

B2.1 Membranes and Membrane Transport

Ver. 2

Guiding Questions

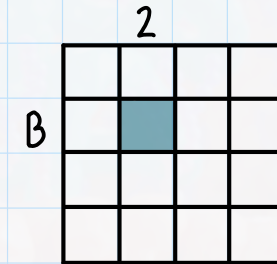
How do molecules of lipid and protein assemble into biological membranes?

What determines whether a substance can pass through a biological membrane?

Linking Questions

What processes depend on active transport in biological systems?

What are the roles of cell membranes in the interaction of a cell with its environment?



Theme: Form and Function

Level of Organization: Cells

Written and drawn by:

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SL Learning Content

B2.1.1	Lipid bilayers as the basis of cell membranes	Phospholipids and other amphipathic lipids naturally form continuous sheet-like bilayers in water.
B2.1.2	Lipid bilayers as barriers	Students should understand that the hydrophobic hydrocarbon chains that form the core of a membrane have low permeability to large molecules and hydrophilic particles, including ions and polar molecules, so membranes function as effective barriers between aqueous solutions.
B2.1.3	Simple diffusion across membranes	Use movement of oxygen and carbon dioxide molecules between phospholipids as an example of simple diffusion across membranes.
B2.1.4	Integral and peripheral proteins in membranes	Emphasize that membrane proteins have diverse structures, locations and functions. Integral proteins are embedded in one or both of the lipid layers of a membrane. Peripheral proteins are attached to one or other surface of the bilayer.
B2.1.5	Movement of water molecules across membranes by osmosis and the role of aquaporins	Include an explanation in terms of random movement of particles, impermeability of membranes to solutes and differences in solute concentration.
B2.1.6	Channel proteins for facilitated diffusion	Students should understand how the structure of channel proteins makes membranes selectively permeable by allowing specific ions to diffuse through when channels are open but not when they are closed.
B2.1.7	Pump proteins for active transport	Students should appreciate that pumps use energy from adenosine triphosphate (ATP) to transfer specific particles across membranes and therefore that they can move particles against a concentration gradient.
B2.1.8	Selectivity in membrane permeability	Facilitated diffusion and active transport allow selective permeability in membranes. Permeability by simple diffusion is not selective and depends only on the size and hydrophilic or hydrophobic properties of particles.
B2.1.9	Structure and function of glycoproteins and glycolipids	Limit to carbohydrate structures linked to proteins or lipids in membranes, location of carbohydrates on the extracellular side of membranes, and roles in cell adhesion and cell recognition.
B2.1.10	Fluid mosaic model of membrane structure	Students should be able to draw a two-dimensional representation of the model and include peripheral and integral proteins, glycoproteins, phospholipids and cholesterol. They should also be able to indicate hydrophobic and hydrophilic regions.

HL Learning Content

B2.1.11	Relationships between fatty acid composition of lipid bilayers and their fluidity	Unsaturated fatty acids in lipid bilayers have lower melting points, so membranes are fluid and therefore flexible at temperatures experienced by a cell. Saturated fatty acids have higher melting points and make membranes stronger at higher temperatures. Students should be familiar with an example of adaptations in membrane composition in relation to habitat.
B2.1.12	Cholesterol and membrane fluidity in animal cells	Students should understand the position of cholesterol molecules in membranes and also that cholesterol acts as a modulator (adjustor) of membrane fluidity, stabilizing membranes at higher temperatures and preventing stiffening at lower temperatures.
B2.1.13	Membrane fluidity and the fusion and formation of vesicles	Include the terms “endocytosis” and “exocytosis”, and examples of each process.
B2.1.14	Gated ion channels in neurons	Include nicotinic acetylcholine receptors as an example of a neurotransmitter-gated ion channel and sodium and potassium channels as examples of voltage-gated channels.
B2.1.15	Sodium–potassium pumps as an example of exchange transporters	Include the importance of these pumps in generating membrane potentials.
B2.1.16	Sodium-dependent glucose cotransporters as an example of indirect active transport	Include the importance of these cotransporters in glucose absorption by cells in the small intestine and glucose reabsorption by cells in the nephron.
B2.1.17	Adhesion of cells to form tissues	Include the term “cell-adhesion molecules” (CAMs) and the understanding that different forms of CAM are used for different types of cell–cell junction. Students are not required to have detailed knowledge of the different CAMs or junctions.

B2.1.1—Lipid bilayers as the basis of cell membranes. B2.1.2—Lipid bilayers as barriers.

B2.1.4—Integral and peripheral proteins in membranes. B.2.1.9—Structure and function of

glycoproteins and glycolipids. B2.1.10—Fluid mosaic model of membrane structure

Cell membranes are an essential component of all cells: ① allows internal conditions to be different from surroundings ② controls entry and exit of substances ③ allows sensitivity and communication

cell structure A2.2

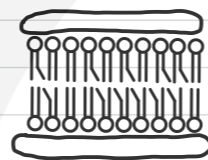
fluid mosaic model: accepted view of the cell membrane structure proposed by Singer and Nicolson (1972): dynamic, flexible structure made primarily of a phospholipid bilayer with proteins and carbohydrates.

↳ "fluid": components can move laterally + "mosaic": non-uniform, made of many different components (lipid, carbohydrate, and protein) in various configurations

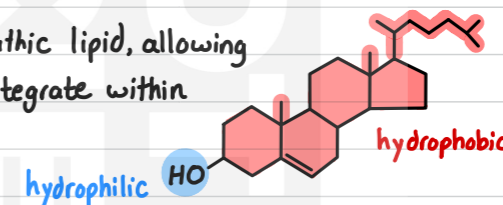
✗ the previous "protein-lipid sandwich" model by Dawson and Danielli (1935) was falsified using:

↳ immunofluorescence: where tagged membrane proteins moved laterally ▶ proteins were mobile i.e. fluid

↳ freeze-fracturing: where the membrane bilayer was split open showing proteins ▶ integral transmembrane proteins



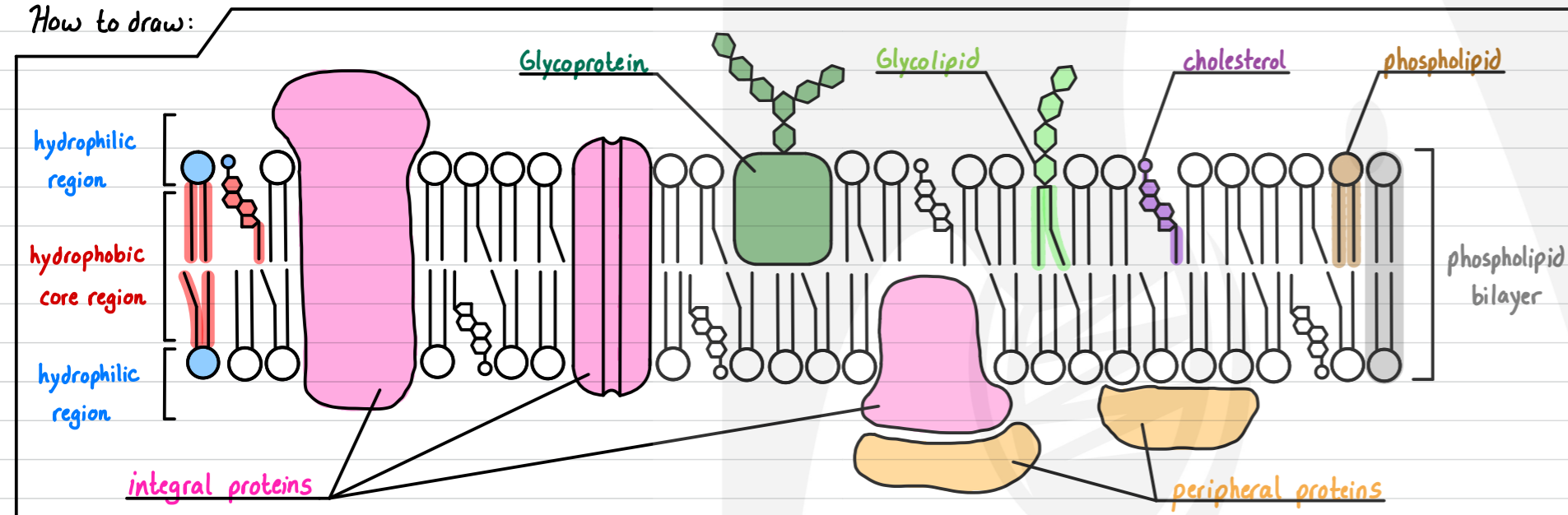
Cholesterol: amphipathic lipid, allowing it to integrate within bilayer



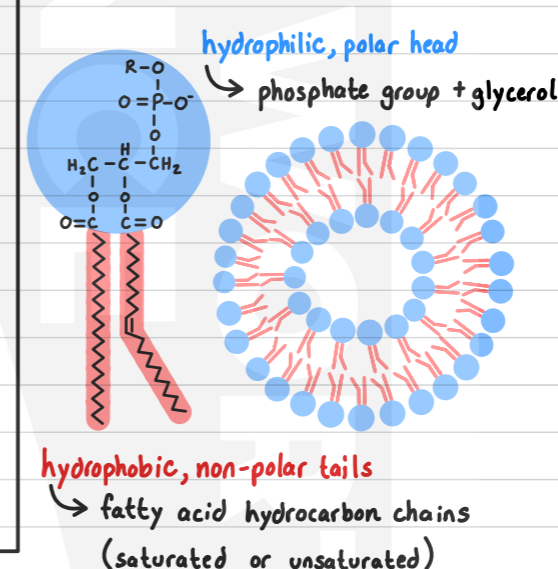
▶ help control membrane fluidity: ensuring they are not too fluid or too stiff

→ expanded in HL

How to draw:



Phospholipids are amphipathic and spontaneously form bilayers in solutions lipids B1.1

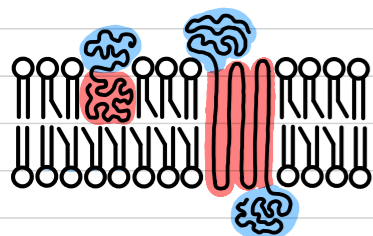


↳ partially permeable barrier between aqueous solutions i.e. inside and outside the cell:

- ✓ hydrophobic molecules - high permeability ex: non-polar steroids (testosterone)
- ✓ very small non-polar molecules - high permeability ex: O₂, CO₂
- ✓ small, uncharged polar molecules - permeable ex: H₂O, ethanol, urea, glycerol
- ✗ large uncharged polar molecules } low permeability require transport proteins ex: glucose, sucrose
- ✗ charged molecules and ions } ex: amino acids, Na⁺, K⁺, Cl⁻, Ca²⁺, H⁺

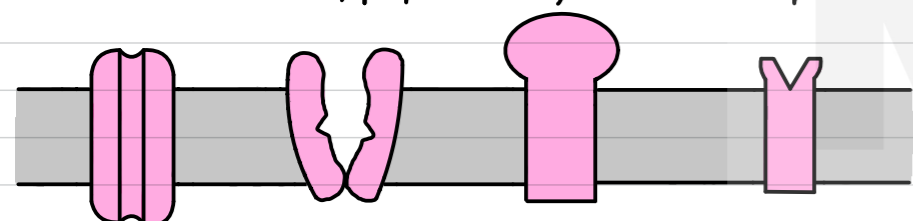
Integral proteins: proteins permanently embedded in the membrane

↳ monotopic (one side) ↳ transmembrane (both sides)



Integral membrane proteins are amphipathic; having hydrophilic regions and hydrophobic regions allowing them to integrate within the phospholipid bilayer

ex: channel carrier/pump enzyme receptor

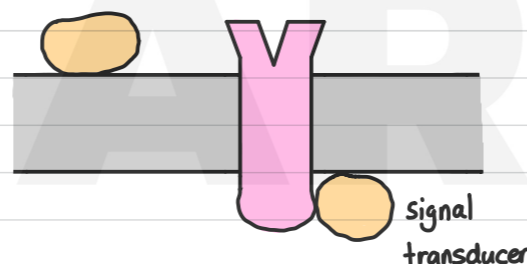


Peripheral proteins: proteins attached (often temporarily) to the surface of the membrane or on an integral protein



Peripheral proteins are hydrophilic allowing them to interact on the surface of the bilayer

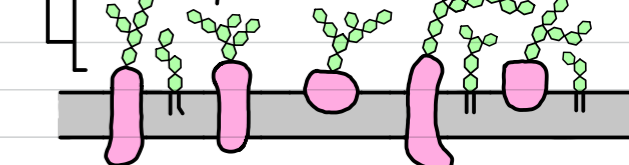
ex: electron carrier



Glycoprotein: polypeptide bound to a carbohydrate

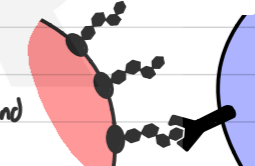
Glycolipid: lipid bound to a short carbohydrate chain

glycocalyx "sugar coat" facing the extracellular space of cells

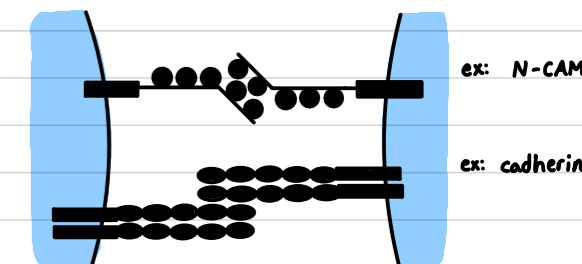


▶ **cell recognition** lipids B1.1
unique shape of glycoproteins and glycolipids act as antigen or surface markers, allowing cells to recognize self from non-self through binding

ex: erythrocytes have both glycoprotein and glycolipid antigens



▶ **cell adhesion** → expanded in HL
glycocalyxes of adjacent cells bind, holding cells and tissues together

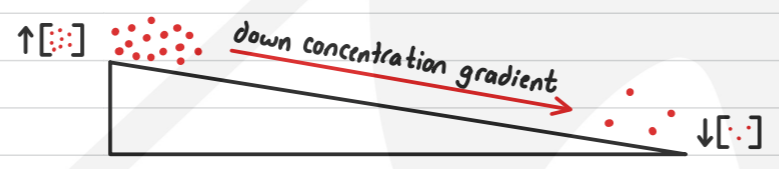


ex: N-CAM

ex: cadherin

Many of the processes of life (such as metabolism, homeostasis, nutrition, excretion) require transport of materials in and out of cells. This can occur both passively or actively.

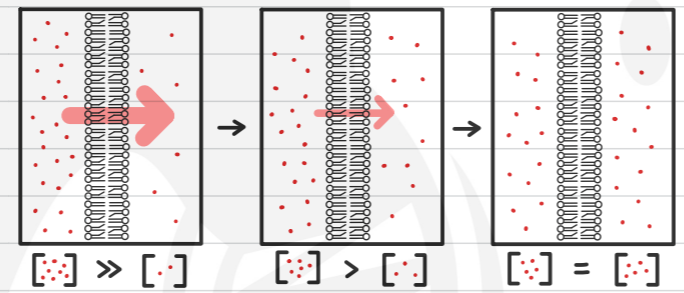
Passive transport: net movement of particles from an area of high concentration to low concentration without the use of ATP



- particles are constantly in random motion (due to kinetic energy) and move independent of each other but as there are more particles in areas of high concentration that can randomly move to areas of low concentration than the other way around, a net movement from high to low concentration will occur passively.
- rate can be increased by increasing concentration gradient and membrane surface area and decreasing distance needed to move gas or liquid

Simple diffusion: passive net movement of particles from an area of high concentration to low concentration in fluids

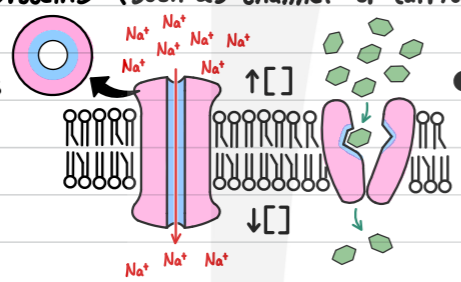
- small / non-polar** molecules can diffuse easily across membranes
 - able to pass through hydrophobic core easily
 - able to pass in between phospholipid molecules
 - ex: O_2 , CO_2 , steroids (testosterone and oestradiol)



* not selective: only depends on size and water-affinity

Facilitated diffusion: passive net movement of particles from an area of high concentration to low concentration using membrane proteins (such as channel or carrier proteins)

Channel proteins: integral membrane proteins which have a hydrophilic pore allowing a passage for ions (ex: Na^+ , K^+ , Cl^- , Ca^{2+}) to cross the membrane's hydrophobic core easily



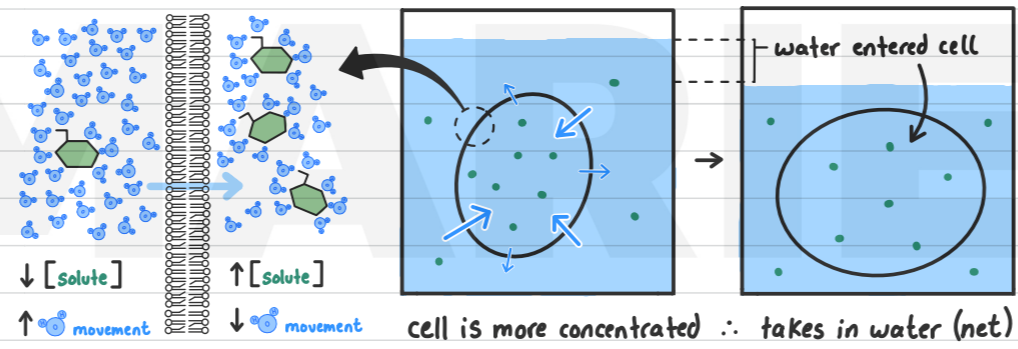
carrier proteins: integral membrane proteins which bind polar (ex: glucose) molecules and undergo conformational change to move them across the membrane

* channels/carriers are selective and only allow certain ions/molecules to cross ex: Na^+ channels only allow Na^+ to diffuse some can also be open or closed, allowing further control ex: voltage-gated ion channels

Osmosis: passive net movement of water from an area of low solute concentration to high solute concentration across a partially permeable membrane

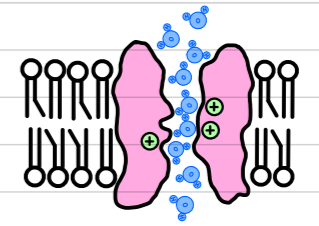
water potential D2.3

- membranes allow the passage of water but restrict the movement of larger or charged solutes, thus causing water to move more
- when water is interacting with and dissolving solutes its movement is restricted \blacktriangleright water in a dilute solution is more free and likely to move to a more concentrated solution
- equilibrium when overall solute concentration is equal on both sides



Aquaporins: channel proteins which selectively allow passage of water

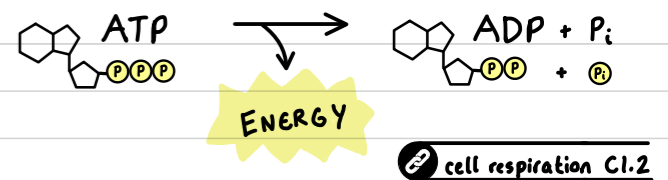
- greatly increases permeability to water and osmotic rate
- located in collecting ducts in kidneys and plant roots for water absorption



Aquaporin has a very narrow pore which is positively charged only allowing water through (excluding H^+)

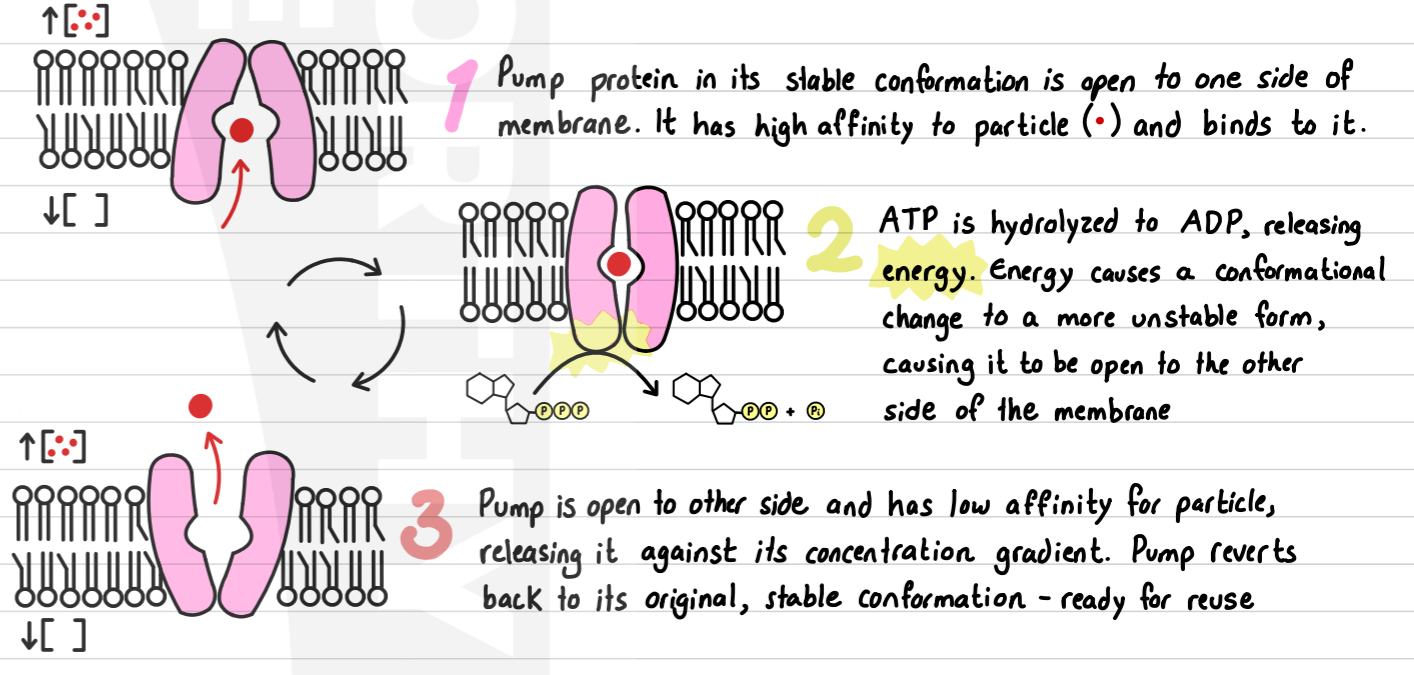
Active transport: movement of particles from an area of low concentration to high concentration using ATP

- particles in an area of low concentration are less likely to move to an area of high concentration than the other way around, thus for this to occur reliably an external energy input is required
- ATP is the cell's 'energy currency' storing potential energy from cellular respiration. When hydrolyzed it releases this energy to power metabolic processes

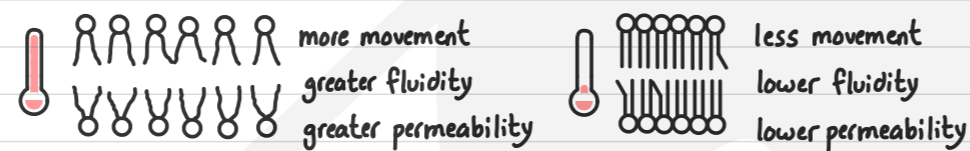


Pump proteins: transmembrane proteins which use chemical energy - ATP in order to transport particles across membranes against their concentration gradient ex: sodium-potassium pump

* Pump proteins allow selective permeability: only transport specific ions or molecules in one direction

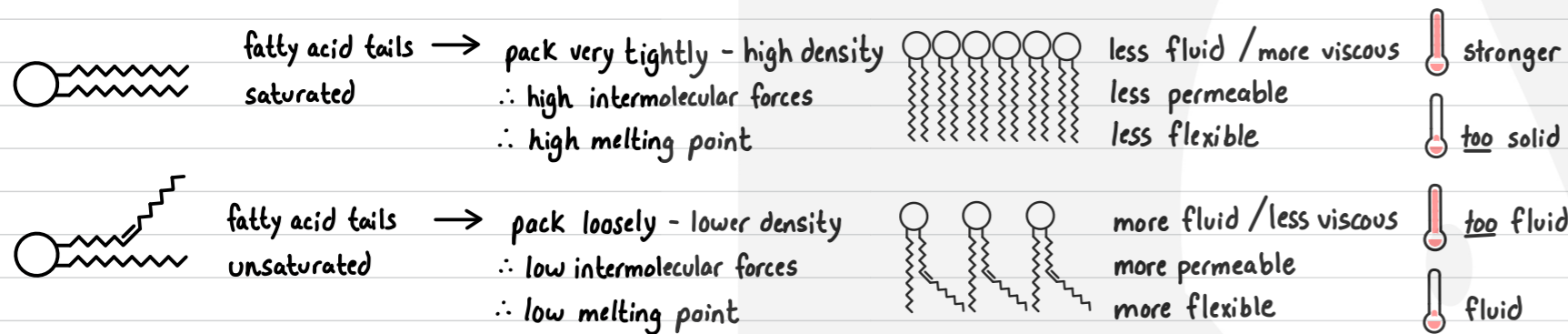


Temperature impacts membrane fluidity i.e. the degree of random movement of the components, namely phospholipids which can move laterally and rotate



Impact of phospholipid fatty acid composition on membrane fluidity

the fatty acid composition of phospholipids can be saturated (no double bonds) or unsaturated (≥ 1 double bond) **lipids BI.1**



General trend: the relative percentage composition of saturated and unsaturated fats differ depending on surrounding temperature. Higher percentage of saturated fatty acids leads to a stronger, too solid membrane. Higher percentage of unsaturated fatty acids leads to a too fluid membrane.

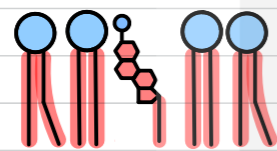
Adaptation: Fish living in Antarctic waters (ex: *Chionodraco hamatus*) have membranes rich in unsaturated fatty acids.

The temperate freshwater fish *Acipenser fulvescens* increases its membrane unsaturated content when lake temperatures decrease.

The caribou *Rangifer tarandus* has different membrane fatty acid composition in different tissues, as a trend: the further away tissues are from the body core, the more unsaturated fatty acids (hooves > upper leg > body).

Impact of cholesterol on membrane fluidity

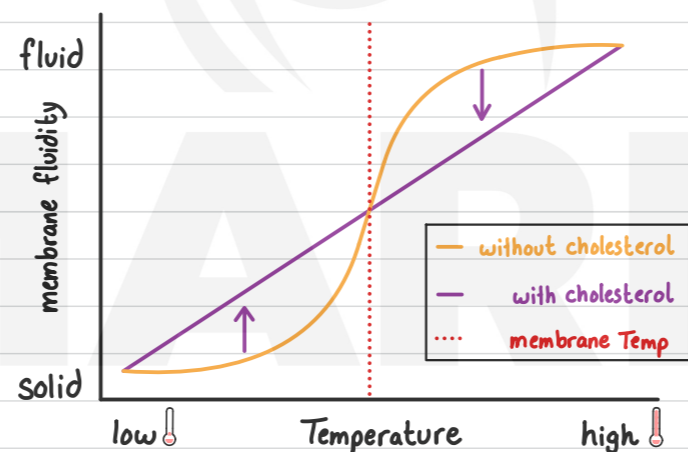
cholesterol embeds itself in the plasma membrane as its amphipathic - OH 'head' is polar, body is non-polar. \times cholesterol is present in animal but not plant membranes.



cholesterol acts as a membrane fluidity modulator:

Cholesterol decreases fluidity by constraining phospholipid movement - stabilizing membrane.

Cholesterol increases fluidity by disrupting phospholipid tight packing - preventing stiffening.

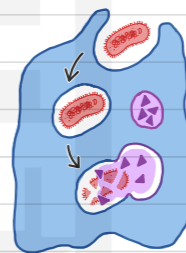


The fluidity of the membrane allows for phospholipid bilayers to change shape and fuse, and thus the formation (endocytosis) and fusion (exocytosis) of vesicles

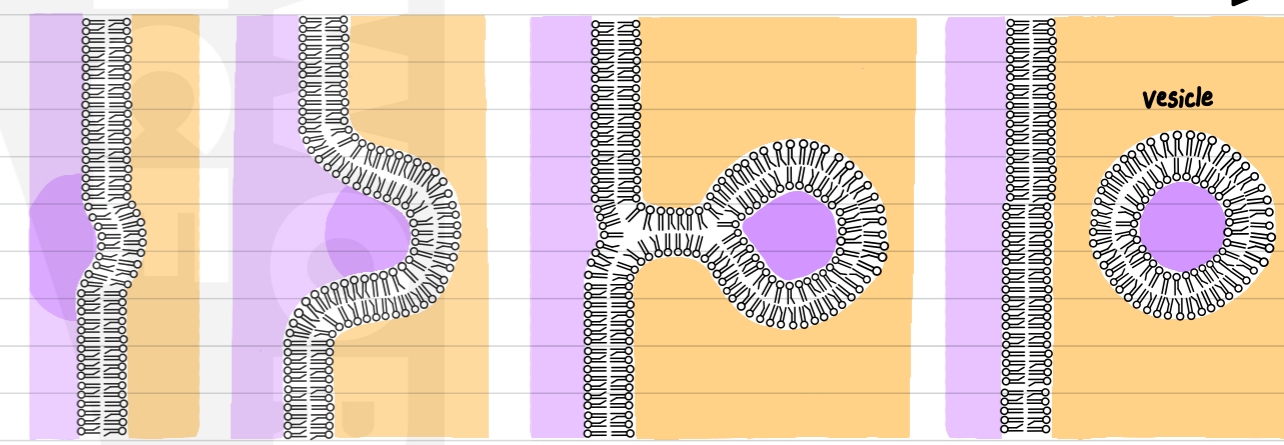
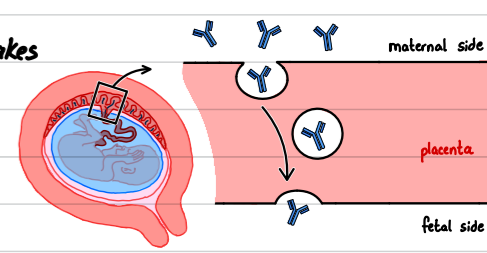
Endocytosis: the formation of a vesicle from the invagination and pinching off of a piece of the plasma membrane - bringing extracellular content within the cell. Process requires ATP. Fluids (pinocytosis) and solids (phagocytosis).

ex:

Phagocytic white blood cells and paramecia engulf and destroy pathogens / food particles using phagocytosis.



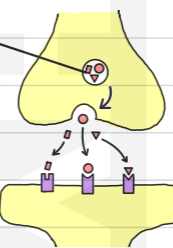
Developing fetus takes in antibodies into its bloodstream from the mother via the placenta.



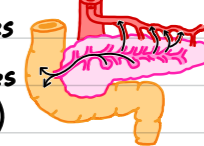
Exocytosis: the fusion of a vesicle with the plasma membrane - discharging vesicle contents into the extracellular space (i.e. outside the cell). Process requires ATP.

ex:

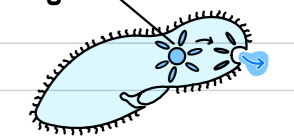
Neurotransmitters (such as Acetylcholine) are released by neurons during synaptic transmission in order to propagate nerve impulses.



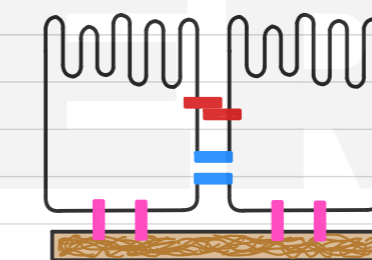
Pancreas secretes digestive enzymes (such as lipase) into the duodenum and hormones (such as insulin) into the blood stream for signaling.



Paramecium osmoregulates by loading and expelling excess water using contractile vacuoles.



cell-adhesion molecules (CAMs): cell-surface proteins/glycoproteins which link cells with other cells forming junctions - providing structure and tissue formation.



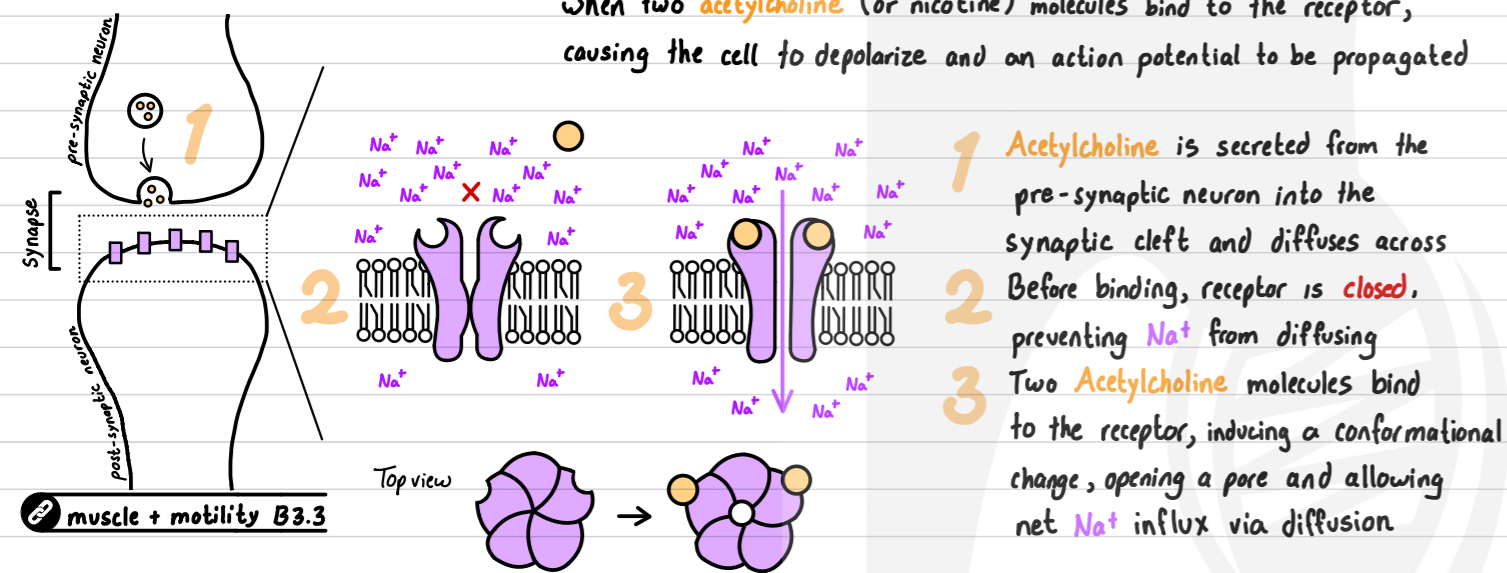
- seal cells together, creating a barrier
- act as a bridge, allowing communication and material exchange
- connect cells to extracellular matrix, providing anchorage

Channel proteins allow for facilitated diffusion, transporting specific materials that otherwise would only diffuse slowly or not at all across a phospholipid bilayer (such as ions). While they do not control direction of flow (always a net flow high to low concentration) they can be opened or closed reversibly to control transport

Neurotransmitter-gated ion channel: Transmembrane protein channels which allow the diffusion of a specific ion 'Gated' as they open or close in response to binding of a neurotransmitter

✗ neurotransmitters are signalling molecules which are secreted by a neuron at synapses to cause an effect
ex: Acetylcholine, Glutamate, GABA, Dopamine, Serotonin, Epinephrine

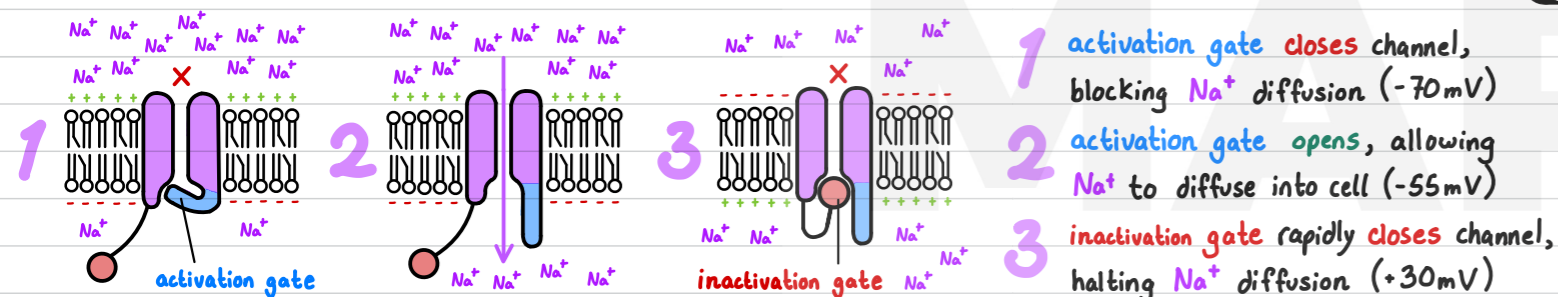
↳ **Nicotinic acetylcholine receptors**: gated ion channel allowing diffusion of sodium (Na^+) into the cell when two acetylcholine (or nicotine) molecules bind to the receptor, causing the cell to depolarize and an action potential to be propagated



Voltage-gated ion channel: Transmembrane protein channels which allow the diffusion of a specific ion 'Gated' as they open or close in response to a specific membrane potential (voltage)

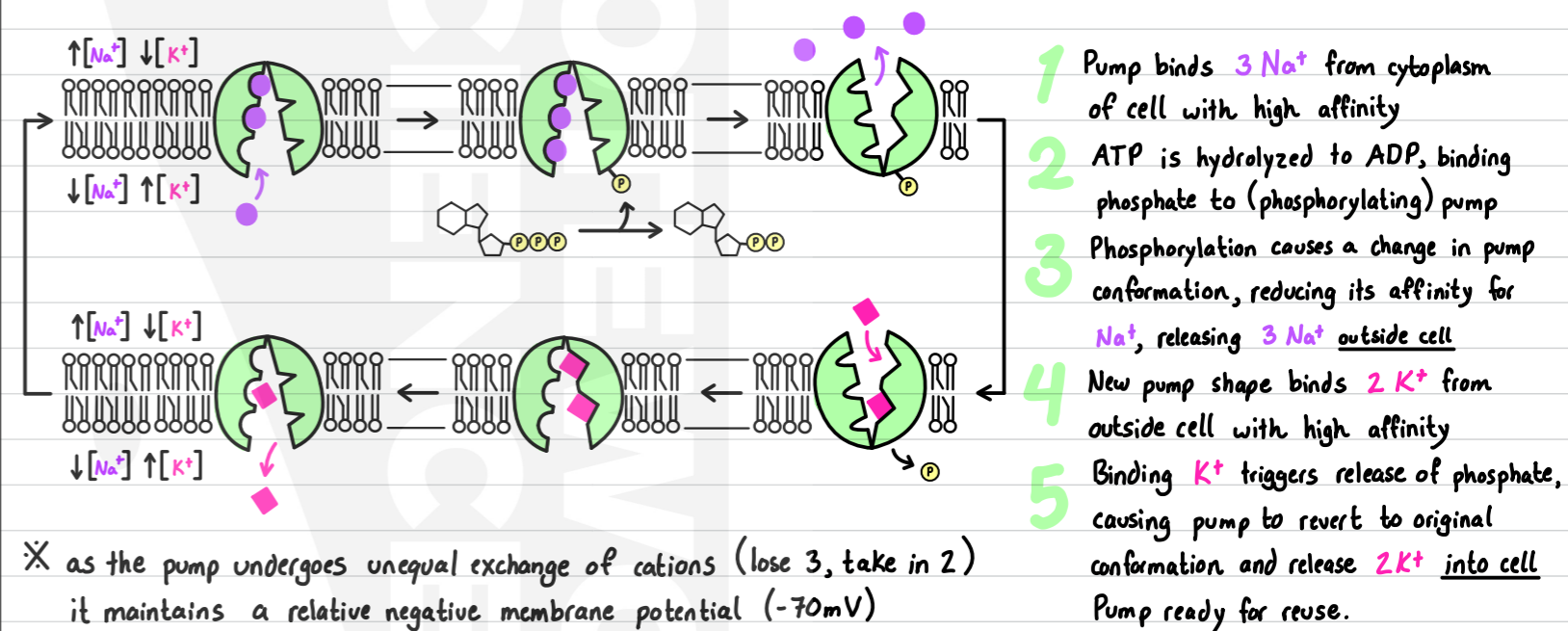
✗ potential difference / voltage is the amount of electric potential energy per unit charge between two points (V or $\text{J}\cdot\text{C}^{-1}$)
membrane potential is the difference in electric potential (V) between the inside and outside of the cell
↳ inside of the cell $\sim -70\text{mV}$ compared to the outside \rightarrow generated by sodium and potassium leak channels

↳ **voltage-gated sodium channel**: gated ion channel allowing diffusion of sodium (Na^+) into the cell when there is an increase in membrane potential (-70mV to -55mV) causing the cell to depolarize (negative to positive)



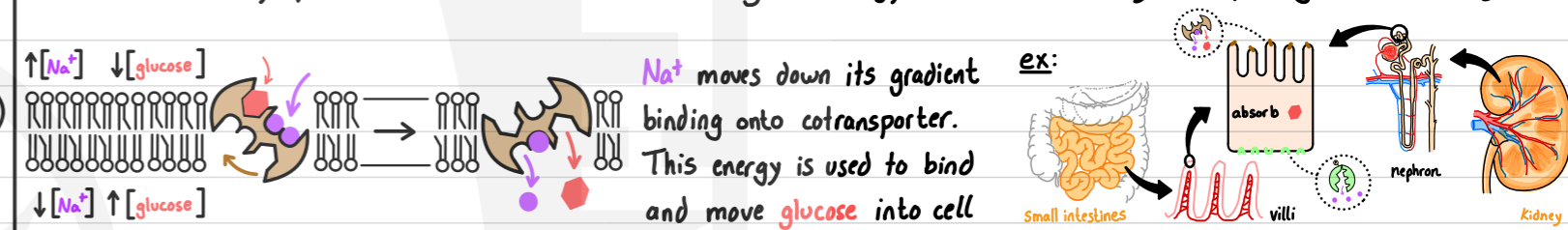
Exchange transporters (antiporter): Transmembrane protein which transports different substances in opposite directions across the membrane against their respective gradients, thus 'exchanging' them

↳ **Sodium-Potassium pump** (Na^+/K^+ -ATPase): exchange transporter moving 3Na^+ and 2K^+ against their respective concentration gradients across the membrane using ATP

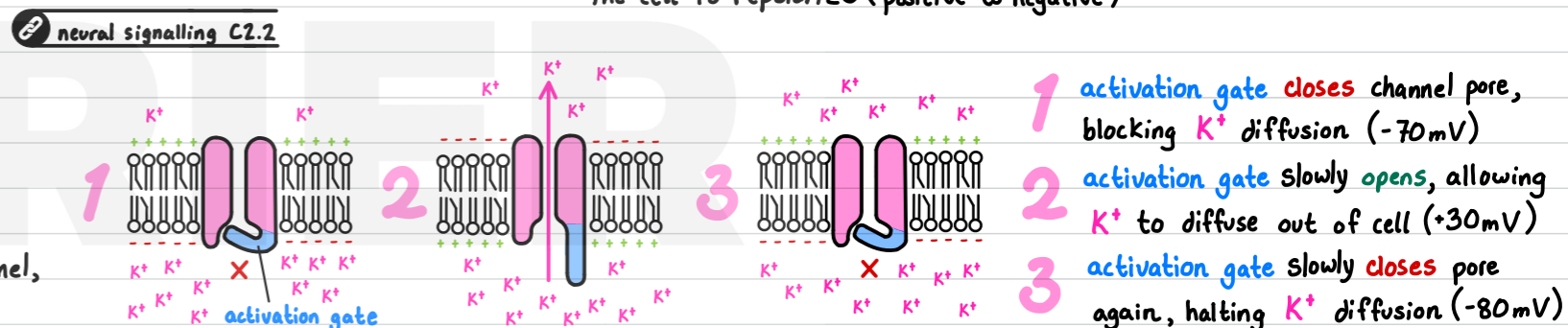


Indirect active transport: uses the energy produced by the movement of one substance down its concentration gradient to transport another against its concentration gradient. Direct ATP use not required

↳ **Sodium-glucose cotransporter** (symporter): cotransporter protein which transports glucose against its concentration gradient into the cell using the energy from simultaneously transporting Na^+ down its gradient



↳ **voltage-gated potassium channel**: gated ion channel allowing diffusion of potassium (K^+) out of the cell when the membrane potential has flipped (-70mV to 30mV) causing the cell to repolarize (positive to negative)

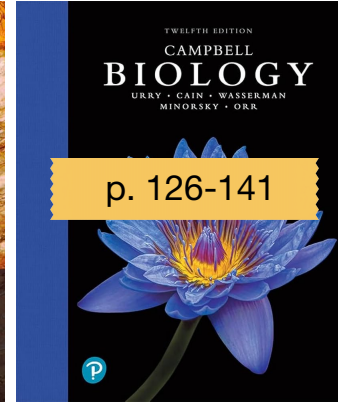
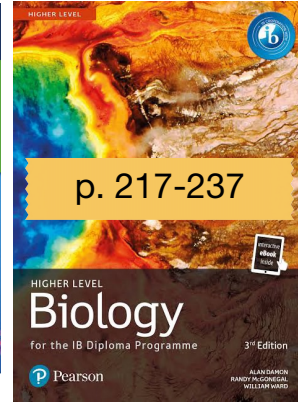
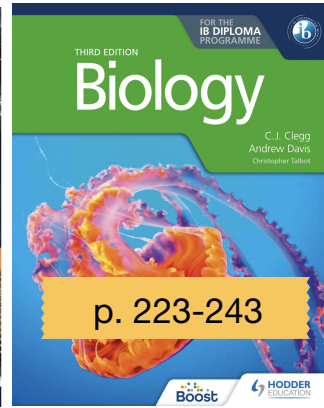
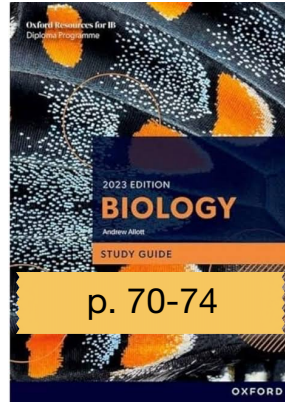
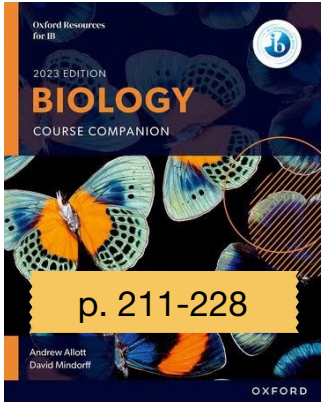


Resource Links

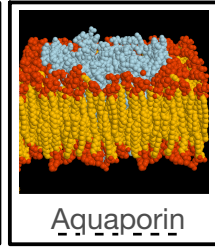
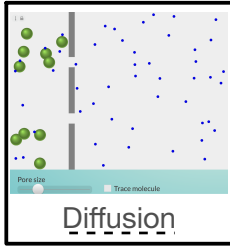
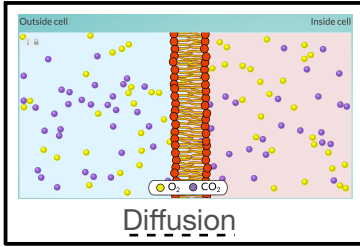
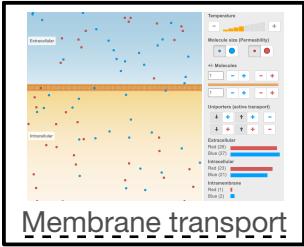
each resource is hyperlinked



Textbooks



Simulators / Interactives



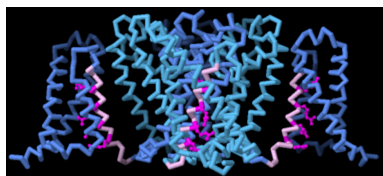
Articles

Benga G. (2012). The first discovered water channel protein, later called aquaporin 1: molecular characteristics, functions and medical implications. *Molecular aspects of medicine*, 33(5-6), 518–534. <https://doi.org/10.1016/j.mam.2012.06.001>

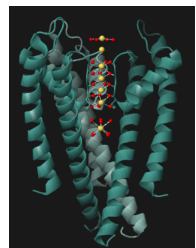
Ernst, R., Ejsing, C. S., & Antonny, B. (2016). Homeoviscous Adaptation and the Regulation of Membrane Lipids. *Journal of molecular biology*, 428(24 Pt A), 4776–4791. <https://doi.org/10.1016/j.jmb.2016.08.013>

Janiszewska, M., Primi, M. C., & Izard, T. (2020). Cell adhesion in cancer: Beyond the migration of single cells. *The Journal of biological chemistry*, 295(8), 2495–2505. <https://doi.org/10.1074/jbc.REV119.007759>

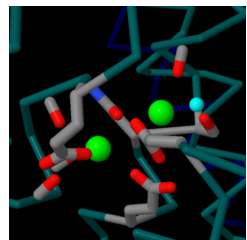
3D models



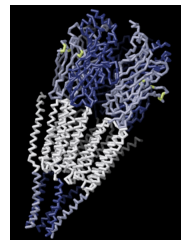
Voltage-gated Sodium channel



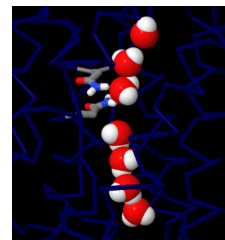
Potassium channel



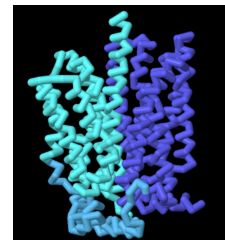
Sodium-Potassium Pump



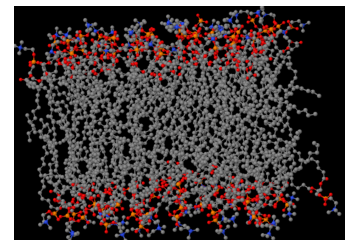
Acetylcholine Receptor



Aquaporin



Glucose transporters



Phospholipid bilayer