Cellular transport

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2565

Concentration – the amount of solute in a solution.

Solute – the dissolved substance in a solution.

Solution – a mixture in which two or more substances are mixed evenly.

Concentration gradient - the gradual difference in the concentration of solutes in a solution between two regions.

- All cells have a **cell membrane** made of proteins and lipids
- Some cells have **cell membranes *and* cell walls**, i.e., plants, fungi, and bacteria

- Cell membranes and cell walls are **porous** allowing water, carbon dioxide, oxygen and nutrients to pass through easily

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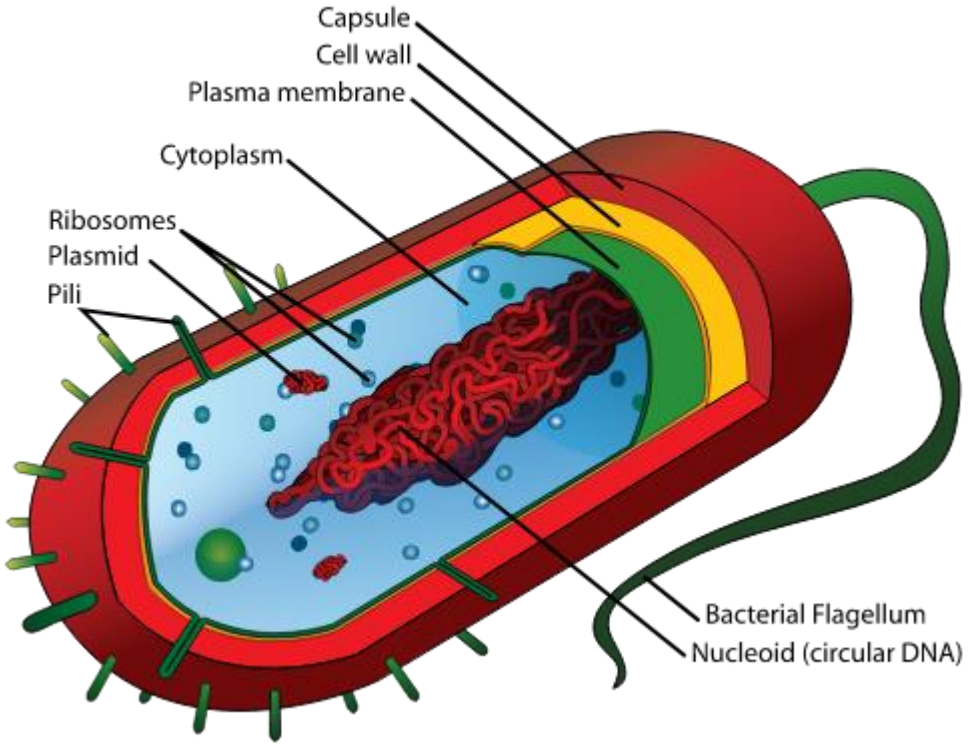
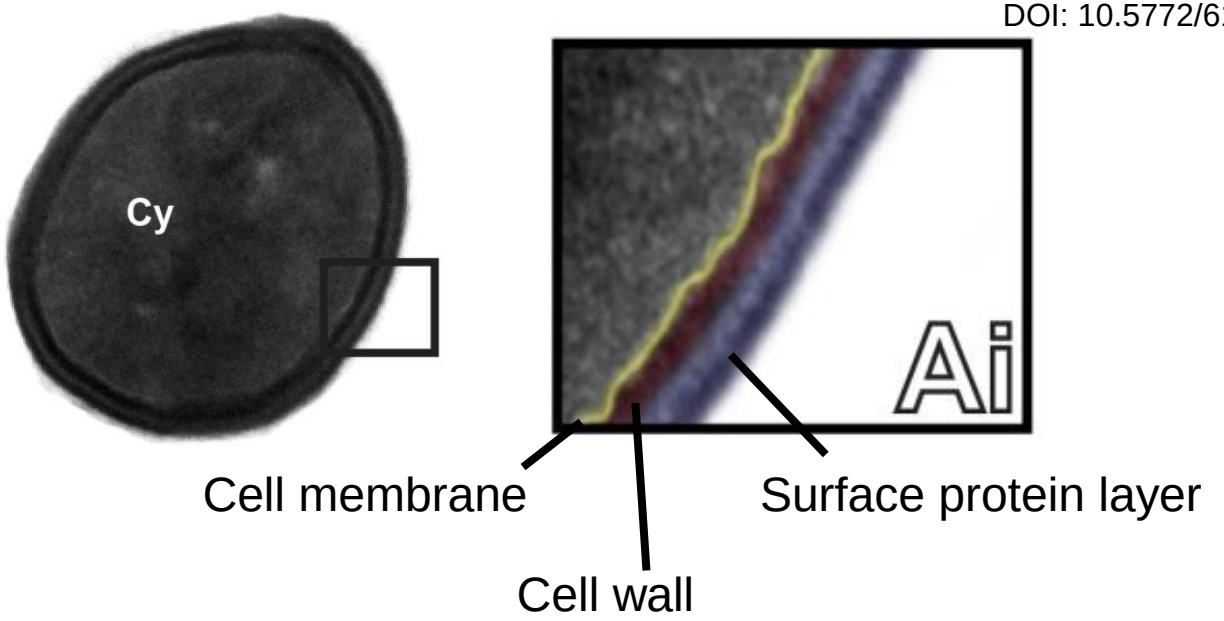
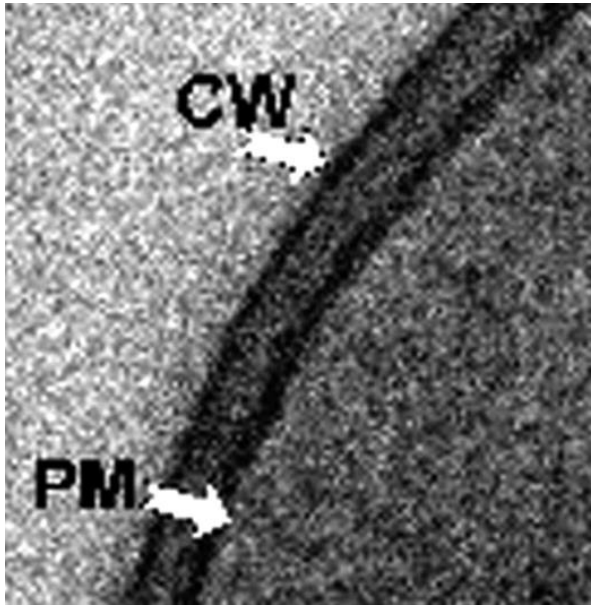
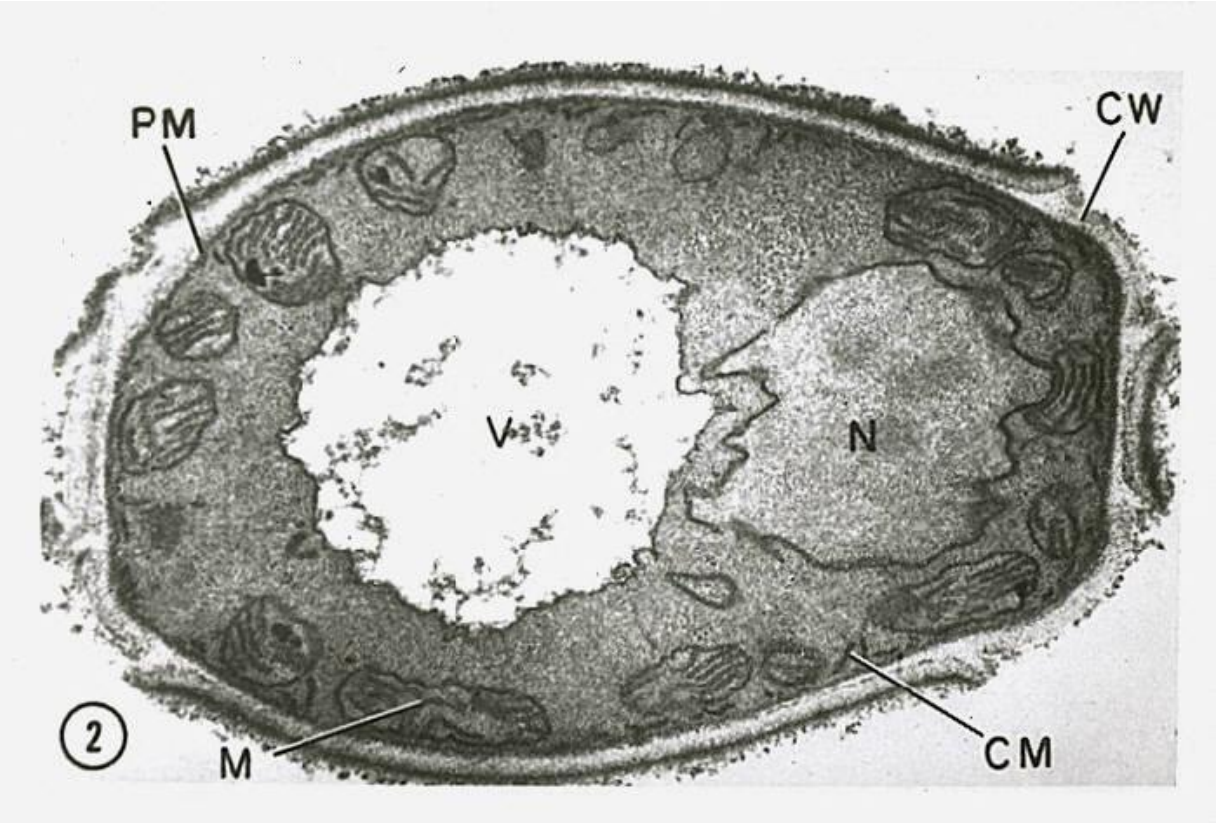






https://doi.org/10.1128/JB.186.11.3286-3295.2004

Prokaryotes



Yeast *Candida* sp.

Eukaryotes

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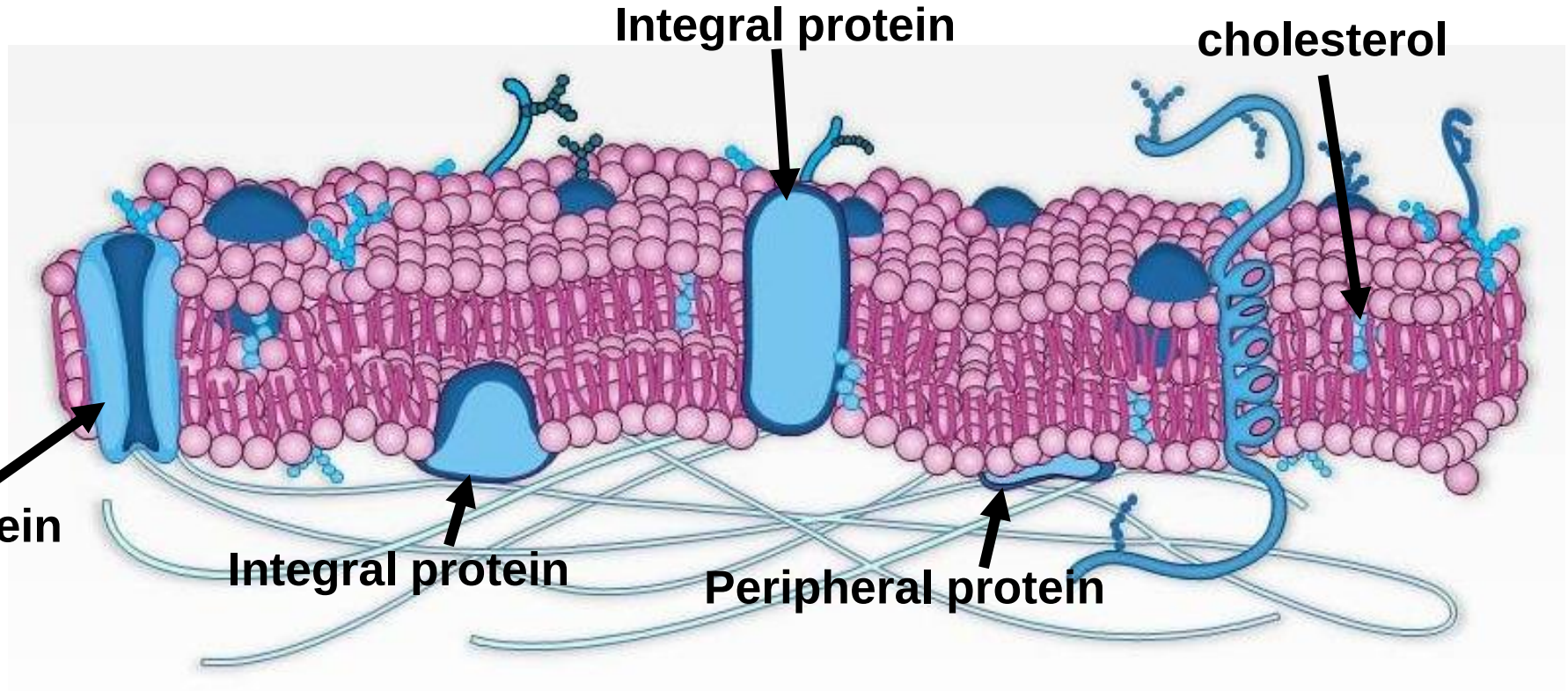
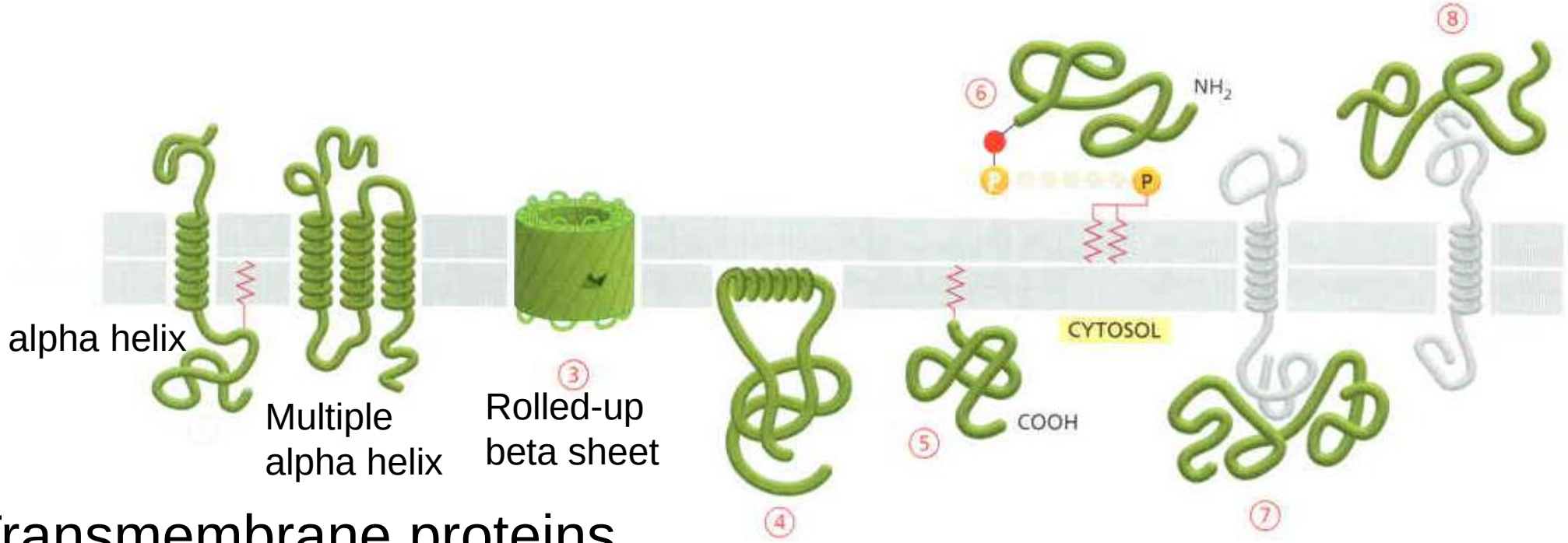
Cell membrane: phospholipid bilayer



Cell membrane: phospholipid bilayer

Various proteins associated with the lipid bilayer

Attached via covalent bond to another lipid



- Hydrophobic interior -- the lipid bilayer of cell membranes prevents the passage of most polar molecules.

- Allows the cell to maintain concentrations of solutes in its cytosol that differ from those in the extracellular fluid.

- Cells must transfer specific water-soluble molecules and ions across their membranes in order to ingest essential nutrients, excrete metabolic waste products, and regulate intracellular ion concentrations.

- Cells use specialized transmembrane proteins to transport inorganic ions and small water-soluble organic molecules across the lipid bilayer.

- Cells can also transfer macromolecules and even large particles across their membranes, but the mechanisms involved in most of these cases differ from those used for transferring small molecules.

- The importance of membrane transport is reflected in the large number of genes in all organisms that code for transport proteins (ca.15-30% of the membrane proteins in all cells).

- Some cells devote up to 60% of their total metabolic energy consumption to membrane transport processes.

- Cell membrane separates the components of a cell from its environment—surrounds the cell
- “Gatekeeper” of the cell—regulates the flow of materials into and out of cell—selectively permeable
- Cell membrane helps cells maintain homeostasis—stable internal balance

Why is cell transport important?

Homeostasis - maintaining a steady state
Metabolism - chemical reactions that convert “food” into energy

Helps cells achieve equilibrium - when concentrations of molecules of a substance are the same everywhere

Why is cell transport important?

Component	Intracellular concentration	Extracellular concentration
Na^+	5-15	145
K^+	140	5
Mg^{2+}	0.5	1-2
Ca^{2+}	10-4	1-2
Cl^-	5-15	110

- O_2 and CO_2 and **non-polar solutes** such as urea can diffuse into and out of cells **across the lipid of the plasma membrane.**

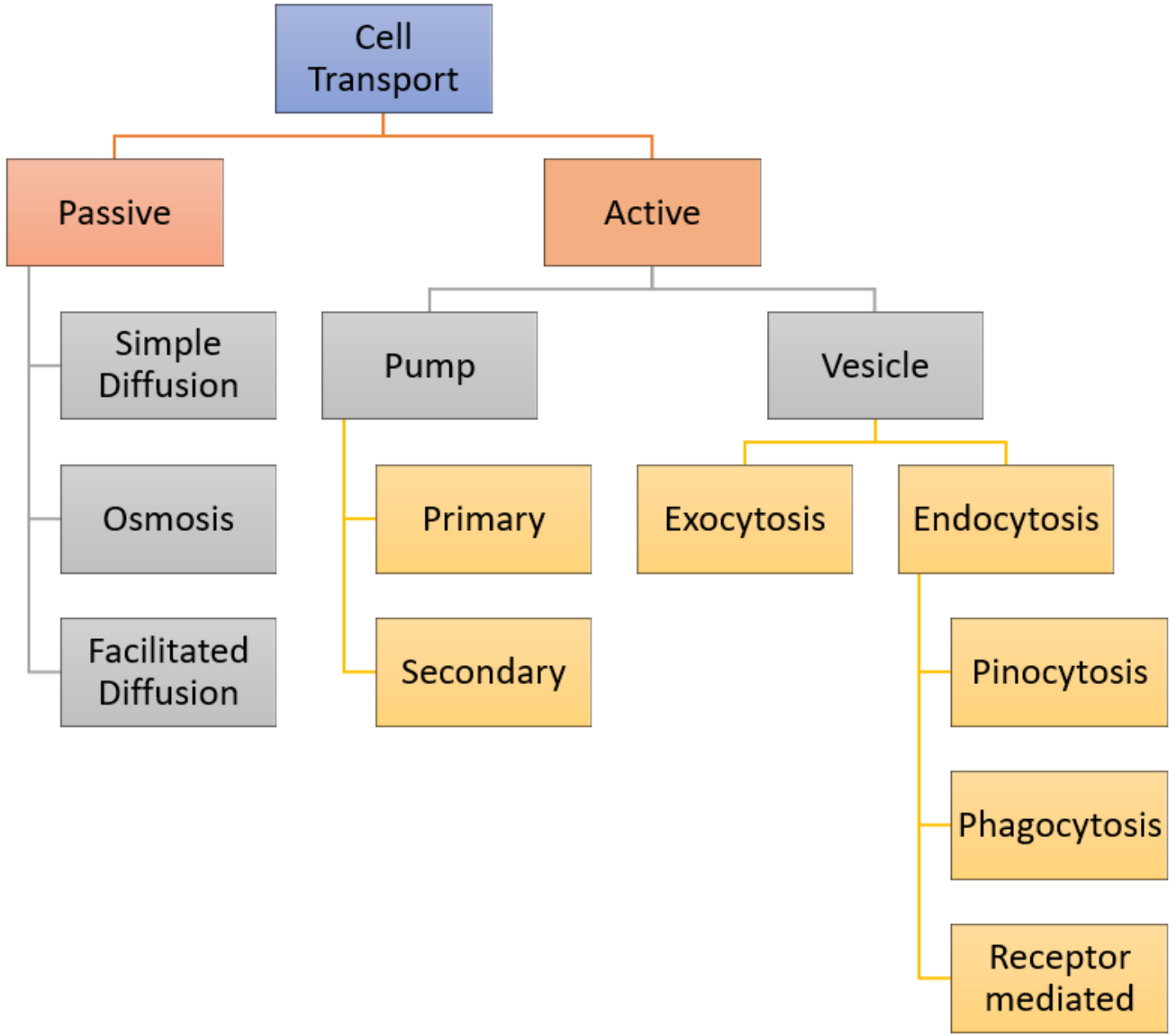
- **Water and ions** can only diffuse in and out of cells through a **channel or pore** (and only then if the channel is open).

- Ion channels are present in all plasma membranes, but they will be open or closed depending on the needs and the function of the cell.

Types of cellular transport

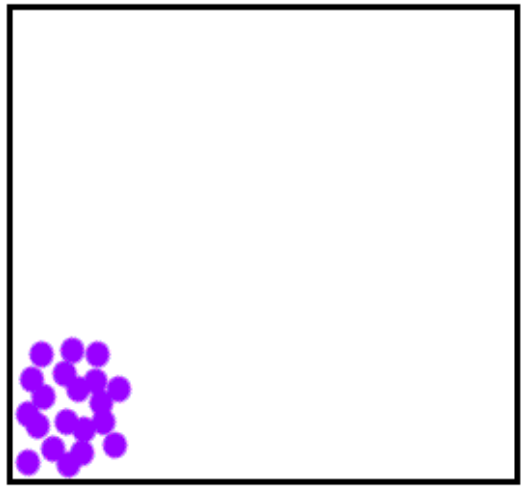
- **Passive** Transport: cell **does <u>not</u> use** energy
  - Diffusion
  - Facilitated diffusion
  - Osmosis
- **Active** Transport: cell **does use** energy
  - Protein pumps
  - Endocytosis
  - Exocytosis

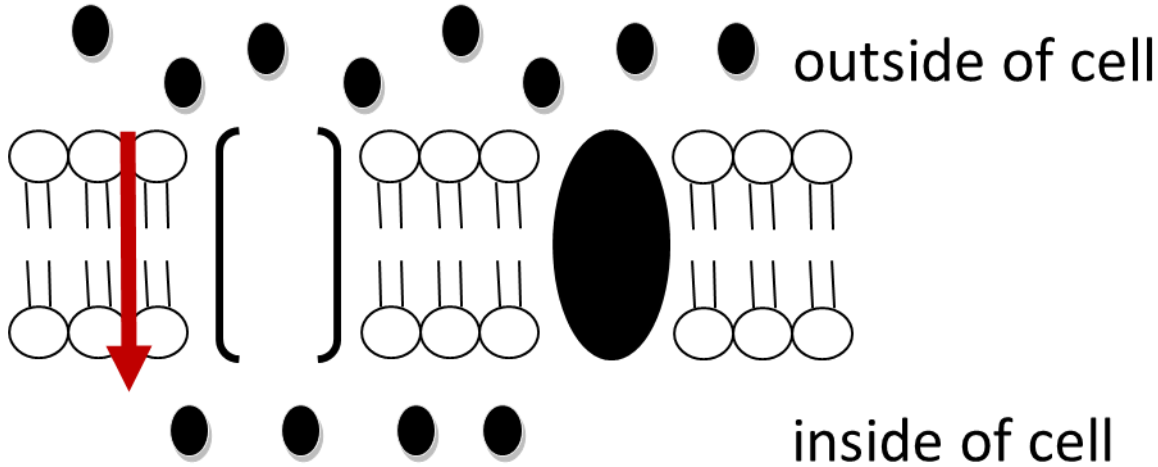
Types of cellular transport



Passive Transport
Diffusion

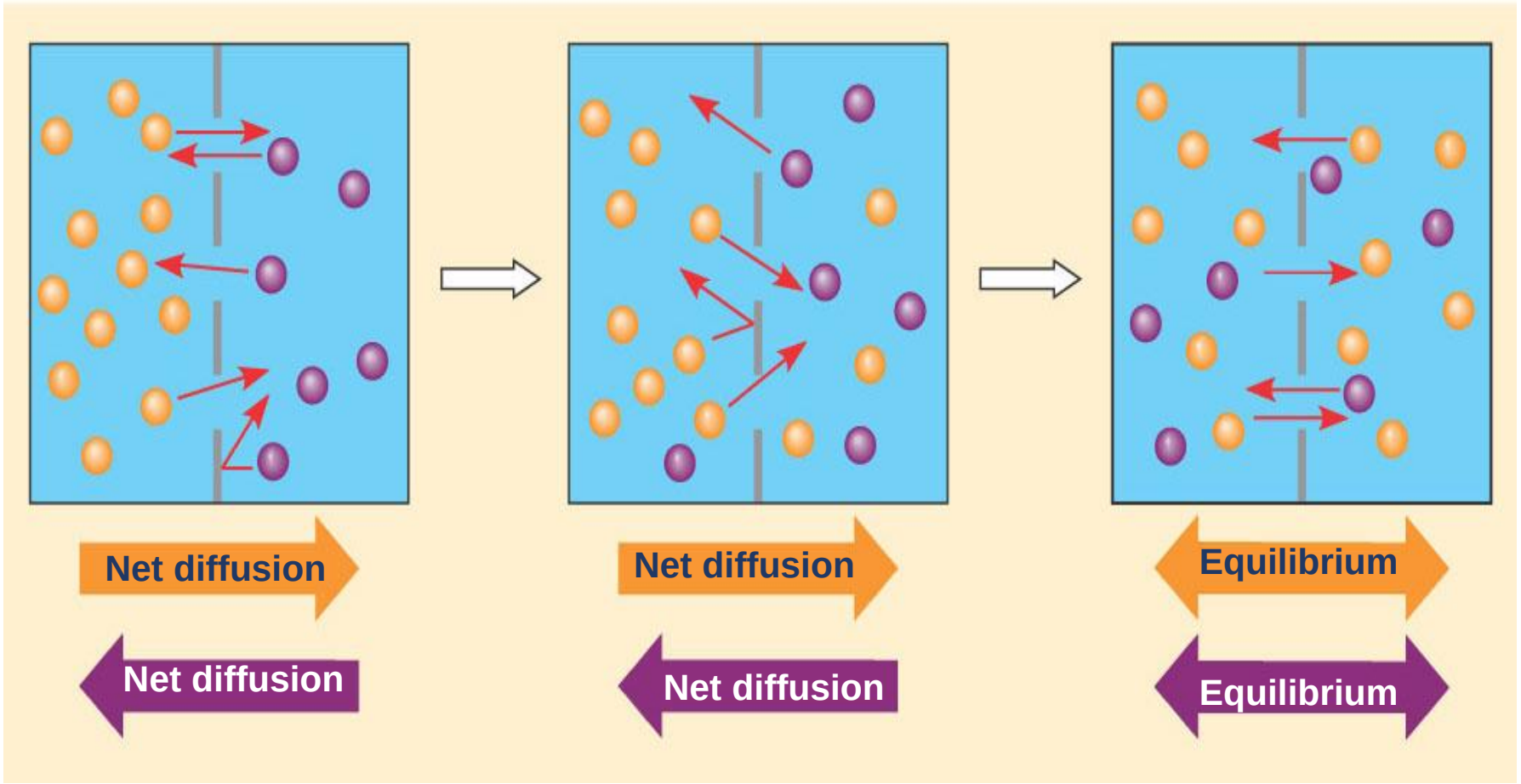
Movement of **particles** from an area of **greater** concentration to an area of **lesser** concentration until *equilibrium is reached*.





Passive Transport
Diffusion

- The molecules (in gas, liquid, or solid) are in constant motion due to their kinetic energy.
- The molecules are in constant movement and collide with each other.
    - These collisions cause the molecules to move in random directions.
- Over time, more molecules will be *propelled into the less concentrated area*.
    - *Net movement* of molecules is always from more *tightly packed areas to less tightly packed areas*.

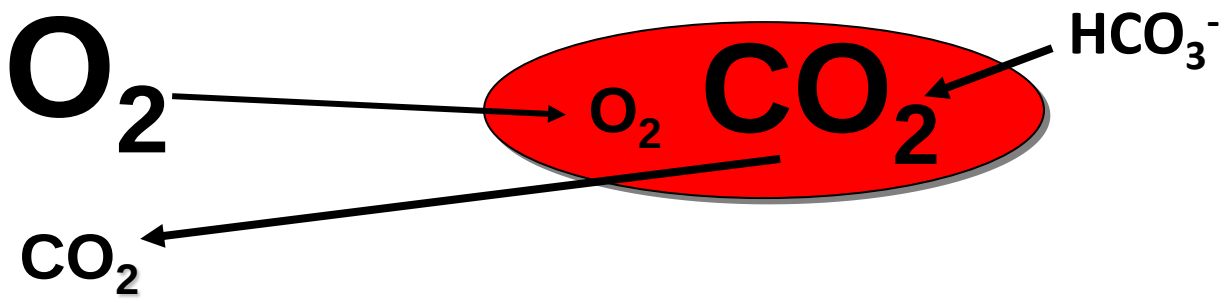

Net diffusion
Net diffusion
Net diffusion
Net diffusion
Equilibrium
Equilibrium

Passive Transport
Diffusion

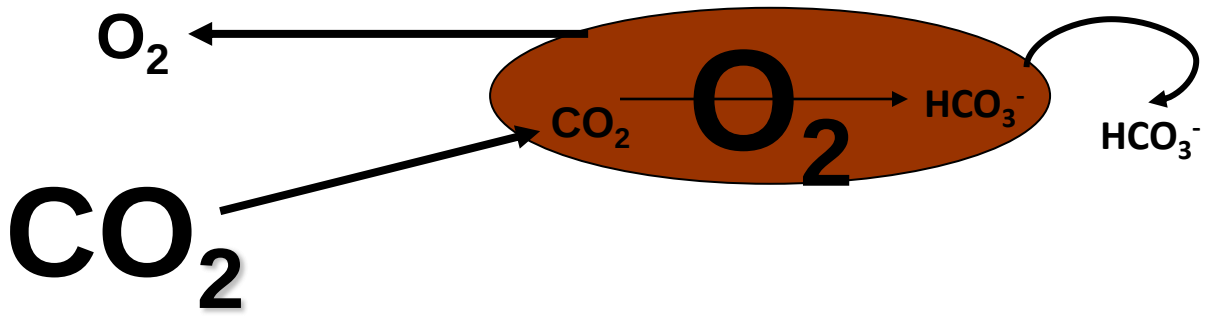
- Odors diffuse through the air
- Salt diffuses through water
- Nutrients diffuse from the blood to the body tissues

Simple diffusion

Lungs Oxygen crossing red cell membrane high -> low



Tissues

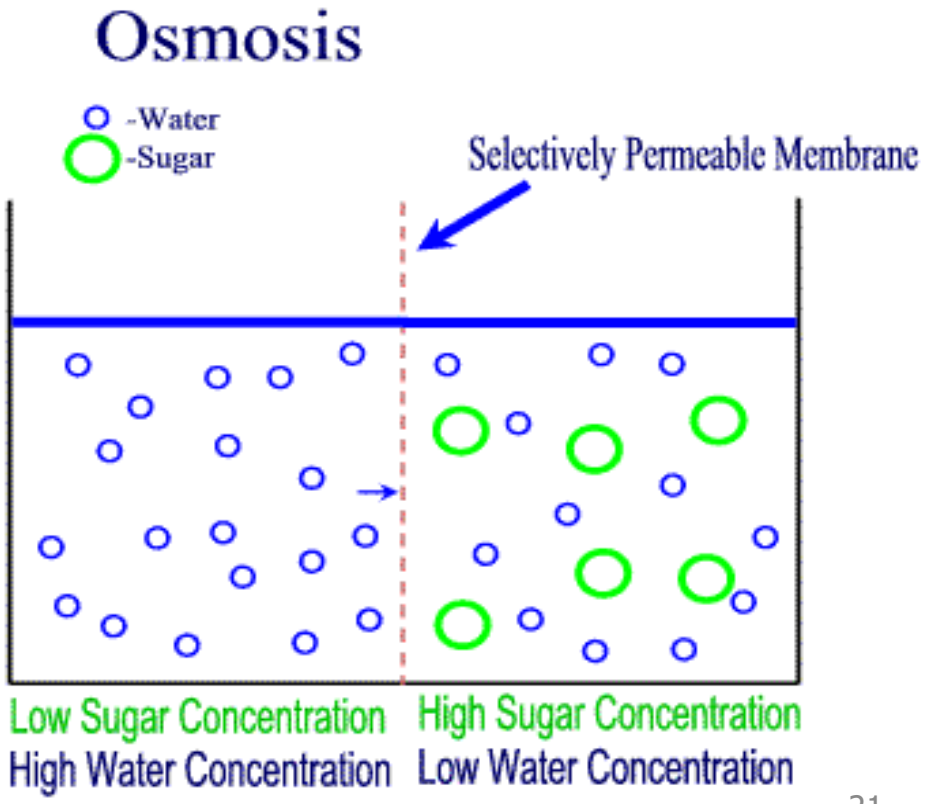


Passive Transport
Osmosis

A specific type of diffusion

Osmosis is the diffusion of **water** through a *selectively permeable membrane* like the cell membrane

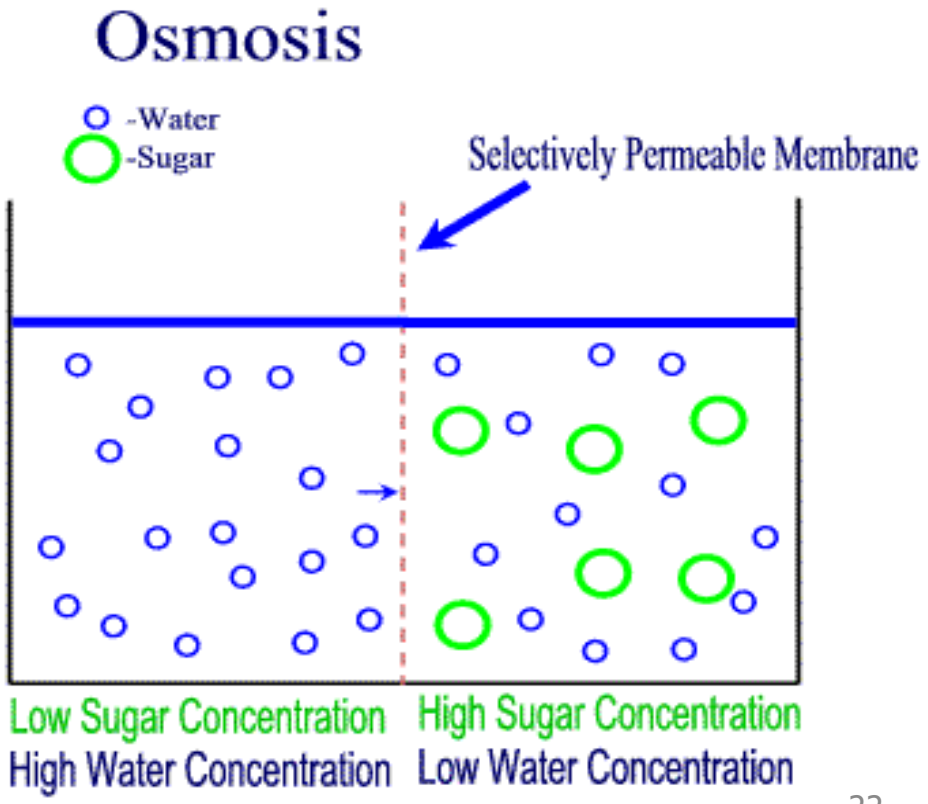
Water diffuses across a membrane from an area of high concentration to an area of low concentration.



Passive Transport
Osmosis

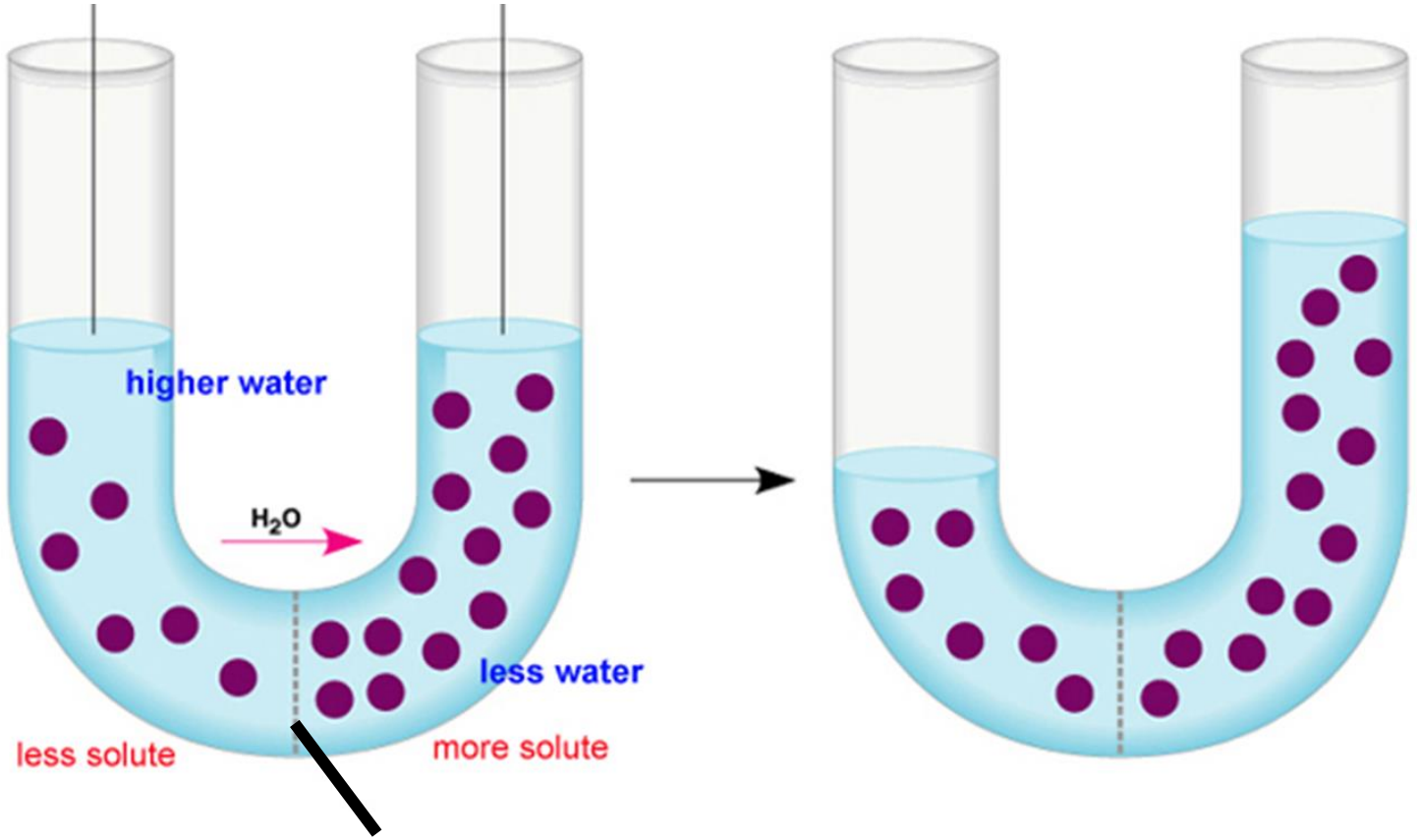
Semi-permeable membranes:
Thin layers of material that allow some things to pass through them but prevent other things from passing through.

Cell membranes
✓: small molecules, O_2, H_2O, CO_2
✗: large molecules, glucose, sucrose, proteins, starch



Hypotonic solution

Hypertonic solution



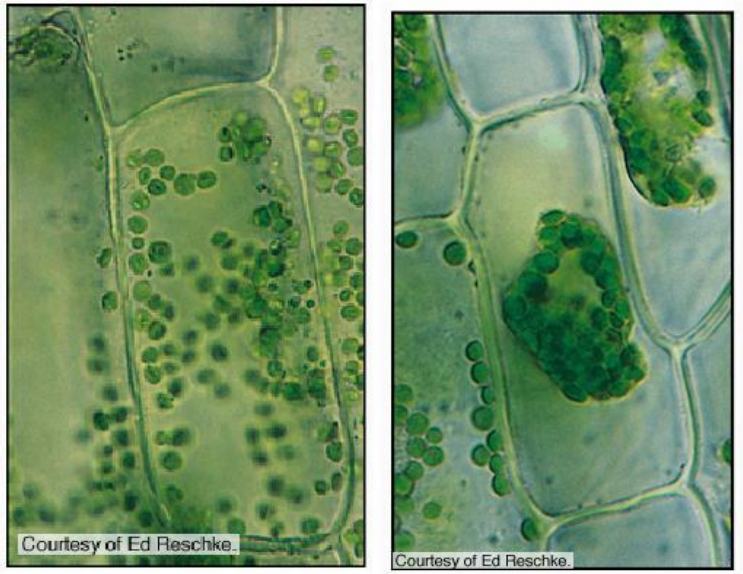
Semi-permeable membrane

Hypertonic solutions

contain a **high** concentration of solute *relative to another solution* (e.g., the cell's cytoplasm)

When a cell is placed in a hypertonic solution, the water diffuses out of the cell, causing the cell to shrivel.

Plasmolysis

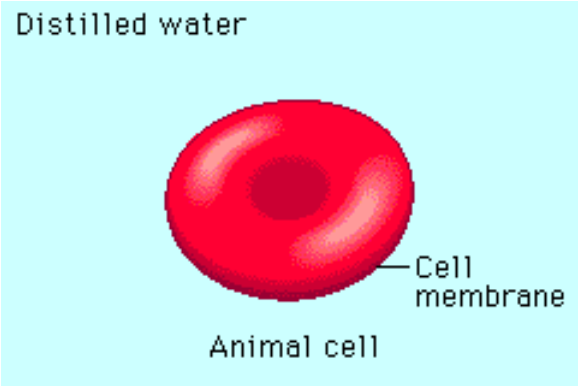


Hypotonic solutions

contain a **low** concentration of solute relative to another solution (e.g., the cell's cytoplasm).

When a cell is placed in a hypotonic solution, the water diffuses into the cell, causing the cell to swell and possibly explode.

Cytolysis

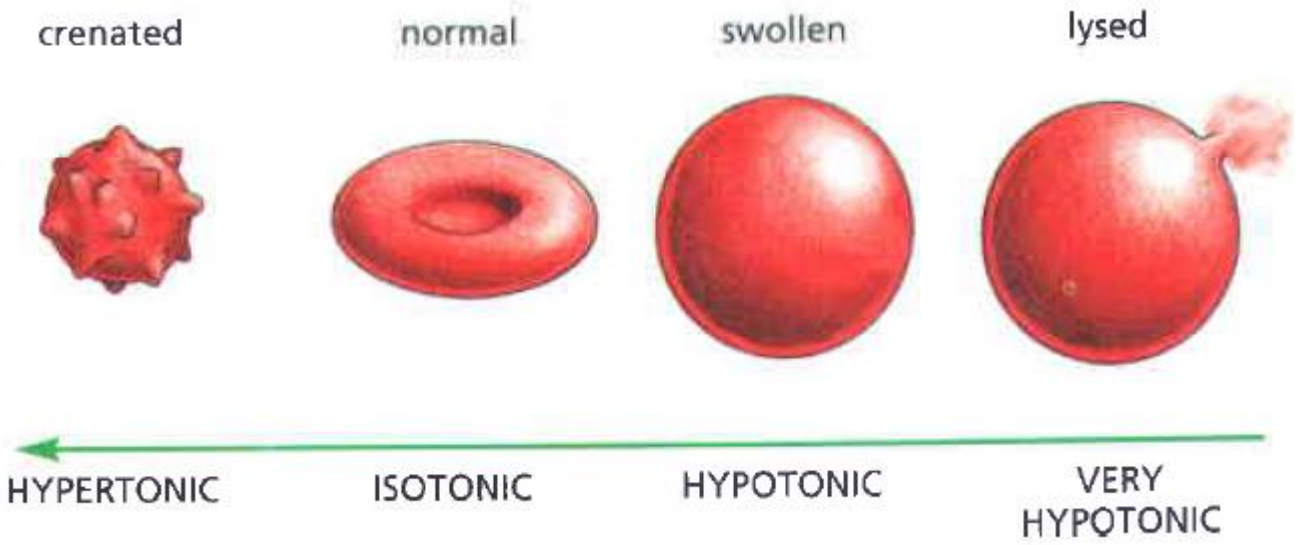


Plant cells are turgid and generally healthiest in a hypotonic environment, where the uptake of water is eventually balanced by the elastic wall pushing back on the cell.

Isotonic solutions

contain the **same** concentration of solute as another solution (e.g., the cell's cytoplasm).

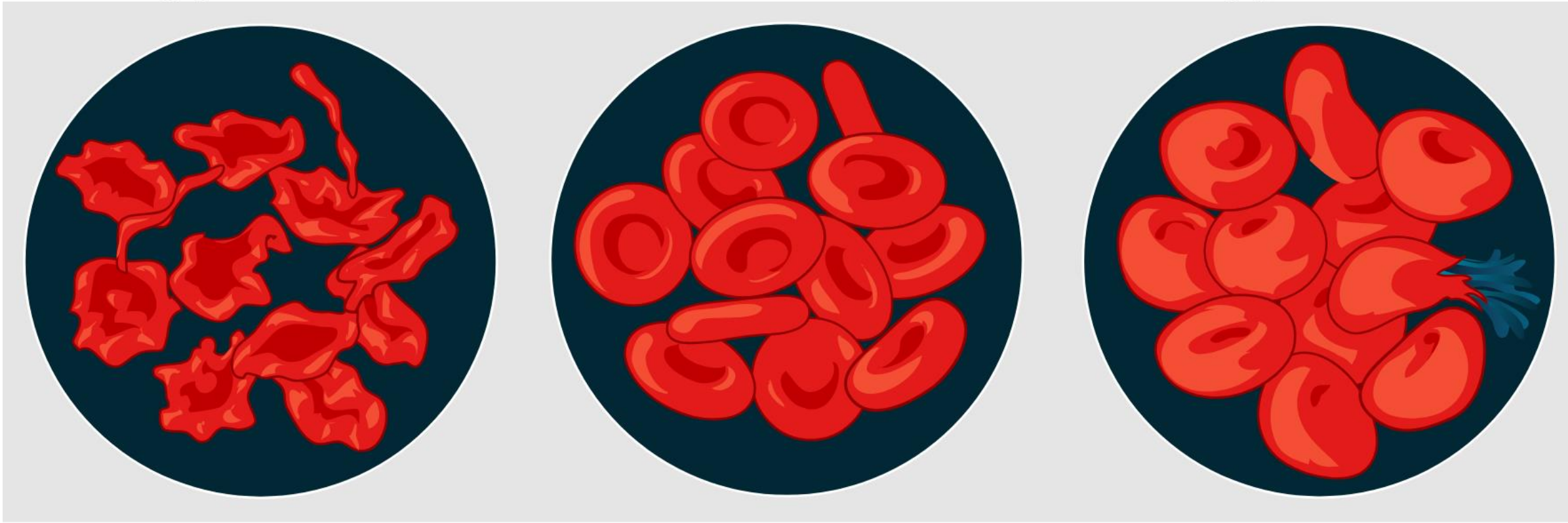
When a cell is placed in an isotonic solution, the water diffuses into and out of the cell at the same rate. The fluid that surrounds the body cells is isotonic.

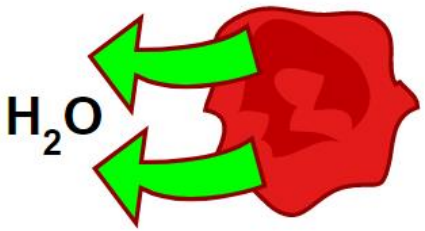


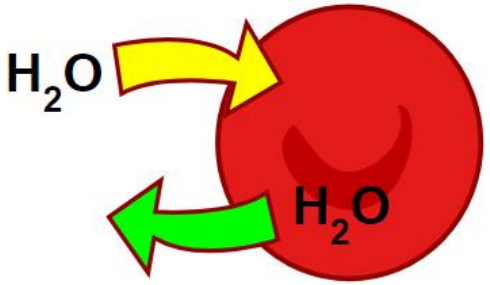
Hypertonic

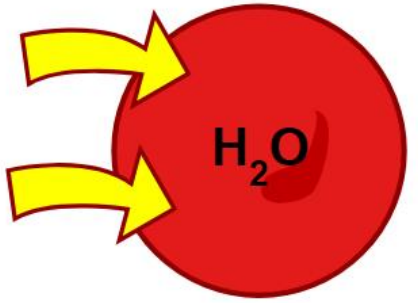
Isotonic

Hypotonic





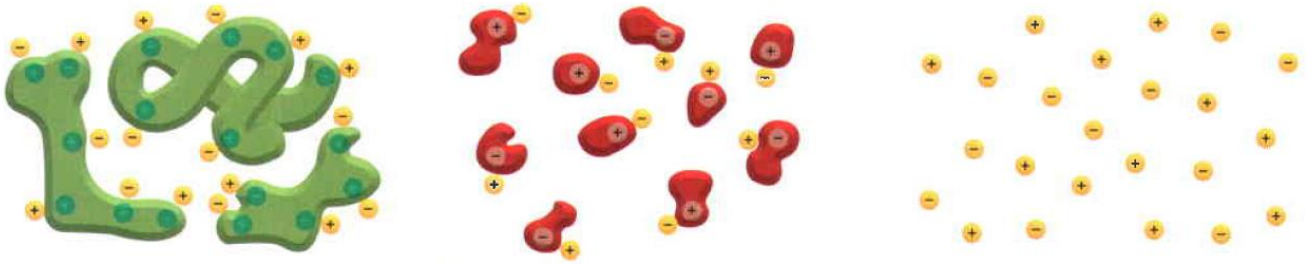




Shriveled/Plasmolyzed

Lysed/Turgid

Sources of intracellular osmolarity



Macromolecules attract many inorganic ions of opposite charge

As the results of active transport and metabolic process, the cell contains a high concentration of small organic molecules (sugars, amino acids,…). These molecules also attract ions.

Inorganic ions from outside slowly cross the plasma membrane. But never reach equilibrium because macromolecules attract these ions (Gibbs-Donnan Effect).
Concentration of inorganic ions is higher inside the cell.
Water coming in…

Passive Transport
Facilitated diffusion

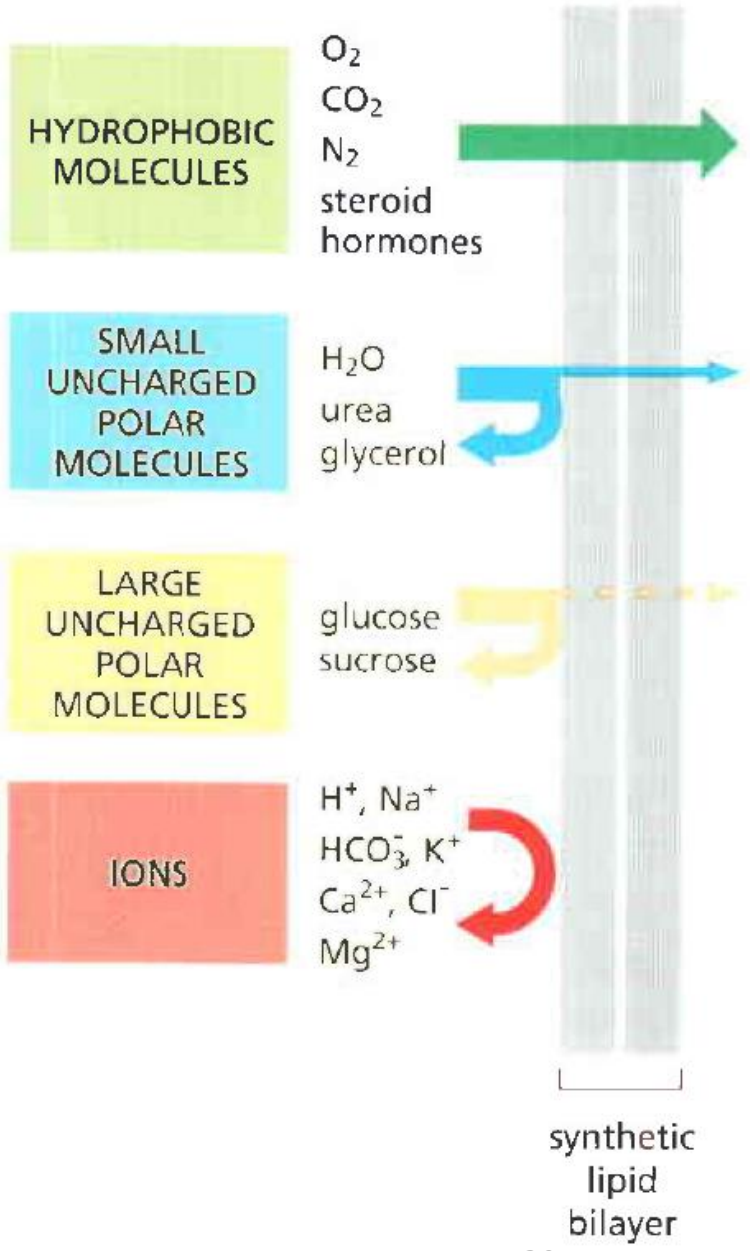
Protein-free lipid bilayers are highly impermeable to ions

- Generally, the smaller the molecule and the more soluble it is in oil (the more hydrophobic, or nonpolar, it is), the more rapidly it will diffuse across a lipid bilayer.

- Small nonpolar molecules, such as O2 and CO2, readily dissolve in lipid bilayers and therefore diffuse rapidly across them.

- Small uncharged polar molecules, such as water or urea, also diffuse across a bilayer, but very slowly.

- Lipid bilayers are highly impermeable to charged molecules (ions).



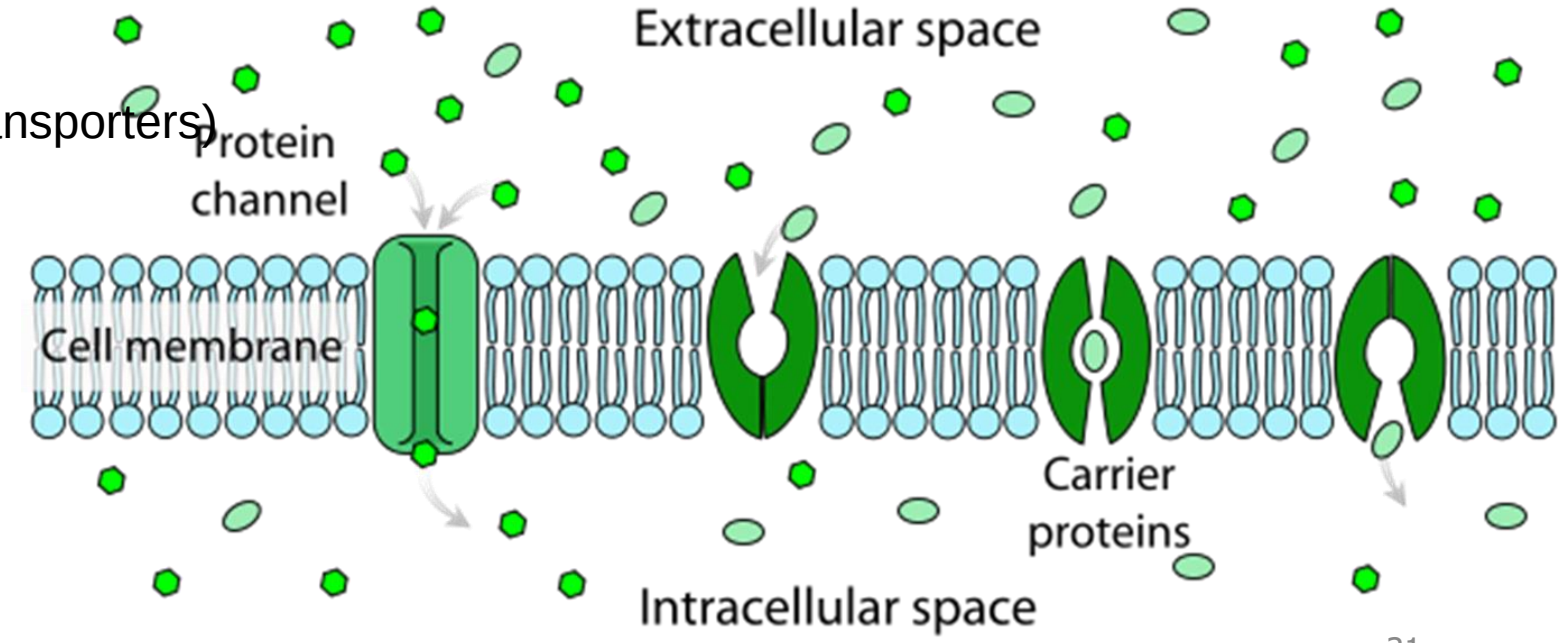
Passive Transport
Facilitated diffusion

Movement of larger molecules like glucose through the cell membrane

- larger molecules must be “helped”

Two main types of membrane transport proteins

- **Carrier** proteins (aka transporters)
- **Channel** proteins



Passive Transport
Facilitated diffusion

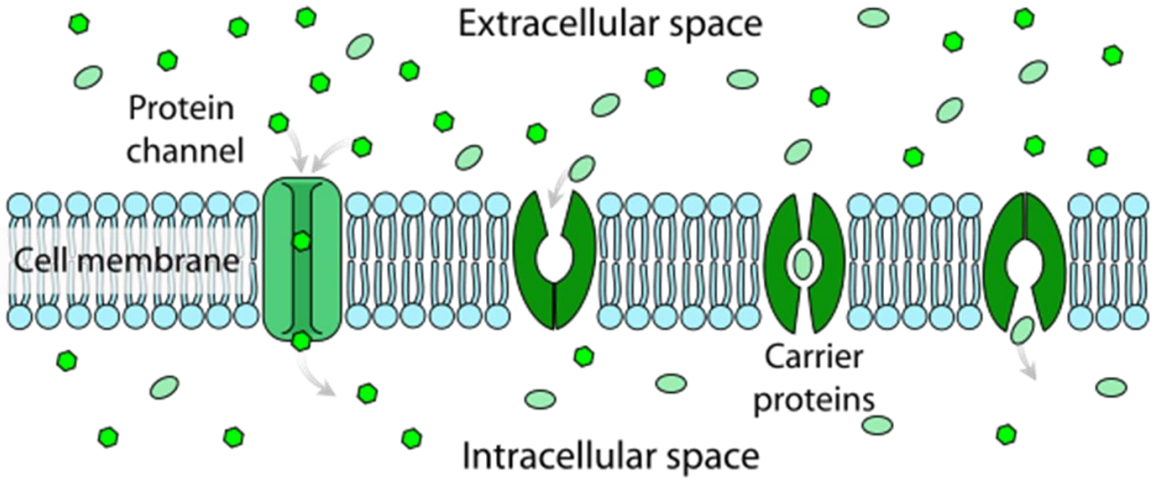
Two main types of membrane transport proteins

- **Carrier** proteins (aka transporters)

  Bind the specific solute to be transported and undergo a series of conformational changes to transfer the bound solute across the membrane.

- **Channel** proteins

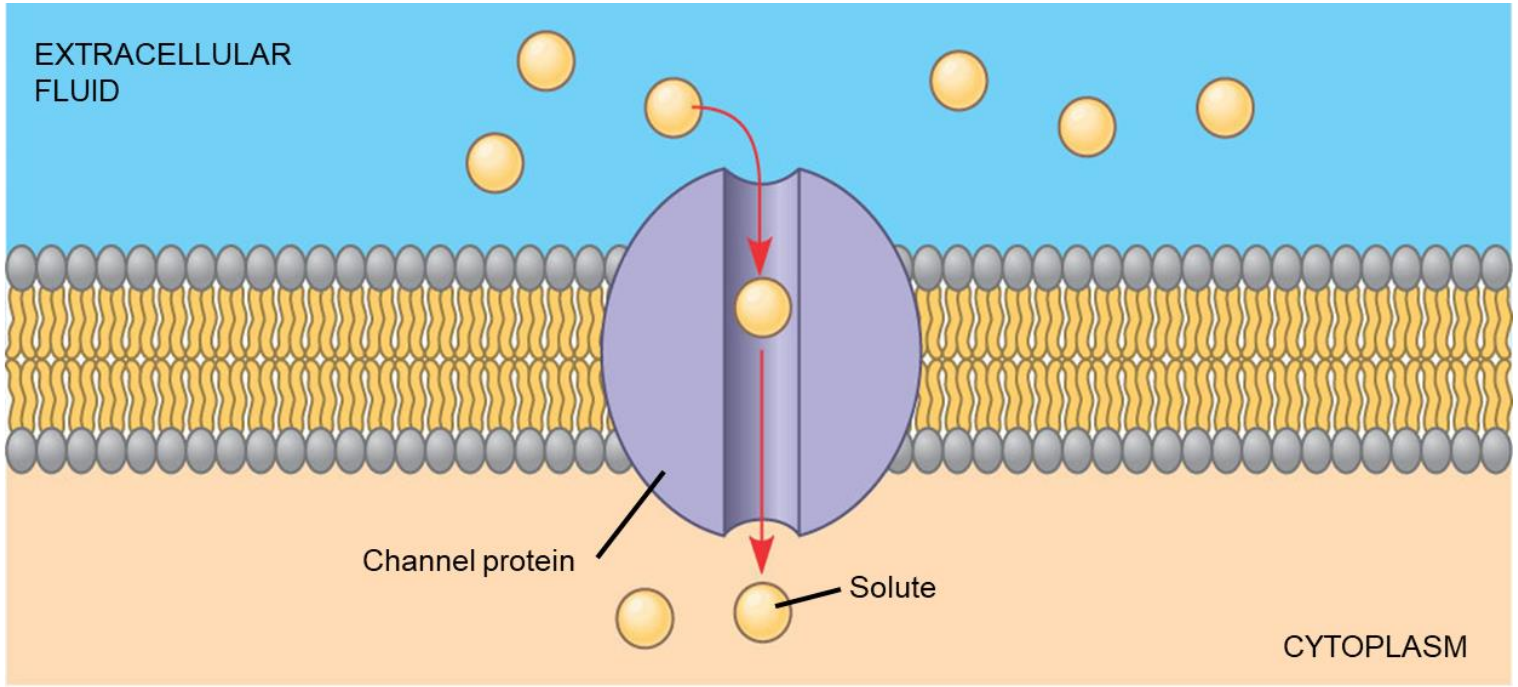
  Interact weakly to the solute to be transported. They form aqueous pores that extend across the lipid bilayer.



Channel proteins

Aqueous channel
Hydrophilic pore
Very rapid
Selective –size/charge

channel proteins mediate ***only*** **passive** transport



(a) A channel protein (purple) has a channel through which water molecules or a specific solute can pass.

Channel proteins

Ion channels

similar to carrier proteins, but are specific for certain ions, e.g., Na^+, Cl^-, K^+, Ca^{2+}

- These ions are important for many cell functions, but are not soluble in lipids
  need to pass through these ion channels
- Some channels are always open, others close

Channel proteins

Aquaporin

water channels

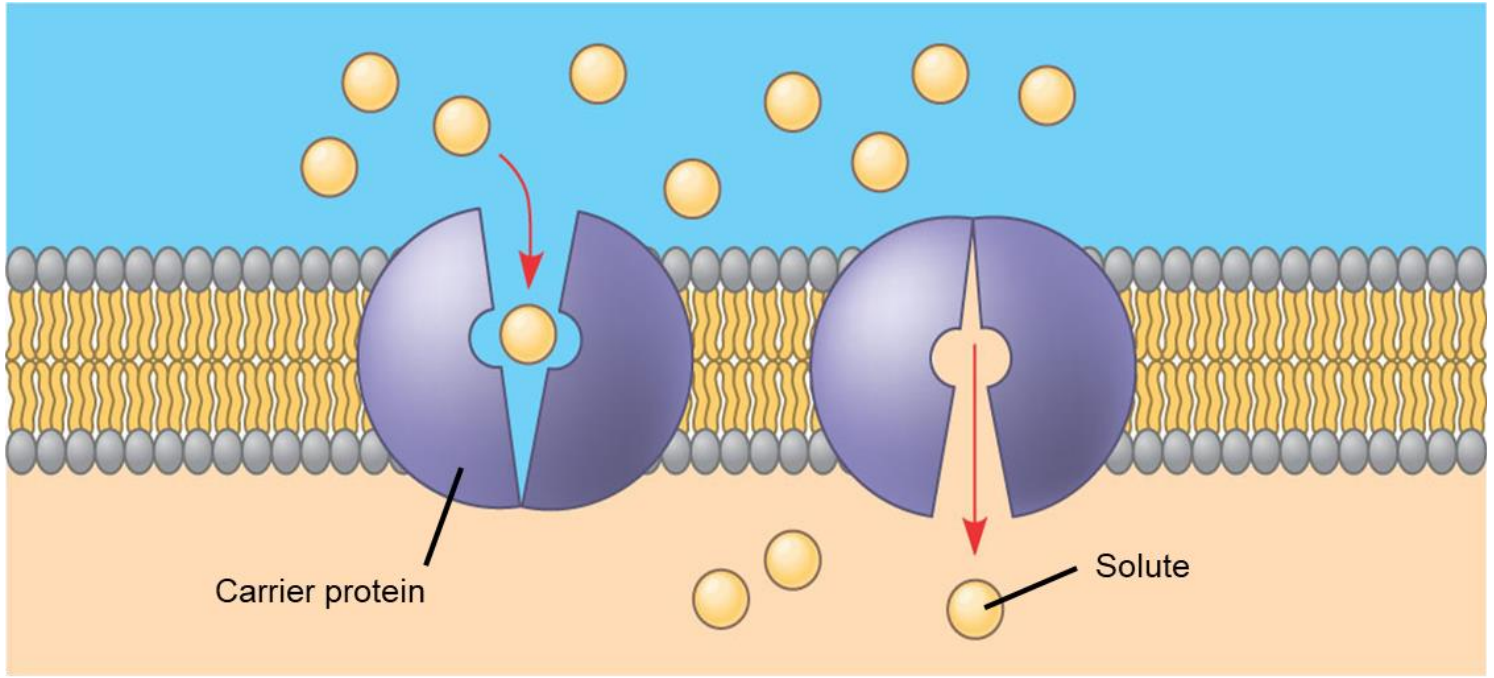
channels in the transfer of water and small solutes (glycerol, urea, and some ions) across the membrane.

The phospholipid bilayer is basically permeable to small polar molecules.
Water can slowly permeate the bilayer by simple diffusion.

Carrier proteins

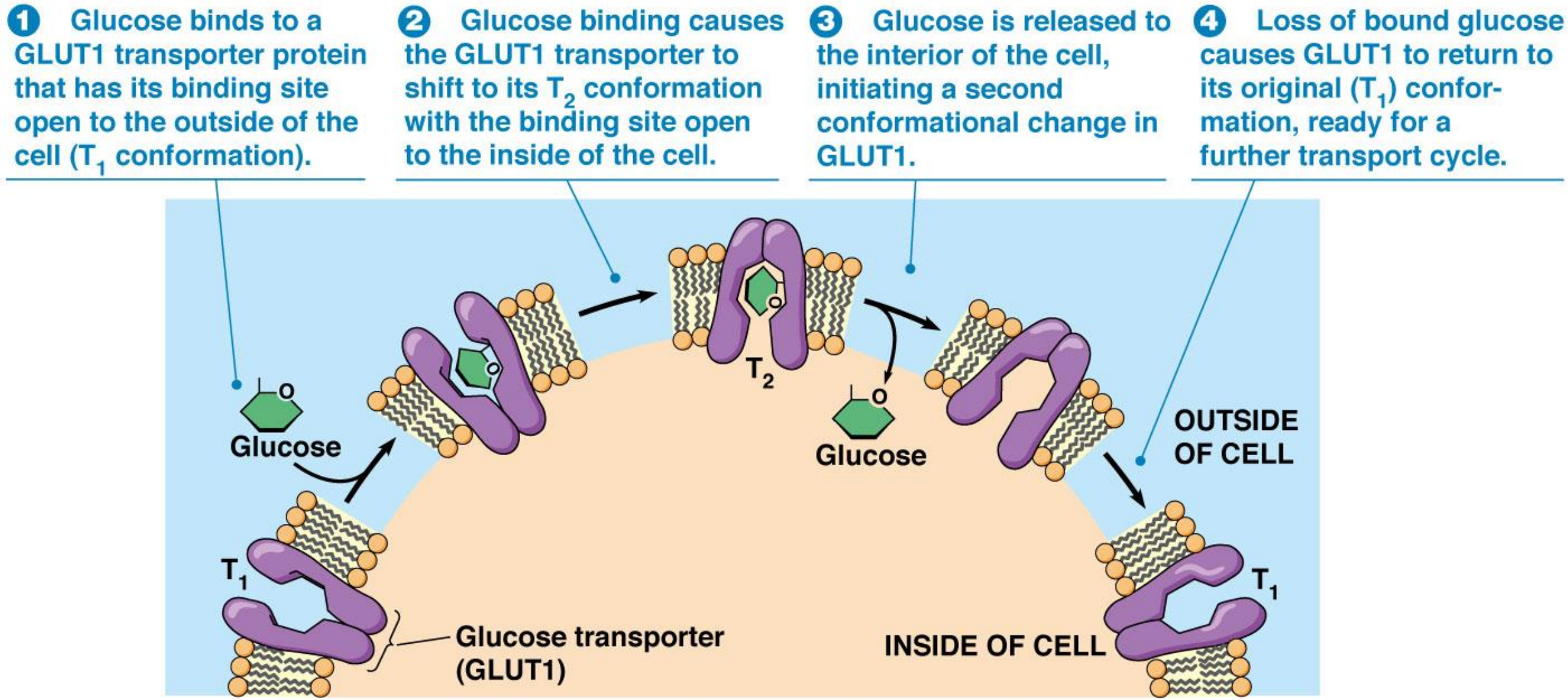
Bind solute,
Conformational change,
Release

Selective binding



(b) A carrier protein alternates between two conformations, moving a solute across the membrane as the shape of the protein changes. The protein can transport the solute in either direction, with the net movement being down the concentration gradient of the solute.

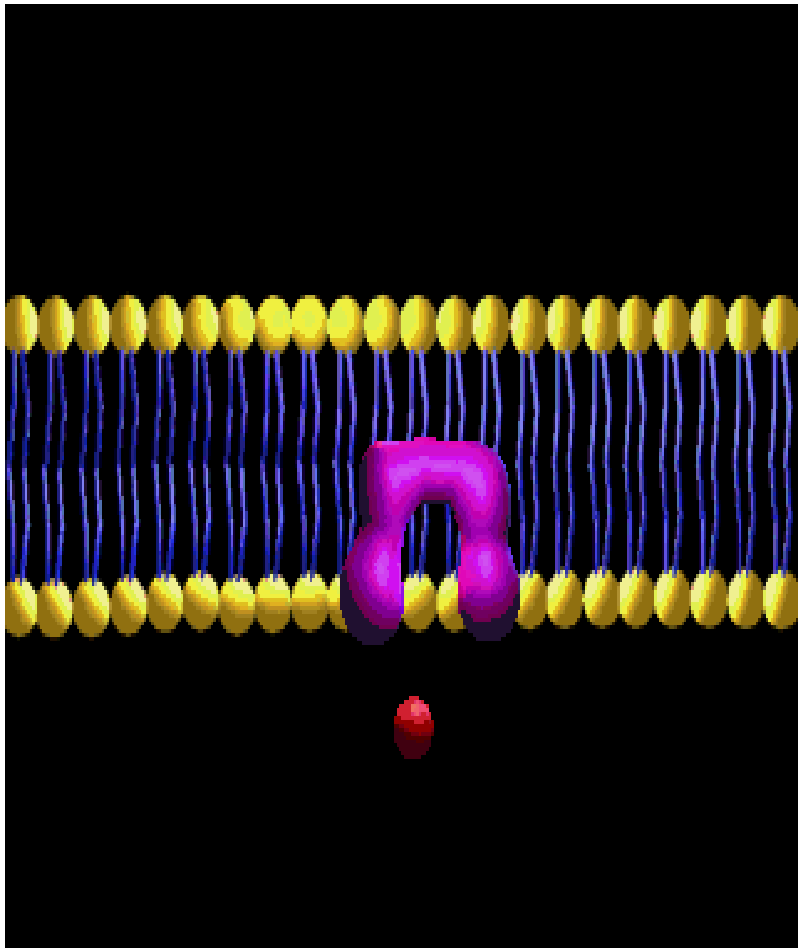
Carrier proteins



Carrier proteins

Some carrier proteins do not extend through the membrane.

They bond and drag molecules through the lipid bilayer and release them on the opposite side.



Carrier proteins

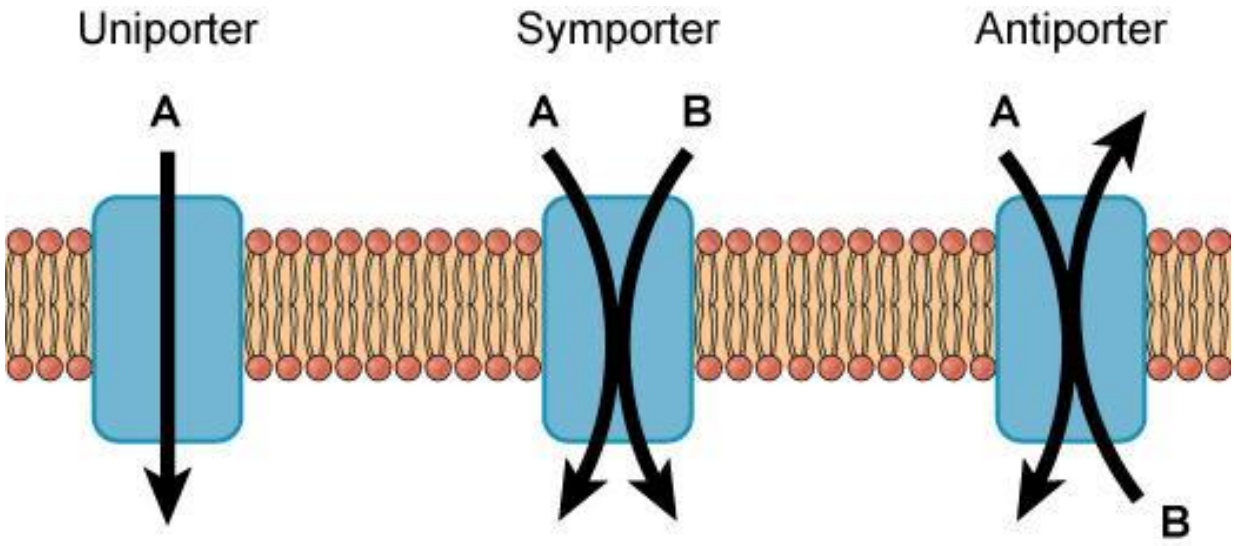
Three types

Uniporter – one solute transported

Symporter – two solutes in the same direction

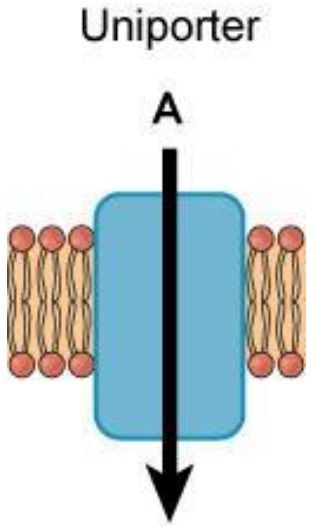
Antiporter – two solutes in opposite directions

} cotransport



Carrier proteins

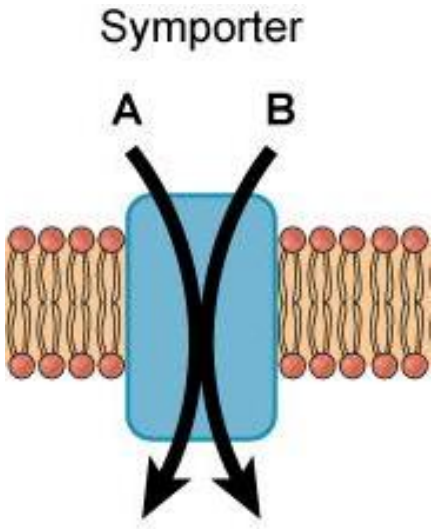
Uniport – one solute transported



- Glucose transporter: allow glucose to enter cell
- Potassium channels

Carrier proteins

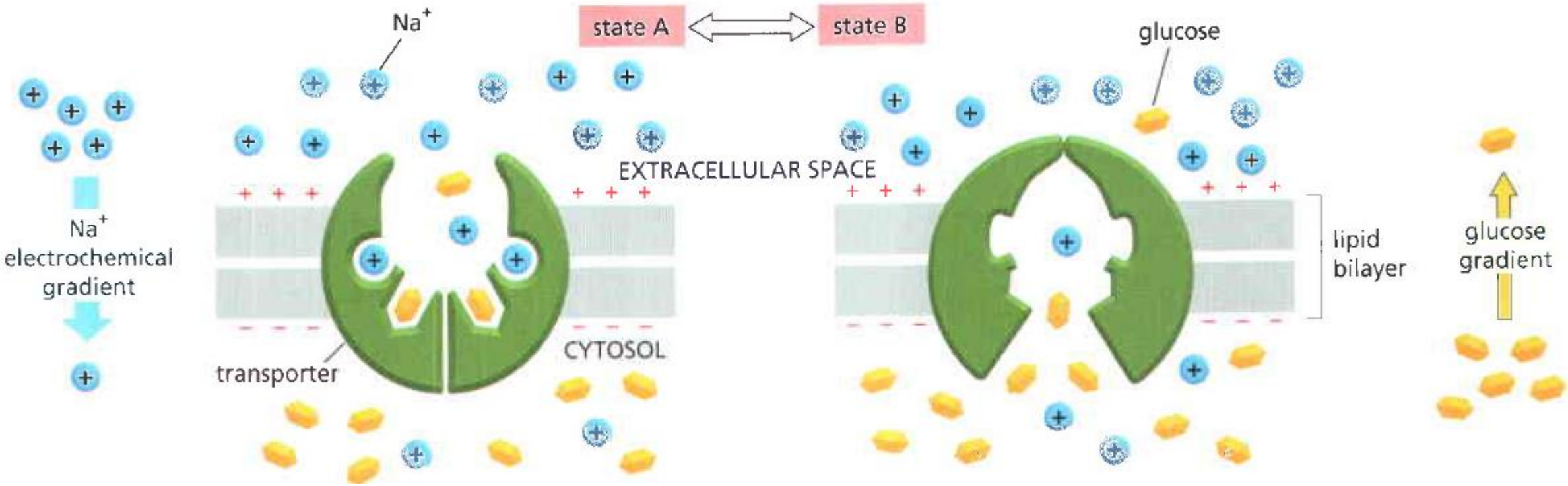
Symport – two solutes in the <u>same</u> direction



- Molecules are transported across the cell membrane at the same time.
- Na^+–glucose symport

Carrier proteins

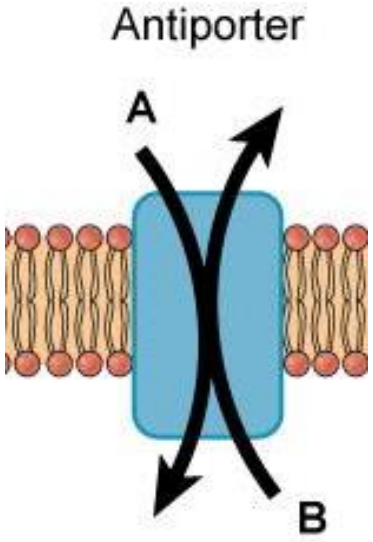
Symport – two solutes in the <u>same</u> direction



Na^+– glucose symport: Binding of either ligand induces a conformational change that increases the protein's affinity for the other ligand.

Carrier proteins

Antiport – two solutes in <u>opposite</u> directions



- Involved in secondary active transport of two or more different molecules or ions across a phospholipid membrane in opposite directions.
- Na^+/H^+ antiporters: Na^+ in, H^+ out

Carrier proteins

Carrier Proteins can mediate either:

Passive transport
driving force: concentration/electrochemical gradient

or

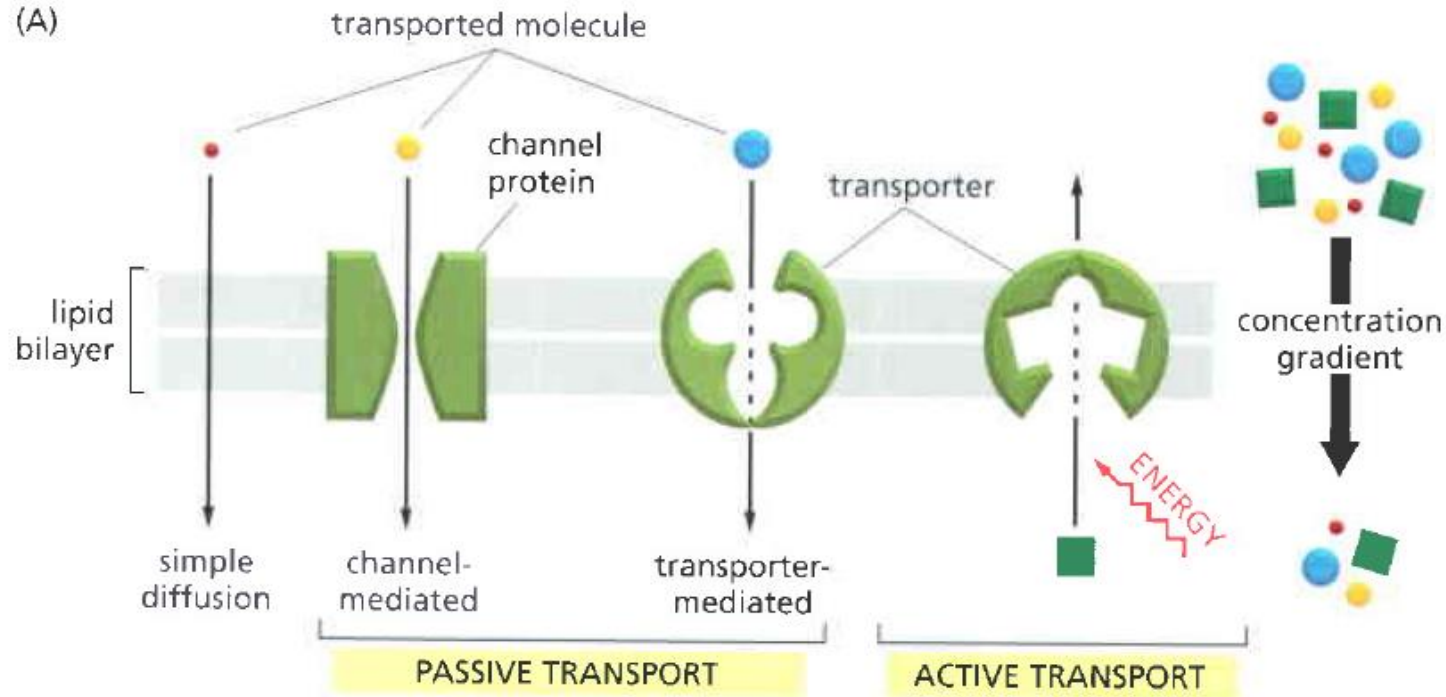
Active transport
against a gradient; unfavorable
requires energy input

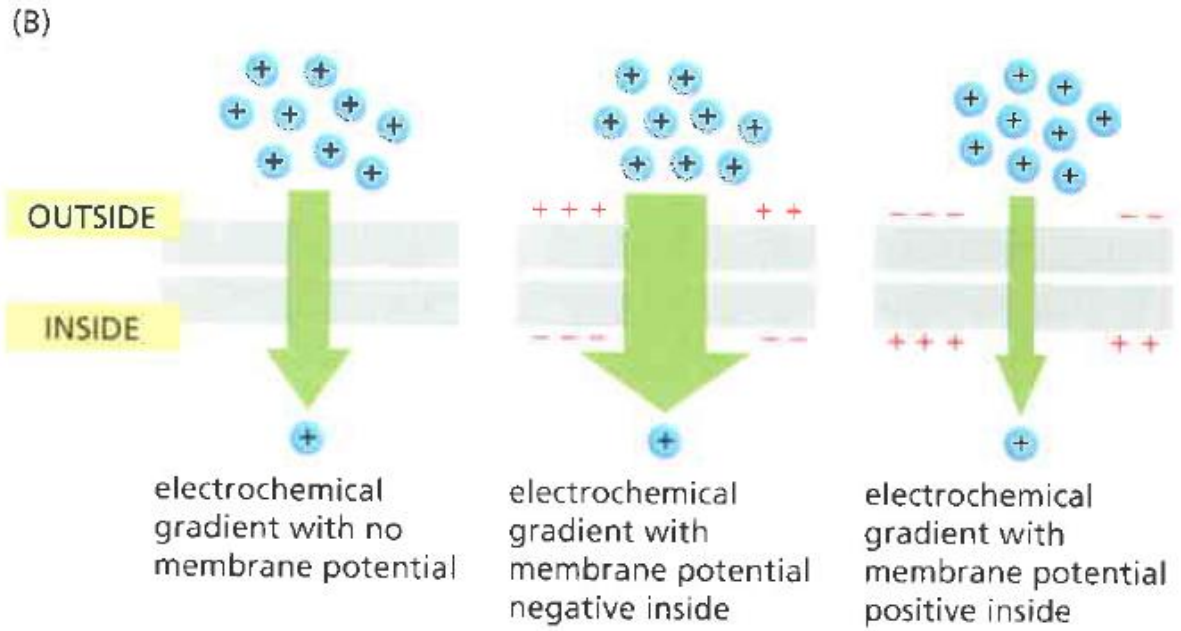
Summary

- Controlling the movement of things in and out of the cell is an important role of the plasma membrane.
- **No energy** is needed for **passive** transport
  from an area of higher concentration to an area of lower concentration.
- Simple **diffusion**
  very small, hydrophobic molecules, oxygen, carbon dioxide, enter and leave the cell

Summary

- **Osmosis** is the diffusion of water molecules across a membrane
  Water moves in or out until its concentration is the same on both sides of the plasma membrane.
- **Facilitated diffusion** is the movement of a substance across a membrane with the help of transport proteins, such as channel proteins or carrier proteins, in the membrane.
  Large or hydrophilic molecules and charged ions enter and leave the cell.





Concentration gradient + electrical gradient
= electrochemical gradient

Active Transport

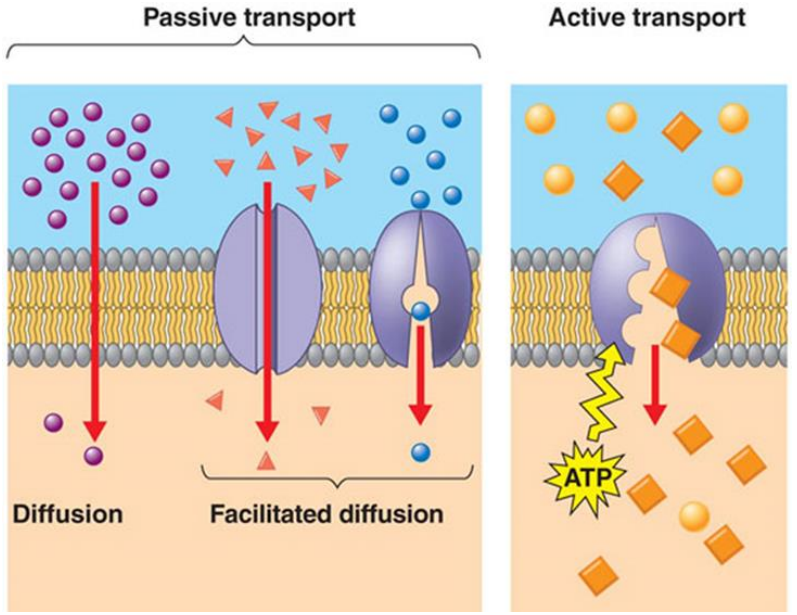
Movement of molecules from **low to high** concentration.

Energy is required as molecules must be pumped against the concentration gradient, usually in the form of ATP hydrolysis.

Carrier protein moves solute **against** its concentration gradient

Two types of active transport:

- Pump
- Vesicle transport



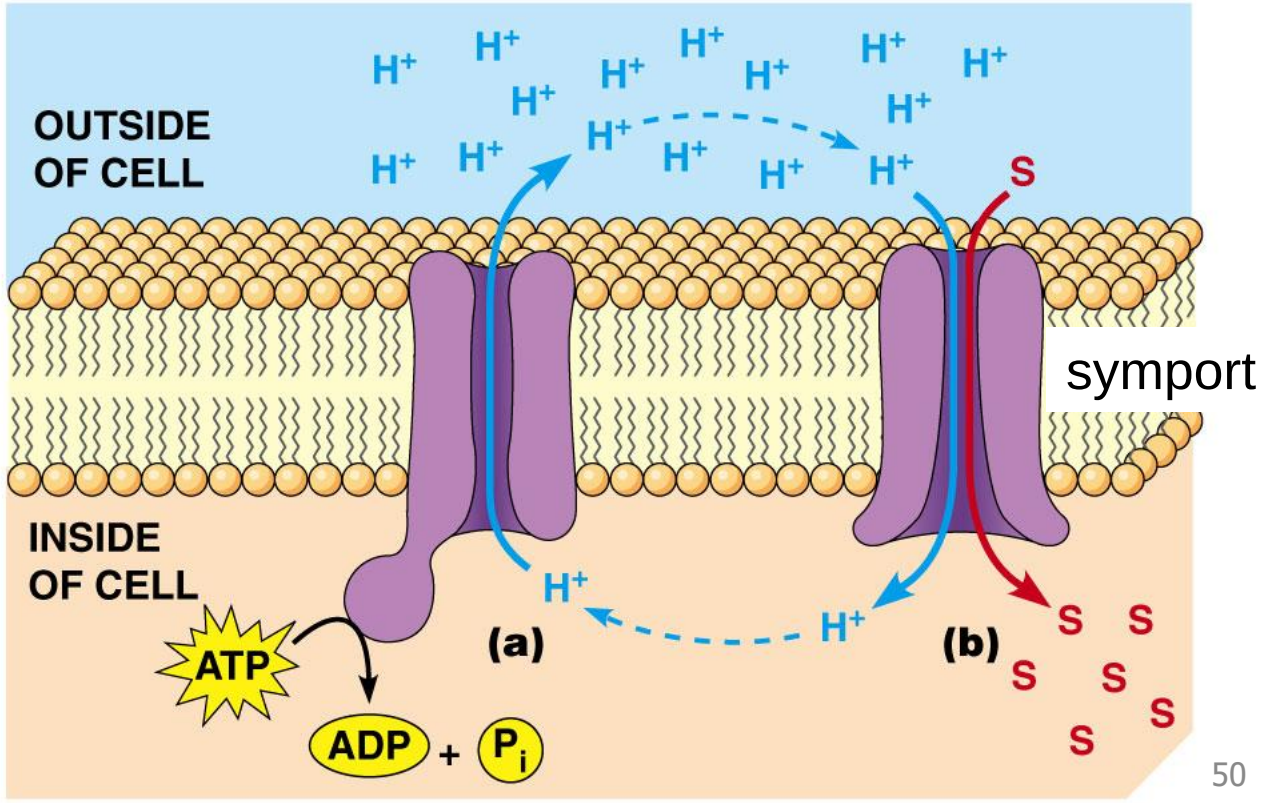
Direct and indirect active transport

Direct/primary:
Transport coupled to exergonic reaction, **ATP** hydrolysis

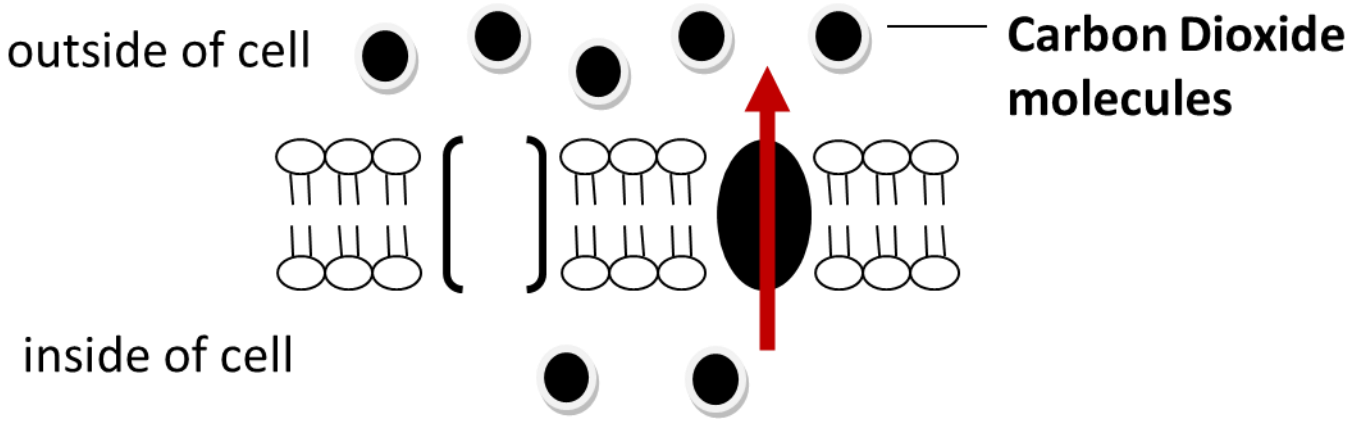
Indirect/secondary:
Transport driven by cotransport of ions

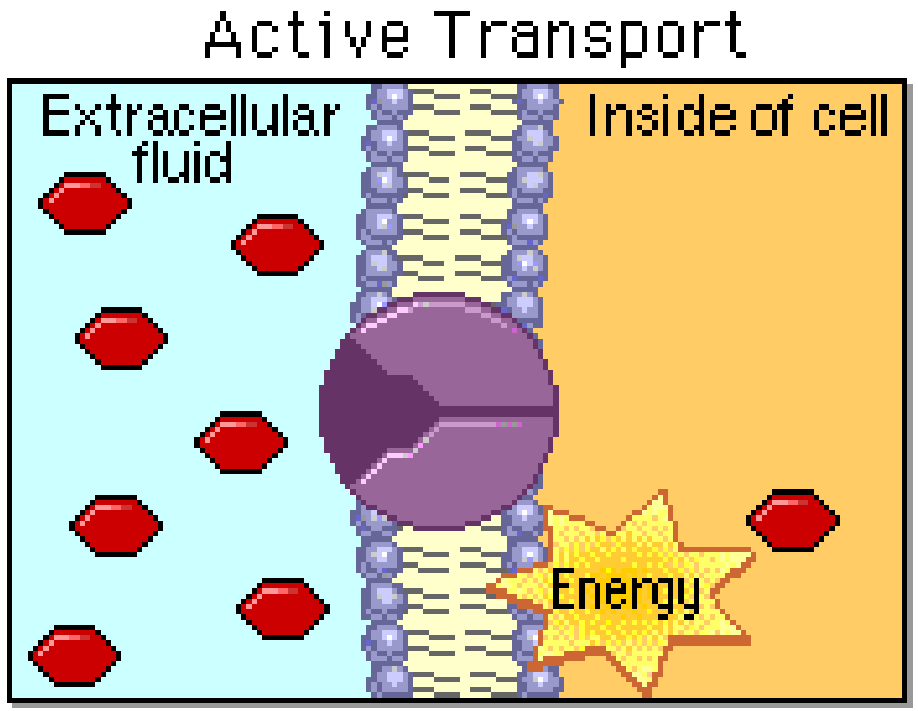
(a) Direct active transport involves a transport system coupled to an exergonic chemical reaction, most commonly the hydrolysis of ATP. As shown here, ATP hydrolysis drives the outward transport of protons, thereby establishing an electro-chemical potential for protons across the membrane.

(b) Indirect active transport involves the coupled transport of a solute S and ions—protons, in this case. The exergonic inward movement of protons provides the energy to move the transported solute, S, against its concentration gradient or electrochemical potential.



Body cells must pump carbon dioxide out into the surrounding blood vessels to be carried to the lungs for exhale. Blood vessels are high in carbon dioxide compared to the cells, so energy is required to move the carbon dioxide across the cell membrane from low to high concentration.

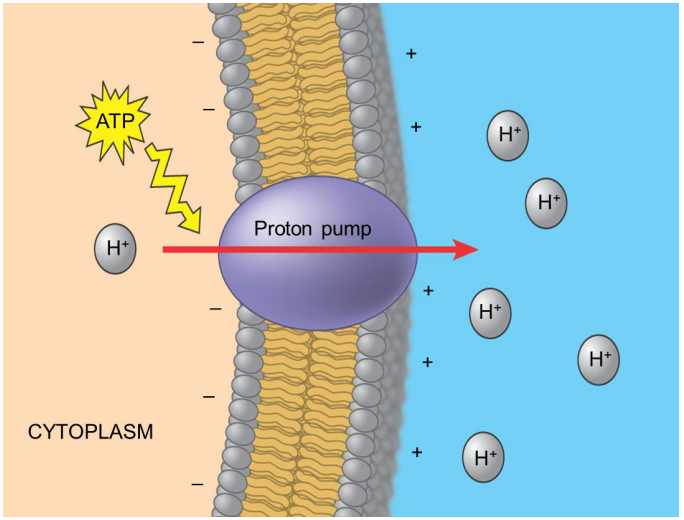




Active transport: Proton Pump (H^+/K^+ATPase)

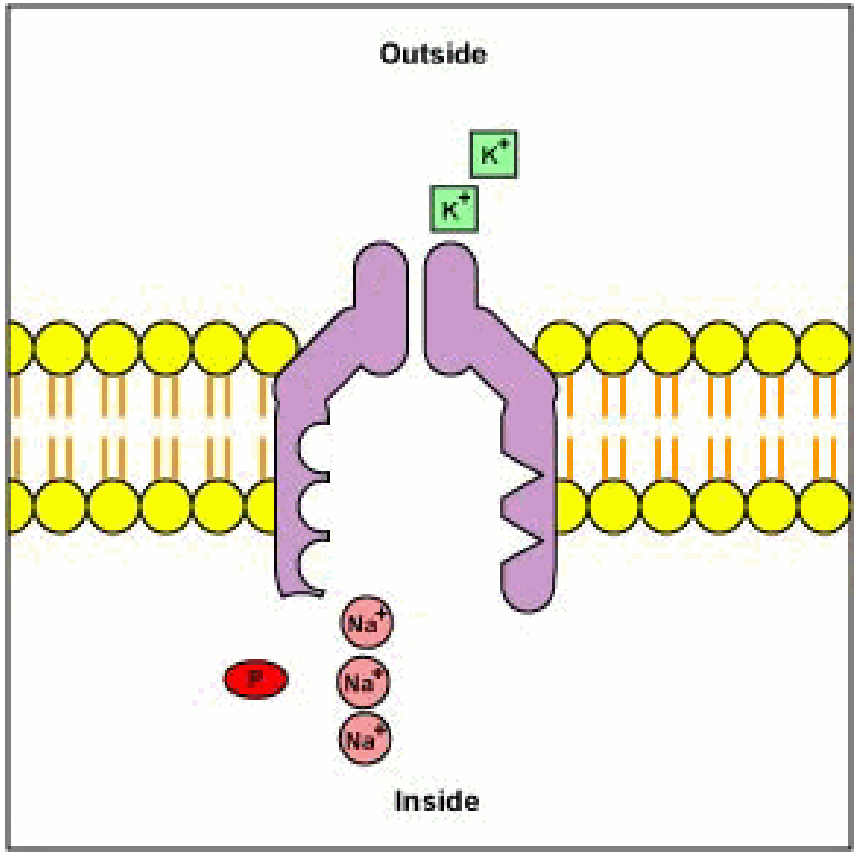
An **electrogenic pump**

Is a transport protein that *generates the voltage* across a membrane



common pathway for acid secretion in gastric parietal cells

Active transport: Na^+K^+ Pump (Na^+K^+ATPase)



Direct/primary active transport

ATP is directly utilized by an enzyme to move a substance across a membrane

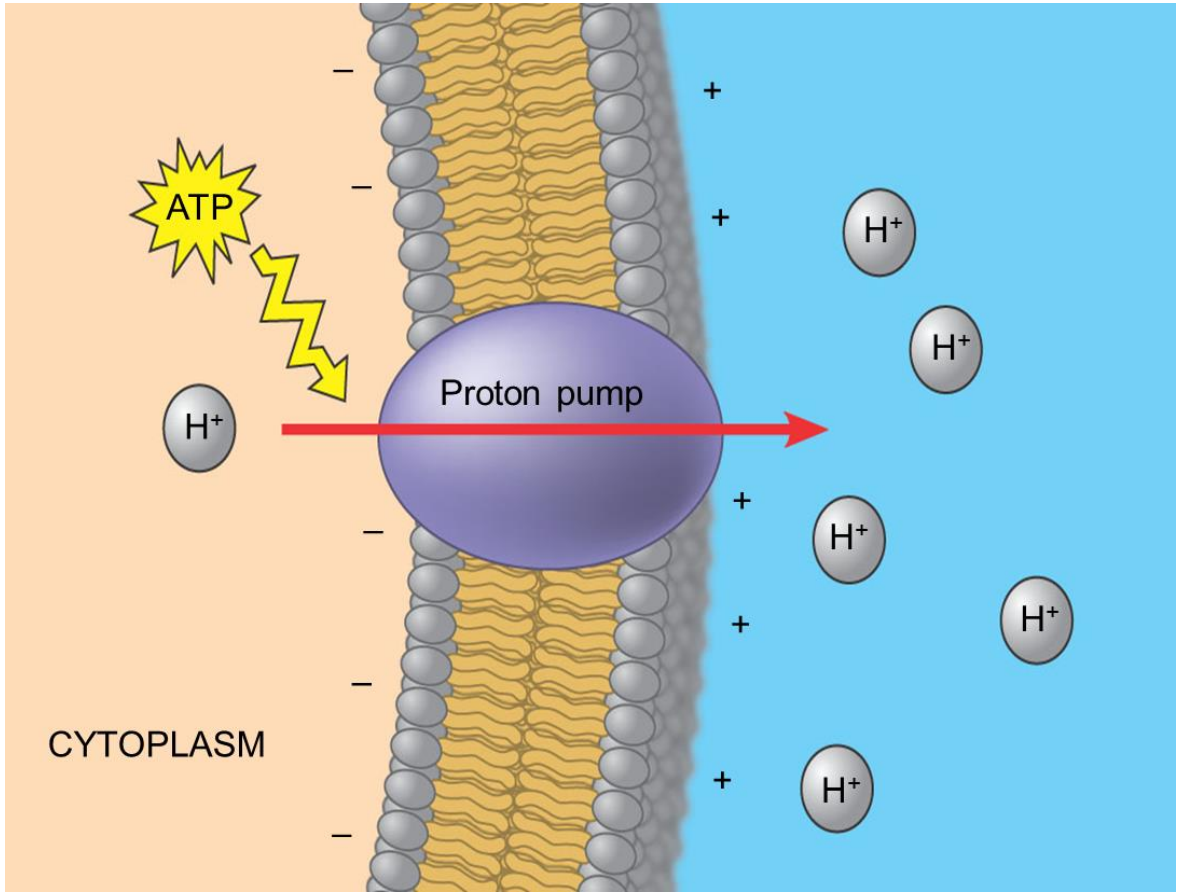
Pumping Na^+ out and K^+ in
-- against concentration gradients.

Also requires carrier proteins

Active transport: Proton Pump (H^+/K^+ATPase)

An **electrogenic pump**

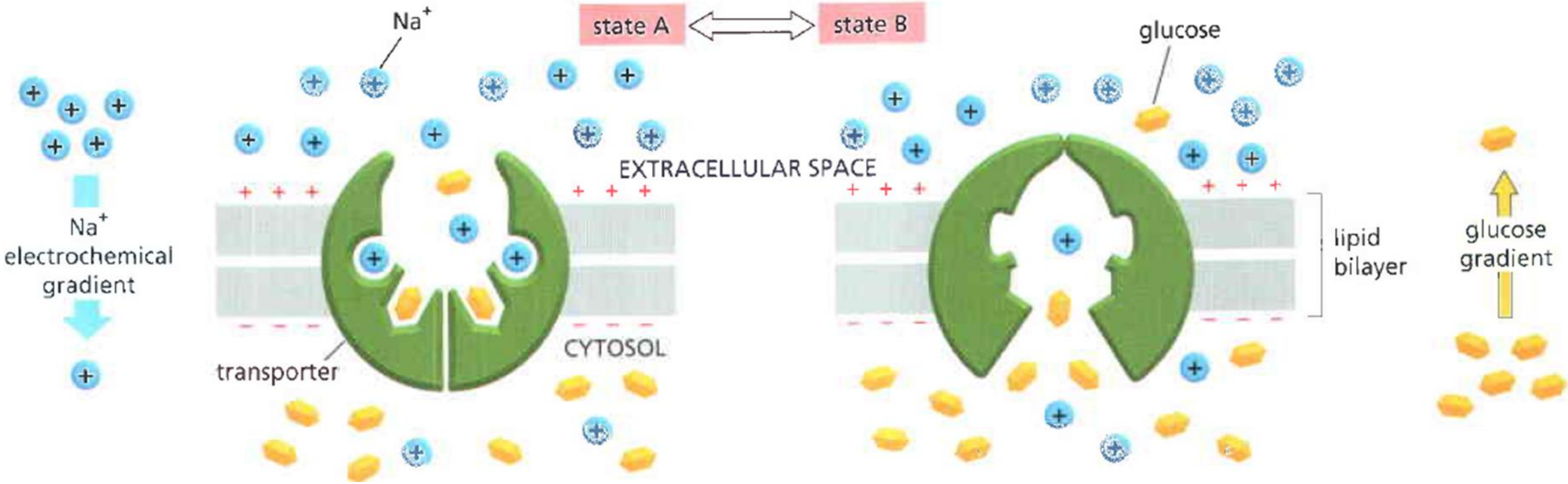
Is a transport protein that *generates the voltage* across a membrane



Indirect active transport:

Na^+ gradient drives other transport

Na^+ - glucose symport

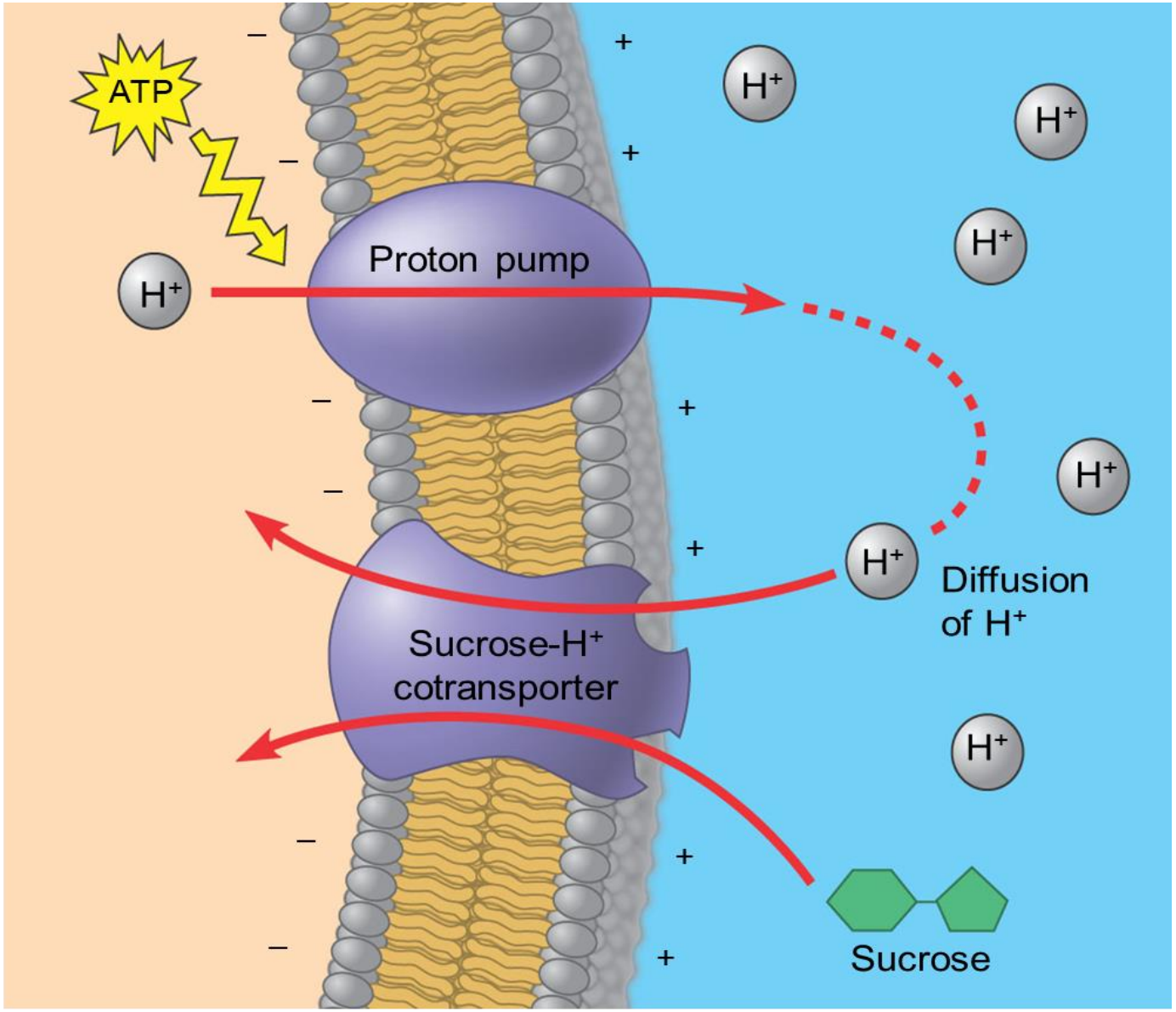


Pump oscillates between 2 conformations;

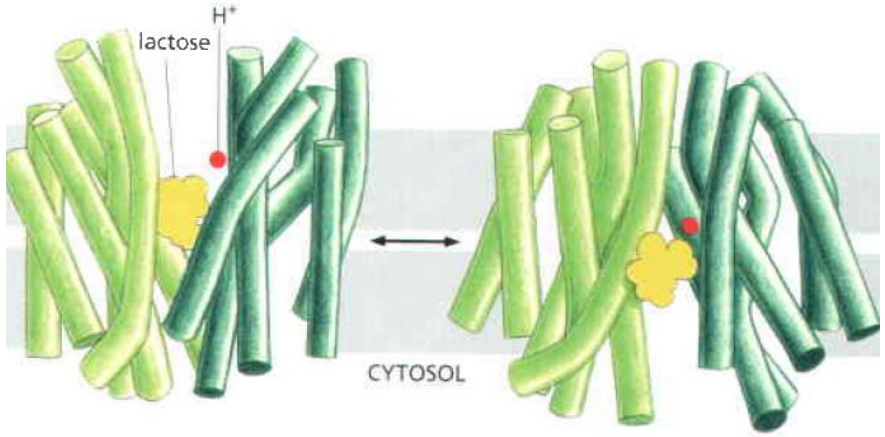
A is open to outside; binding of Na^+ induces a conformational change that increases the binding affinity for glucose. Lots more Na^+ outside, so tend to bind more in the A conformation, cooperative binding.

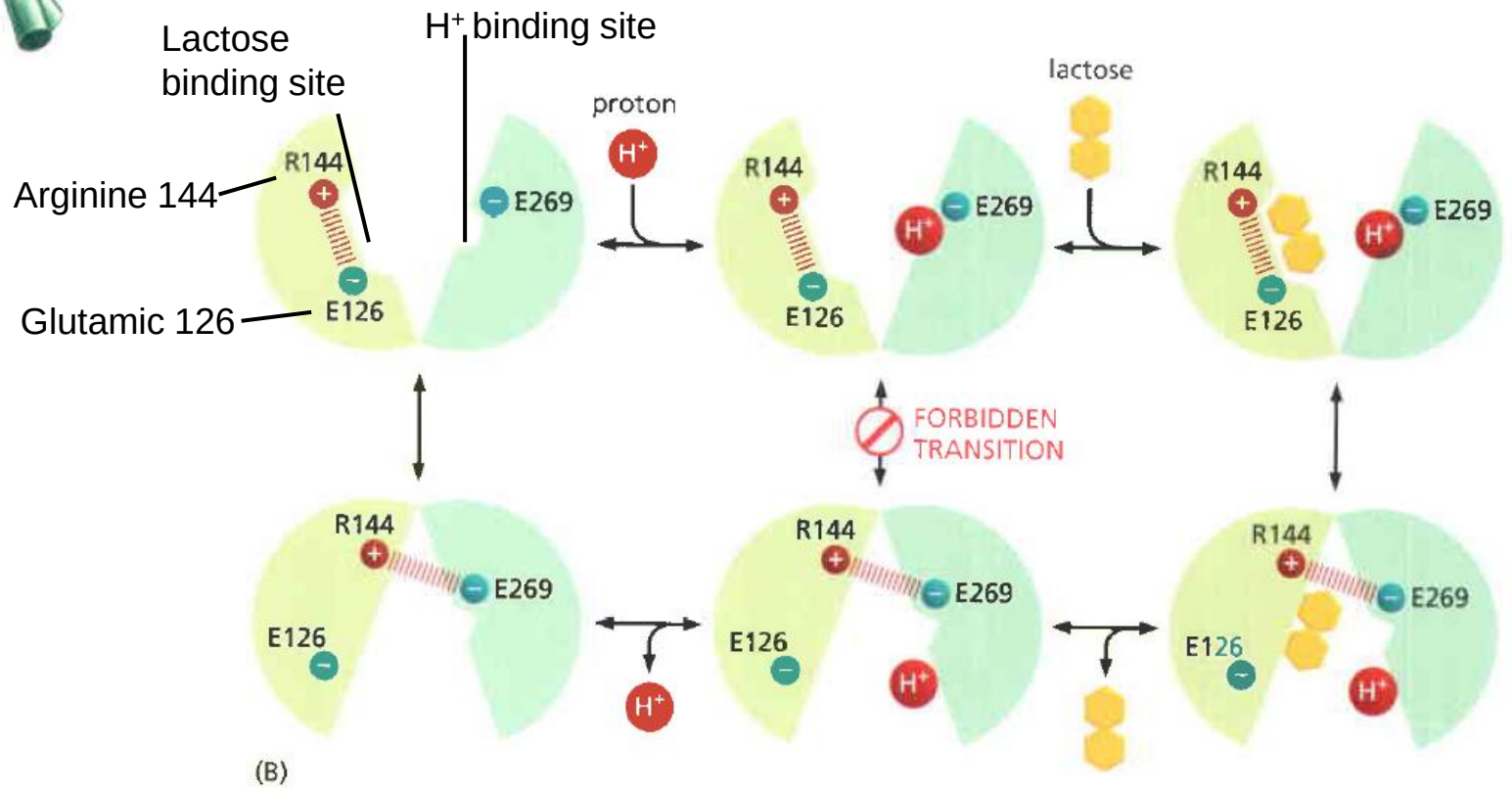
The Na^+ that enters the cell is pumped out by an **ATP-driven Na^+ pump**.

Cotransport: active transport driven by a concentration gradient

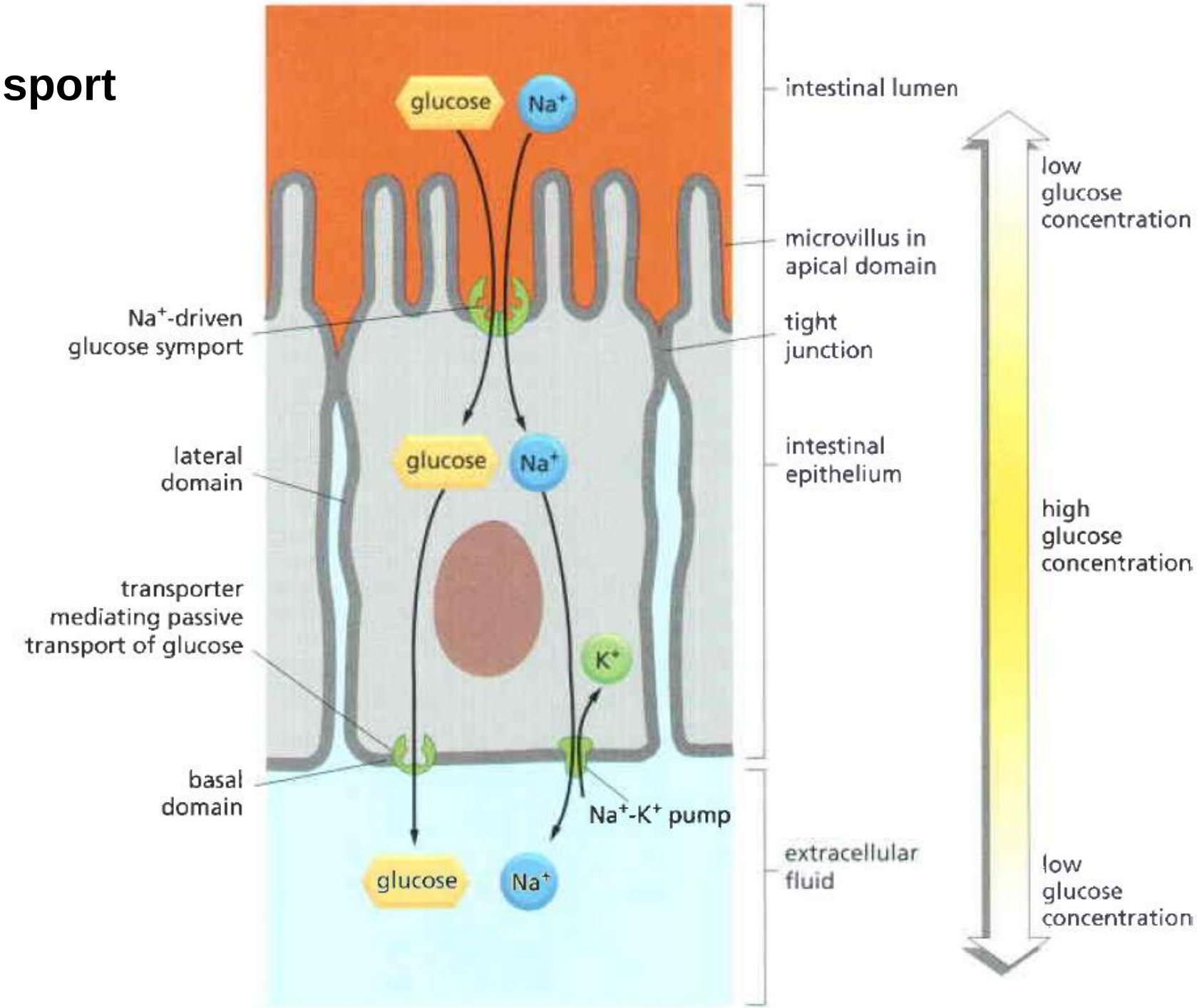


Lactose permease: H^+-driven symporter





Transcellular transport



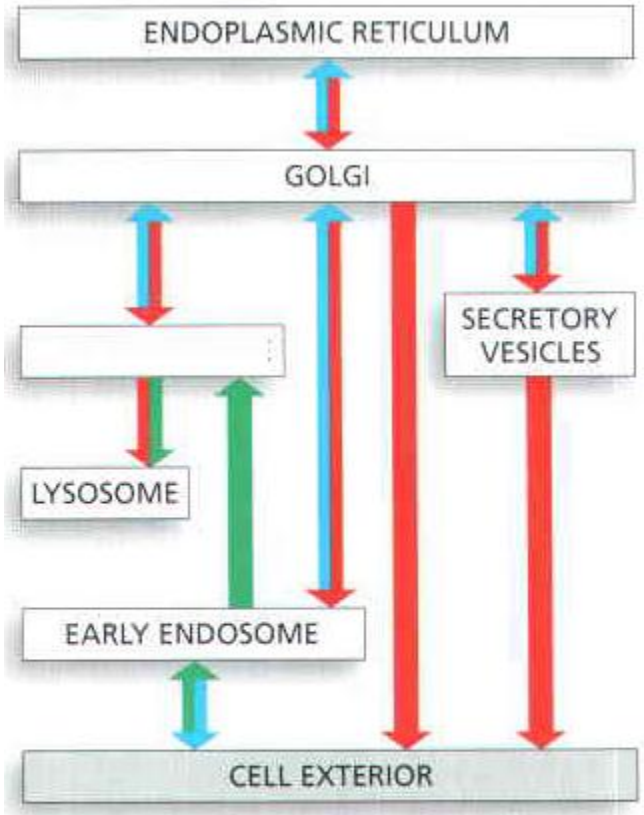
Endocytosis and Exocytosis

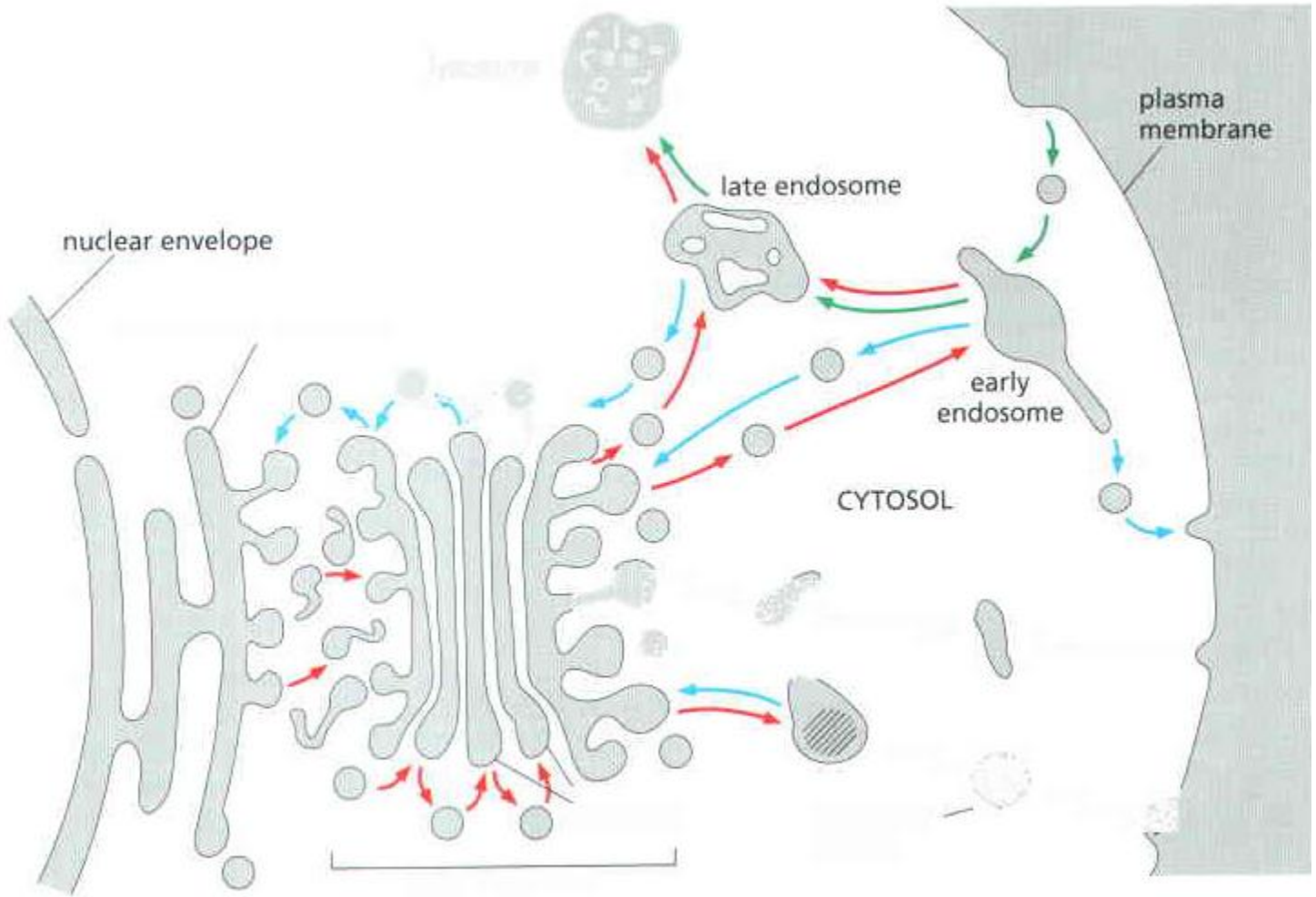
Mechanisms by which very **large molecules** (such as food and wastes) get **into** and **out** of the cell

White blood cells surround and engulf bacteria by endocytosis

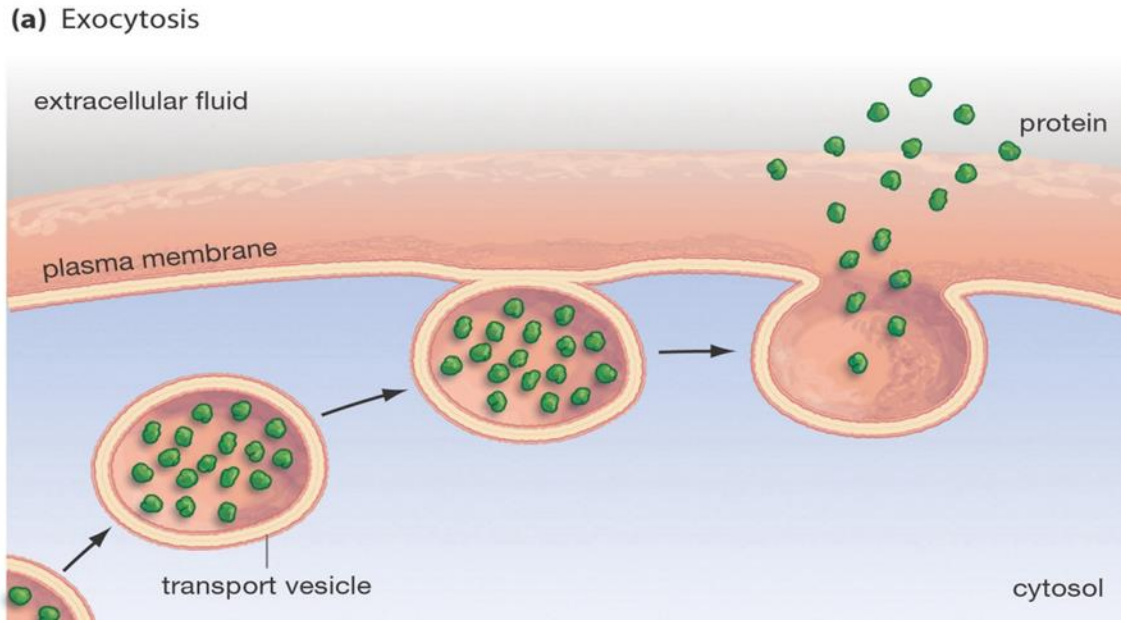
Exocytosis

- forces material **out** of cell in bulk
- membrane surrounding the material fuses with cell membrane
- Cell changes shape – requires energy
- e.g., hormones or wastes released from cell


ENDOPLASMIC RETICULUM
GOLGI
SECRETORY VESICLES
LYSOSOME
EARLY ENDOSOME
CELL EXTERIOR


plasma membrane
late endosome
nuclear envelope
early endosome
CYTOSOL

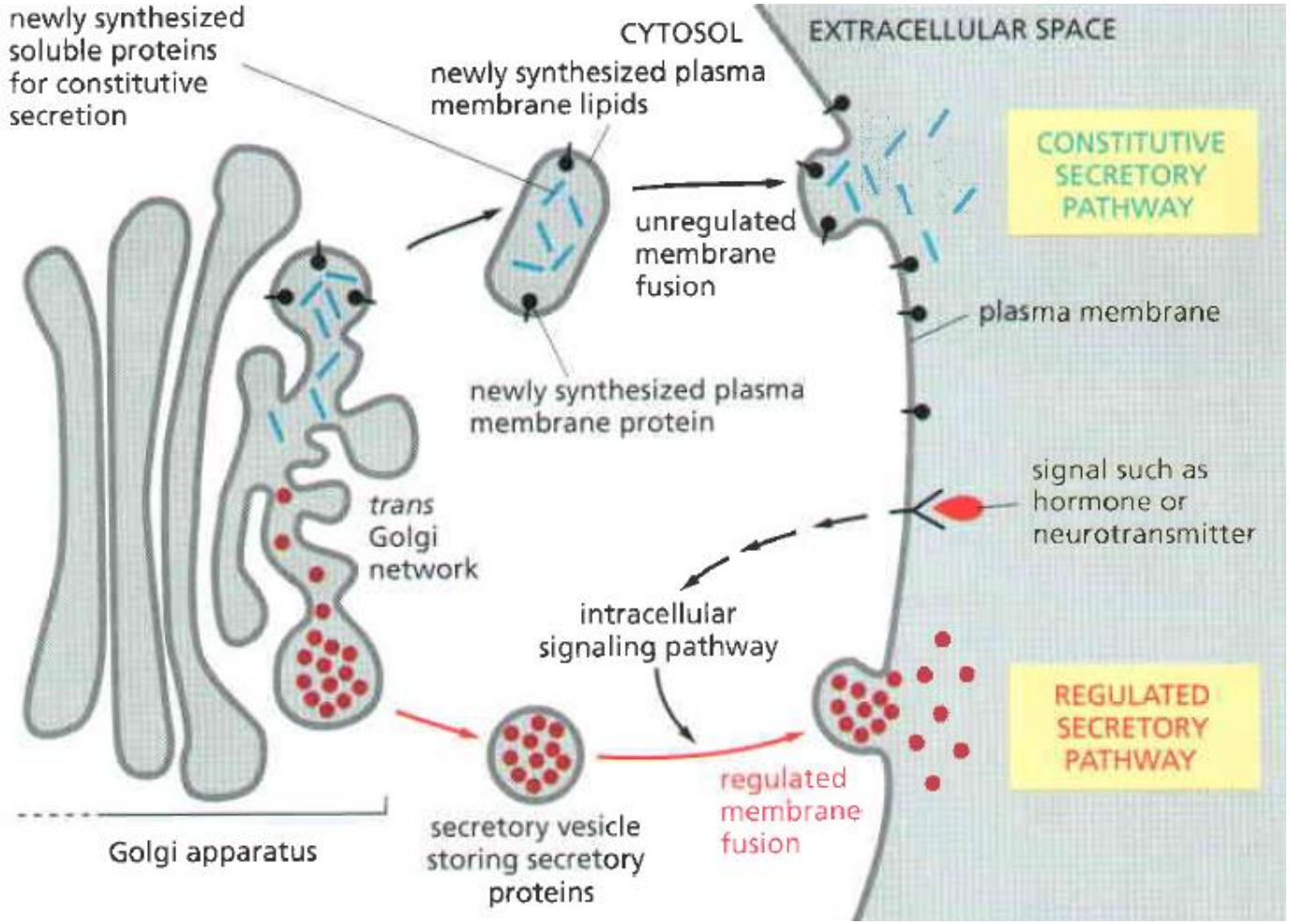
Exocytosis



Type of active transport

- Moving things **out**
- Using vesicles that fuse the with the plasma membrane.
- Hormones, nerve cells

Exocytosis



Default pathway. No signal needed.
Immediate delivery to membrane

Secreting on demand.
Products are stored in secretory vesicles.

Exocytosis

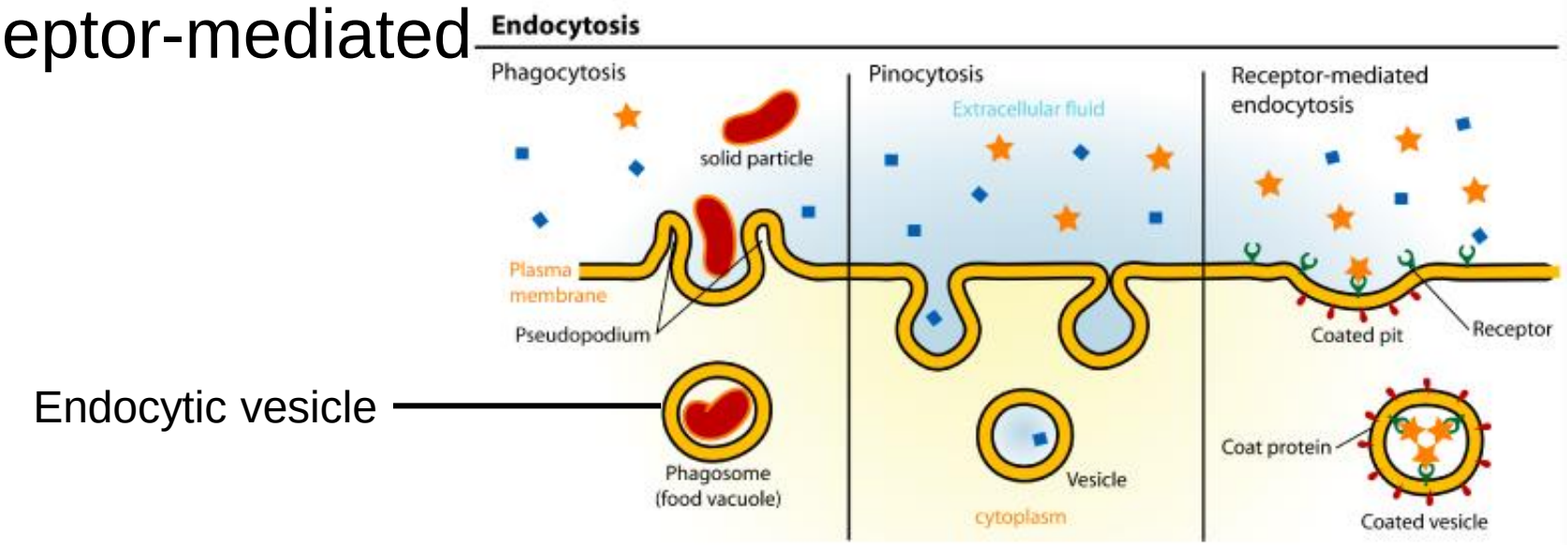
Exocytosis:
Vesicle fusing with plasma membrane during cytokinesis and phagocytosis.
Vesicles derived from lysosome help in wound repair.

Endocytosis

Type of active transport

Taking up large molecules (or other cells) **into** the cell by one of three forms of endocytosis.

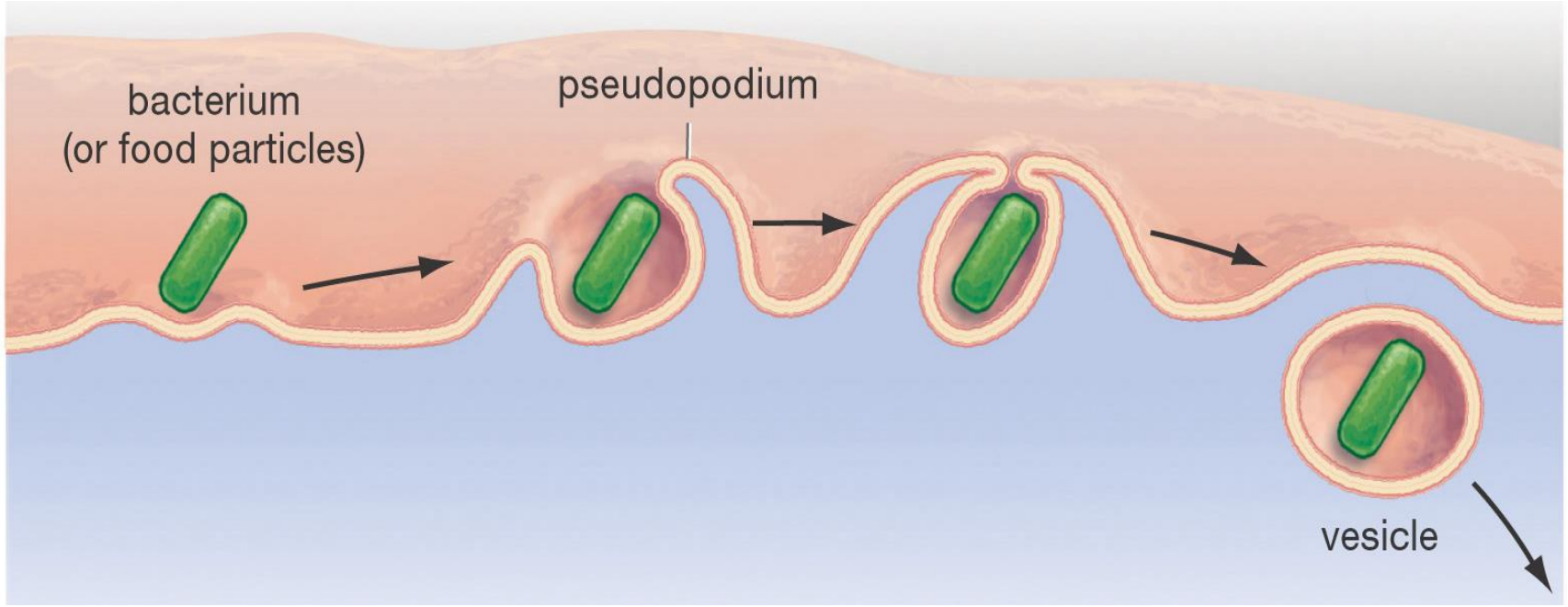
- Phagocytosis: cell eating
- Pinocytosis: cell drinking
- Receptor-mediated



Endocytosis

Phagocytosis

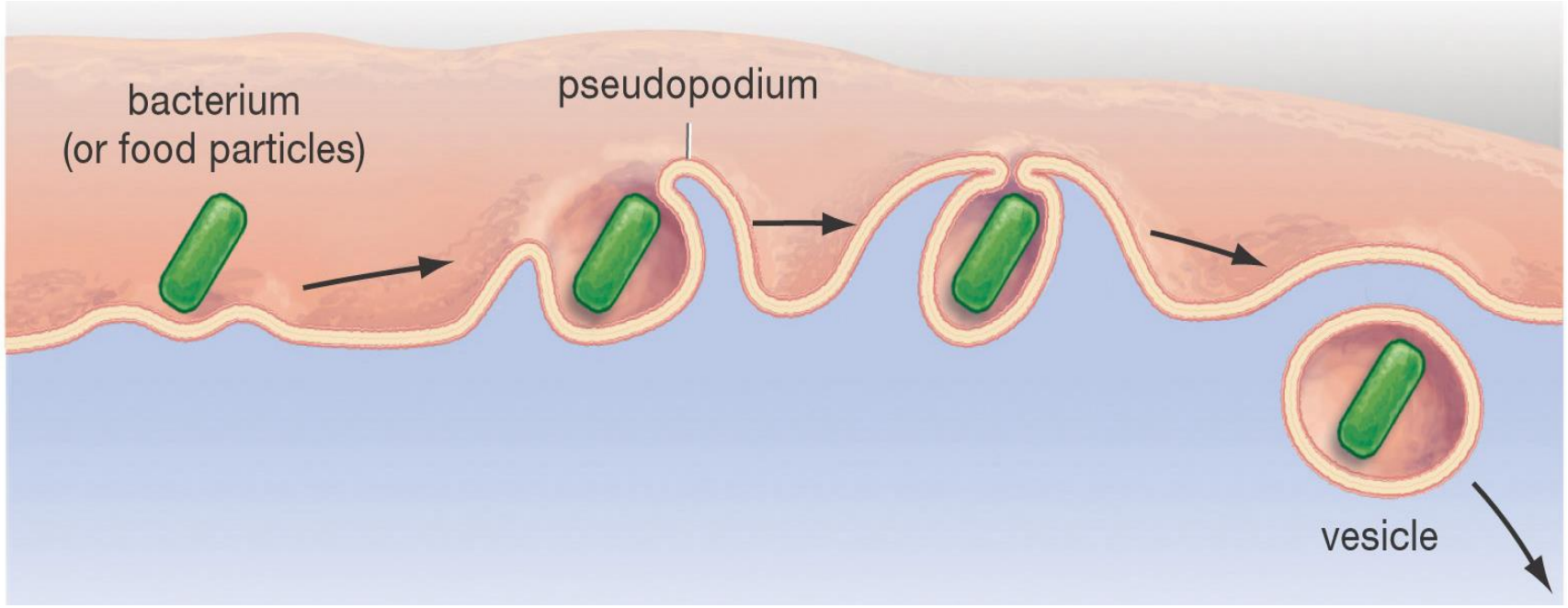
Used to engulf large particles such as food, bacteria or dead cells into phagosomes.
Cell Eating



Endocytosis

Phagocytosis

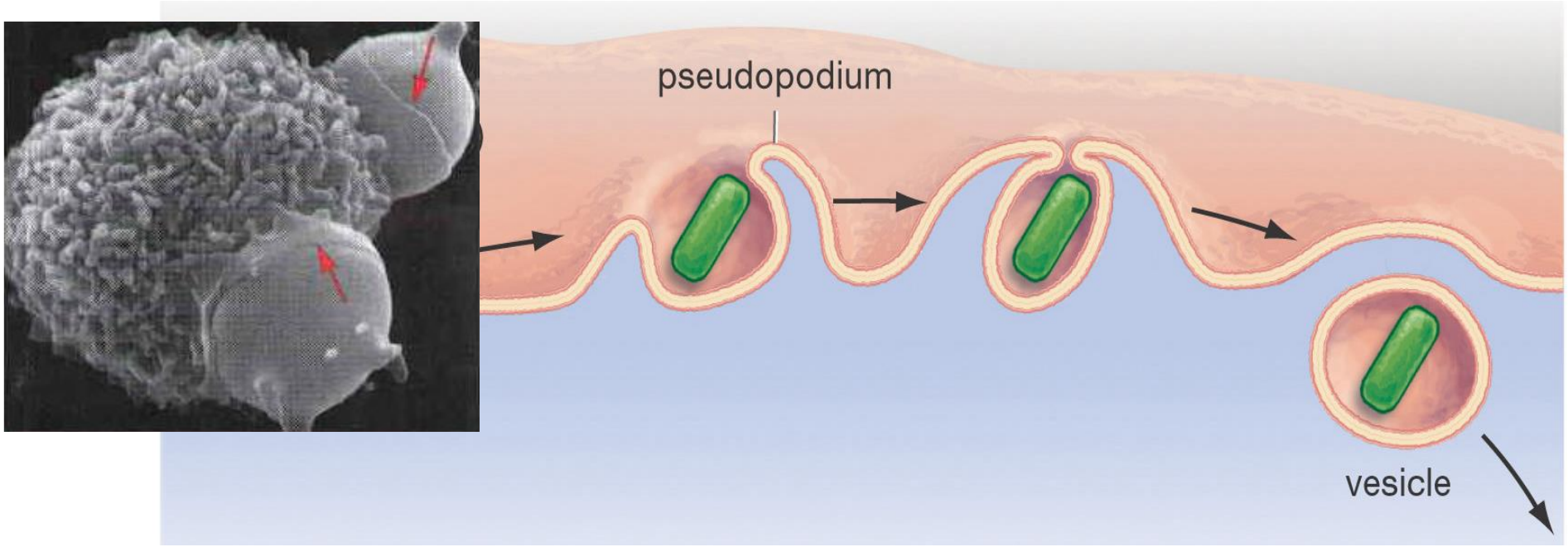
In protozoa, phagocytosis is a form of feeding (phagosome > lysosome > nutrients in cytosol).



Endocytosis

Phagocytosis

Phagocytosis is mainly found in specialized cells: white blood cells (macrophages and neutrophils).



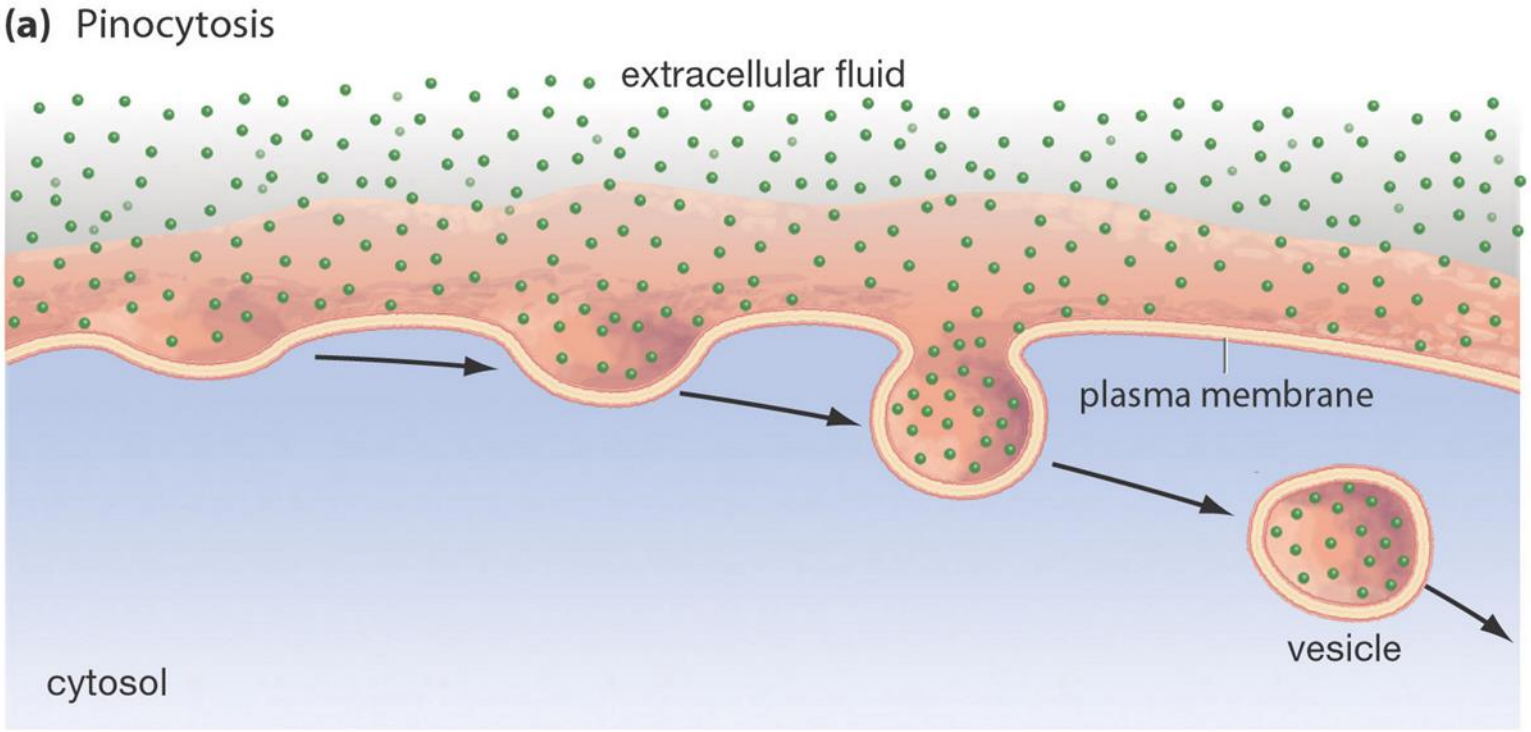
Endocytosis

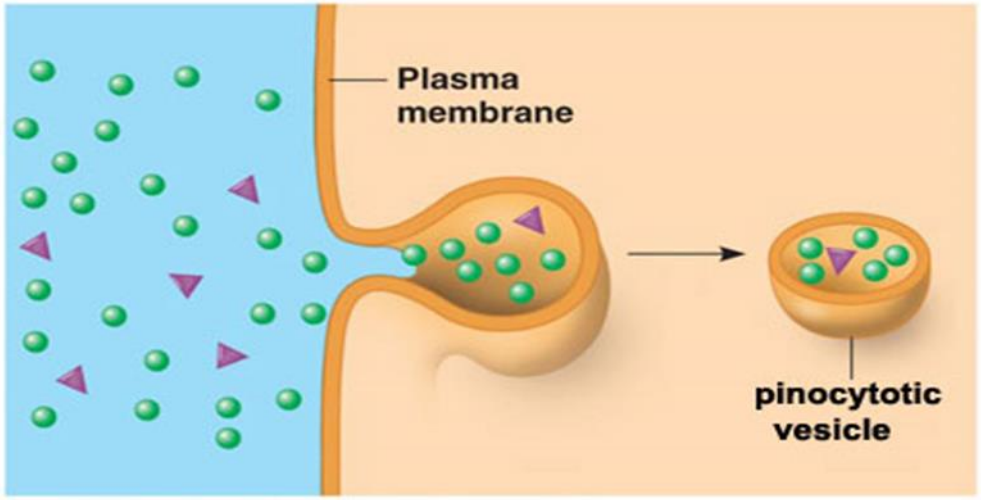
Pinocytosis

Most common form of endocytosis.

Cell drinking

Takes in **dissolved molecules** as a vesicle.

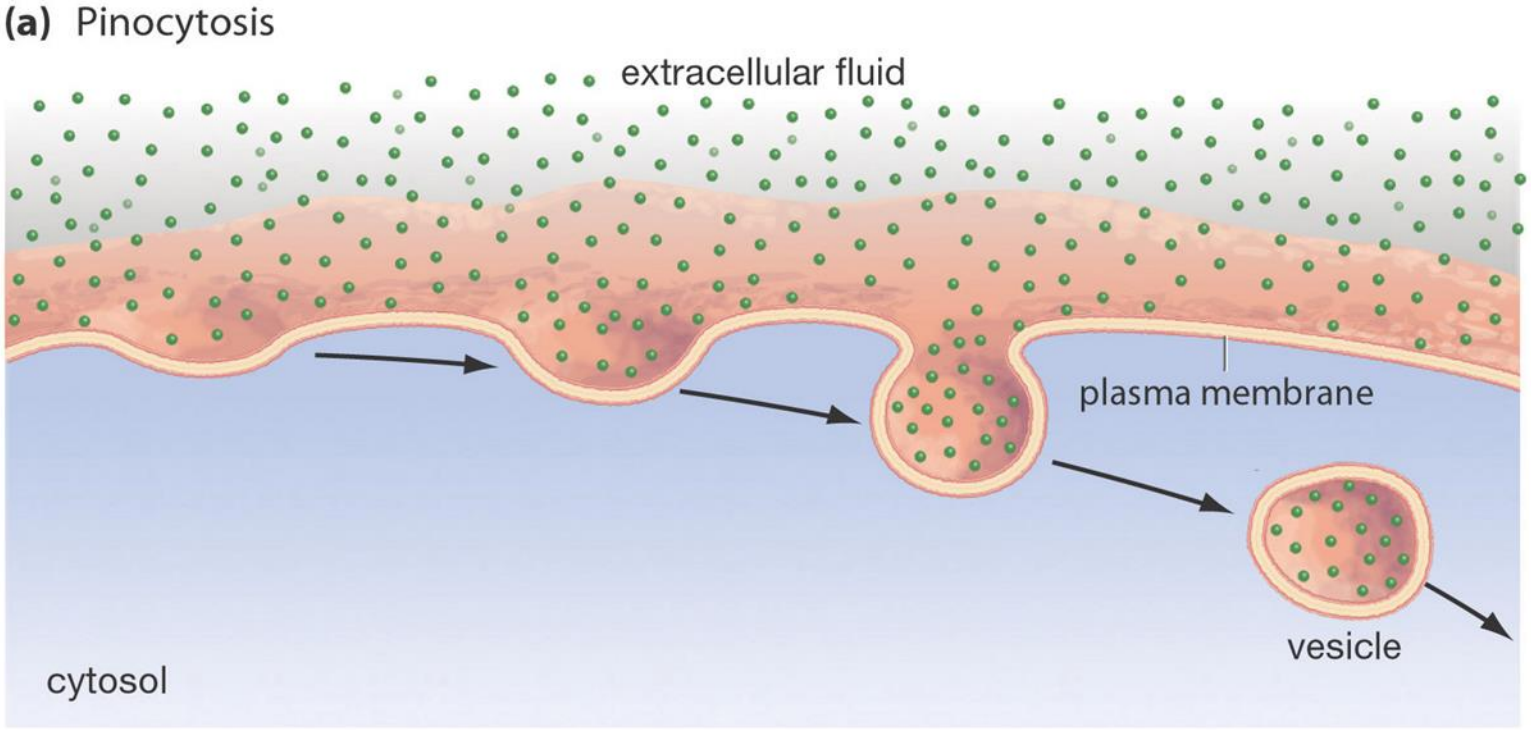




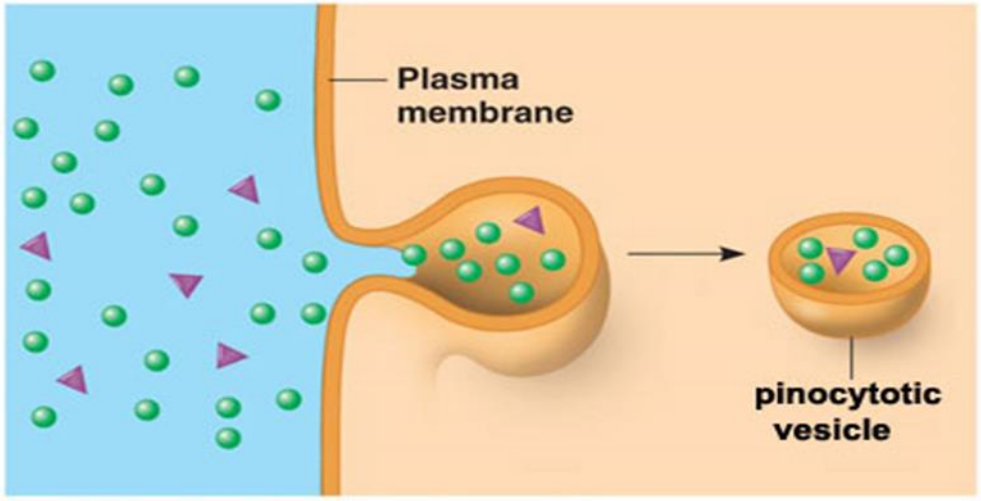
Endocytosis

Pinocytosis

Pinocytotic vesicles will later be joined the cell membrane.



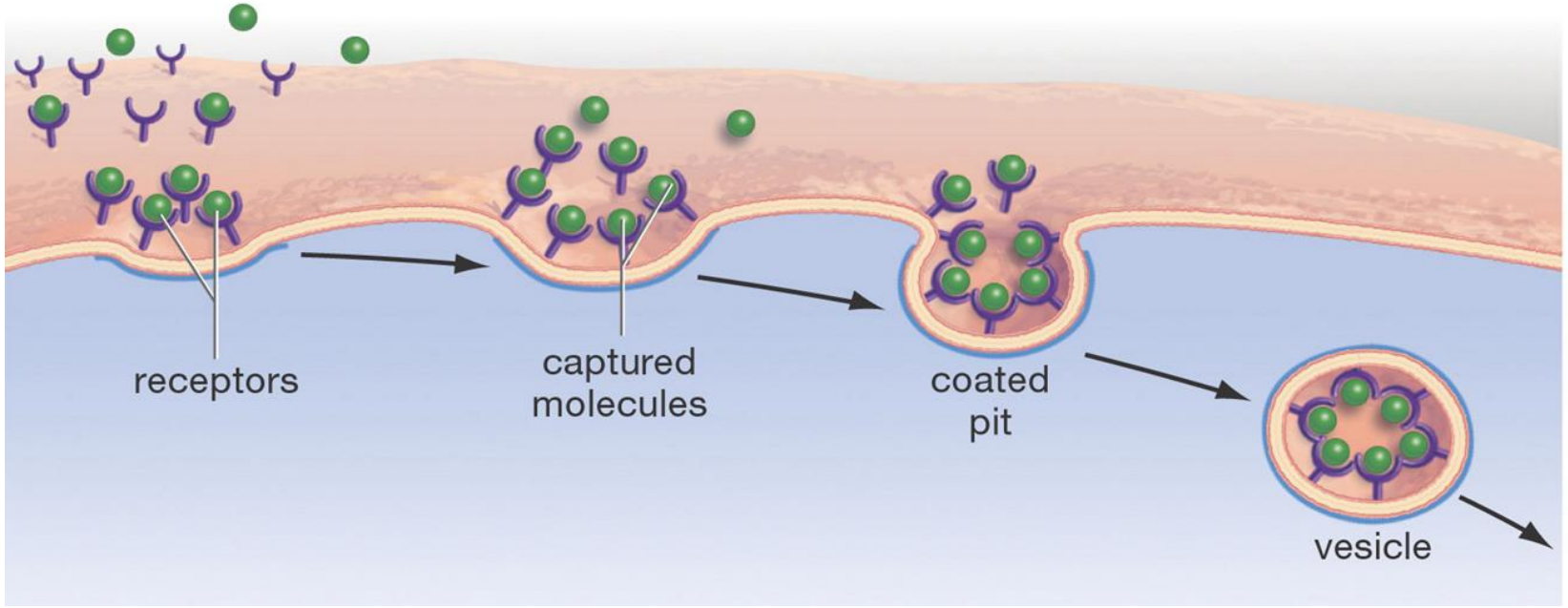
Endocytic-exocytic cycle



Endocytosis

Receptor-Mediated Endocytosis

Some integral proteins have **receptors** on their surface to recognize and take in hormones, **cholesterol**, etc.



Summary

- Active transport requires energy to move substances across a plasma membrane
- The sodium-potassium pump is a mechanism of active transport that moves Na^+ out of the cell and K^+ into the cell, both against a concentration gradient
- Vesicle transport is a type of active transport that uses vesicles to move large molecules into or out of cells.

Bacteria and plants have cell walls that prevent them from over-expanding.

In plants the pressure exerted on the cell wall is called Turgor pressure.

A protist like paramecium has contractile vacuoles that collect water flowing in and pump it out to prevent them from over-expanding.

Marine fishes pump salt out of their specialized gills so they do not dehydrate.

Animal cells are bathed in blood. Kidneys keep the blood isotonic by remove excess salt and water.

Explain how transport across the plasma membrane is related to the homeostasis of the cell.

Why can generally only very small, hydrophobic molecules across the cell membrane by simple diffusion?

What are the similarities and differences between channel proteins and carrier proteins?

Can the glucose simply diffuse across the cell membrane? Why or why not?

Define active transport

What is the main difference between passive and active transport?

Name two types of vesicle transport.

What are the similarities and differences between phagocytosis and pinocytosis?