *plant products* (some exceptions do exist, e.g. fish lipids are oils, not fats).



**Figure 2.2** Structural formula of a lipid (triglyceride)

**Uses of lipids in cells**

- Lipids form an extremely important *structural part of all membranes* in cells.
- Lipids are important *biological fuels*, storing large quantities of energy for both plant and animal cells. Lipids are stored in the cytoplasm of cells—as oil droplets in plants and as fat droplets in animal cells. Carbohydrates can be converted into fats by enzymes and these fats are stored within cells such as adipose (fat) tissue beneath the skin of many animals (e.g. mammals and birds). When food is abundant, this store of fats is increased to be used during times of food shortages.
- Some lipids are essential *structural parts of hormones* which are chemical messengers produced by cells (e.g. steroids).

**Proteins**

**Structure**

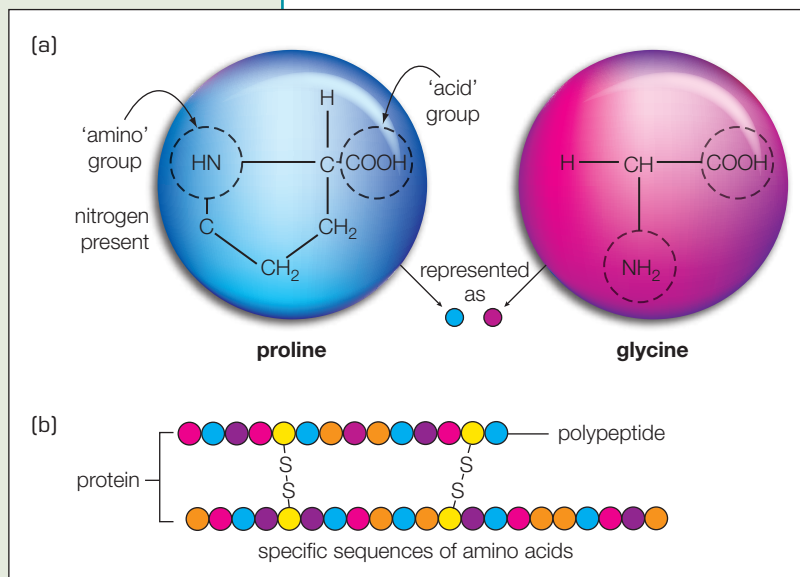
**Proteins** are large, complex macromolecules and they are the second most abundant chemical in cells. Proteins are made up of one or more long chains of nitrogen-containing amino acids. Each chain is called a **polypeptide**. Proteins contain the chemical elements carbon, hydrogen,

oxygen and nitrogen and some may contain sulfur and phosphorus. The amino acids in each linear sequence or polypeptide chain are held together by chemical bonds (forces of attraction) known as **peptide bonds**. *One or more polypeptides* can be twisted together into a particular shape, resulting in the overall structure of a *protein*. There are about 20 different amino acids and these can be put together in chains of up to 300 amino acids. The *sequence and arrangement of the amino acids* determines the type of protein, just like sequences of the letters of the alphabet can be used to make words and then sentences.

**Uses of proteins in cells**

- Proteins form *structural* components in cells and tissues; together with water, they form the basic structure of protoplasm (the cytoskeleton) in cells and form part of tissues such as bone, hair and nails.
- Proteins are an important structural part of **cell membranes** and, together with lipids, they regulate the passage of substances across cell membranes.
- Proteins may be important in conjunction with other molecules, such as DNA, to keep them compactly packaged inside cells.
- Some proteins have a *functional* role in cells; for example, *enzymes* are proteins that control all the metabolic (chemical) reactions of the cell.
- Proteins occur suspended in the protoplasm of cells or combine with other macromolecules to form an important structural part of all cell membranes.
- Nitrogen-containing compounds (nitrogenous compounds) cannot be stored in the bodies of animals and so they are often broken down and excreted as nitrogenous wastes.

**Figure 2.3**  
Protein structures:  
(a) structural formula of amino acids proline and glycine;  
(b) two polypeptide chains making up a protein (e.g. insulin)



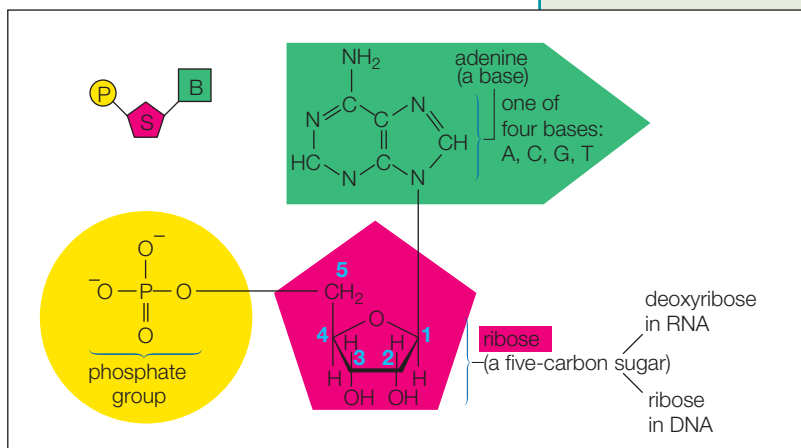
## Nucleic acids

### Structure

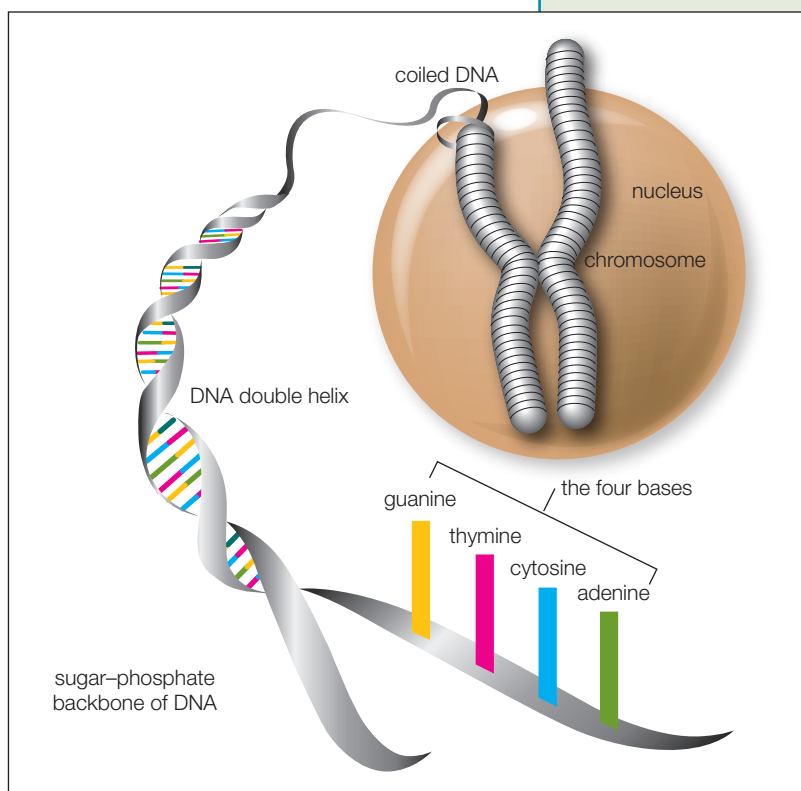
Nucleic acids contain the elements carbon, hydrogen, oxygen, nitrogen and phosphorous. All nucleic acids are made up of simple repeating units (monomers) called **nucleotides**, linked together to form single chains (RNA) or double strands (DNA), often of great length (see page 102). Each nucleotide is made up of a simple sugar (ribose or deoxyribose), a phosphate and a nitrogenous base. It is the sequence of bases which differs, providing the 'genetic code' for a cell.

### Uses of nucleic acids in cells

- DNA (deoxyribonucleic acid) stores the information that *controls the cell* and thereby the whole organism. DNA is the main chemical making up chromatin material in the nucleus, although small amounts are also found in mitochondria and chloroplasts.
- DNA is responsible for *transmitting inherited information* from one cell to another during cell division and from one generation to another during reproduction.
- RNA (ribonucleic acid) is a nucleic acid found in small amounts in the nucleus, but in larger amounts in the cytoplasm; associated with ribosomes. There are three types of RNA. One type, the messenger RNA, is involved in passing on information that is stored in DNA, transporting a transcribed copy from the nucleus to the cytoplasm. The other types of RNA assist the message to be '*translated*' into proteins. (You will learn more details of this in your HSC course.)



**Figure 2.4** Structural formula of a nucleotide



**Figure 2.5** A diagram of the unravelling of a chromosome that shows the way that DNA is packaged in a cell



**FIRST-HAND  
INVESTIGATION**  
**BIOLOGY SKILLS**

P11.1; P11.2; P11.3  
P12.1; P12.2; P12.3  
P13.1

## Investigating chemicals in cells

- *plan, choose equipment or resources and perform a first-hand investigation to gather information and use available evidence to identify the following substances in tissues:*

- glucose
- starch
- lipids
- proteins
- chloride ions
- lignin

In this investigation, you will learn the standard tests to identify particular chemical substances and will then apply them to test cells or products of living cells for the presence of these chemicals.

### Background information

All tissue that is living, or once was living, is made up of cells and these cells contain chemical substances. The chemicals may form part of the structure of these cells or may be held in a storage form within the cells.

### Handy hints

- Read the section on standard tests for organic chemicals that follows (see Table 2.3).
- You are going to design an experiment to test for the presence of the *cellular* chemicals: glucose, starch, lipids, proteins, chloride ions and lignin. *Plant tissues* that could be tested include any type of fruit or vegetable matter and *animal tissues* such as meat or fish, but it is sometimes simpler to test the *products* that have been produced by animal cells (e.g. milk, butter or eggs) or the products of plant cells (e.g. grape juice or apple juice).
- It is best if the cells are macerated (broken up) to allow the reagents to interact with the cell chemicals, so you may want to place the tissue of your choice in a blender or grind it using a mortar and pestle.
- Remember that many of the tests rely on observing a colour change and so you should select your tissue or cell products carefully to give the best results.

### Planning a valid scientific investigation

When planning the method, remember to ensure that your investigation is a 'fair' test.

- Use a *control* to ensure the validity of the experiment and to ensure that it tests what it sets out to test. To design a control remove the factor that you are testing for and compare the results with the

experiment when the factor was present. This comparison should show that if that factor is missing (control), you will not get a positive result, but if the factor is present (experimental), it is that factor which gives a positive result. In each chemical test, you will need to set up two sets of apparatus:

- experimental*—the factor being tested is the only variable and all other factors are kept constant
- control*—all factors are controlled and kept constant as for the experimental test and the (variable) factor being tested in the experimental is left out.

For example if you are using Benedict's reagent to test for the presence of glucose in a solution, your control test tube should contain Benedict's solution and water only, but no glucose. Your experimental test tube should contain Benedict's solution and *glucose* in water. This allows you to make a fair comparison between the results of the experimental and the control. Design similar controls for all your chemical tests.

- Identify the **independent variable** (the one that you, as the experimenter, change) and the **dependent variable** (the one that you measure/observe and record in your results). It is termed *dependent* because its outcome depends on changes that you make in the experiment.
- List all other variables that you should keep constant.
- Identify any risks or dangers that could be encountered in this practical and state what measures you will implement to ensure safety.

### Task

#### Aim

To test for the presence of cellular chemicals. Design an experiment to test whether any of the following chemicals are present in cells of your choice: carbohydrates (starch or glucose), proteins, lipids, chloride ions and lignin.

## Planning the experiment

### Preparation

1. List all the plant and/or animal tissues or products that you have selected to test and name the organic substance(s) for which each will be tested. A large table would be a suitable format to record this.
2. Read each standard test as described in Table 2.3 and record the equipment you will need for your test.

### Recording your investigation

3. Write an aim, hypothesis, materials and methods for the investigation, and include safety precautions.
4. Draw up a table in which you can record your results. It should have a suitable number of rows and columns, each with an appropriate heading so that you simply have to fill in the results when you conduct the investigation.
5. Conduct the first-hand investigation, recording your results in the table as you proceed. Read the aim again and then write a general conclusion for the overall investigation. If your experiment was not successful, state this in the conclusion.
6. In your discussion, describe how you would modify your method, materials or equipment to improve your investigation if you were to repeat it. Compare your results with expected results and discuss any discrepancies here. Answer the discussion questions that have been set. (Refer to details on these *investigative skills* on page x.)

### Ensuring validity, reliability and accuracy

Read the skills section on pages x–xii and take note of 12.4e and f; write a brief note in your

discussion to assess the **validity**, **reliability** and **accuracy** of your results.

The **scientific method** involves doing a 'fair' test:

- validity improves with multiplicity (many sets) of results (i.e. use *large sample sizes* or *many trials*). Validity also relies on using a *controlled* experiment which measures only *one variable at a time*; all others should be kept constant
- reliability—the same method should yield the *same results when repeated by other people*
- accuracy—the results should comply with *similar scientific information* (e.g. data in scientific journals); also involves selecting the most *precise measuring equipment* you have available and *correct use* of the equipment to avoid human error.

### Standard tests for organic chemicals

Test each substance (excluding the lipids) by placing a known amount of the chemical into water in a test tube and then add a set amount of indicator. A second test tube will be required for each control. Some samples may have to be ground up using a mortar and pestle before being placed in the test tube. See details in Table 2.3.

### Safety considerations

Some indicators and materials that you will use are irritants to skin, eyes and mucous membranes of the nose. Identify which chemicals are irritants. Describe ways to avoid contact with, or the inhalation or ingestion of any chemicals or materials used. Running water should be used as a rinsing agent.



Detailed information on *validity*, *reliability* and *accuracy*



Results table—chemicals in cells

**Table 2.3** Standard indicators used to test for the presence of organic chemicals

Chemical being identified	Indicator used	Heat/no heat	Positive result	Negative result
Starch	Iodine	No heat	Blue–black/purple	Yellow–brown, no colour change
Glucose	Benedict's solution	Heat in a water bath using a Bunsen burner	Orange–red	Pale blue, no colour change
Protein	Biuret's test: ■ 5 drops dilute sodium hydroxide ■ 3 drops copper sulfate	No heat	Purple	Pale blue, no colour change
Lignin	3 drops of toluidine blue	No heat	Blue–green	Pale blue, no colour change
Chloride ions	3–5 drops of silver nitrate	No heat	A white, precipitate (white solid material that settles to the bottom of your test tube)	No precipitate



## 2.2

## Cell membranes, diffusion and osmosis

■ *identify that there is movement of molecules into and out of cells*

For any cell to function it must interact with its surrounding environment and with the cells which surround it. Substances required by cells for their functioning need to move into cells and waste substances need to pass out of cells. These substances enter or exit cells through the cell membrane.

### Substances that enter and leave cells

Substances needed by cells are *gases* (oxygen and carbon dioxide), *nutrients* (sugars, amino acids, glycerol and fatty acids) and water, the main solvent in cells, as well as mineral salts dissolved in water

Substances that must leave cells are *wastes* (urea, uric acid and excess carbon dioxide) and *products* secreted by cells that may be needed to coat the outside of cells (e.g. mucus) or may pass to other cells (e.g. hormones).

### Boundaries

The movement of these chemicals occurs across the cell boundary which may be a cell membrane only (animal cells) or a cell membrane and a cell wall (plant cells). In both plant and animal cells, the **cell membrane** is in direct contact with the cytoplasm and it controls the passage of *water* and *other molecules* (many in a dissolved form) into or out of living cells.

Cell membranes are **selectively permeable** (sometimes referred to by the simplified term **semi-permeable**) because they allow only certain molecules to pass through them. Microscopic pores that exist in the cell membrane determine what molecules may or may not enter a cell. (See Table 2.4.) The pores in the cell membrane work in a manner similar to the gates in the boundary or fence surrounding a school—people who are associated with the school are allowed in and strangers are refused entry. People walking into the school use pedestrian

gates, but if people want to drive into the school in motor vehicles they need to do so through special gates, since the pedestrian gates are too small. Similarly, the pores of a cell membrane may restrict molecules because of their size and larger molecules will need special assistance to enter cells.

Plant cells may have a cell wall in addition to this membrane. In contrast to the selectively permeable nature of a cell membrane, a cellulose cell wall is **permeable**—it is a non-selective boundary that allows water and most molecules to pass freely inwards or outwards. The movement of these molecules is restricted only when they come into contact with the cell membrane. Some cells on the outside of plant parts (such as the surface cells of leaves) need to restrict the loss of water so that they do not dehydrate. Because cellulose is permeable these cells need an extra layer called a waxy cuticle, on the outside of their cellulose walls, to reduce water loss.

### Movement across membranes of cells

Movement across the *cell membrane* occurs when substances need to pass from one cell to another or when substances are exchanged between cells and their surrounding environment.

Movement across *organelle membranes*: some intracellular transport involves substances passing between the cytoplasm and membrane-bound organelles such as chloroplasts or mitochondria. The passage of molecules through these membranes is similar to that of molecules moving through the cell membrane, as they share the same basic structure.

To understand how membranes control and regulate the movement of substances, biologists examine the structure of membranes and try to relate this to their functioning.

## 2.3

## Current model of the cell membrane

- **describe the current model of membrane structure and explain how it accounts for the movement of some substances into and out of cells**

The detailed chemical structure of a cell membrane cannot be seen, even with an electron microscope. Many years of research have gone into attempting to accurately describe the structure of cell membranes and our current accepted understanding is based on a model called the **fluid mosaic model** of cell membranes.

## Models in science

(PFA P2) *Why do we use models in science?* Models are used in science to help our understanding of things:

- to represent something too large or too small to be seen
- to explain something complex in a simple manner
- to make predictions of expected results.

*More importantly, how do we know that the model that we use is correct?*

Before a model is accepted, it needs to be *validated*—that is, certain predictions should be made and, when tested using the model, should hold true. Often models are accepted for

a period of time until a prediction is made that is no longer supported by that model. At that point the model must be adjusted or changed to include the new prediction. Therefore, as scientists, we need to always be aware of the limitations of any model and be conscious of what is based on scientific fact and what is based on scientists' explanations of how they understand phenomena. Theories and models tend to change as science progresses, technology improves and more information becomes available. The current model for cell membranes, proposed in 1972, replaces the previous model which was proposed in 1935.

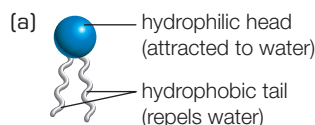
## The current model of membrane structure: the fluid mosaic model

The structure of the selectively permeable cell membrane is described as a *fluid-mosaic*, based on a model proposed by J. Singer and G. Nicholson in 1972. This model proposes a 'lipid sea' with 'many and various proteins floating on and in it'. The model has been accepted because the behaviour of membranes, estimated surface area, chemical analysis and electron microscope studies are all compatible with the model and it accounts for most functions associated with cell membranes.

## Lipid component

The 'fluid' part of the cell membrane is composed of two layers of **phospholipids**, in which:

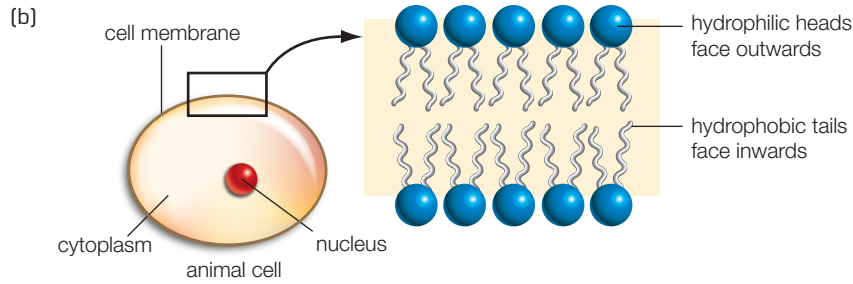
- their hydrophobic ('water-hating') tails are positioned inwards (towards each other)
- their hydrophilic ('water-loving') heads are positioned facing outwards (towards the cytoplasm on one side and to the outside of the cell on the other side, see Fig. 2.6a).



**Figure 2.6**  
Phospholipids:  
(a) a phospholipid molecule

PFA  
P2

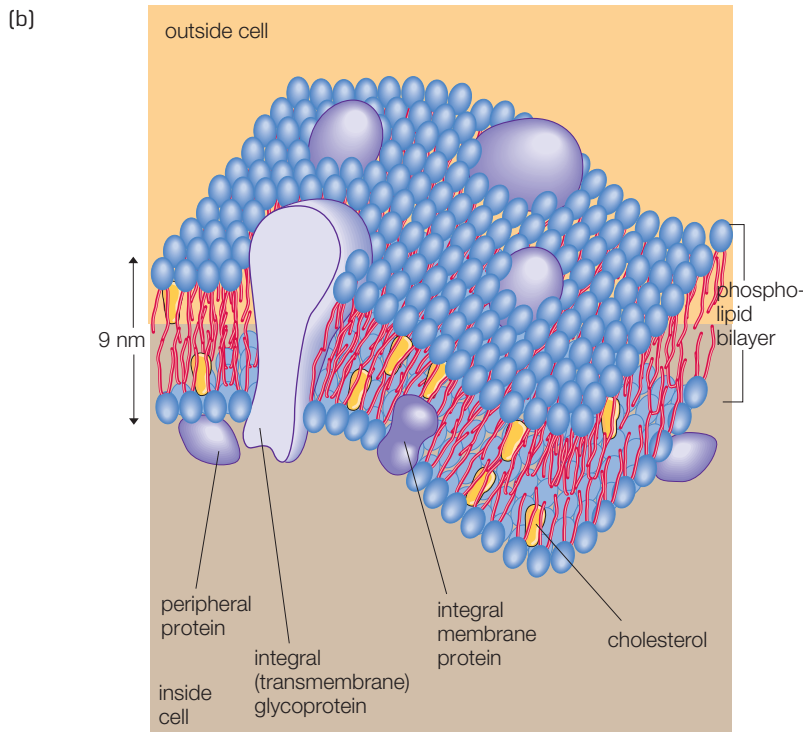
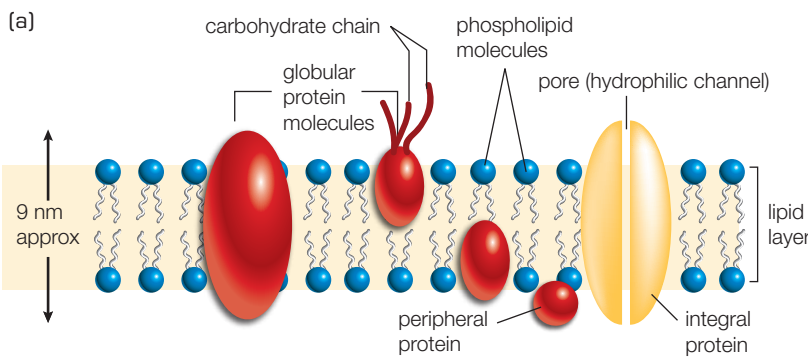
**Figure 2.6**  
Phospholipids:  
(b) a lipid bilayer  
showing phospholipid  
alignment



This layering is termed a **bilayer** and it is not rigid in structure, hence the term ‘fluid’ mosaic. This structure forms the basis of the cell membrane and all other membranes within cells. Proteins are then interspersed throughout this structure. The diagram above would be termed a *unit membrane* and would

be presented in a diagram of a cell by a single line (see Fig 2.6b).

**Figure 2.7**  
(a) Diagram  
representing the fluid  
mosaic model of a cell  
membrane;  
(b) A 3-dimensional  
view of the fluid  
mosaic model of  
a cell membrane



**Protein component**

Protein molecules are scattered throughout the lipid bilayer, suspended in it. Some proteins penetrate all the way through the bilayer forming channels that allow some materials to cross the membrane. Other proteins may be partly embedded in the membrane and it seems that some proteins are fixed in place, but others travel about freely. The proteins are described as ‘floating’ in the lipid bilayer ‘like icebergs in a lipid sea’, giving a *mosaic* effect.

Some proteins function as pores (temporary or permanent), others form active carrier systems or channels for transport, while others (glycoproteins) have carbohydrates attached for cell recognition.

**Other components**

- *Carbohydrates* may be attached to the outer surface of the cell membrane and play a role in cell recognition. They are termed glycolipids and glycoproteins, depending on the part of the membrane to which they are attached.

- *Microtubules* may be attached to the inner surface of the cell membrane, forming the anchorage of the cytoskeleton (internal skeleton of the cell).

The type of carbohydrates and proteins attached to a cell surface are important for the immune system in mammals to recognise whether cells belong to that organism (‘self’) or if foreign or invading cells have entered the body (‘non-self’). These surface

molecules therefore act as a 'uniform' by which cells can be recognised. They are the reason why bacteria are attacked and killed and why tissue matching is so important in organ transplants. (You will learn about these markers called *antigens* in more detail in your HSC course.)

### Evidence for the fluid mosaic model

- The membrane allows lipid-soluble substances to pass through easily, suggesting a lipid basis.
- The behaviour of membranes, for example how they reseal themselves when punctured with a fine needle, led to the idea that they are not rigid, but are more like a fluid.
- Monolayer or bilayer—when the expected total area of a monolayer of cell membrane was estimated for a particular cell, it turned out to be twice the surface area of the cell, suggesting that it is arranged as a bilayer.

- An earlier model of the cell membrane, which suggested more simply that it consisted of lipids coated by proteins, was supported by electron microscope work: staining for particular chemicals showed three layers—a lipid centre with a protein layer on either side. The currently accepted fluid mosaic model is a progression from the earlier model because it accounts for the fact that not all membranes are identical (e.g. when a mouse membrane was combined with a human membrane, mouse proteins moved to become dispersed within the human membrane).

### The permeability of membranes

The **permeability** of a membrane refers to its ability to allow substances to pass through it. Table 2.4 is far more simplistic than the workings of a cell membrane, but it gives some understanding of the terms permeable, impermeable and selectively permeable barriers.

**Table 2.4** A simple explanation of the permeability of barriers

Terminology	Description	Diagram
Impermeable	If a barrier is impermeable it does not allow any molecules to pass through it (e.g. a plastic bag). It does not have any pores through which the molecules can pass.	
Permeable	If a barrier is permeable it will allow all molecules to pass through it and it probably has large spaces or pores.	
Selectively permeable (semi-permeable or partially permeable)	Some barriers are selectively permeable—they only allow certain molecules to pass through and others are held back. These barriers may be thought of as having small pores.	

## The movement of molecules across cell membranes

The permeability of a membrane to a molecule depends on the molecule's:

- size
- electrical charge
- lipid solubility.

Small molecules move across membranes fast. Water-soluble (hydrophilic) molecules have difficulty penetrating a membrane, whereas lipid-soluble molecules do not; for example, urea and ethanol have *high permeability*.

Electrically-charged molecules are not very soluble in lipids and therefore

have *low membrane permeability*, whereas neutral molecules (e.g. gases such as carbon dioxide and oxygen) have a high permeability.

Although water is a charged molecule, membranes are *highly permeable* to it. Water moves through special tiny hydrophilic pores in the membrane by a process called **osmosis**.

Molecules that have low permeability rely on carrier proteins to transport them across membranes in cells (this will be dealt with in more detail later in this chapter).



### FIRST-HAND INVESTIGATION

PFA's

P2

### BIOLOGY SKILLS

P12.1; P12.2; P12.4  
P14.2; P14.3

## The selectively permeable nature of cell membranes

### ■ *perform a first-hand investigation to model the selectively permeable nature of a cell membrane*

#### Introduction

Use two tea strainers to model the selectively permeable nature of cell membranes.

Prepare a mixture of icing sugar and lollies such as Smarties. Place two teaspoons of each into one tea strainer and then, using an elastic band, tie the handles together. Shake the tea strainer 'cell' over a sheet of coloured paper and record in a table which substances pass through. Validate your model by using a variety of other substances (these may include salt, sugar granules and any other substances such as tea leaves and water).

#### Discussion questions

1. Explain what you think is the purpose of the syllabus requiring you to model the selectively permeable nature of a cell membrane.
2. Draw and label your model and, using a different coloured pen, write next to the appropriate label what structures of a selectively permeable membrane are represented.
3. Describe in what ways your model successfully shows the selectively permeable nature of a membrane.
4. Discuss any limitations in the working of your model, when compared with the functioning of a selectively permeable cell membrane.
5. Justify the validity of your model.
6. The description of a cell membrane being like a school fence (see page 108) could also be considered a model that shows the selectively permeable nature of membranes. Discuss an aspect of membrane functioning described in that model which is not shown in the tea-strainer model.

## Osmosis, diffusion and active transport

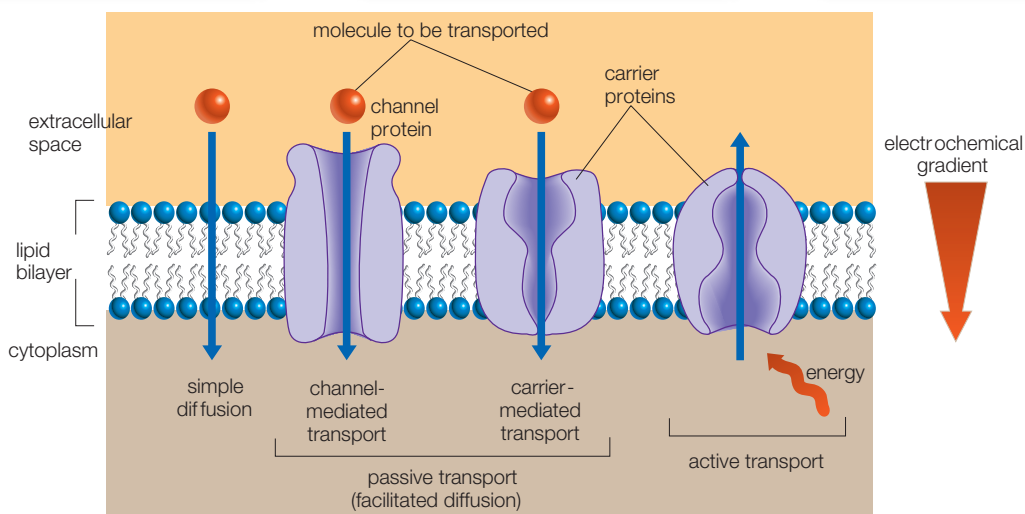
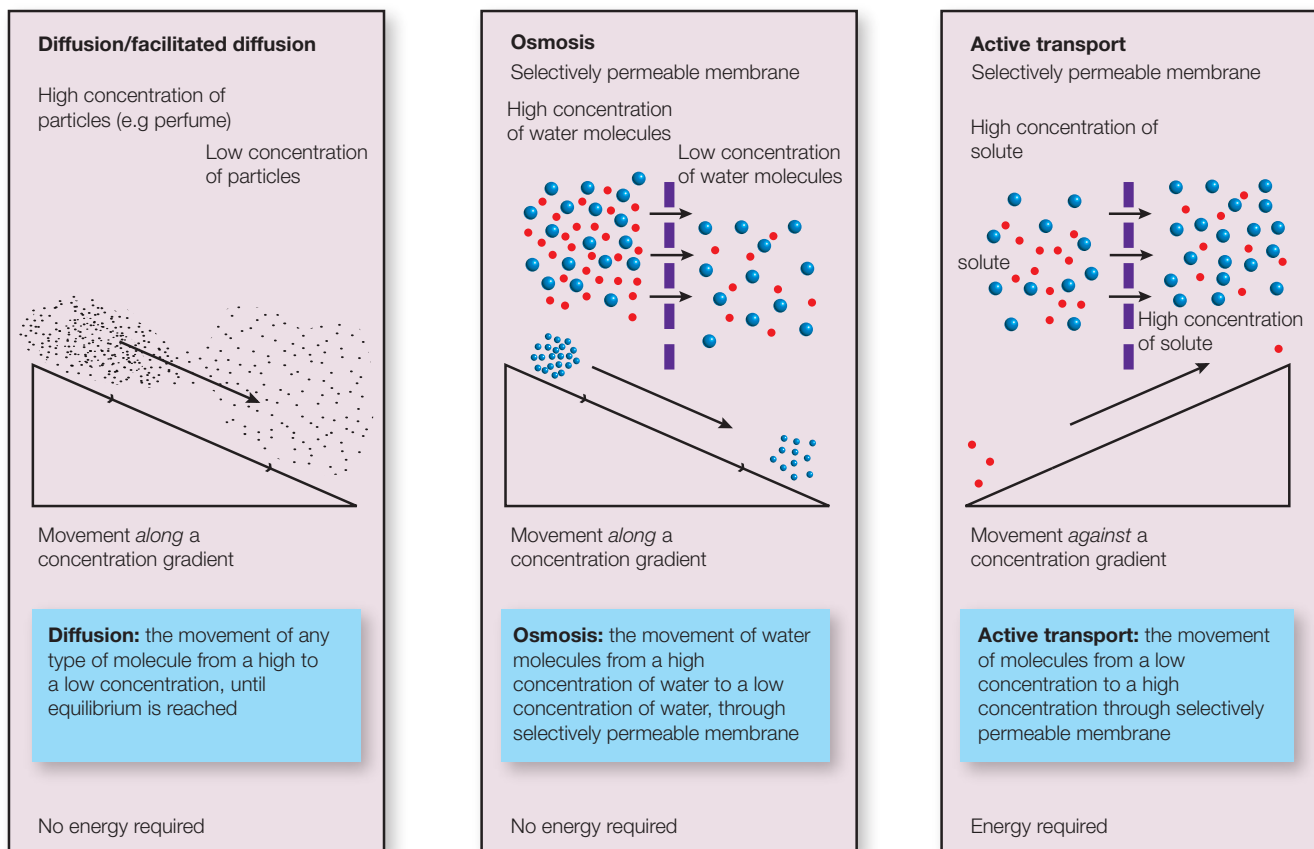
# 2.4

### ■ compare the processes of diffusion and osmosis

The movement of materials into and out of cells takes place either *passively* or *actively*. **Passive movement** includes the processes of **diffusion**

and **osmosis**, types of movement requiring no energy input from the cell. **Active transport** requires an input of cellular energy to actively

**Figure 2.8** Diffusion, osmosis and active transport across cell membranes



move molecules. Diffusion and osmosis result from the random movement of particles, called Brownian motion, whereby particles continually collide and move randomly. When particles are in a higher concentration in one region than other regions, their constant movement slowly results in the particles spreading out from this highly-concentrated region and eventually becoming evenly distributed within the space.

### Diffusion

**Diffusion** is the movement of *any* molecules from a region of high concentration to a region of low concentration of that substance, until **equilibrium** is reached. This does not require an energy input.

### Simple diffusion

For example, if deodorant is sprayed at the front of the classroom, its smell becomes evident to the nearest students in the front row at first and then slowly, as the particles spread out, to students further away. The particles of deodorant move from the front of the room, where they were in the highest concentration, to the rest of the room, where they were in low concentration, until they are equally spread throughout the room (equilibrium is reached).

Diffusion could involve the movement of solid, liquid or gas molecules through another medium that may also be solid, liquid or gas. Examples are the movement of perfume through the air (gas through gas), milk in tea (liquid through liquid), sugar in tea (solid through liquid) and ink up filter paper (liquid through solid).

Movement from a high to a low concentration is described as movement along a **concentration gradient** (a gradient is a slope). Picture the movement of a rock rolling down a hill (molecules moving down a

concentration gradient), needing no energy (see Fig. 2.8). The rate of diffusion changes, depending on the concentration gradient. If there is a greater difference in the concentration of substances, the concentration gradient will be steeper and the diffusion will occur faster. Diffusion can also speed up or slow down, depending on the temperature: heat increases the rate of diffusion because the kinetic energy of the particles speeds up.

When equilibrium is reached, the molecules continue to move randomly, but do not move in any particular direction.

### Biological examples of simple diffusion

Lipid soluble molecules and small, simple molecules diffuse across cell membranes. Living organisms rely on diffusion to function in a large number of instances. Try to think of examples of substances that move by simple diffusion in animals (including humans) and plants. Some examples are listed below to help you.

- Oxygen diffuses from the air (where it is in higher concentration) into cells in the lungs of humans (where it is in lower concentrations).
- Oxygen diffuses from the cells of the lungs into the blood capillaries in the lungs (these capillaries can then carry the 'oxygenated' blood away from the lungs).
- In plants, carbon dioxide diffuses from the surrounding air into cells in the leaves of plants for photosynthesis.
- Some 'unnatural' solutes that diffuse across membranes in our bodies are anaesthetics (into the lungs and then the bloodstream), alcohol (from the digestive tract into the bloodstream) and pesticides such as DDT (across the skin).

Some larger molecules and electrically-charged molecules move

## CLASSROOM ACTIVITY



### Demonstration of simple diffusion—diffusion of a liquid in a liquid

#### Aim

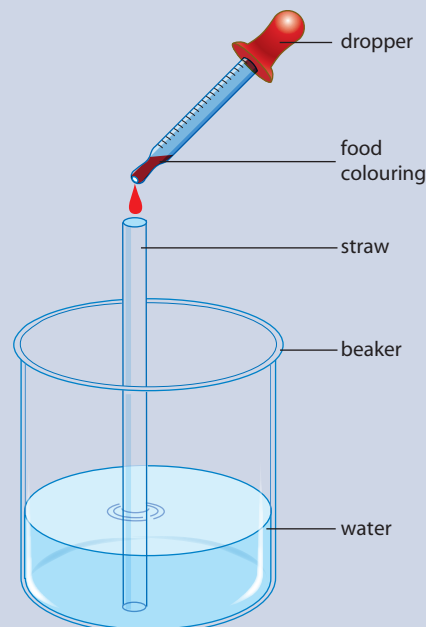
To demonstrate the diffusion of a liquid through a liquid and to investigate if it diffuses at the same rate at different temperatures.

#### Materials

Food colouring liquid, drinking straw, two beakers, hot water and cold water.

#### Method

Label one beaker 'cold' and the other 'hot', then three quarters fill each with cold and hot water as labelled. Place a drinking straw into the beaker, touching the bottom, and pour one drop of food colouring into the straw. Remove the straw, leaving the food colouring in the centre of the beaker (try not to disturb the water as the straw is withdrawn). Observe the movement of the colour through the water over the next half hour and then again after 24 hours.



**Figure 2.9** Experiment to demonstrate diffusion

too slowly by simple diffusion to satisfy the needs of cells. To overcome this problem, proteins in the cell membrane may act as *membrane transporters*, accelerating the movement of molecules across the membrane. If this movement is along a concentration gradient, no energy input is required and the process is termed **facilitated diffusion**.


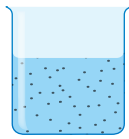
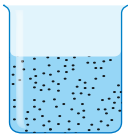
#### Facilitated diffusion (passive protein-mediated transport)

*Facilitated diffusion* is similar to simple diffusion where molecules move along a concentration gradient, but in facilitated diffusion this movement is assisted (facilitated) by carrier proteins in the membrane. Each protein that acts as a membrane-transporter is specific

to one solute or several similar solutes. It allows the movement of a large or charged molecule to occur more rapidly than would be expected as a result of simple diffusion for that molecule. The protein may act in one of two ways—as a **channel protein** or a **carrier protein**. (See Fig. 2.8.)

A *channel* is the fastest form of transport. A channel is similar to a drinking straw, it is formed by a protein that spans the cell membrane and allows direct passage from one side of the membrane to the other. Channels work like gates and they have 'open' and 'closed' states, determined by electrical or physical signals (comparable to electronic gates or those that rely on physical opening and closing).



Solution <sup>a</sup>	Solution A	Solution B	Solution C
			
	100% water	5% salt 95% water	20% salt 80% water
Water concentration	Highest	Lower than A	Lower than A and B
Solute concentration	Lowest	Higher than A	Higher than A & B
Relative solute concentration = tonicity <sup>b</sup>	Hypotonic to B and C	Hypertonic to A and hypotonic to C	Hypertonic to both A and B
Concentrated/dilute solution <sup>c</sup>	Dilute	More concentrated than A	More concentrated than A and B
Osmotic potential/osmotic pressure <sup>d</sup>	Lowest	Higher than A	Higher than A and B
Direction of osmosis	A → → → B and C	B → → → C	-----

**Table 2.5** Terminology related to osmosis

<sup>a</sup>A solution is a mixture made up of a *solvent* (e.g. water) in which a *solute* (e.g. salt or sugar) is dissolved.

<sup>b</sup>The *solute concentration* determines the *tonicity* of a solution. It is used to *compare* how concentrated two solutions are in relation to one another. The term *hypertonic* is used to describe the solution with the *larger* number of *dissolved substances* (hyper = large or over abundant, e.g. hyperactive = overactive) and the term *hypotonic* describes the solution with fewer dissolved substances (hypo = small/under). If both solutions have the same concentration of solutes, they are termed **isotonic**.

<sup>c</sup>To remember the meaning of the terms *concentrated* and *dilute*, think in terms of mixing cordial with water—too much cordial and it is too concentrated, too little and it is too dilute. These terms refer to the concentration of *solute* (cordial) in water. If cordial has a very high *water concentration*, is it *dilute* or *concentrated*? Check the use of these terms in relation to water concentration in the table above.

<sup>d</sup>Osmotic potential or pressure describes the ability of a solution to draw water towards itself by osmosis. That is, the greater the concentration of dissolved substances, the lower the water concentration and the more likely the solution will attract water by osmosis (movement from a high to a low *water* concentration).

A *carrier protein* binds with a solute and then the protein changes shape or conformation to move the solute to the other side of the membrane. Once it releases the solute on the other side, the carrier returns to its original shape. Because the carriers can become saturated, the process is slower than that of channel-mediated transport, but quicker than the expected rate for simple diffusion. Biological examples of facilitated diffusion in cells include the uptake by plant roots of mineral salts from the soil and the absorption of mineral salts in the large intestine of animals.

The movement of water through cell membranes involves protein channels and so it is considered to

be a specialised form of facilitated diffusion known as osmosis.

### Osmosis

Osmosis is the movement of *water* molecules from a region of high water concentration to a region of low water concentration through a selectively permeable membrane. It does not require an energy input.

The movement of water through cell membranes is passive but, because water is a charged molecule, the movement is not directly through the bilayer of lipids. Water moves through special tiny protein channels in cell membranes called **aquaporins** ('water pores'). As a result, the movement

of water across membranes is much more rapid than would otherwise be expected. Tissues with a high-water permeability have a greater number of aquaporins in their cell membranes (e.g. kidney cells).

The rate of water movement through the membrane is affected by two things:

1. solute concentration—the concentration of dissolved substances in the solution
2. opposing physical pressure or tension exerted on the water (how much it is being squeezed or pulled) by the space that it is moving into.

### The effect of solute concentration on osmosis (see Fig. 2.5)

To understand how *water* concentration is affected by the number of solutes dissolved in it, think how distilled water (100 per cent water) has a greater water concentration than a solution of 5 per cent salt and 95 per cent water. The water concentration in a solution of 20 per cent salt and 80 per cent water would have an even lower water concentration. So, the higher the solute concentration in a solution, the lower the water concentration will be. Table 2.5 illustrates this and introduces some of the terminology that is often used in relation to water concentrations and osmosis.

### Osmosis and cells

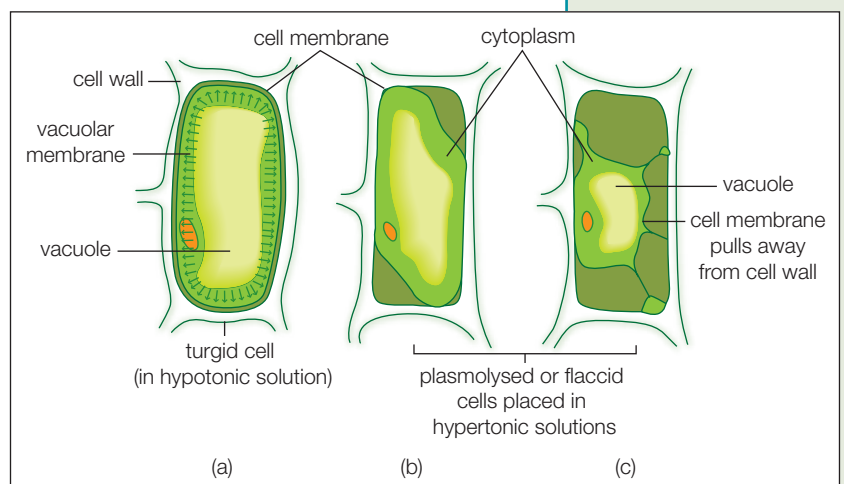
When a cell has a higher solute concentration than the water surrounding it, water drawn towards the cell can only continue to move into that cell if the cell is able to physically expand to allow space for the incoming water (see Fig. 2.10). (This would also apply to the osmosis experiment conducted on page 119, where the movement of water from the beaker into the sucrose solution was limited by the available space in the dialysis tubing.) The cellulose wall of a cell is only slightly elastic. When the cell

wall is distended by incoming water and stretches to capacity, it exerts an opposing force or *pressure* on the incoming water. If this opposing force, known as **wall pressure**, is equal to or greater than the force of the water moving in (**osmotic pressure**) water will no longer be able to enter the cell. The expanded cell is then said to be in a state of **turgor**. Plants rely on turgid cells for support.

Plant cells that are placed in a solution that is more concentrated than the cell contents, or plant cells that are exposed to air, will lose water to their surroundings by osmosis. Water may continue to leave the cells until the cell contents (cytoplasm and cell membrane) begin to shrink, leaving a gap between the cell membrane and wall. This state is termed **plasmolysis**. Plasmolysed or **flaccid** cells no longer provide sufficient support to the plant and the plant wilts. Wilting may be temporary (e.g. watering a plant may allow it to recover and become upright once again) or permanent. (See Fig. 2.10.)

Diffusion and osmosis both rely on a concentration gradient to direct the flow of substances and are examples of passive movement with no input of energy. Sometimes in living things, a chemical may need to be moved *against* the concentration gradient and to do this requires energy.

**Figure 2.10** Turgor pressure in plant cells: (a) turgid cell placed in a hypotonic solution; (b) and (c) plasmolysed or flaccid cells in hypertonic solutions



### Active transport

Active transport is the movement of molecules from an area of *low concentration* to an area of *high concentration*, requiring the input of energy.

Active transport requires a carrier protein that spans the membrane to actively move chemicals from a *low* to a *high* concentration, utilising cellular energy. An example of active transport is when glucose and amino acids are reabsorbed by kidney cells so that they are not lost in urine or when the end products of digestion are loaded from the intestine into the bloodstream to absorb food after eating.

### Endocytosis and exocytosis—transport of large molecules across membranes

When particles larger than individual molecules need to enter or leave cells, the cell membrane of an animal cell is able to surround and engulf the particle in a process known as endocytosis. ('endo' = into/inside; 'cyto' = cell). A typical example would be when a white blood cell in the human body

engulfs and digests bacteria to fight infection. The membrane enfolds and encloses the particle in a vesicle (sac) which pinches off and the particle enters the cell (see Fig. 2.11). If a solid particle is engulfed, the process is termed **phagocytosis** ('cell eating'). Sometimes fluid is engulfed and the process is then called **pinocytosis** ('cell drinking').

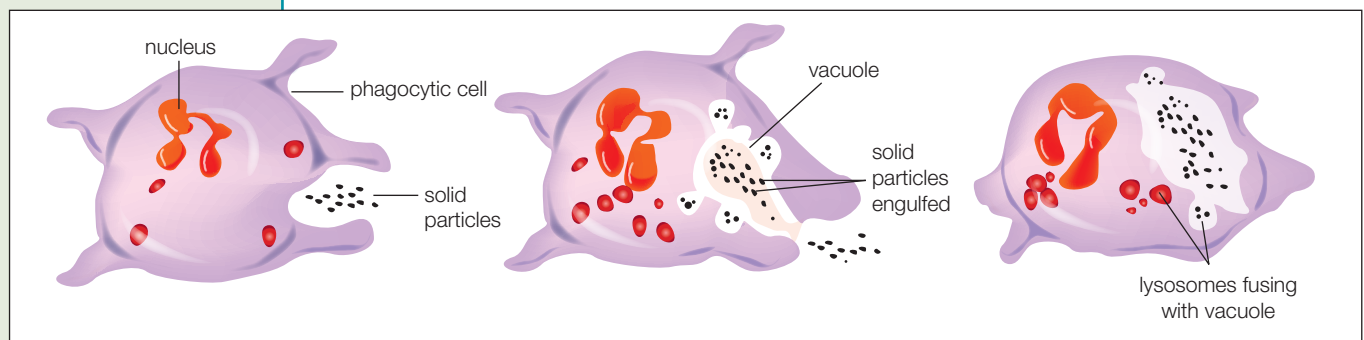
In a reverse situation, membrane-like vesicles can be transported to the surface of the cell and emptied out, a process called exocytosis. This could happen when a cell secretes hormones that it has made (see diagram on page 97).

All of these processes are made possible by the fluid mosaic nature of the cell membrane, because of its ability to flow around a particle and seal up when it joins with other membranes.

**Table 2.6** Movement of substances into and out of cells—comparing active and passive transport

	Active transport	Passive transport
Entry point	Through carrier proteins	Through carrier proteins (facilitated diffusion) or between phospholipids (osmosis and diffusion)
Rate of movement	Fast	Slow
Concentration	Low to high	High to low
Energy	Energy required	Energy not required
Examples of molecules transported	Sugar and amino acids	Water, oxygen, carbon dioxide, sugars and amino acids

**Figure 2.11** Phagocytosis—a white blood cell engulfing bacteria



## Demonstrating osmosis and diffusion

### ■ perform a first-hand investigation to demonstrate the difference between osmosis and diffusion

Suggestion for co-operative learning: allow students to work in pairs, each partner labelling themselves A or B. Split the class into two—all students labelled A do the osmosis experiment and students labelled B carry out the diffusion experiment. Students need to answer Question 1 individually before explaining their experiment to their partners and then they can jointly discuss and answer Questions 2 and 3, comparing osmosis and diffusion.

#### Aim 1—osmosis

To demonstrate osmosis using dialysis tubing as a selectively permeable membrane.

#### Materials—osmosis

Two 200 mL beakers, distilled water, sucrose solution, cotton thread, two glass rods, two 15 cm strips of dialysis tubing, 25 mL measuring cylinder, filter funnel, marking pen and plastic cling wrap to prevent evaporation.

#### Aim 2—diffusion

To demonstrate diffusion using dialysis tubing.

#### Materials—diffusion

Two 200 mL beakers, distilled water, dilute iodine solution, a mixture of starch (cornflour starch or rice water) in water, cotton thread, two glass rods, two 20 cm strips of dialysis tubing, 25 mL measuring cylinder, filter funnel, marking pen and plastic cling wrap to prevent evaporation.

Read the method below, identifying all the variables that you will need to keep constant in this experiment. (List these in your discussion—see Question 1.1.)

#### Method

- Cut two strips of dialysis tubing of the same length.
- Tie one end of each strip securely with a piece of cotton, leaving the other end untied.
- Open the untied end of the tubing (this is made easier if you wet it under a running tap). Using a funnel and a measuring cylinder, pour a measured volume (about 15–20 mL) of sugar solution (osmosis) or starch mixture (diffusion) into the tubing so that the tubing is two-thirds full. (Record the exact volume of sugar solution used in each.)
- Tie the top of the tubing with cotton. Attach it as shown in Figure 2.12 to a glass rod.
- Repeat the previous two steps, this time filling the tubing with distilled water instead of sugar (osmosis control). Keep the control for the starch solution the same as the experiment, except place no iodine in the beaker.
- Suspend the *experimental* and the *control* apparatus each in a beaker of distilled water (osmosis experiment) or in a beaker of distilled water with iodine solution (diffusion experiment) as shown in Figure 2.12. Ensure that the tied ends of the dialysis tubing are just above the distilled water in the beaker to prevent leakage. Do not have the tubing too far out of the water as evaporation may occur and this will interfere with the accuracy of your results.
- Mark the level of water in the beaker with a marking pen.
- Cover the top of the experiment with plastic wrap to prevent the water in the beaker from evaporating. Leave the apparatus to stand for several hours or overnight.

#### FIRST-HAND INVESTIGATION

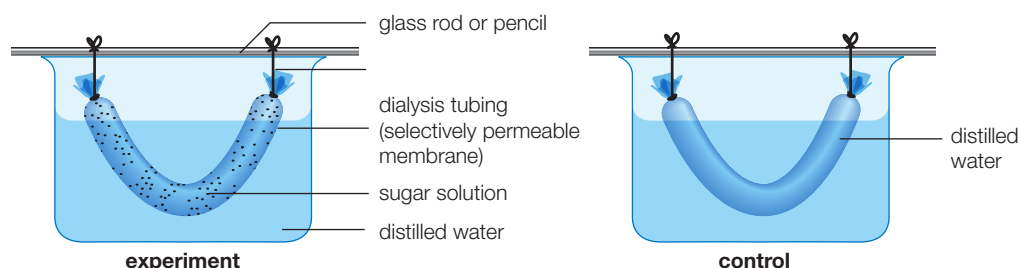
#### BIOLOGY SKILLS

P11.3

P12.1; 12.2; 12.4

P13.1

P14.1; 14.2; 14.3



**Figure 2.12**  
Experiment to demonstrate osmosis



Results tables for diffusion and osmosis experiments

- Record your results in the form of a table. Draw up a table and remember to include headings.  
*Osmosis experiment*—record the volumes of solutions in each dialysis bag and in each beaker (both the experimental and the control) at the start of the experiment, and then again after 24 hours. You should also record observations such as changes in the fullness of the dialysis tubing. (Remember to note the exact number of hours that the experiment was left standing.)  
*Diffusion experiment*—record the volumes of solutions in each dialysis bag and in each beaker (both the experimental and the control) at the start of the experiment and then again after 24 hours. You should also record observations such as the colour of solutions in the dialysis bag and in the beaker at the start of the experiment, at the end of the lesson and after 24 hours.
- Your results will be both **quantitative** (measured, e.g. using a measuring cylinder) and **qualitative** (e.g. a description of how full the bags are, drawing diagrams at different stages of the experiment, or a description of any colour change). Think about the advantages of qualitative versus quantitative results.

## Results

Record results in a table and/or use diagrams.

## Conclusion

It can be concluded that ..... has taken place and ..... has moved from a high concentration to a low concentration through a selectively permeable membrane.

## Discussion

### Individual

1. Answer the following questions before discussing the experiment with your partner:
  - 1.1. **List** all the variables in this experiment that should be kept constant.
  - 1.2. **Identify** the dependent and independent variable.
  - 1.3. **Justify** the conclusion given above, using evidence from your experiment.
  - 1.4. **Describe** ways that you could modify this experiment to improve its accuracy.
  - 1.5. **Discuss** the advantages and disadvantages of qualitative versus quantitative results.

### Partners

2. Record the following as a table of comparison using the results form each experiment:
  - 2.1. Compare the variables that you kept constant.
  - 2.2. Compare your dependent and independent variables.
  - 2.3. Validate your experiments (i.e. explain how you tested what you set out to test).
3. In a written paragraph, describe how the experiments *distinguish* between osmosis and diffusion.

# 2.5

## Surface area: volume ratio and rate of movement

- *explain how the surface area to volume ratio affects the rate of movement of substances into and out of cells*

### What is surface area?

The surface area of an object is that part of the object exposed to its surroundings (see Fig. 2.13). If the object is a cube (e.g. a die):

- the *area of one side* is calculated as the length multiplied by the width,  $l \times w$ , and is measured in  $\text{cm}^2$ .  
For example in a cube that is

2 cm in width and 2 cm in height, each side will have an area of  
 $2 \text{ cm} \times 2 \text{ cm} = 4 \text{ cm}^2$

- the *surface area of the whole cube* is calculated by taking into account that there are *six* sides to a cube (think of a die):  $6 \times (l \times w)$ .  
In a 2 cm cube it would be:  
 $6 \times (2 \times 2) \text{ cm}^2 = 24 \text{ cm}^2$

## What is volume?

The volume of an object is the amount of space that it occupies. To calculate the volume of a cube, the length, width and depth must all be multiplied together:  $l \times w \times b$  (measured in  $\text{cm}^3$ ).

In a 2 cm cube, this would be:  
 $2 \text{ cm} \times 2 \text{ cm} \times 2 \text{ cm} = 8 \text{ cm}^3$

## What is surface area to volume ratio?

A ratio is a fraction that allows us to compare things. It is obtained by dividing the two things to be compared. For example the ratio *surface area:volume* is the same as obtained from the fraction:  $\frac{\text{surface area}}{\text{volume}}$

In the example above, the cube would be:  $\frac{SA}{V} \frac{24 \text{ cm}^2}{8 \text{ cm}^3} = \frac{3}{1}$

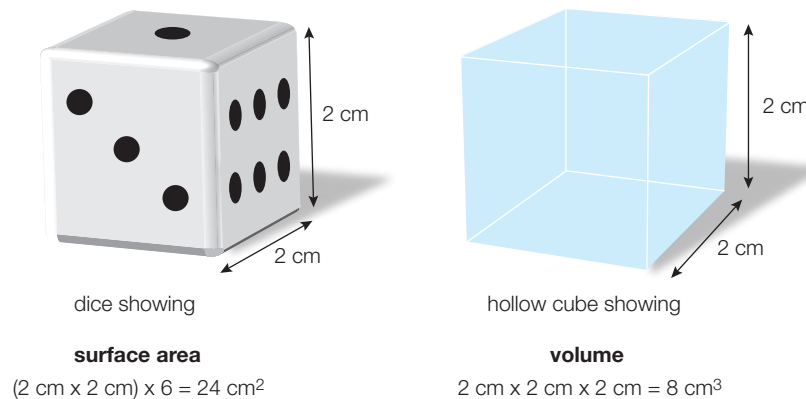
Therefore the ratio would be 3:1.

## How the surface area to volume ratio affects the rate of movement of substances into and out of cells

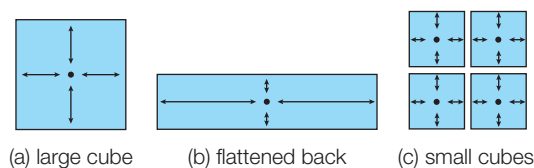
Substances that enter cells must travel from the outside environment across the surface of the cell and then diffuse inwards until they reach the centre of the cell. If a cell has a large volume, the organelles in the centre of the cell are further from the outside (see Fig. 2.14). If a cell is flatter or smaller, the organelles in the centre are close to the outer surface. This increases the efficiency of substances diffusing into or out of a cell due to the cell having a larger surface area to volume ratio. The folding of a cell also increases the surface area to volume ratio, increasing the efficiency of substances entering and leaving the cell.



Extension activity—  
to demonstrate  
surface area



**Figure 2.13** Surface area (e.g. a die) and volume (e.g. a hollow cube)



**Figure 2.14** Distance over which diffusion occurs to reach the centre in cells of different shapes and sizes: (a) a large cube, (b) a flattened block, (c) small cubes



## Investigating the surface area to volume ratio and rate of movement

### FIRST-HAND INVESTIGATION

PFA's

P2

### BIOLOGY SKILLS

P12.1; P12.2; P12.4

P1.31

P14.1; P14.3

### ■ *perform a first-hand investigation to demonstrate the effect of surface area to volume ratio on rate of diffusion*

#### Introduction

Understanding the relationship between the size of cells (volume) and their surface area helps us to realise how the physical limitation of the size of cells is important if they are to function effectively. In order to carry out necessary chemical activities (metabolism) cells need to absorb substances that they require from the surroundings. This uptake is often dependent on the process of diffusion. Diffusion is a slow process and so, to be more effective, the number of molecules that can be taken up in a particular space of time should be increased. The **hypothesis** to be tested is that, by increasing the surface area over which uptake occurs (for an object of a particular volume), diffusion can be increased and molecules can reach the centre of an object *sooner* than if the object has a lower surface area to volume ratio. Therefore, although the rate of diffusion is still the same, by increasing the *amount* of diffusion occurring, the *overall rate of movement* increases.

This investigation makes use of a model to investigate the effect of the surface area to volume ratio on cellular diffusion. Cells of different sizes are represented by gelatin cubes, a simplification to try to increase understanding of the concept and to allow predictions to be made. When interpreting the behaviour of substances in the model (in this instance, the movement of the chemicals by diffusion) the limitations of the model must be taken into account. For example one limitation is that the jelly cubes do not have a selectively permeable boundary such as a cell membrane. The validity of the model should also be assessed (see PFA P2 on page ix). For example the lack of a cell membrane and an energy source suggests that no active transport can take place, indicating that only diffusion, as stated in the hypothesis, is being investigated.

#### Aim

This model will be used to investigate:

- the change in the surface area to volume ratio with 'cell' size
- the effect of a change in the surface area to volume ratio on the rate of diffusion.

#### Equipment

Agar-phenolphthalein-sodium hydroxide cubes (gelatin blocks) (three sizes: sides = 1 cm, 2 cm and 3 cm), 0.1 M hydrochloric acid (approx 150 mL), ruler (with centimetre and millimetre markings), knife or razor blade, paper towel, a 250 mL beaker, a plastic spoon and a stopwatch.

#### Formulae to be applied

Surface area (SA) of 1 side = length<sup>2</sup>

Total surface area = 6 × length<sup>2</sup>

The units for SA are cm<sup>2</sup>

Volume (V) = length<sup>3</sup>

The units of volume are cm<sup>3</sup>

Work out the SA to V ratio

$$\frac{SA}{V} = \frac{\text{--- cm}^2}{\text{--- cm}^3}$$

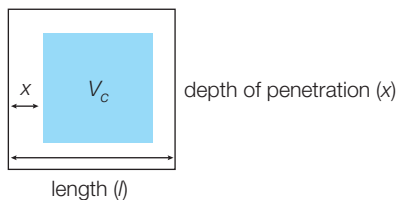
#### Safety

Wear a laboratory coat as phenolphthalein can stain clothing. Take care not to get HCl on skin or in eyes—use a dropper and do not rub your eyes. Wear safety glasses. If acid comes in contact with any part of the body irrigate well with water. Turn gelatin blocks using a teaspoon; do not handle chemicals.

#### Procedure

- Before starting the practical calculate the surface area to volume ratio of each of the cubes (see first three columns of Table 2.7). Assume that the cubes have exactly 3 cm, 2 cm or 1 cm sides. Due to the indicator (phenolphthalein) and the presence of the base (NaOH, sodium hydroxide) in the cubes they will appear pink in colour.
- Place one of each size cube (1 cm<sup>3</sup>, 2 cm<sup>3</sup> and 3 cm<sup>3</sup>) into the 250 mL beaker, making sure that each cube is not touching the others.

- Cover the cubes with the hydrochloric acid and leave for 10 minutes, using a plastic spoon to turn the cubes over every 2 minutes.



**Figure 2.15** Gelatin cube showing depth of penetration

- Remove the cubes from the acid after the 10 minutes, quickly blotting dry the surface of the cubes using paper towel. Cut each cube into two using the razor blade. Measure the depth of penetration of acid into each cube in millimetres and record it in Table 2.7.
- Complete the remaining calculations in the table, determining the volume of each cube that remains coloured and calculating the percentage penetration in the last column as a measure of the proportion of the cube affected by diffusion, in cubes of different sizes.

## Questions

1. **Identify** the trend in the change in surface area to volume ratio as the volume of the cube increases.
2. **Assess** the accuracy of any measurements and calculations made and their relative importance in this practical.
3. **Describe** the evidence that indicates that diffusion in the cube has occurred.
4. **Identify** which cube (cell) showed the greatest *depth* of penetration of acid and which showed the least. Was this what you would have expected? **Explain**.
5. **Explain** why it was necessary to calculate the *percentage* acid penetration for each cube.
6. When a cell divides, it produces two identical cells that, at first, are half the size of the original cell. **Describe** the change to the:
  - (a) total surface area
  - (b) total volume
  - (c) surface area to volume ratio for each cell.
7. These cells will then grow, but to a limited size. **Clarify** the significance of the results of this investigation for multicellular living organisms.
8. **Discuss** the limitations of the jelly cubes representing cells.



Enrichment questions and 'Think about it'

Cube size (l) cm	Surface area, SA ( $6 \times l^2$ ) cm <sup>2</sup>	Volume, V (l <sup>3</sup> ) cm <sup>3</sup>	$\frac{SA}{V} = SA:V$	Depth of penetration (x) mm	Volume left coloured $V_c = (l - 2x)^3$	% left coloured $\left(\frac{V_c}{V}\right) \times 100$	% acid penetration = $100 - V_c\%$
1							
2							
3							

**Table 2.7** Results of surface area to volume ratio investigation



## REVISION QUESTIONS



Worksheet—  
chemicals in cells

1. Draw a diagram of a plant/animal cell as seen under the electron microscope. Label each part of the cell. Identify what chemicals make up each part of the cell and, using a different-coloured pen, write the name of the chemicals next to each respective part that has been labelled.
2. Draw up a table to compare the organic chemicals found in cells. Your table should compare the monomers of each compound, the chemical elements (atoms) that comprise that compound, where in the cell each is found and two functions or uses of the chemicals in cells.
3. Identify the three main components of a cell membrane and describe how each is necessary for membrane functioning.
4. Complete the following table comparing the structure and function of a cell membrane with that of a cell wall.

Cell membrane	Cell wall
Chemical composition	A simpler structure made mainly of strands of the carbohydrate cellulose; also contains pectin and may have additional thickening such as lignin and suberin.
Where it is found	Directly surrounds the cytoplasm, is the outer boundary in animal cells and forms part of the boundary in plant cells.
Function	Provides support and shape, limits the expansion of cells and plays a role in cell turgidity. Allows water and most molecules to pass freely into and out of cells.
Access to molecules	It has pits with strands of cytoplasm passing through them to allow the passage of substances between cells.

**Table 2.8**

Comparison of the cell membrane and the cell wall

5. In the form of a table, compare the processes of diffusion, osmosis and active transport under the following headings:
  - Type of substances that move
  - Concentration gradient along which they move
  - Energy requirements
  - Only across selectively permeable membranes—yes or no?
  - Examples in living organisms.
6. If solution X contains more dissolved substances than solution Y, what process is involved in moving:
  - (a) water from Y to X?
  - (b) solutes from X to Y?
  - (c) solutes from Y to X?
7. If we cut two identical cubes of potato and leave one to stand in water while the other stands in a 20 per cent glucose solution for 12 hours, predict which will have the greater mass and explain why. (*Hint:* In each case in which direction will water molecules move?)
8. The terms *turgid* and *flaccid* are used to refer to the condition of plant cells. Draw a labelled diagram to illustrate what is meant by each of these terms.



Answers to  
revision questions