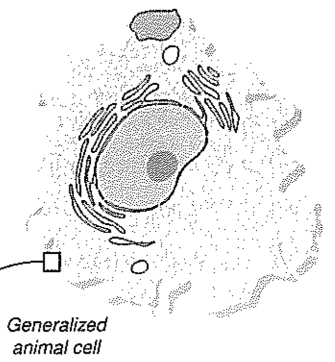
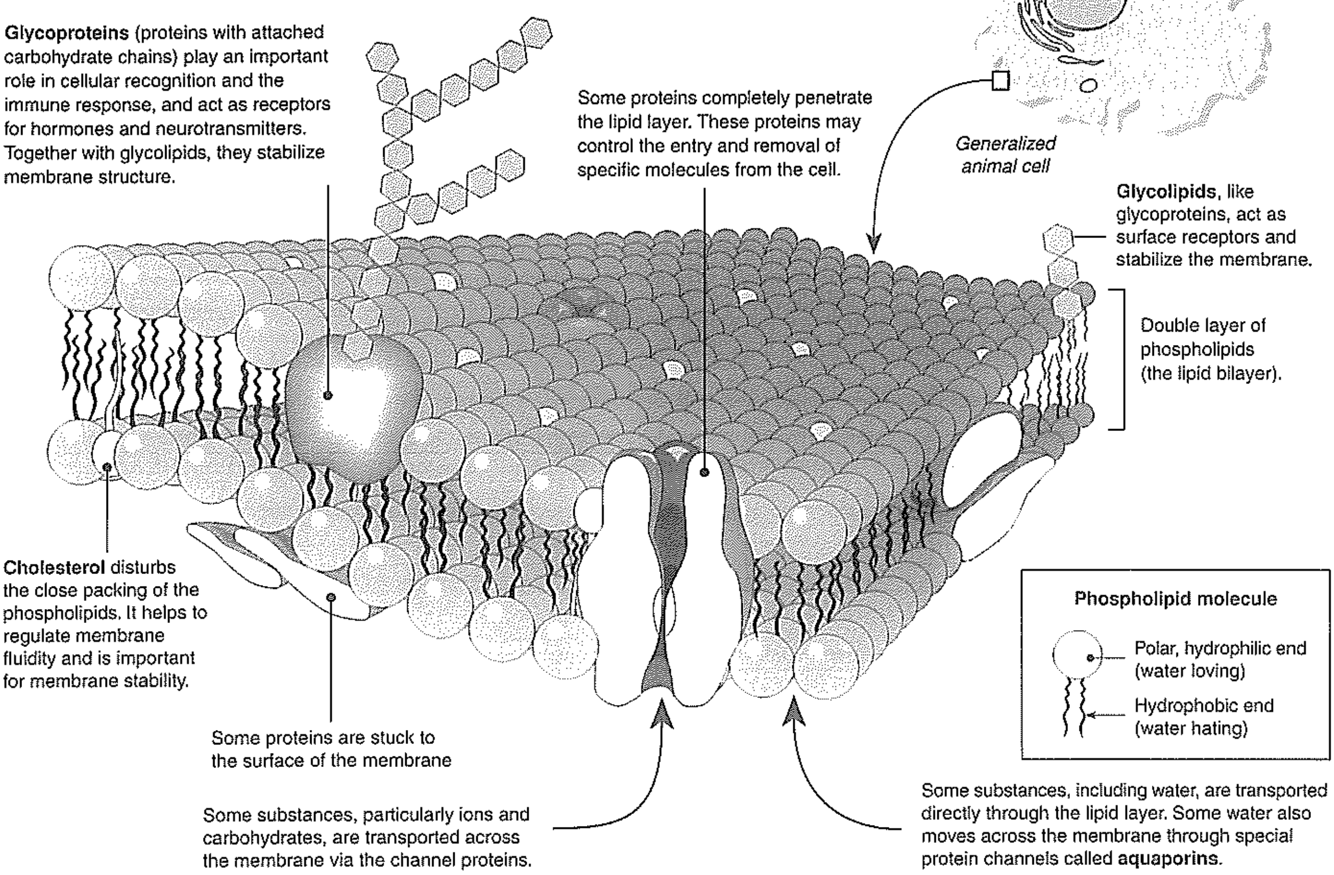
The Structure of Membranes

All cells have a **plasma membrane** forming the outer limit of the cell. Cellular membranes are also found inside eukaryotic cells as part of membranous **organelles**, such as the endoplasmic reticulum. Present day knowledge of membrane structure has been built up as a result of many observations and experiments. The now-accepted model of membrane structure is the **fluid-mosaic model** (below). The plasma membrane is more than just a passive envelope; it is a dynamic structure actively involved in cellular activities. Specializations of the plasma membrane, including microvilli and membrane junctions (e.g. desmosomes and tight junctions), are particularly numerous in epithelial cells, which line hollow organs such as the small intestine.

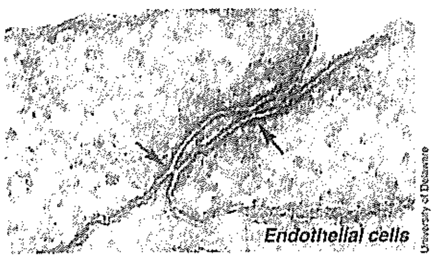
The Fluid Mosaic Model

The currently accepted model for membrane structure, the **fluid mosaic model**, satisfies the observed properties of cellular membranes. In this model there is a double layer of phospholipid molecules (fats) which are arranged with their hydrophobic 'tails' facing inwards. This self-orientating property allows cellular membranes to reseal themselves when disrupted. The double layer of lipids is quite fluid, within which the proteins move quite freely. The mobile proteins are thought to have a number of functions, including roles in active transport.

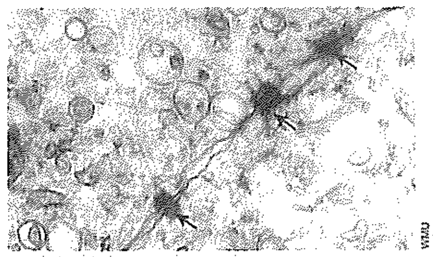




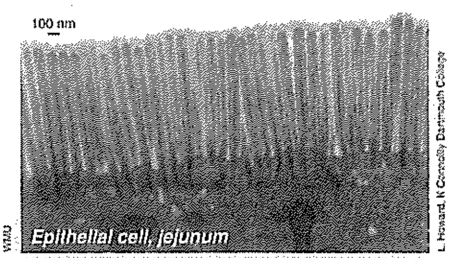
Membrane Specializations



Tight junctions bind the membranes of neighboring cells together to form a virtually impermeable barrier to fluid. Tight junctions prevent molecules passing through the spaces between cells.



Desmosomes (arrowed) are anchoring junctions that allow cell-to-cell adhesion. Desmosomes help to resist shearing forces in tissues subjected to mechanical stress (such as skin cells).



Microvilli are microscopic protrusions of the plasma membrane that increase the surface area of cells. Microvilli are involved in a wide variety of functions, including absorption (e.g. in the intestine).

1. (a) Explain how phospholipids organize themselves into a bilayer in an aqueous environment: ____________________

____

____

____

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Related activities: The Role of Membranes in Cells
Web links: Membrane Structure Tutorial, Animal Cell Junctions

(b) Explain how the fluid mosaic model accounts for the observed properties of cellular membranes:

2. Explain how the membrane surface area is increased within cells and organelles:

3. Discuss the importance of each of the following to cellular function:

(a) High membrane surface area:

(b) Channel proteins and carrier proteins in the plasma membrane:

4. (a) Name a cellular organelle that possesses a membrane:

(b) Describe the membrane's purpose in this organelle:

5. Describe the purpose of cholesterol in the plasma membrane:

6. Describe the role of each of the following membrane junctions and give an example of where they commonly occur. The first example is completed for you:

(a) **Gap junctions**: Communicating junctions linking the cytoplasm of neighboring cells. They allow rapid passage of signals between cells, e.g. electrical messages in cardiac muscle cells.

(b) **Tight junctions**:

(c) **Desmosomes**:

7. Explain why tight junctions are especially abundant in epithlelial cells, e.g. in the skin and intestine:

8. Use the symbol for a phospholipid molecule (below) to draw a **simple labelled diagram** to show the structure of a plasma membrane (include features such as lipid bilayer and various kinds of proteins):

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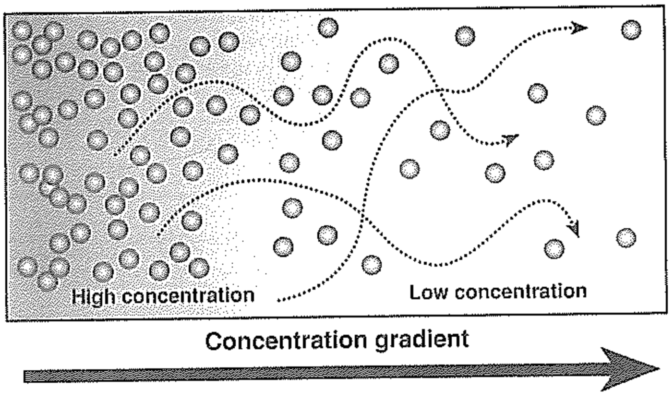
Passive Transport Processes

The molecules that make up substances are constantly moving in a random way. This random motion causes molecules to disperse from areas of high to low concentration (i.e. down a **concentration gradient**). This process is called **diffusion**. All types of diffusion, including **osmosis**, are **passive transport** processes, in that they require no expenditure of energy. Diffusion occurs freely across membranes, as long as the membrane is permeable to that molecule (**partially permeable membranes** allow the passage of some molecules but not others). Simple diffusion may occur directly across the lipid bilayer, whereas facilitated diffusion utilizes transmembrane proteins to assist the diffusion of specific molecules. **Filtration** is also a passive process, in which fluid pressure is used to push substances through a membrane or capillary wall. Filtration obeys the same rules of movement as diffusion, but the gradient involved is a pressure gradient rather than a concentration gradient.

Diffusion of Molecules Along Concentration Gradients

Diffusion is the movement of molecules (and ions) from regions of high to low concentration, with the end result being that the molecules become evenly distributed. In biological systems, diffusion often occurs across **partially permeable membranes.** Each type of diffusing molecule (gas, solvent, solute) moves along its own **concentration gradient**. Various factors (right) determine the rate at which this occurs.



If molecules are free to move, they move from high to low concentration until they are evenly dispersed.

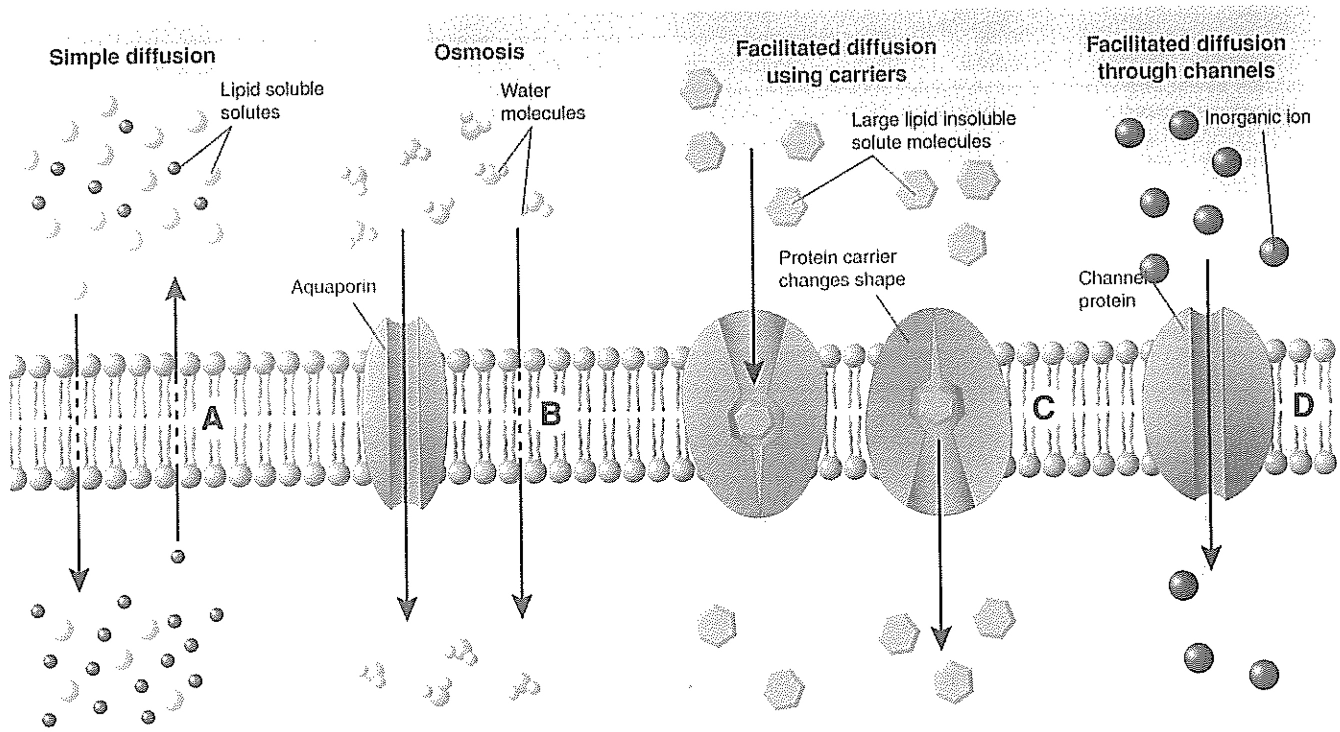
Factors affecting rates of diffusion for any given diffusing molecule

- **Concentration gradient:** The greater the concentration gradient, the higher the diffusion rate.
- **Surface area:** The larger the area across which diffusion occurs, the greater the rate of diffusion.
- **Barriers to diffusion:** Thicker barriers slow diffusion rate. Pores in a barrier enhance diffusion.
- **Temperature:** Diffusion rates are higher at higher temperatures (within the body this is a negligible factor).

These factors are expressed in **Fick's law**, which governs the rate of diffusion of substances across membranes. It is described by:

$$\frac{\text{Surface area of membrane} \times \text{Difference in concentration across the membrane}}{\text{Length of the diffusion path (thickness of the membrane)}}$$

Diffusion Through Membranes



A: Some molecules (e.g. gases and lipid soluble molecules) diffuse directly across the plasma membrane. Two-way diffusion is common in biological systems, e.g. at the alveolar surface of the lung, CO_2 diffuses out and oxygen diffuses into the blood.

B: Osmosis describes the diffusion of water across a partially permeable membrane (in this case, the plasma membrane). Some water can diffuse directly through the lipid bilayer, but movement is also aided by specific protein channels called **aquaporins**.

C: In **carrier-mediated facilitated diffusion**, a lipid-insoluble molecule is aided across the membrane by a transmembrane carrier protein specific to the molecule being transported (e.g. glucose transport into red blood cells).

D: Small polar molecules and ions diffuse rapidly across the membrane by **channel-mediated facilitated diffusion**. Protein channels create hydrophilic pores that allow some solutes, usually inorganic ions, to pass through.

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Related activities: Absorption and Transport
Web links: Cellular Transport

Cellular Tonicity and Osmotic Pressure

In the study of physiology, it is important to understand the consequences of changes to the solute concentrations of cellular environments. The tendency of a solution to 'pull' water into it is called the **osmotic pressure** and it is directly related to the concentration of solutes in the solution. The higher the solute concentration, the greater the osmotic pressure and the greater the tendency of water to move into the solution (see previous page on factors affecting diffusion rates). In biology, **relative tonicity** (isotonic, hypotonic, or hypertonic) is used describe the difference in osmotic pressure between solutions. Only solutes that cannot cross the plasma membrane affect tonicity.

Tonicity of solution relative to the cytosol	Extracellular environment (solution)	Intracellular environment (cytosol)	Consequence to a cell in the solution
Isotonic	Equal osmotic environment		Normal shape and form
Hypotonic	Lower solute concentration	Higher solute concentration	Water enters cell causing the cell to burst (cell **lysis**)
Hypertonic	Higher solute concentration	Lower solute concentration	Water leaves cell causing shrinkage (**crenation**)

Delivery of intravenous (IV) fluid

Michael Berry (Wikipedia)

The relative tonicity of cells can be used to predict the consequences of changes in solute concentration either side of a partially permeable membrane (i.e. the plasma membrane surrounding each of the body's cells). Such predictions are important in a practical sense as, for example, during the delivery of **intravenous fluid** to patients (*intravenous means within vein*). To prevent life-threatening changes to cell volumes, intravenous (IV) fluids must present the same osmotic environment as the blood cells they will be surrounding when delivered (e.g. 0.9% saline solution).

1. Describe two properties of an exchange surface that would facilitate rapid diffusion rates:

   (a) ______________________ (b) ______________________

2. Describe two biologically important features of diffusion:

   (a) ______________________

   (b) ______________________

3. Describe how facilitated diffusion is achieved for:

   (a) Small polar molecules and ions: ______________________

   (b) Glucose: ______________________

4. Explain concentration gradients across membranes are maintained: ______________________

5. Explain the role of aquaporins in the rapid movement of water through some cells: ______________________

6. Fluid replacements are usually provided for heavily perspiring athletes after endurance events.

   (a) Identify the preferable tonicity of these replacement drinks (isotonic, hypertonic, or hypotonic): ______________________

   (b) Give a reason for your answer: ______________________

7. Describe what would happen to a patient's red blood cells if they were treated with an intravenous drip containing:

   (a) Pure water: ______________________

   (b) A hypertonic solution: ______________________

   (c) A hypotonic solution: ______________________

8. The malarial parasite lives in human blood. Relative to the tonicity of the blood, the parasite's cell contents would be hypotonic / isotonic / hypertonic (circle the correct answer).

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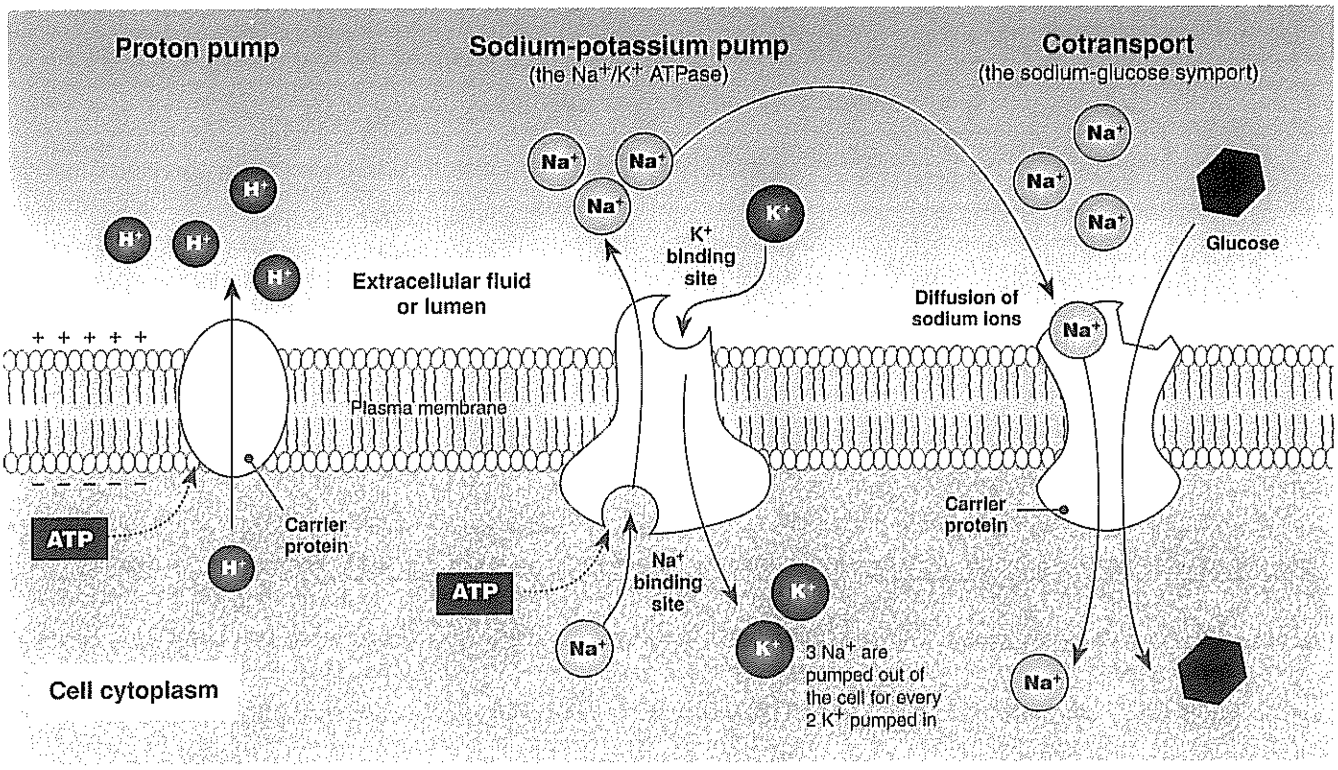
Ion Pumps

Diffusion alone cannot supply the cell's entire requirements for molecules (and ions) in all situations; sometimes molecules must be moved in a certain direction according to the specific needs of the cell. The movement of molecules against their concentration gradient requires **energy expenditure** and is achieved through **active transport** mechanisms (ion pumps and cytosis). **Ion pumps** are specific transmembrane carrier proteins that harness the energy of ATP to move molecules from a low to a high concentration. When ATP transfers a phosphate group to the carrier protein, the protein changes its shape, moving the bound molecule across the membrane. Three types of membrane pump are described below. The sodium-potassium pump (center) is almost universal in animal cells. The concentration gradient created by ion pumps such as this and the proton pump (left) is frequently coupled to the transport of other larger molecules, as shown below right. Note that glucose enters most cells by facilitated diffusion (i.e. passively) but moves by active transport into the intestinal epithelial cells. In this way, uptake of glucose from ingested food continues despite what might be highly fluctuating glucose levels in the intestines.



Proton pumps

ATP driven proton pumps use energy to remove hydrogen ions (H^+) from inside the cell to the outside. This creates a large difference in the proton concentration either side of the membrane, with the inside of the plasma membrane being negatively charged. This potential difference can be coupled to the transport of other molecules.

Sodium-potassium pump

The sodium-potassium pump is a specific protein in the membrane that uses energy in the form of ATP to exchange sodium ions (Na^+) for potassium ions (K^+) across the membrane. The unequal balance of Na^+ and K^+ across the membrane creates large concentration gradients that can be used to drive transport of other substances (e.g. cotransport of glucose).

Cotransport (coupled transport)

A gradient in sodium ions drives the active transport of **glucose** in intestinal epithelial cells. The specific transport protein couples the return of Na^+ down its concentration gradient to the transport of glucose into the intestinal epithelial cell. A low intracellular concentration of Na^+ (and therefore the concentration gradient) is maintained by a sodium-potassium pump.

1. Explain why the ATP is required for membrane pump systems to operate: __________

2. (a) Explain what is meant by cotransport: __________

(b) Explain how cotransport is used to move glucose into the intestinal epithelial cells: __________

(c) Explain what happens to the glucose that is transported into the intestinal epithelial cells: __________

3. Describe two consequences of the extracellular accumulation of sodium ions: __________

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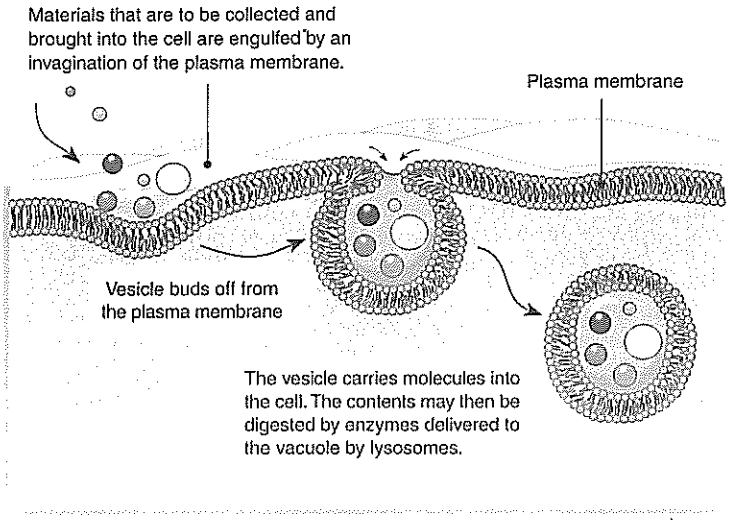
Exocytosis and Endocytosis

Most cells carry out **cytosis**: a form of **active transport** involving infolding or outfolding of the plasma membrane. Cells are able to do this because of the flexibility of the plasma membrane. Cytosis results in the bulk transport of materials into or out of the cell and is achieved through the localized activity of microfilaments and microtubules in the cell cytoskeleton. Engulfment of material is termed **endocytosis.** Endocytosis typically occurs in certain white blood cells of the human defense system (e.g. neutrophils, macrophages). **Exocytosis** is the reverse of endocytosis and involves the release of material from vesicles or vacuoles that have fused with the plasma membrane. Exocytosis is typical of cells that export material (secretory cells).

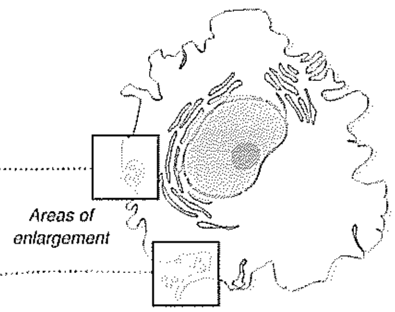


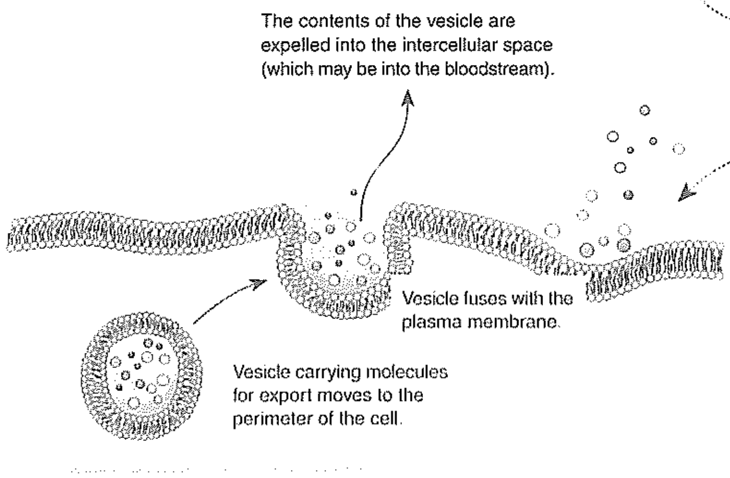
Endocytosis

Endocytosis (left) occurs by invagination (infolding) of the plasma membrane, which then forms vesicles or vacuoles that become detached and enter the cytoplasm. There are two main types of endocytosis:

Phagocytosis: "cell-eating"
Example: Phagocytosis of foreign material and cell debris by neutrophils and macrophages. Phagocytosis involves the engulfment of **solid material** and results in the formation of vacuoles.

Pinocytosis: "cell-drinking"
Examples: Uptake in the cells of the liver. Pinocytosis involves the uptake of **liquids** or fine suspensions and results in the formation of pinocytic vesicles.





Exocytosis

Exocytosis (left) is the reverse process to endocytosis. In multicellular organisms, various types of cells are specialized to manufacture and export products (e.g. proteins) from the cell to elsewhere in the body or outside it. Exocytosis occurs by fusion of the vesicle membrane and the plasma membrane, followed by release of the vesicle contents to the outside of the cell.

1. Distinguish between **phagocytosis** and **pinocytosis**: ______________________________

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2. Describe an example of phagocytosis and identify the cell type involved: ______________________________

____

3. Describe an example of exocytosis and identify the cell type involved: ______________________________

____

4. Explain why cytosis is affected by changes in oxygen level, whereas diffusion is not: ______________________________

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5. Identify the processes by which the following substances enter a living macrophage:

(a) Oxygen: ____________________ (c) Water: ____________________

(b) Cellular debris: ____________________ (d) Glucose: ____________________

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Related activities: The Role of Membranes in Cells, The Action of Phagocytes, Passive Transport Processes **Web links:** Cellular Transport