Lesson Two

Movement of Substances in and out of Cells

Aims

By the end of this lesson you should be able to:

- understand the processes of diffusion, osmosis and active transport by which substances move into and out of cells
- understand how factors affect the rate of movement of substances into and out of cells, including the effects of surface area to volume ratio, distance, temperature and concentration gradient
- investigate diffusion and osmosis using living and non-living systems

Context

This lesson covers element (d) of Section 2: 'Structure and functions in living organisms' of the Edexcel specification.

Edexcel IGCSE Biology Chapter 1 pages 9–11 and Chapter 11 pages 122–126.

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Introduction

All organisms must transport substances (materials) from place to place inside their bodies. There are two completely different ways in which this is done:

- By **mass flow**, where the substances are swept along in a flow of water or air. This is how materials are moved in the bloodstream. Mass flow transport is fast, even over long distances.

- One particle at a time, by three processes called **diffusion**, **osmosis** and **active transport**. These processes are slow so they can only be used over very short distances.

To remain alive, a cell must move a variety of substances in and out across the cell membrane. Substances can only cross the cell membrane one particle at a time, not by mass flow. So if any substance enters or leaves a cell it does so by diffusion, by osmosis, or by active transport.

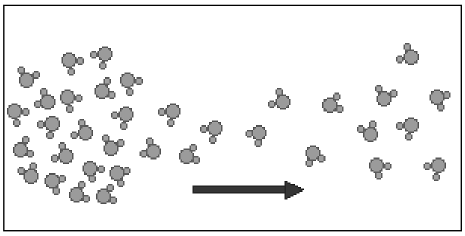
Some important Terms

As you will be aware, matter is made up of tiny invisible balls called **atoms**. Atoms can join together to form groups called **molecules**. Atoms or molecules can become electrically charged, in which case they are called **ions**. Biologists use the term **particles** to include atoms, molecules and ions. It is particles which move by diffusion, osmosis or active transport.

Particles only enter or leave cells when they are **dissolved** in water to form a **solution**. A solution is made up of two parts: the water itself is called the **solvent**. The substance that is dissolved in the water is called the **solute**.

Diffusion

Definition: diffusion is the spreading of a substance from a place of higher concentration to one of lower concentration (i.e. down a **concentration gradient**) because of the random movement of particles.



higher concentration

lower concentration

Concentration means how closely the particles are packed together.

Diffusion works because the particles in a liquid or a gas move around at random, like people milling about aimlessly in a crowd. The particles in a gas like air move much faster than those in a liquid like water, so substances diffuse much faster through air than through water.

Activity 1	In a room where the air is completely still, open a bottle of strong-smelling liquid, or light some incense, on one side. Walk to the other side and wait. The smell will eventually reach you because the incense particles diffuse through the air. How long does this take? Compare this with the time taken for the colour to spread through the water in Activity 2.

Activity 2	Take a glass of water, make sure it is completely still, and add to it either a drop of ink or a drop of food colouring. Write down what happens: 1. immediately 2. after half an hour 3. the next day

	1. 2. 3.

Cells and Diffusion

A substance can enter a cell by diffusion provided two conditions are fulfilled:

- the cell membrane is **permeable** to this substance, i.e. will let it through freely
- the concentration of the substance is higher outside the cell than inside.

A good example of a substance which *enters* a cell by diffusion is oxygen. Because the cell uses up oxygen in a process called **respiration**, its concentration inside the cell tends to go down. Oxygen diffuses *in* across the cell membrane down the concentration gradient which this sets up.

Carbon dioxide is an example of a substance which *leaves* a cell by diffusion. Because the cell makes carbon dioxide during respiration, its concentration inside the cell tends to go up. Carbon dioxide diffuses *out* across the cell membrane down a concentration gradient.

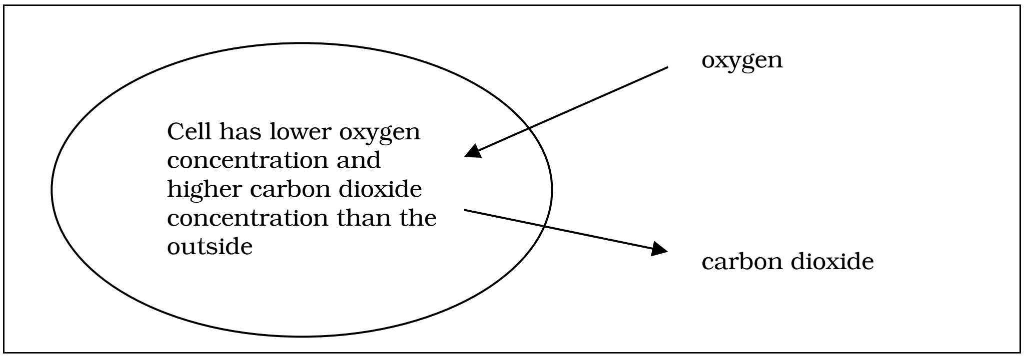


Diagram 1: Diffusion of gases into and out of a cell across the cell membrane

Some other important examples of diffusion you will meet in the course are:

- movement of oxygen and carbon dioxide between the blood and air at the lungs
- movement of nutrients out of the small intestine into the blood
- movement of oxygen and carbon dioxide into and out of a leaf

In each case the materials are moving, particle by particle, down a concentration gradient.

Speeding up Diffusion

Because diffusion is a slow process, organisms adopt various strategies to speed it up. This enables them to get the materials they need fast enough. These strategies use the effects of **temperature**, **surface area to volume ratio, distance** and **concentration gradient** on the rate of diffusion.

(1) Temperature

As the temperature increases, the particles in liquids and gases move around faster. This increases the rate of diffusion.

Unfortunately, human beings and other mammals cannot raise their internal temperatures much beyond the normal body temperature of 37^{O}C, or the structure of their cells is damaged and they die. But this is one reason why warm-blooded animals like us can be more active in cold weather than cold-blooded animals like reptiles and insects. It is also one reason why seeds germinate faster, and clothes are washed more effectively, in warm conditions than cold conditions.

Get it right!

The **rate** of a process means how fast it goes. The higher the rate, the faster the process, and the less time it takes to complete.

The **temperature** of a liquid means how hot or cold it is. The higher the temperature, the warmer the liquid. In biology we always measure temperatures in ^{o}C, not ^{o}F.

(2) Surface area to volume ratio

The larger the surface of a cell, the faster materials can move in or out. The effect is similar to a large number of people trying to get into or escape from a room – the wider the door space, the faster they can do it.

However for a cell, the key thing is not its surface area as such, but its **surface area to volume ratio**. The rate at which it *uses up* its materials depends upon its *volume*, but the rate at which it can *take in* new materials depends upon the cell membrane's *surface area*. So the larger its surface area *compared to its volume*, the happier the cell will be.

Unfortunately, as a cell gets bigger, its volume increases much faster than its surface area. If you double the dimensions of a cell:

- its volume increases by $2 \times 2 \times 2 = 8$ times
- but its surface area only increases by $2 \times 2 = 4$ times

So as it gets bigger its surface area to volume ratio falls, and it becomes unable to get materials in as fast as it uses them up.

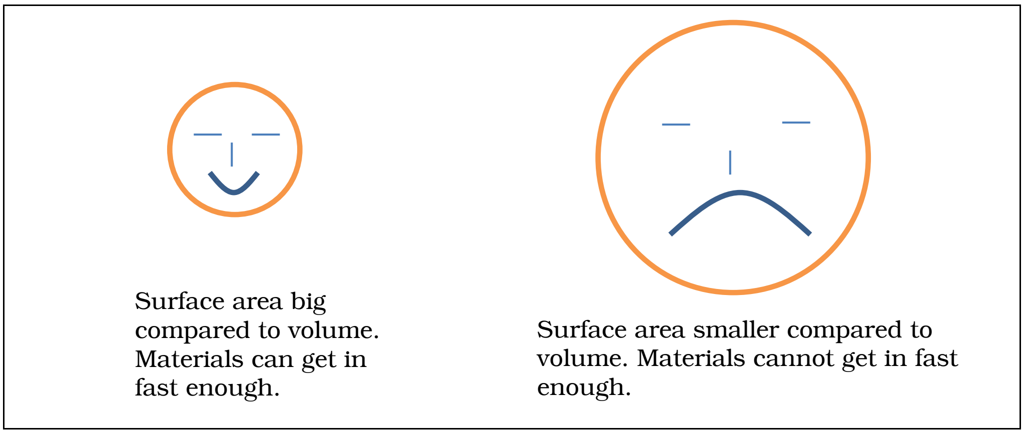


Diagram 2: Cell size and surface area to volume ratio

Get it right!

As a cell gets bigger, its surface area increases, as does its volume. They <u>both increase</u>. But it surface area to volume ratio <u>decreases</u>.

A cell can increase its surface area to volume ratio in three ways:

- *Remain small*: This is the main reason why cells are as small as they are. Once they get any bigger they cannot get materials in fast enough and they die.
- *Become flat rather than round*: This increases the surface area while the volume stays constant. The cells lining the air spaces in our lungs adopt this strategy.
- *Make the cell membrane wiggly rather than straight*: Cells lining the small intestine which absorb digested food, and root hair cells which absorb materials for plants from the soil, adopt this strategy.

Activity 3

See if you can work out why:

(a) insects are always small;
(b) flatworms (like the tapeworm that lives in the human gut) are flat;
(c) The gills of a young tadpole are feathery.

Hint: neither insects nor flatworms carry oxygen around in their blood.

Activity 4	(a) Work out the volume of a cube whose sides are 1cm long (Volume = length x breadth x height, and its units are cm^3) (b) Now work out its surface area (The area of each face = length x breadth, and the units of area are cm^2) (c) Now calculate its surface area to volume ratio (area / volume) (d) Repeat this with a cube whose side is 4cm. (e) Take the cube from (d) and flatten it into a block 1 cm x 8cm x 8cm. Work out the new surface area to volume ratio.

(3) Distance and concentration gradient

Substances move by diffusion from higher to lower concentration, as we saw above. But the *rate* of diffusion depends upon *the difference in concentration per centimetre*, which is known as the **concentration gradient**.

The situation is similar to a boy rolling a ball down a hill. Yes, the ball will roll downhill. But the steeper the hill, the faster the ball will roll. In the same way, the steeper the concentration gradient, the faster materials will move down it by diffusion.

Organisms can increase concentration gradients to speed up diffusion in two ways:

- *Keep the distance short*: This means the same concentration drop occurs across a shorter distance, giving a steeper concentration gradient as in diagram 3.

  This is the main reason why the cell membrane is so thin. (If it was any thinner it would break too easily, killing the cell.) It is also the reason why the membranes separating the air from the blood in the lungs are thin, and why leaves are flat.

  Keep the concentration difference great: This means it has a greater concentration drop occurring across the same distance, again resulting in a steeper concentration gradient.

  For example, when you breathe in fresh air, it raises the concentration of oxygen in the air in the lungs. This is now much higher than the concentration of oxygen in the blood, so oxygen diffuses into the blood faster.

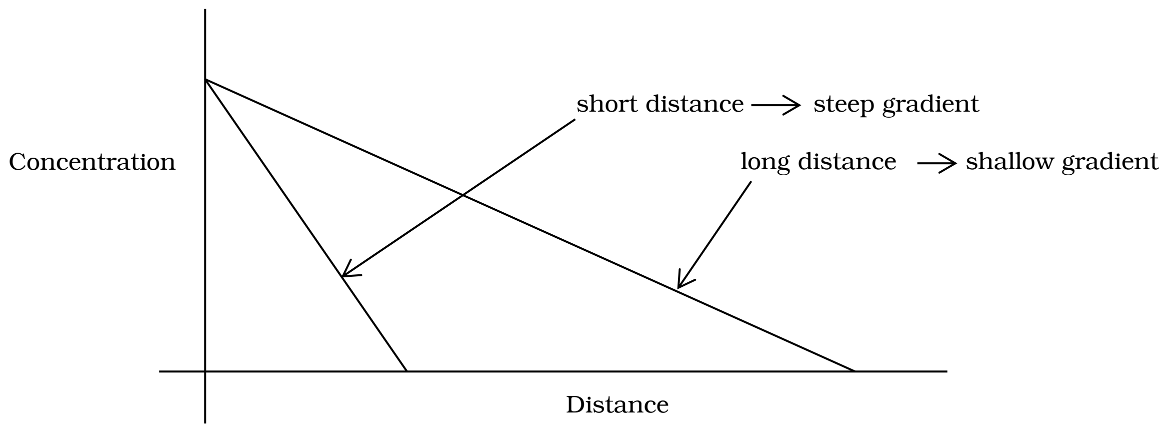


Diagram 3: The effect of distance on concentration gradient.

Activity 5	See if you can draw a diagram, similar to the one just above, which explains the effect of increasing the concentration difference.

Log on to Twig and look at the film titled: **Transport across the Cell Membrane**

www.ool.co.uk/1044rv

Journey inside the cell to see how the cell membrane acts as both a barrier and an entrance. How does it take in nutrients while keeping out potentially damaging molecules?

Active Transport

Diffusion always moves substances from a higher to a lower concentration i.e. down a concentration gradient. But sometimes cells and organisms need to take in materials that are at a lower concentration in their surroundings than in their cytoplasm. This is done by a process called active transport, also called "active uptake".

Diffusion

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HIGHER CONCENTRATION LOWER CONCENTRATION

<--------------------------

active transport

Active transport can only take place across a cell membrane, and it *uses energy* to push the substance up the concentration gradient. This energy is provided by respiration in the cell. It uses special carrier molecules built into the cell membrane which use this energy as they work.

Definition: active transport is the movement of a substance across a membrane against a concentration gradient. This process needs an input of energy.

Active Transport and Cells

Cells only use active transport when essential because it uses energy. But we shall meet it in places such as:

- the kidney, where it is used to pump glucose back into the blood against a concentration gradient. Otherwise some glucose would be lost in the urine;
- plant roots, which can take in ions from the soil even when they are less concentrated in the soil than in the plant itself.

Osmosis

Osmosis is the process by which water moves into and out of cells.

Definition: osmosis is the net movement of water across a partially permeable membrane, from a region of higher water potential to one of lower water potential.

Several points in this definition require some explanation:

1. Osmosis only concerns the movement of *water* – no other substance.
2. A **partially permeable membrane** or **ppm** (also called a "selectively permeable membrane" or a "semi-permeable membrane)" is one that lets some substances across but not others. The cell membrane around a cell is one sort of partially permeable membrane. **Visking tubing**, used in dialysis machines, is another. A ppm has very small holes in it. Small particles, including water molecules, are small enough to pass through these holes. But larger particles, including many solute particles, are too

big to do so. See figure 11.2 on page 122 of *Edexcel IGCSE Biology*, which illustrates this.

3. Water molecules always pass in both directions through a ppm (as in figure 11.2). A "net" movement of water means that *more* water molecules pass from higher to lower water potential than in the other direction.

4. The **water potential** of a solution measures how keen it is it to lose water. This is explained in the next section.

Get it right!

Osmosis involves:

- Only the movement of *water* (no other substance)
- Only through a *partially permeable membrane* (not elsewhere)
- From a higher to a lower water potential.

The textbook has two different definitions of osmosis. The one on page 123, involving water potential, is more sophisticated than the other one. Use this version if asked to define water potential in the exam.

Water potential

The "water potential" of a solution is a measure of how keen it is to lose water. So, if two solutions are separated by a ppm, water will move *out of* the solution that has the higher water potential, by osmosis.

Two things decide the water potential of a solution:

1. The amount of solute (solid) dissolved in it. The presence of solute *decreases* a solution's water potential. Pure water has the highest water potential, and the water potential drops as a solution gets more and more concentrated.

2. The hydrostatic pressure (physical push) exerted on it from the outside. Hydrostatic pressure *increases* a solution's water potential. The bigger the push, the greater the water potential.

Get it right!

Biologists call a solution with lots of solute dissolved in it a "concentrated solution". But this is a solution with a low concentration of water molecules. Conversely, they call a solution with only a little dissolved solute a "dilute solution". This is one with a high concentration of water molecules.

So, when you see the terms "concentration" or "concentrated", always look carefully to see whether it is the concentration of the water, or the solute dissolved in it, that is being talked about.

Osmosis and animal cells

An animal cell is surrounded by a cell membrane, which is a ppm. So water can enter and leave it by osmosis.

The cell membrane is only thin and weak. It does not "push" on the cell contents inside: it exerts no hydrostatic pressure. This means that the water potential inside a cell is decided only by the concentration of its cytoplasm or the fluid in its vacuole – the more concentrated this is, the lower its water potential.

Two things follow:

1. If you put an animal cell into a solution that is *more dilute* than its cytoplasm, including pure water, water enters by osmosis. The cell swells up, splitting the fragile cell membrane, and bursts. This bursting is called **lysis** (Greek for "splitting"). The cell is now dead.

2. If you put an animal cell into a solution that is *more concentrated* than its cytoplasm, water leaves by osmosis and the cell shrinks. This is not always fatal, but it stops the cell working, and it will quite quickly die unless it is rescued. See Figure 11.6 on page 124 of the textbook.

It follows that animal cells must always be surrounded with fluid that has the same water potential as their cytoplasm, or they will stop working. The cells in the human body are surrounded by **tissue fluid** whose water potential is carefully controlled for exactly this reason.

Osmosis can be useful as well, however. For example, if you are thirsty and you drink some water, the solution in your stomach is now more dilute than the solution in your blood plasma. So water moves by osmosis across the partially permeable stomach wall into your blood to correct the problem.

Osmosis and Plant Cells

Plant cells are also surrounded by a cell membrane which is a ppm. But outside this there is in addition a tough cell wall – see figure 11.3 on page 123 of the textbook. If water enters the cell by osmosis, making it bigger, this cell wall stretches and pushes back with hydrostatic pressure. This pressure raises the water potential inside the cell, which stops more water entering.

Three things follow:

1. If you put a plant cell in pure water, water at first enters by osmosis: the cytoplasm (and the cell sap in the sap vacuole) is a more concentrated solution, so has a lower water potential. However, as water enters the cell expands, and this stretches the cell wall. As the cell wall stretches more and more, it pushes back harder and harder, raising the water potential inside more and more. Eventually the water potentials inside and outside are equal, and no more water enters. The cell, plump and with a stretched cell wall, is said to be **turgid**. A turgid cell is “happy”. See the left of Figure 11.4 on page 124 of the textbook.

2. However, if a plant cell is in a concentrated solution, with a lower water potential than inside the cell, water *leaves* by osmosis. As water leaves, the cell shrinks, and the cell wall goes limp. The cell is now said to be **flaccid**. A flaccid cell is “unhappy”. See the middle of Figure 11.4.

3. If still more water leaves by osmosis, the sap vacuole in the centre of the cell shrinks away to nothing, and the cytoplasm and cell membrane are pulled away from the cell wall into the middle of the cell. This is shown on the right of Figure 11.4. The cell is now said to be **plasmolysed**, and is dying.

A photo of some plasmolysed rhubarb cells, as seen down a microscope, is given at figure 11.5 on page 124.

Get it right! Plant and animal cells behave very differently if placed in pure water. Animal cells swell up, lyse and die. Plant cells become turgid: their "happy" state. It is the cell wall around a plant cell which makes the difference.

Osmosis Experiments

Instructions on how to observe plasmolysis in onion cells are given in Experiment 11 on page 125. You should read the account of this experiment carefully. Figure 11.5 on page 124 of the textbook shows what the results look like down a microscope.

Activity 6

Try this activity now so you can see osmosis happening for yourself. This activity uses raw potato as a partially permeable membrane.

Cooked and raw potatoes are cut in half, hollowed out, and placed in dishes of water. Sugar is added to each hollow as shown in the diagram below. The raw potato acts like a partially permeable membrane, so water moves by osmosis into its hollow where there is a more concentrated solution. This does not happen in the cooked potato, because cooking destroys the cell membranes in the potato cells, so it does not act as a partially permeable membrane.

If you are unable to do the experiment yourself, there is a good video of it on YouTube at www.ool.co.uk/0216bi.

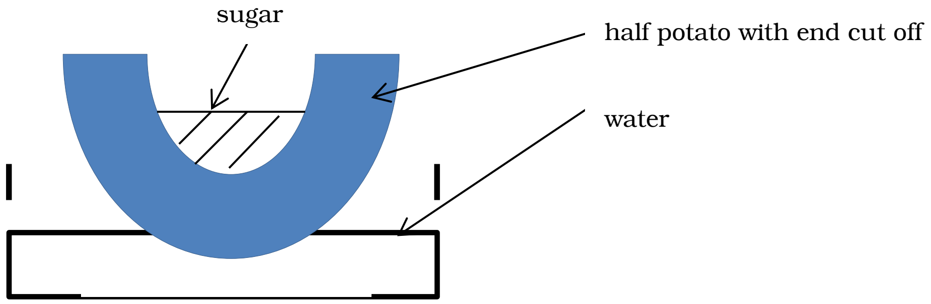


Diagram 5: An osmosis experiment using potatoes

In the experiment shown below, a more dilute solution in tube A is separated from a more concentrated solution in tube B by a partially permeable membrane. Water flows from A to B by osmosis with the result shown. In the boxed enlargement, the small blobs are the small water molecules, and the larger blobs the larger solute molecules:

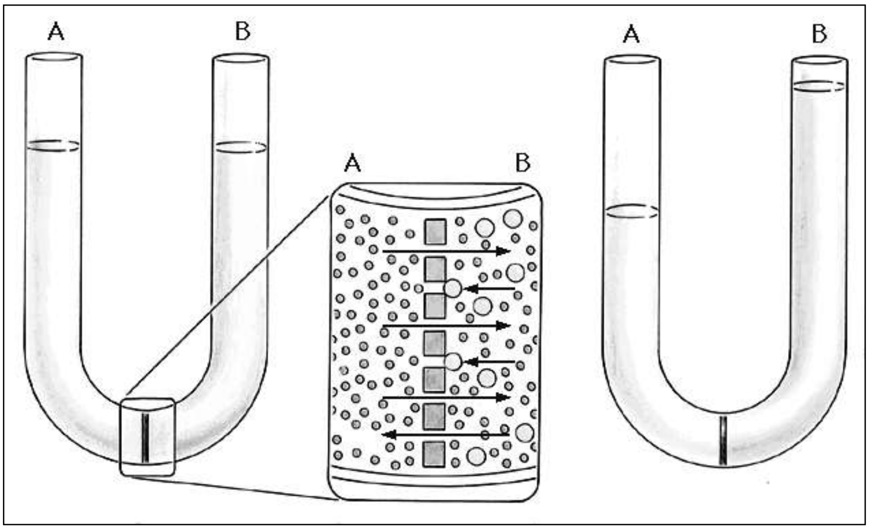


Diagram 6: A simple osmosis experiment

Study figure 11.1 on page 122 of the textbook. Water enters the visking tubing "sausage" by osmosis, forcing the coloured sucrose solution up the capillary tube.

Activity 7	Experiment 12 on page 126 of *Edexcel GCSE Biology* is a classic experiment involving osmosis in uncooked potato chips. Read through the account of the experiment carefully, and then answer the following questions:
	(a) Do the cells in the potato chips have cell membranes, cell walls, or both? (b) Why has the chip in the tap water (i) increased in mass (ii) remained stiff? (c) Why has the chip in the sucrose solution (ii) decreased in mass (ii) become flexible?

If possible, try this experiment yourself at home, measuring the lengths of the chips rather than their masses to see the changes caused by osmosis. It works better if the chips are quite long.

(d) If a chip has no change in mass or length at all, what does this tell you?

(e) Suggest two reasons why the results obtained using the mass of the chips are more accurate than results obtained using their length.

Now is the time to read through Chapter 1 pages 9 – 11 and Chapter 11 pages 122–126 of *Edexcel IGCSE Biology*. They cover the same topics as this lesson, so will add to your understanding of the material.

Keywords

Diffusion	**Surface Area**
Partially permeable	**Concentration gradient**
Solute	**Osmosis**
Active transport	**Particle**
Turgid	**Flaccid**
Water potential	**Plasmolysed**
Visking tubing	**Lysis**

Summary

Lesson Two: Movement in and out of Cells

DIFFUSION	--------	down a concentration gradient		
	--------	speeding it up	------	increase temperature
			------	increase surface area to volume ratio
			------	increase concentration gradient
ACTIVE TRANSPORT	-------	up a concentration gradient, across a membrane		
	-------	uses energy		
OSMOSIS	-------	water, across a partially permeable membrane		
	-------	from higher to lower water potential		
	-------	animal cells		
	------	plant cells		
	-------	osmosis experiments		

What you need to know

- The definitions of diffusion, osmosis and active transport
- How to speed up diffusion
- The factors which affect the water potential of a solution
- Some experiments to investigate diffusion and osmosis
- How osmosis affects plant and animal cells

What you might be asked to do

- Given the conditions, decide which of the three processes is taking place, and in which direction substances will move
- Explain the similarities and differences between the three processes

- Explain how a given cell or organism is adapted to make diffusion more efficient
- Explain how osmosis affects plant and animal cells
- Interpret experiments on osmosis

Suggested Answers to Activities

Activity 1

This should only take a few seconds. It is much faster than Activity 2.

Activity 2

1. Some of the ink can be seen to be starting to spread out.
2. The ink has spread throughout the water unevenly.
3. The ink and the water should be fully mixed.

The ink has gradually diffused through the water.

Activity 3

In all three cases this increases their surface area to volume ratio, so oxygen for respiration can get in fast enough.

Activity 4

(a) $1 \times 1 \times 1 = 1cm^3$

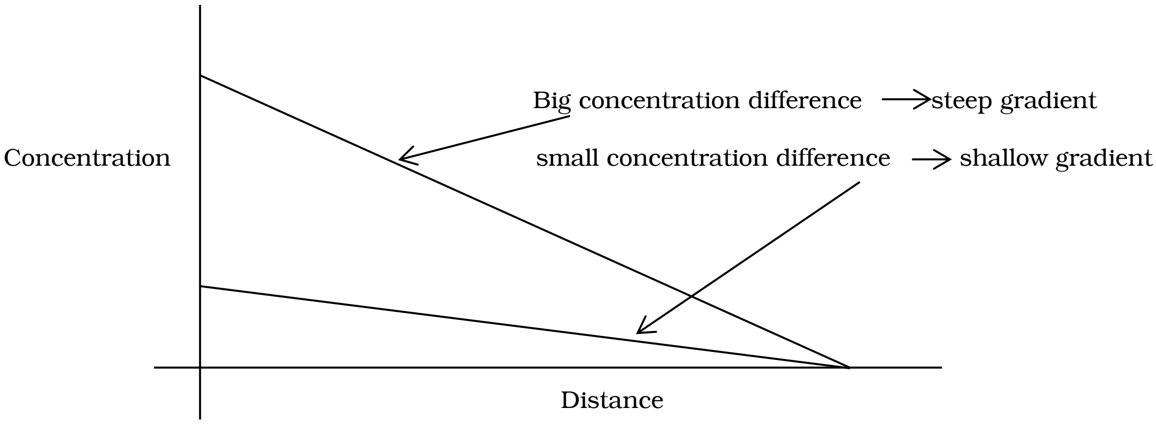
(b) $6 \times (1 \times 1) = 6cm^2$ (there are six faces!)

(c) $6 / 1 = 6$

(d) Volume = $4 \times 4 \times 4 = 64$

Surface Area = $6 \times (4 \times 4) = 96$

Activity 5



Activity 7

(a) Both, because they are plant cells.

(b) (i) Water has entered the cells by osmosis, making them (and therefore the whole chip) heavier.

(ii) The water entering stretches the cell walls of the cell, making them turgid. They are pushing against each other making the whole chip stiff.

(c) (i) Water has left the cells by osmosis, making them (and therefore the whole chip) lighter.

(ii) The water leaving the cells means that the cell walls are no longer stretched; the cells have gone flaccid. They are no longer pushing against each other, so the chip goes limp.

(d) No water has moved in or out by osmosis. This suggests that the contents of the cells have the same water potential as the solution in which they are placed.

(e) (1) You can measure more accurately with a balance than a ruler. You might only measure the length of the chip to the nearest millimetre out of about 50mm, which is an error of about 2%. However, a good balance will weigh to the nearest 0.01g out of, say, a chip mass of 20g, which is an error of only 0.05%

(2) When a chip swells up, it expands in all three dimensions, not just in its length. This is picked up by the increase in mass, which is therefore bigger proportionally than the increase in length alone.

Tutor-marked Assignments and Command Words

You are about to tackle your first tutor-marked assignment (TMA). Each assignment consists of a number of questions, similar in style to the ones you will face in the exam. Each question includes one or more **command words**. These are verbs like 'describe' and 'explain' and they are meant to tell you what *kind* of answer a teacher or examiner is looking for. Often it is a clue how *much* you should be writing as well.

For instance, you might see this: '**Name** the movement of a substance across a membrane against a concentration gradient.' 'Name' is the command word. Your answer is 'active transport' – that will get you full marks. You will get no extra marks for saying anything more *about* active transport, or including 'active transport' in a full sentence.

You will gradually learn to spot these words. You don't need to worry too much at this early stage but here, for reference, is a list of some of the command words you will find in Biology questions. The list is supplied by Edexcel. As you work through the later assignments, refer back to this list and try to tailor your answers according to the command words given. Good luck!

Here is the list:

Describe – students will be required to write prose answers to demonstrate the facts remembered about a topic.
Evaluate – students will be asked to analyse information and explain the underlying biology.
Explain – students will need to comment on the underlying biology.
Recall – students will be expected to remember brief facts.
Recognise – students will be expected to identify parts on a diagram.
Understand – students will need to appreciate the importance and relevance of biological facts.

Tutor-Marked Assignment A

Question 1

These three organelles are found in cells: nucleus, chloroplast, mitochondrion.

(a) Describe the function (job) of each organelle. (6 marks)

(b) Which would you find in: (i) a human muscle cell (ii) a leaf cell from a plant (iii) a cell from the root of a plant? (3 marks)

(c) Explain the difference between your answers for (ii) and (iii) above. (2 marks)

(Total mark 11)

Question 2

(a) Name the Kingdom to which each of these organisms belongs:

(i) mushroom

(ii) *Chlorella*

(iii) moss

(iv) *Lactobacillus* (4 marks)

(b) Look at the diagram of the protoctist called *Euglena* on page 22 of *Edexcel IGCSE Biology*.

(i) What features of this cell make it more like a plant cell than an animal cell? (2 marks)

(ii) What feature(s) of this cell make it more like an animal cell than a plant cell? (1 mark)

(iii) Why is Euglena classified as a protoctist rather than as an animal or a plant? (1 mark)

(iv) Estimate the width of the cell (ignoring the flagellum) at its widest part in micrometres. (1 mark)

(v) Calculate the width of the cell in millimetres. (1 mark)

(Total marks 10)

Question 3

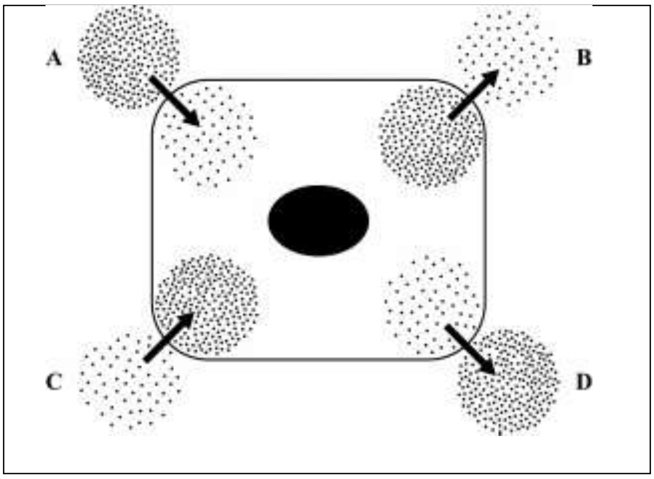
Complete this table, by writing "yes" or "no" in each box, to show the features possessed by different types of life:

	Nucleus	Cell membrane	Cell Wall	Mitochondria	Chloroplasts
Fungi					
Viruses					
Animals					
Bacteria					
Plants					
Protoctists					

(Total mark 6)

Question 4

(a) The diagram shows four ways in which molecules may move into and out of a living animal cell.



The dots show the concentration of molecules. Which arrow, A, B, C or D, represents:

(i) movement of oxygen molecules? (1 mark)

(ii) movement of carbon dioxide molecules? (1 mark)

(b) Name the process by which these gases move into and out of the cell. (1 mark)

(c) (i) Which arrow A, B, C or D represents the active uptake of sugar molecules by the cell? (1 mark)

(ii) Explain the reason for your answer. (2 marks)

(Total mark 6)

Question 5

An Amoeba is an animal-like protoctist that lives in freshwater ponds. Its cell has a special structure called a contractile vacuole. This structure can be seen repeatedly filling with water, and then moving to the cell membrane to eject the water to the outside of the cell. If cyanide is added to the Amoeba's water, the contractile vacuole stops working, and the Amoeba dies.

(a) Explain why an Amoeba needs a contractile vacuole. (5 marks)

(b) Suggest why the Amoeba dies when cyanide is added to its water. (4 marks)

(Total mark 9)

Question 6

Read carefully the introduction and table from question 1 on page 133 *Edexcel IGCSE Biology*. Use this information to answer the following;

(a) Calculate the percentage change in mass for the chip in solution B. Show your working. (2 marks)

(b) Name the process which caused the chips to lose or gain mass. (1 mark)

(c) (i) Which solution was likely to have been the most concentrated? (1 mark)

(ii) Explain your answer. (2 marks)

(d) (i) Which solution had a water potential closest to the cell sap of the potato cells? (1 mark)

(ii) Explain your answer. (1 mark)

(Total marks 8)

(Total marks for TMA A: 50)