Bio Factsheet

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Transport Mechanisms in Cells

The internal environment of the cell is isolated from its surroundings by the cell membrane. The cell membrane regulates transport of substances in and out of cells (Factsheet 8 - The cell surface membrane).

This Factsheet will describe transport mechanisms which occur inside cells and their functions within the cells. (Similar mechanisms also operate in the cell surface membrane). The mechanisms are:

- **diffusion and facilitated diffusion.**
- **active transport.**
- **proton pumps.**
- **cytoplasmic streaming.**
- **transport in vesicles.**

The internal volume of the cell is huge compared with the size of the molecules within the cell. Some of these molecules need to be distributed fairly evenly throughout the cytoplasm, for example, amino acids (so that they stand a better chance of meeting and combining with transfer-RNA molecules for use in polypeptide synthesis). Other molecules need to be transported to and from specific locations in the cell. For example, polypeptides must be transported from the rough endoplasmic reticulum to the Golgi body (so that they can combine to make proteins, or combine with other substances to make, for example, nucleoproteins).

> ***Remember**:- water is often referred to as 'the universal solvent' because it will dissolve a very wide range of substances. It thus allows them to be transported, either by diffusion, in solution, through the body of water, or by actual flowing of the water itself, carrying the dissolved substances.*

Intracellular membranes

Membranes inside cells, forming such structures as mitochondria, chloroplasts, smooth and rough endoplasmic reticulum and Golgi body, all have a similar structure to the cell surface membrane, although the relative proportions of the molecular components may differ. For example, membranes surrounding chloroplasts contain very little carbohydrate.
Intra-cellular membranes may:

- act as reaction surfaces,
- act as intracellular transport systems (vesicles),
- provide separate intracellular compartments, thus isolating different
- chemical reactions.

Intracellular transport thus requires transport of solutes to, away from, and across membranes.

Diffusion

Diffusion is defined as, 'the net movement of molecules or ions from a region of their high concentration to a region of their low concentration'. It will occur in the cell wherever a concentration gradient exists and will continue until the diffusing substance is evenly distributed. Examples of diffusion inside cells are:

- oxygen absorbed through the cell membranes of animals and plants, or released from the photosynthesising chloroplasts of plants, will diffuse towards the mitochondria where oxygen is being used in aerobic respiration.
- carbon dioxide absorbed into photosynthesising plant cells will diffuse from the cell membrane towards and into the chloroplasts, to be used in photosynthesis. Respiratory carbon dioxide in non-photosynthetic plant cells and in animal cells will diffuse from where it is produced, by decarboxylation reactions in the mitochondria and cytoplasm, to the cell membrane where it is released from the cell. (Some of the carbon dioxide will diffuse in the form of hydrogen carbonate ions).
- glucose and other sugars, amino acids and ions absorbed through the cell membranes of animal and plant cells will diffuse throughout the cell to where they are used. Glucose, amino acids and other products of photosynthesising cells will diffuse from the chloroplasts to where they are used in the cell.

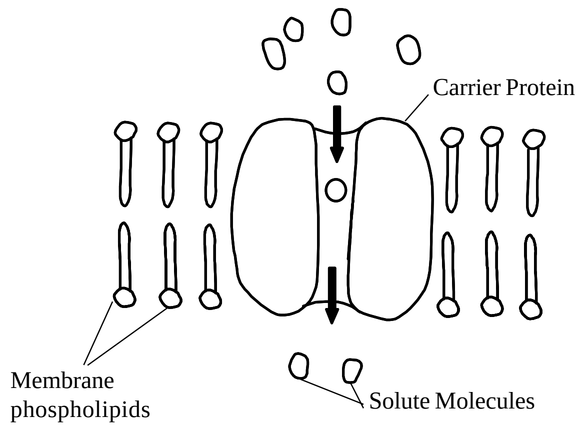
Facilitated diffusion is a process that enables diffusion to occur across membranes, for example, membranes of chloroplasts, mitochondria and endoplasmic reticulum. Facilitated diffusion is the 'passive movement of molecules down a concentration gradient across a membrane, and involves special carrier proteins in the membrane'. The carrier proteins may:

- contain special hydrophilic (water-liking) channels through which solutes can pass, or
- move in the membrane forming openings (gates), ferrying the solutes across.

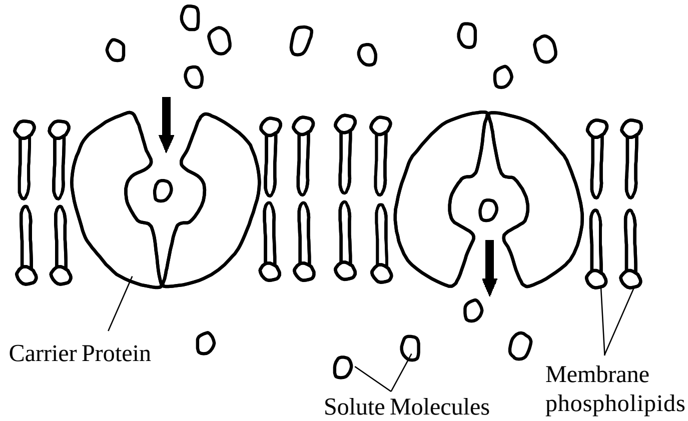
Facilitated diffusion does not require an energy source such as ATP to drive it.

Fig. 1. Facilitated diffusion

a) Hydrophilic channel allows solutes through



b) Carrier protein opens (forms a 'gate') allowing solutes through



In facilitated diffusion the carrier protein can transport the solute either way depending on the concentration gradient. Carrier proteins are specific to particular solute molecules. The carrier protein for the facilitated transport of glucose is called a **permease.** The glucose is bound to the permease on one side of the membrane and is released from the permease on the other side of the membrane, as in fig. 1.(b) above. In a plant cell, glucose may be released through chloroplast membranes and absorbed into plastids (amyloplasts) to be stored as starch.

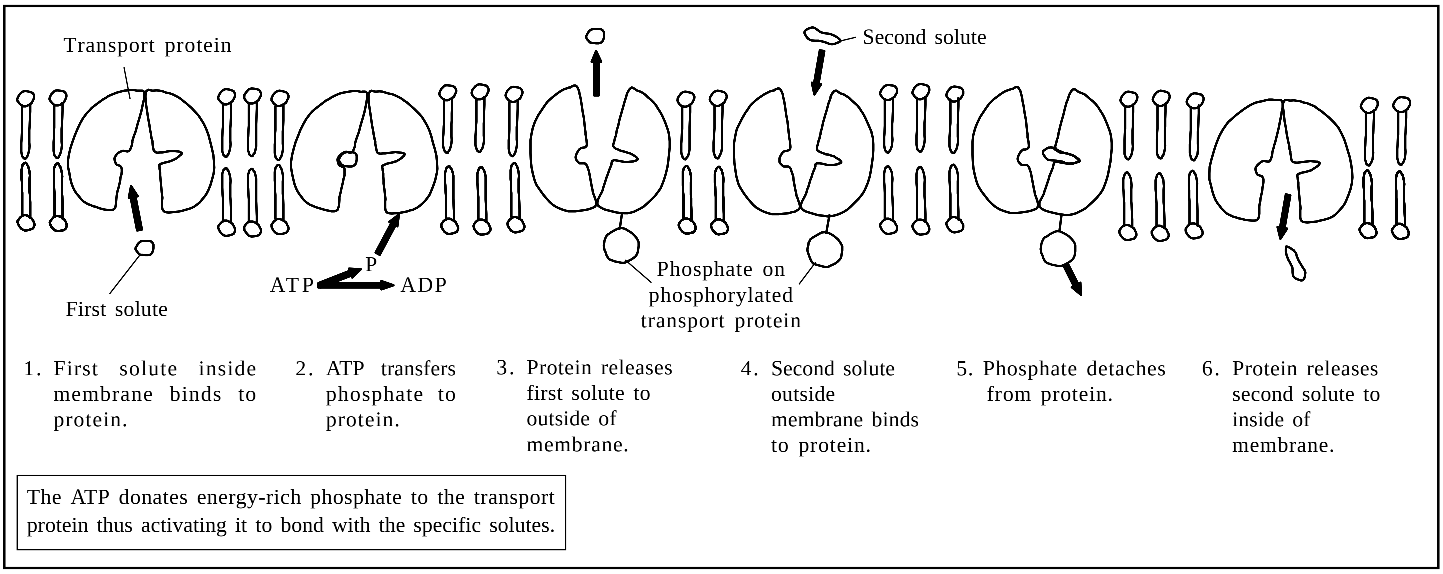
Active transport
Active transport is the movement of substances, usually against a concentration gradient, across a membrane, and involves the expenditure of energy. The energy usually comes from ATP, generated by respiration in the mitochondria. Active transport involves carrier proteins in the membrane. The carriers are specific to the substances they transport. The carriers may move:

- a single substance in a single direction (**uniport** carriers) For example, some calcium pumps.
- two substances in the same direction (**symport** carriers) For example, glucose-sodium pumps.
- two substances in opposite directions (**antiport** carriers). For example sodium-potassium pumps.

A calcium pump is involved with the regulation of calcium concentrations inside the cell. The cytoplasm normally has a calcium concentration of around 10^{-7} moles dm^{-3}. The spaces of the endoplasmic reticulum have a calcium concentration around 10^{-3} moles dm^{-3}. The calcium pump on the endoplasmic reticulum membranes pumps calcium from cytoplasm into the endoplasmic reticulum, creating a 10,000 fold concentration increase. A similar pump is used to pump calcium ions back into the sarcoplasmic reticulum of muscle, after contraction.

The exact mechanisms of active transport pumps are uncertain but a probable mechanism is illustrated in figure 2.

Fig. 2. Possible mechanism for active transport (antiport).

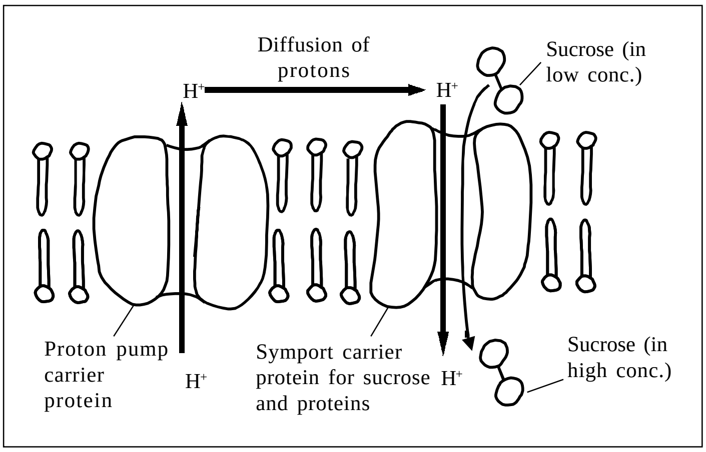


Proton pumps
These are active transport mechanisms use to transport hydrogen ions (protons) across membranes. Proton pumps are present in the vacuolar membranes (tonoplasts) of plant cells, yeasts and fungi, in the endoplasmic and lysosomal membranes of animal cells, in the inner mitochondrial membrane and in chloroplast thylacoid membranes.
In many cases proton pumps enable other molecules to be transported with the protons. For example:

- sucrose is transferred across membranes (for example, chloroplast membranes, cell surface membrane) in conjunction with protons,
- ATP in the mitochondria is released by a proton pump mechanism during aerobic respiration,
- ATP in the chloroplasts is released by a proton pump mechanism during the light-dependent stage of photosynthesis.

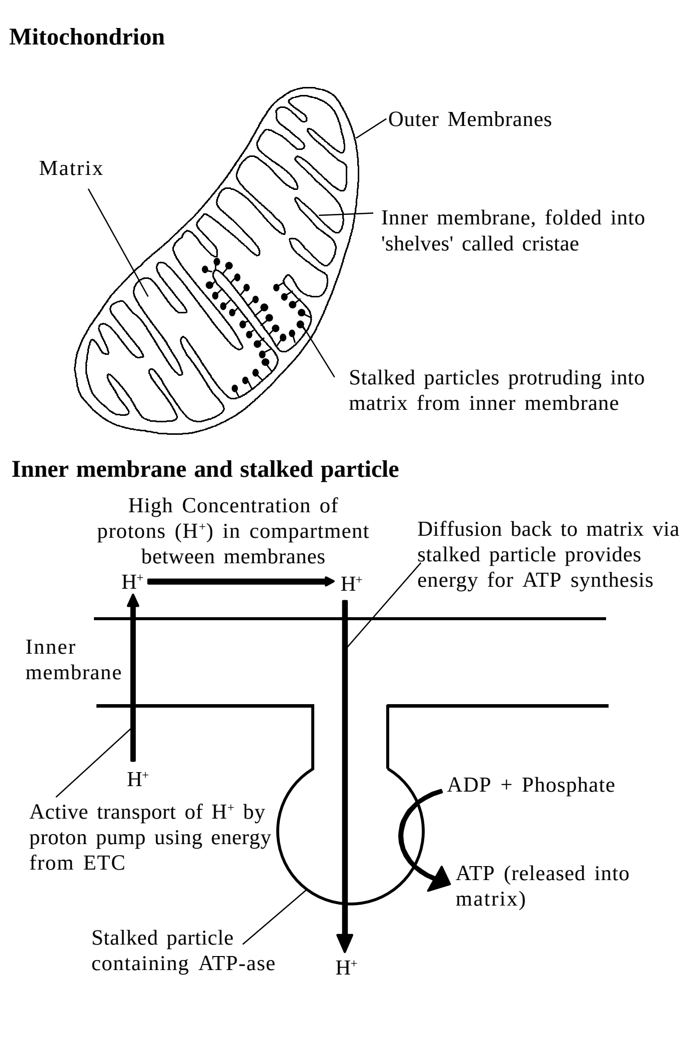
This is an example of **cotransport** in which the active transport of one substance indirectly drives the movement of another substance against a concentration gradient. The proton pump actively drives protons across the membrane (using energy from ATP). This forms a high concentration of protons which then diffuse back across the membrane via the symport carrier protein. This, by an unknown mechanism, enables sucrose to be actively transported across the membrane via the symport carrier, against the sucrose concentration gradient.

Fig. 3. Transport of sucrose across membranes



The proton pump operating across the inner mitochondrial membrane uses energy from the electron transport chain (ETC) to pump protons from the mitochondrial matrix into the compartment between the inner and outer mitochondrial membranes. The protons accumulate so that a steep concentration gradient exists between the compartment and the matrix. The inner membrane is impermeable to protons except through channels located in the stalked particles of the inner membrane. The protons diffuse back to the matrix through these channels and this provides energy to drive the synthesis of ATP from ADP and phosphate. The enzyme ATP-ase, in the stalked particles catalyses the ATP synthesis.

Fig. 4. ATP synthesis in the mitochondrion



The proton pump enabling ATP generation in chloroplasts works in a similar way. It is situated in the thylacoid membranes and releases the ATP to the stroma.

> ***Exam Hint**: – questions on cotransport have been asked several times in recent exams. The main example tested is the active transport mechanism of glucose (and galactose) which works in conjunction with a sodium pump (instead of a proton pump).*

Cytoplasmic streaming

Diffusion is a relatively slow process and so many cells speed up movement of materials by cytoplasmic streaming. Under the microscope, evidence of streaming can be seen in the movement of food vacuoles around an *Amoeba* cell, or in the movement of chloroplasts around the vacuole of a palisade mesophyll cell. Movement of such organelles, due to the streaming of cytoplasm, is called **cyclosis**. The streaming may involve all the cytoplasm or just part of it – plant cells tend to show streaming that circulates the cytoplasm in definite currents around the tonoplast membrane of the vacuole. Mass flow along the length of sieve tube elements, in phloem, is thought to involve cytoplasmic streaming.

The streaming is generated by active movements of actin microfilaments which are bound to the endoplasmic reticulum. Myosin, also bound to the endoplasmic reticulum, interacts with the actin filaments and pulls them moving the endoplasmic reticulum. This moves the nearby cytoplasm along. The interaction of actin and myosin requires energy from ATP.

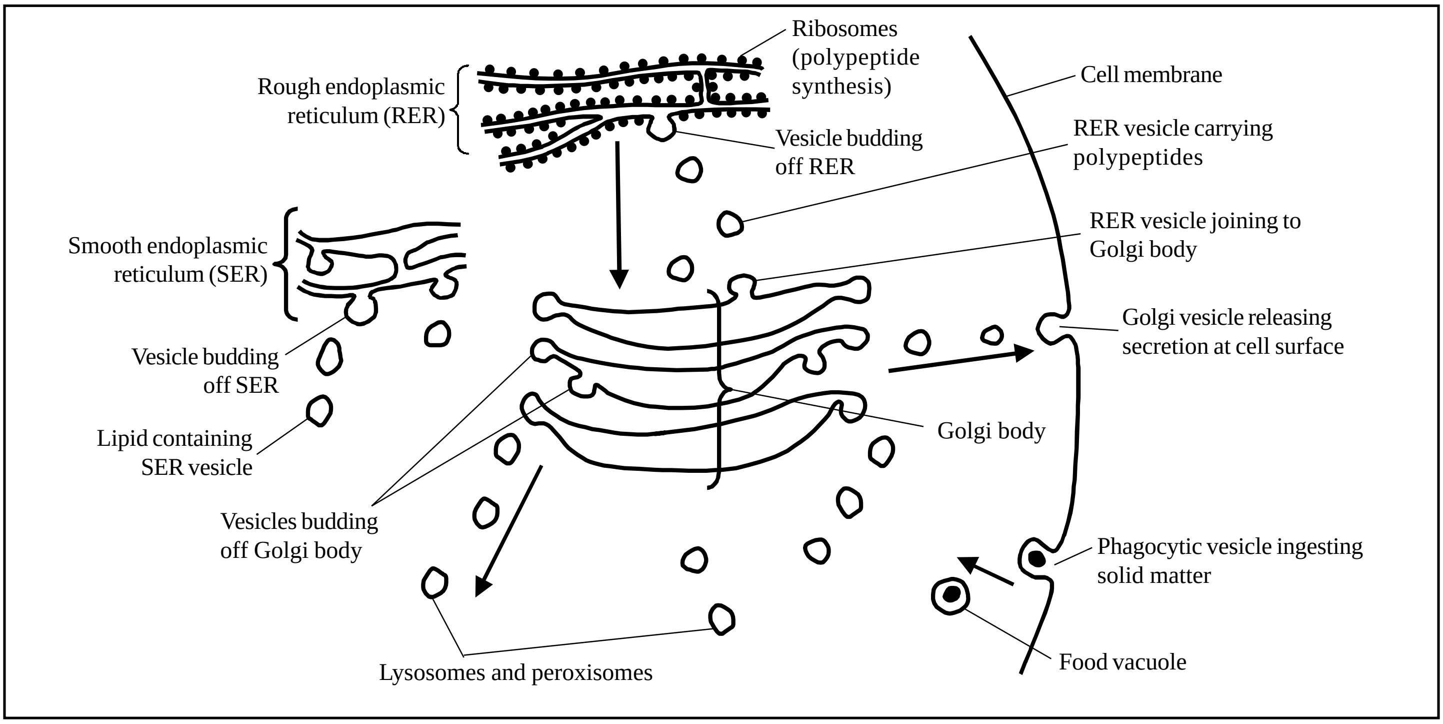
> ***Remember** – actin and myosin are contractile proteins They make up the structure of muscle fibres and are responsible for muscle contraction.*

Transport in vesicles

Vesicles are membrane bound sacs formed from various organelles within the cell used to transport substances throughout the cell or to specific locations of the cell. Examples are:

- vesicles budded off from the rough endoplasmic reticulum that migrate to the Golgi body and fuse with it. They carry polypeptides synthesized in the rough endoplasmic reticulum for processing into proteins and other derivatives by the Golgi body.

Fig 5. Examples of vesicles in a cell



- vesicles bud off from the Golgi body, containing substances synthesized by the Golgi body. These substances are often enzymes and the vesicles may:
  1. move to the cell surface membrane, fuse with it and release their contents to the outside (**secretory vesicles**).
  2. contain protein splitting enzymes (lysozyme) and disperse throughout the cytoplasm as **lysosomes**. These can be involved in intracellular digestion when required.
  3. contain peroxidase enzymes and disperse throughout the cytoplasm as **peroxisomes**.

  These are used to break down toxic hydrogen peroxide produced by cell metabolism.

- vesicles also bud off from the smooth endoplasmic reticulum. These transport lipid substances that may be dispersed throughout the cell, or released at the cell surface (for example, secretion of steroid hormones).

- vesicles budded off from the cell surface membrane into the cytoplasm. These may be **phagocytic vesicles** which engulf solid material from outside the cell and bring it into the cytoplasm (forming a food vacuole) or **pinocytic vesicles** which ingest liquid material from outside the cell to bring it into the cytoplasm.

Practice Questions

1. Read through the following passage about active transport and then complete it by inserting appropriate words or phrases into the gaps.

   Active transport can transport substances across membranes against a …………………….. . The substance is transported using a specific ………………. and requires the use of energy. The calcium pump in cells obtains energy from …….. . In mitochondria the synthesis of ATP, from the ……………….. , is enabled by a …………. pump. The driving energy for this comes from the …………………………. . A similar mechanism exists in the …………….. membranes of the chloroplast, enabling generation of ATP from the …………………… stage of photosynthesis. **Total 8**

2. Glucose can be transported across membanes by facilitated diffusion or by active transport in conjunction with sodium ions. Suggest possible mechanisms for:
   a) the transfer of glucose across a membrane by facilitated transport, and **4**
   b) the transfer of glucose across a membrane by active transport. (Hint – refer back to sucrose transport using a proton pump). **5**

   Total 9

3. Complete the following table relating to transport by cytoplasmic vesicles. **Total 4**

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides			
Protease enzymes			
Lipids			
Peroxidase enzymes			

4. Suggest explanations for the following:
   (a) Exposure of mitochondria to cyanide ions prevents ATP synthesis by the mitochondria. **4**
   (b) Cytoplasmic streaming in plant cells is slowed up by exposure to cold conditions. **4**
   (c) Liver (hepatic) cells contain more cytoplasmic vesicles than plant parenchyma cells. **4**

   Total 12

Answers

1. concentration gradient; carrier (protein); ATP; stalked particles; proton; electron transport chain/ETC; thylacoid; light-dependent; **Total 8**

2. (a) specific carrier protein in membrane reacts with glucose; carrier protein called a 'permease';
   releases glucose on the other side of the membrane/ forms a gate/ channel to allow passage of glucose;
   can go either way across the membrane depending on the concentration gradient; **4**
   (b) sodium pump carries sodium ions across membrane using a specific carrier protein; driven by energy from ATP;
   produces high concentration of sodium ions which can only diffuse back through the membrane at 'sodium – glucose gates';
   diffusion back of sodium ions provides energy to carry glucose molecules through membrane; ref to symport carrier; **5**

   Total 9 marks

3.

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides	Rough endoplasmic reticulum/RER	Rough endoplasmic reticulum/RER	Transport polypeptides to Golgi body;
Protease enzymes	Lysosomes	Golgi body	Intracellular digestion of proteins;
Lipids	Smooth endoplasmic reticulum/SER	Smooth endoplasmic reticulum/SER	Storage /secretion of lipids/steroids;
Peroxidase enzymes	Peroxisomes	Golgi body	Breakdown of toxic peroxides;

Total 4

4. (a) cyanide ions block cytochrome oxidase/prevent the electron transport chain from working;
   thus no energy is available to drive the proton pumps on the inner membrane;
   thus no protons/hydrogen ions diffuse back through the stalked particles to the matrix;
   thus ATP-ase in the stalked particles is not activated to synthesise ATP from ADP and phosphate; **4**

   (b) cytoplasmic streaming requires ATP as energy source;
   to make actin microfilaments combine with myosin, thus pulling the endoplasmic reticulum which moves the cytoplasm;
   ATP synthesis/use requires enzymes/ref ATP-ase;
   enzymes are temperature dependent and slow up in cold conditions; **4**

   (c) liver cells are metabolically much more active compared to plant parenchyma cells;
   synthesize many proteins/plasma proteins/fibrinogen and so many RER vesicles will be present;
   synthesize and store lipids so many SER vesicles will be present;
   detoxify peroxides and so many peroxisomes will be present; **4**

   Total 12

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