elevate

YEAR 11

BIOLOGY

MODULE 1

LESSON FOUR

THEORY

1.1.2 **investigate a variety of prokaryotic and eukaryotic cell structures, including but not limited to: modelling the structure and function of the fluid mosaic model of the cell membrane**

Recall that all cells, regardless of whether they are eukaryotic or prokaryotic, are composed of a watery fluid called cytoplasm which contains the dissolved or suspended contents of the cell, and the outer boundaries of the cytoplasm are defined by the plasma membrane.

The plasma membrane is also known as the cell membrane, or (infrequently) the trilemma. It is critical to cell function and has a surprisingly complex structure.

In this lesson we will explore current models of how the plasma membrane is structured, and how materials are transported through it.

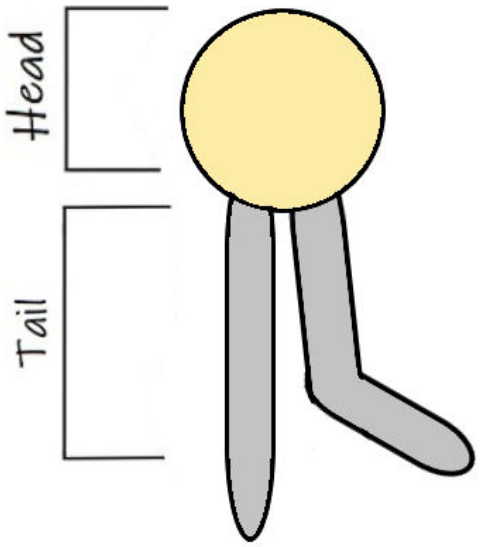
Cell Membrane

The current model of the cell membrane is called the fluid mosaic model.

In this model, the cell membrane is proposed to be a phospholipid bilayer with the ability to 'flow' and change shape like a 2D fluid and a mosaic-like pattern of embedded or attached proteins.

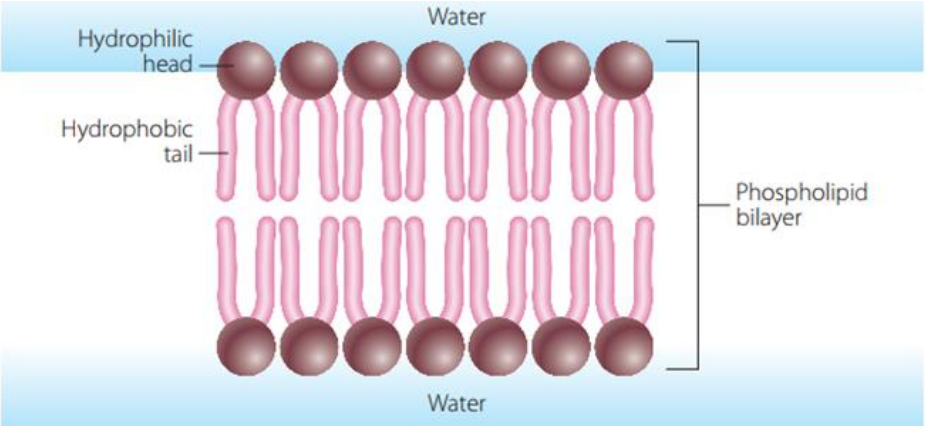
Lipid Component

First let us break down the meaning of "phospholipid bilayer". The cell membrane is composed of 'phospholipids. These are molecules that have a phosphate 'head' and two fatty acid 'tails'.



The phosphate head is charged and therefore attracted to water molecules - it is called 'hydrophilic'. The fatty acid tails are mostly neutral and therefore are repelled by water molecules - they are called 'hydrophobic'. Hence phospholipids will arrange themselves in water in two layers so that the heads are pointing outwards into solution and the tails are sandwiched in the middle of the layer between the heads. This maximises favourable interactions with water molecules.

THEORY



At its most basic, the cell membrane is simply a 3D, spherical phospholipid bilayer. It is likely that the cell membranes of very early lifeforms had this structure (though perhaps with different lipids).

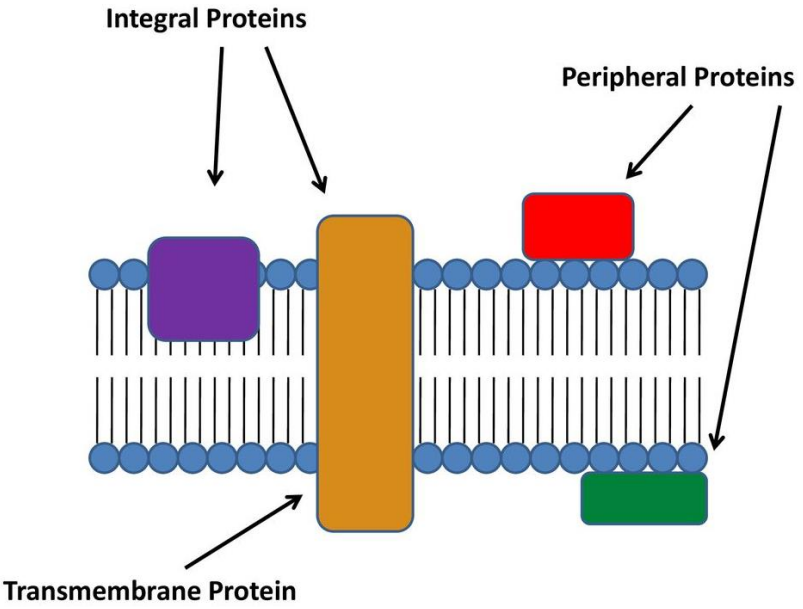
In human cells, cholesterol is interspersed among the phospholipids. It holds phospholipids at a specific distance from each other. In cold temperatures, this prevents phospholipids from packing too close together and gives the membrane flexibility. In hot temperatures, cholesterol prevents the phospholipids from separating too far apart and limits the 'fluidity' of the cell membrane.

Protein Component

The fluid mosaic model shows that the cell membrane contains various membranes dispersed throughout the membrane.

There are three classes of proteins that can be found in the cell membrane:

- Transmembrane proteins - pass through the entire phospholipid bilayer
- Integral proteins - penetrate the phospholipid bilayer but do not cross it like transmembrane proteins
- Peripheral proteins - loosely attached to the periphery of the phospholipid bilayer



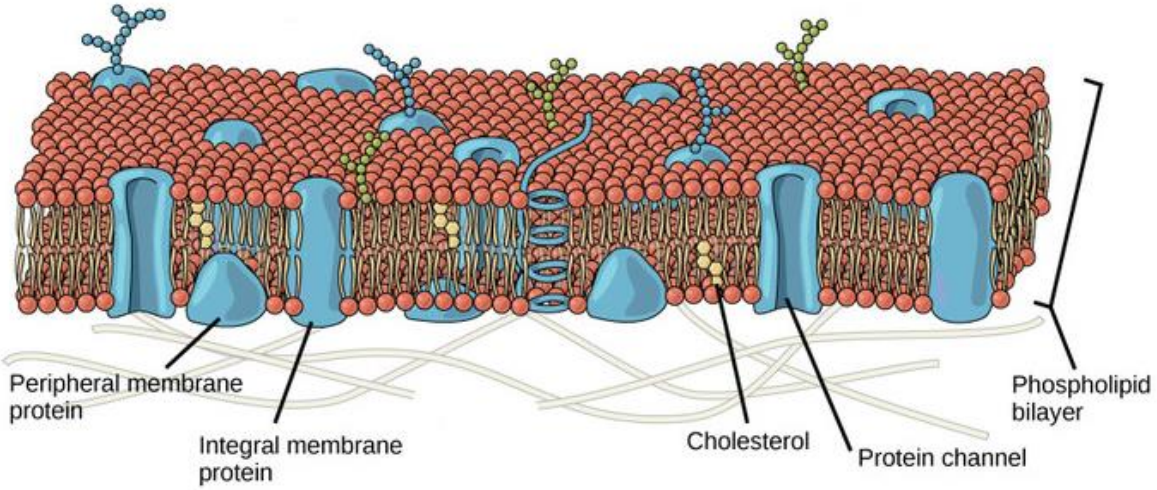
THEORY

The proteins found in the cell membrane are usually not fixed. Instead, they often drift throughout the phospholipid 'sea'.

Membrane proteins can have an enormous range of functions. Transmembrane proteins allow for communication between the outside and inside of the cell, like various receptors or ion channels. Integral proteins can help with cell-to-cell adhesion while some peripheral proteins can sometimes act like cell 'ID tags'. The arrangement and/or presence of proteins on a cell's surface is usually one of the factors that defines a cell's function.

To summarise the fluid mosaic model:

- Phospholipids arrange themselves in a bilayer so their tails point inwards and heads point outwards
- Cholesterol is spread among the phospholipids to manage membrane fluidity
- Various proteins are embedded in or attached to the phospholipid bilayer and perform a variety of functions.



Cellular transport

Cells are living organisms, whether unicellular or multicellular and they need methods to absorb nutrients and resources and dispose of wastes.

Recall the basic organic and inorganic cellular requirements

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The cell membrane delimits the boundaries of a cell. We can therefore define cells as having an intracellular compartment (everything inside the cell) and an extracellular compartment (everything outside the cell). Cells need methods of transporting these nutrients between these compartments through the cell membrane. There are different types of cellular transport

THEORY

Simple diffusion	
Facilitated diffusion	Movement of molecules through a cell membrane protein channel or carrier
Active transport	
Bulk transport	Creation of a vesicle from the cell membrane to transport large substances

There are a few factors that determine how a substance can be transported across the membrane.

Concentration gradient: the movement of a substance from an area of high concentration to an area of low concentration

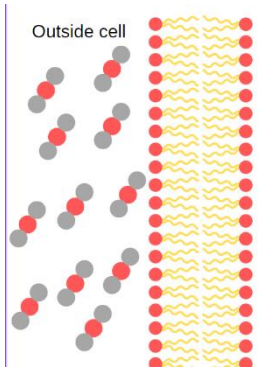
This phenomenon will occur naturally in solutions. For example, when we add coloured dye into water, it will naturally move into the solution, seeking to go from the area of high concentration (dye drop) to low concentration (clear water).

This movement can be attributed to the movement of atoms in molecules, that cause molecules to bump into each other. Therefore, if there is an area of high concentration, the molecules will have more collisions, therefore causing the spreading of the solute into the solution.

Therefore, if we have cells inside water that is filled with CO_2, what would happen?

EXAMPLE QUESTION

Draw the movement of the CO_2 molecules over time

This movement is called **diffusion.**

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Diffusion in cells is the movement of molecules through the cell membrane along the concentration gradient. This is a passive process (no input of energy).

THEORY

There are two types of diffusion:

- *Simple diffusion:* movement of molecules through the cell membrane
- *Facilitated diffusion:* movement of molecules through a protein channel or carrier in the cell membrane

Whether or not a substance can be transported via simple diffusion is based on the substance's chemical characteristics.

Chemical characteristics

The cell membrane has a phosphate outer layer and a lipid inner layer.

- Phosphate is hydrophilic: loves water
- Lipids are hydrophobic: hates water

This means that the lipids will repel anything that is hydrophilic.

Hydrophilic substances are polar molecules, which means that there is an area of the molecule that has a slight charge. The water molecule is also a polar molecule, in which the oxygen atom is slightly negative, and therefore, is attracted to other polar molecules. Lipids are nonpolar so don't like to mix with water.

This means that for a molecule to pass directly through the cell membrane (simple diffusion) it needs to be a **small nonpolar molecule.**

Common examples of small nonpolar molecules that can travel via simple diffusion:

- O_2
- CO_2
- N_2
- NO

What about polar molecules?

Polar molecules such as water and salt ions need to be transported through a protein channel or a carrier protein that will bring the substance across. This is called facilitated diffusion, and it can transport **small polar molecules**. This still only moves along its concentration gradient, so still requires no energy.

Common examples of small polar molecules that can travel via facilitated diffusion:

- Water
- Cations (positively charged ions: Na^+, K^+, Ca^{2+})
- Anions (negatively charged ions: Cl^-, PO_4^{3-}, HCO_3^-)

Transport of Water: Osmosis

Osmosis is the specific movement of water molecules along its concentration gradient across a semipermeable membrane.

There are a few aspects of the osmosis definition:

- Movement of water molecules
- Movement through a selectively permeable membrane (cell membrane)

THEORY

- Passive process (no energy)
- Movement from area of high water potential (low solute concentration) to an area of low water potential (high solute concentration)

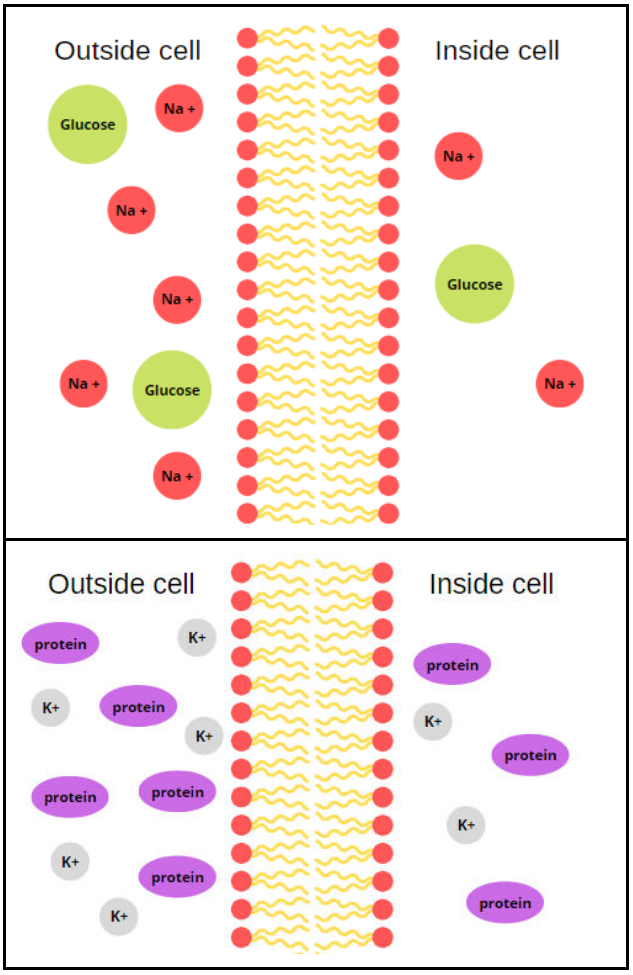
This makes it slightly different from diffusion, because it is very specific to the movement through the selectively permeable cell membrane. It also describes the movement in terms of solute concentration.

Remember that cells are filled with cytoplasm which is an aqueous solution filled with salts and sugars and proteins, all of which are called solutes. Water will move to the area that has lots of solutes and less water, to reduce the concentration of solutes.

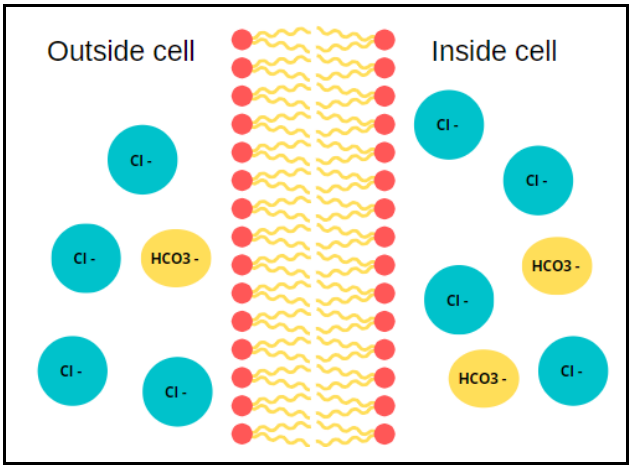
The need for this distinction is because diffusion talks about the concentration of solutes, but water is a common solvent, so measuring the concentration of water is not impossible because it is a pure liquid. Therefore, we need a different term = osmosis!

EXAMPLE QUESTION

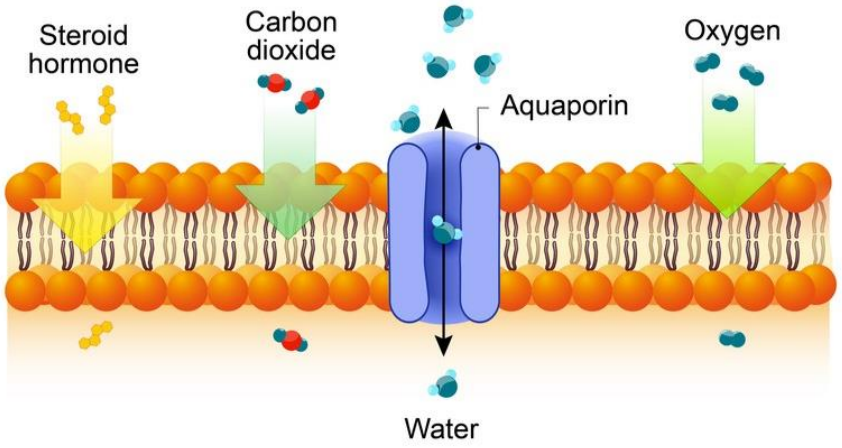
For the following examples, draw an arrow to show in which direction water movement would occur.



THEORY



Therefore, water moves to the area of higher solute concentration. As taught above, water is a small polar molecule, so it needs a channel protein to get through the cell membrane. Water travels through the cell membrane through aquaporins embedded in the membrane.



Because cellular life is based in water, and water makes up a significant portion of our body, it is important to control the amount of water that we can lose from cells.

If cells were in very very salty water, where would the water go?

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If the cells were in pure clean water, where would the water go?

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Therefore, our cells need to sit in fluid at the exact water potential as inside the cell, so that there is little movement of water.

When:

solute concentration (inside cell) = solute concentration (outside cell)

This is an _____, and there is a net zero movement of water across the membrane.

When:

solute concentration (inside cell) > solute concentration (outside cell)

THEORY

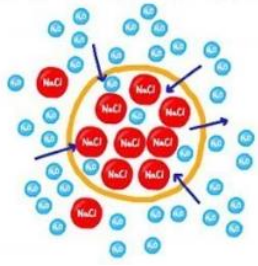
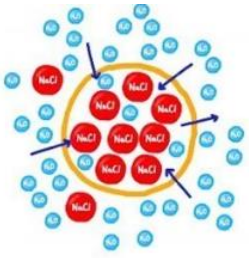
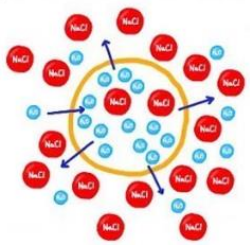
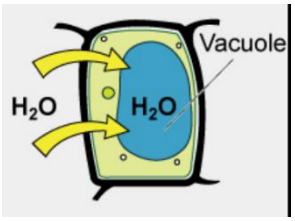
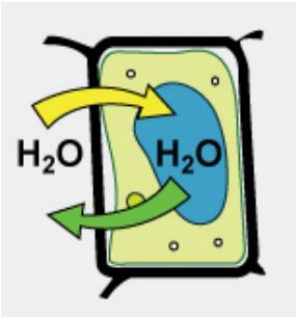
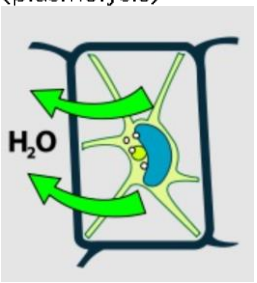
This is a _____, and water will flow into the cell.

When:

solute concentration (inside cell) < solute concentration (outside cell)

This is a _____, and water will flow out of the cell.

In each of these states, animal cells and plant cells react differently, based on the presence (or lack thereof) of the cell wall. The cell wall is a solid structure that maintains the shape of the cell membrane, but in animal cells, the cell membrane is fluid and can rupture easily.

	Hypotonic	Isotonic	Hypertonic
Animal cell	Water rushes in, and inflates the cell, causing it to rupture (cytolysis). 	No net movement of water, so normal shape. 	Water flows out, causing the cell to shrivel (plasmolysis) 
Plant cell	Water rushes in, but the cell wall prevents the rupturing, in fact it presses against the wall, causing turgidity. 	Water flows in and out, but there is lower pressure inside the cell, so it becomes flaccid. 	Water flows out of the cell, causing the cell to pull away from the cell wall, making it shrivel (plasmolysis) 

For the above example questions of water movement in cells (page 7), identify if the cell is in a hypotonic, isotonic or hypertonic solution before water movement.

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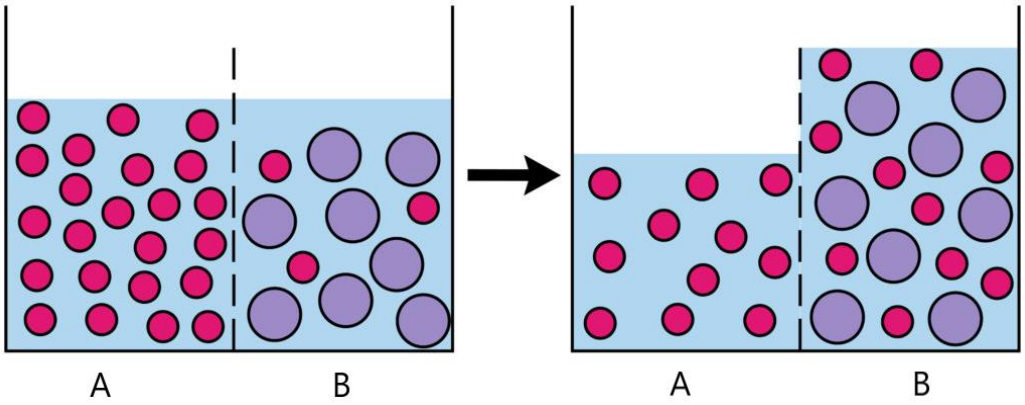
A related concept that is useful to understand is 'osmotic pressure'. To illustrate this concept, suppose you have two compartments separated by a semipermeable membrane: A with 1M solution, and B with 10M solution.

THEORY



Water will move from A into B by osmosis. However, if we apply pressure to compartment B (imagine a piston pressing on the water column in B) then we can prevent the net movement of water. The amount of pressure necessary to achieve this is the 'osmotic pressure'. In other words:

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You will likely encounter this terminology, particularly in the context of cellular biology, so it is important to familiarise yourself with it.

Surface area to volume ratio

So we have established that resources are able to passively diffuse and travel in and out of cells according to its concentration gradient. However, when it gets inside the cell, there are limited structures that can move these materials to all the parts of the cell. And while the Golgi apparatus can move substances, these take energy, and for survival, cells want to save their energy for more important activities. Therefore, cells need to maximise their surface area for diffusion and limit their volume, so that even the very centre of the cell can also receive nutrients.

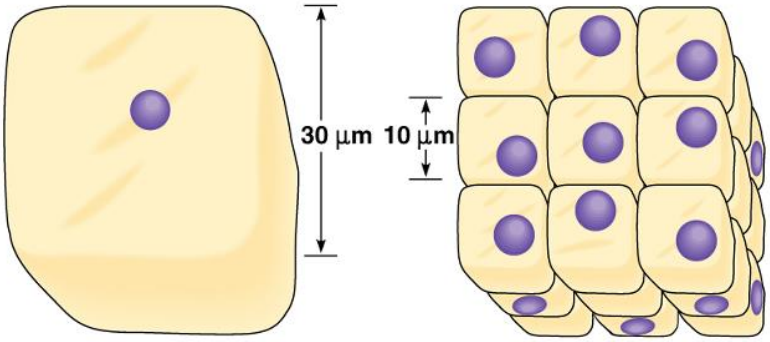
This brings out the idea of SA:V ratio.

Cube dimensions	Volume	Surface area	SA:V ratio
5x5x5			
3x3x3			
1x1x1			

The 1x1x1 cube has a very high SA:V ratio which means that there is a lot of surface area for diffusion, and only a small volume to supply, which means that the entire volume of the cube will have enough nutrients.

For cells, a high SA:V ratio means that the entire cell will be supplied with nutrients and wastes will be disposed of with menial energy expenditure. This also means that the cell is limited by its size, and why bacteria cannot ever be the size of an ant.

THEORY



EXAMPLE QUESTION

Then why are eukaryotic cells bigger than prokaryotic cells?

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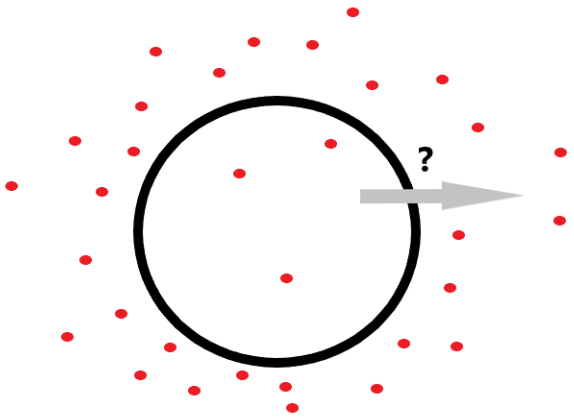
Active Transport

Consider a situation where a cell has less calcium inside than outside the cell. If the cell needs to release even more calcium into its external environment, it cannot achieve this using diffusion alone, because the concentration gradient is directed into the cell. Therefore, there must exist another process to move substances *against* their concentration gradient.



This process is called 'active transport', named so because it requires an *input of energy*. More formally:

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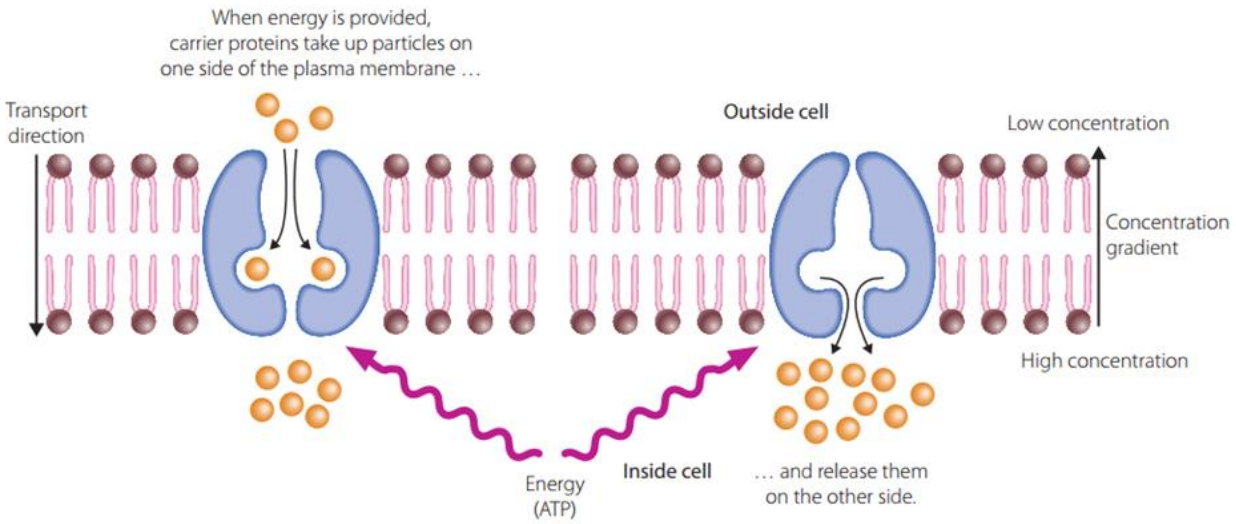
THEORY

A useful analogy would be to think of the concentration gradient as a hill. Going down the hill means moving molecules down the concentration gradient (diffusion) and uses no energy (passive). Going up the hill means moving molecules against the concentration gradient (active transport) and needs energy.

The process of active transport always uses special transporter molecules in the cell membrane. These molecules are able to bind to a substance and then change conformation to move the molecules in the required direction. However, to change conformation, energy in the form of ATP is necessary.



Active transport is needed, for example, by kidney cells to reabsorb glucose, or for neurons to reset their membrane potential.

Bulk Transport

There are some substances that are too large or have certain properties that make them unable to cross the cell membrane, even with the help of carrier proteins. For instance, most hormones are far too large and hydrophilic to directly cross the cell membrane.

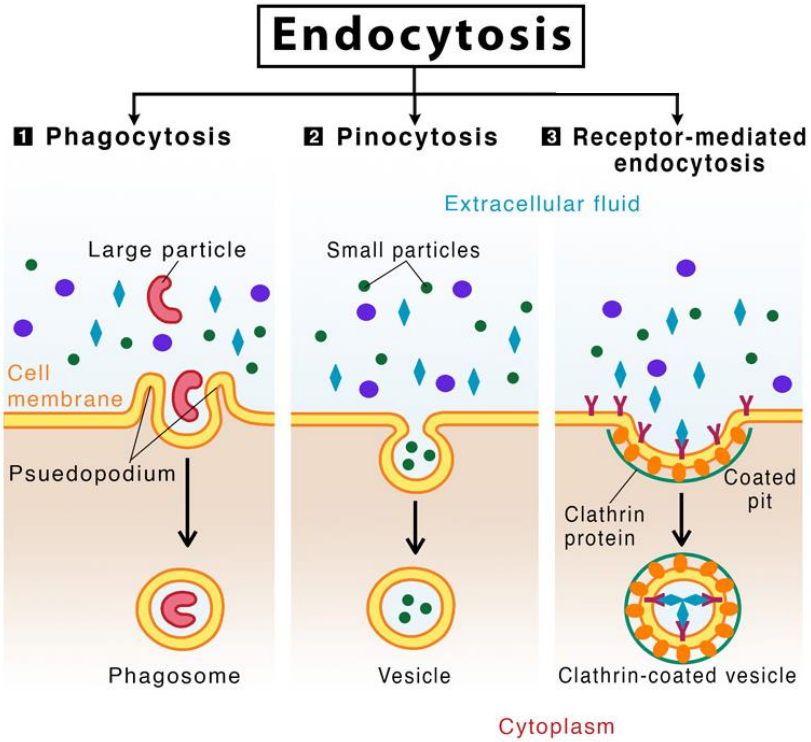
Cells use 'bulk transport' to move such substances into and out of the cell. There are 2 main types of bulk transport: exocytosis and endocytosis.

It is important to note that bulk transport *requires energy input*. Consequently, all bulk transport processes are considered sub-types of active transport.

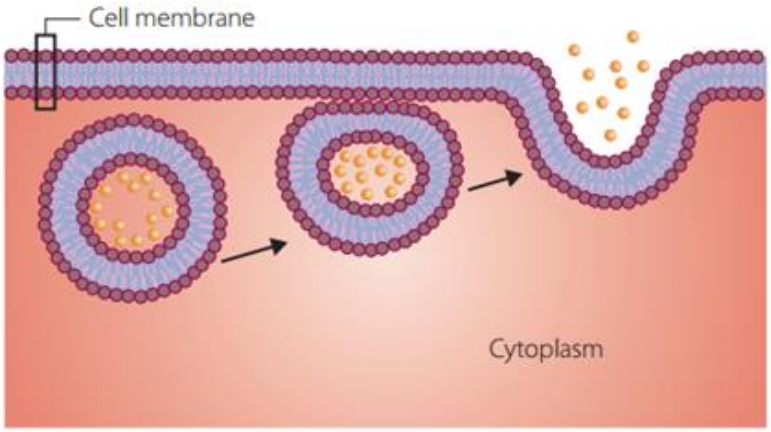
Endocytosis involves the cell membrane 'pinching off' to enclose substances in the outside environment. After the membrane has pinched off, it forms a vesicle which transports the substance into the cell.

There are three types of endocytosis. Phagocytosis is the endocytosis of a solid particle, most commonly bacteria, cell debris or food. The cell will extend feet-like processes called 'pseudopodia' (literally translated as 'false feet') to engulf the solid particle. Pinocytosis is the endocytosis of liquid substances, like fat droplets. Receptor mediated endocytosis is a special type of endocytosis that uses receptors to initiate endocytosis for only certain substances.

THEORY



Exocytosis is the opposite of endocytosis, meaning it uses vesicles to move substances from inside the cell into the external environment. The vesicle will fuse with the cell membrane, thus releasing its contents into the extracellular space.



Exocytosis and endocytosis can transport substances both down and against concentration gradients.

A brief summary table of the different transport processes covered this lesson is below:

	Polarity		Size	
Simple diffusion	Non polar		Small	
Facilitated diffusion		Polar	Small	

THEORY

Active transport	Non-polar	Polar	Small	
Bulk transport (sub-type of active transport)	Non-polar	Polar		Large

PRACTICE QUESTIONS

1. **Which of the following identifies which molecules can enter via simple diffusion?**
    a. Small, polar molecules because the phosphate head is also polar
    b. Small, nonpolar molecules because the membrane is selectively permeable
    c. Small, polar molecules because the cell membrane is tightly packed
    d. Small, non-polar molecules because the lipid tails repel polar molecules
2. **Which of the following is NOT an example of diffusion occurring in real life?**
    a. Flavouring of Coco Pops infusing into the milk
    b. Bath bomb in a hot bath
    c. Emulsifying oil and water in a salad dressing
    d. Smelling petrol fumes when filling up your car
3. **Concentration gradient determines what?**
    a. The speed at which a cell can move
    b. The speed at which a cell can get engulfed
    c. The speed at which a molecule crosses the membrane
    d. The speed at which the flagella can move
4. **Which of the following analogies best describes the cell membrane**
    a. Ticket reader at stations, only allowing valid tickets in and out
    b. Guard outside parliament, only allowing certain people inside
    c. Solid wall around city, blocking all entry
    d. Shopping centre doors, opening to everyone
5. **When does active transport occur?**
    a. When the cell needs to move molecules with concentration gradient
    b. When a cell needs to conduct exocytosis
    c. When polar molecules flow through channel proteins
    d. When a cell uses energy to break down wastes

6. **For the following substances, explain the transport method through the cell membrane in relation to the chemical and physical properties.**
    a. Oxygen

(2 marks)

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    b. Glucose

(2 marks)

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    c. Calcium ions

(2 marks)

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PRACTICE QUESTIONS

d. Engulfing pathogen by a macrophage

(2 marks)

7. **Saline solutions have solutes (normally NaCl) and these are used in IV drips to hydrate sick patients. This solution is at the solute concentration of the cytoplasm in blood cells. Identify what this solution is called (hypo/iso/hypertonic) and suggest what would happen if pure water was pumped into someone's blood?**

(3 marks)

8. **Explain how concentration gradients aid in the survival of cells in terms of energy conservation.**

(3 marks)

PRACTICE QUESTIONS

9. Compare active and passive transport with examples of substances that can be transported by each

(5 marks)

HOMEWORK

1. **What happens to the cell membrane during exocytosis?**
    a. The membrane of the vesicle fuses with the cell membrane, releasing the substance outside
    b. The membrane splits opens and the vesicle exits the cell
    c. A new vesicle forms from the cell membrane and takes the substance out of the cell
    d. The cell membrane engulfs a substances forming a vesicle and brings it into the cell
2. **If the cell membrane lost all its channel proteins, which of the following identifies substances that would be affected?**
    a. Glucose, lipids, proteins
    b. Water, glucose, metal ions
    c. CO_2, metal ions, viruses
    d. CO_2, O_2, small lipids
3. **Which of the following is correct?**
    a. Humans can be macroscopic because they don't use diffusion, but active transport
    b. Bacteria are so microscopic because they rely on diffusion to absorb and release substances
    c. Osmosis is a active process, so it is very easy to transport water in plants
    d. A cell is limited in size, to the point where the SA is equal to the volume
4.
    a. Draw the fluid mosaic model of the cell membrane

(2 marks)

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    b. Explain the selectively permeable nature of the cell membrane, in relation to the chemical features of the barrier.

(4 marks)

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HOMEWORK

5. Assess the importance of the SA:V in limiting the size of cells.

(5 marks)

6. Plant roots are designed to draw water up from the soil through their xylem up to their leaves to conduct photosynthesis. They do this via osmosis, and it is a passive process requiring no input of energy. A student conducted an experiment to observe the effect of how salt impacts the uptake of water. They took nine 15cm cuttings from a mint bush, to have 3 repetitions for each group. They measured the water in each flask using a measuring cylinder, and weighed out the salt using a electronic weighing scale. Assuming that the plant cell cytoplasm had a salt concentration of 5g/100mL and each flask held 200mL, answer the following questions.

5g of salt **10g of salt** **15g of salt**

HOMEWORK

a. Write a hypothesis for this experiment based on the information taught in this lesson and justify your choice.

(3 marks)

b. The following qualitative results were collected after a week.

5g salt	Leaves were looking healthy and the plant was upright in flask
10g salt	Leaves were slightly drooping
15g salt	Leaves were very drooped and pointing down, and stem was bending over

c. Explain these observations for plant cells, and compare how animal cells would respond in these conditions.

(6 marks)

HOMEWORK

d. Evaluate the validity, reliability and accuracy of this experiment.

(6 marks)

H.W ANSWERS

1. C
2. D
3. E
4.

1	Describe how proteins are produced from amino acids • Proteins are essential macromolecules, produced from chains of amino acids. For humans there are 20 amino acids used, of which 9 are essential, so the body cannot synthesise them.
2	Explain why it is important to keep amino acids in relation to the importance of proteins • Proteins are vital for life, as they express the genetic material, giving an organism the distinct features and abilities. They are essential for digestion (enzymes), structure and chemical messages (hormones). Since animal cells cannot synthesise certain amino acids, the role of the lysosome is very important, as it allows the cell to reuse these essential amino acids when the protein is no longer needed. This will increase the animal's chances of survival, by increasing the availability of protein production.

5.

1	Identify and explain that lipids are hydrophobic (repel water) so fat soluble vitamins are also hydrophobic
1	Explain the process of water excretion via osmosis that will remove other water soluble wastes, including water soluble vitamins, but not lipids
1	Conclude that the excretion rate of lipid soluble substances (like vitamins) is much lower than water soluble waste, so water soluble should be eaten everyday, but lipids can be stored.

6.

1	Identify the role of minerals in cells • Minerals are ions that have various uses in cells and in multicellular organisms, and are absorbed via digestion or ingestion
2	2 examples of the use of minerals in cells • Sodium (Na) and potassium (K) to regulate ion and fluid balance and maintain concentration gradients in various locations. • Iron (Fe) is a crucial component of haemoglobin, a protein used to transport oxygen around the body. • Calcium (Ca) is important for cell signalling and as a structural component of bone and teeth.

7.

a.

1	Evaluates the use of test tube 4 (the one with only milk in it) as a negative control • Did not show any curdling, which greatly contributes to the validity of the experiment since it suggests that any curdling observed is due to enzymatic action
1	Makes an overall judgement about validity by referencing at least one more factor: • Other controlled variables include temperature (which affects enzyme activity), volume in test tubes • Experimental design investigated the role of each enzyme separately AND together so that adequate comparison of their roles can be made
2	Evaluates the accuracy of the experiment by referencing at least 2 factors that affect it: • Temperature was kept at 37°C to mimic the conditions that rennin and schmepsin would work at in the stomach, so Bhupen's design accurately reflects the enzymes' role • Trial 3 of test tube 2 produced an outlier result. While other results were reliable, the presence of this outlier suggests there may have been errors in the way Bhupen carried out his experiment, which would compromise accuracy

H.W ANSWERS

b.

1	Explains that rennin displayed the fastest rate of coagulation out of the two (259s on average), which suggests it is the major enzyme involved in curdling. This is coupled with Bhupen's knowledge that rennin "initiates the coagulation of milk", so it is the first enzyme in that pathway.
1	Explains that schmepsin displayed a slower rate of coagulation (507s on average, not including outlier), and is likely an enzyme that acts on milk proteins after they have been broken down by rennin with much slower activity when rennin isn't present.
1	Explains that when the two are combined the fastest rate of coagulation is observed (126s on average), which suggests these two work together in the same pathway.

c.

3	Provides a brief explanation of three functions of proteins (not including as enzymes), including at least one example. These could include: • Structural - form structures that provide structural support in the body or in cells. For example proteins form the cytoskeleton, which helps cells maintain their shape • Movement - contractile proteins can generate movement. Actin and myosin are the proteins responsible for our muscles' ability to contract and relax. • Communication - proteins form receptors in the surface of cells, or can function in long-distance communication as hormones • Transport and storage - can bind to and store compounds while they are transported around the body. For instance, haemoglobin binds to and transport oxygen in the bloodstream. • Responding to stimuli - various proteins can undergo reactions and generate signals when exposed to stimuli. For example, opsins in the eye trigger a chemical cascade when exposed to light.

8.

1	Identify what an autotroph and heterotroph is in a food chain • An autotroph is an organism that produces chemical energy from light energy via photosynthesis. For example, trees conduct photosynthesis and are autotrophs. A heterotroph is an organism that cannot produce its own energy, so much absorb nutrients via ingestion. For example, a giraffe cannot produce energy, so it eats the tree to get energy, therefore being a heterotroph.
2	Explain why carbohydrates are vital for biological processes • Carbohydrates are produced from glucose (or other simple sugar) molecules, and are vital for life. This is because they are used for energy production via respiration. Long chains can be ingested by heterotrophs, and the individual glucose molecules can be used to produce ATP. Carbohydrates are an effective storage for these glucose molecules so that they can be easily available for later use. Therefore, without autotrophs, heterotrophs would be unable to access glucose, and therefore be unable to produce cellular energy.
2	Explain why proteins are vital for biological processes • Proteins are produced from long chains of amino acids. All amino acids contain nitrogen, which cannot be absorbed from the air, because it is in an unusable form. In this way, via the nitrogen cycle, plants are able to uptake dissolved nitrogen in water to be used for the synthesis of amino acids. Proteins are the only way that an organism can express the individual traits encoded in their DNA. Furthermore, proteins conduct numerous biological processes, including digestion (enzymes), support and chemical messages (hormones). In this way, without proteins, a living organism would not exist. Autotrophs are vital to provide the amino acids that heterotrophs can use to build proteins.
1	Provide a justification of the importance of autotrophs like plants in a food chain • Therefore, without plants to produce carbohydrates and amino acids, heterotrophs would not exist, as life is only enabled by the use of cellular energy and proteins.