Biology from an EE perspective
Lecture 8

Transport of molecules & ions across cell membranes

Membrane potential in electrically active tissue

Electric potential change to muscle contraction

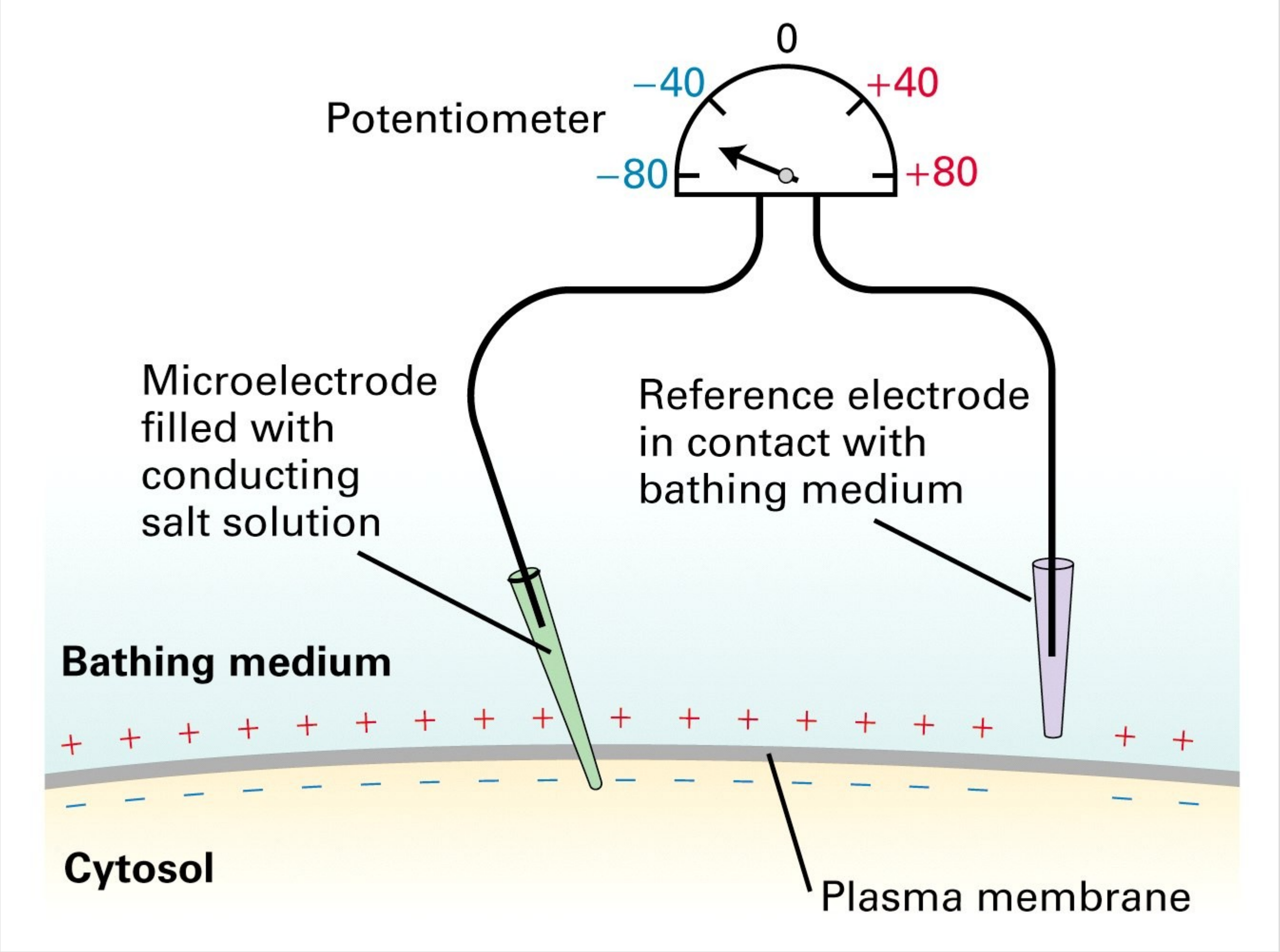
Rakesh K Lal

Lecture Overview

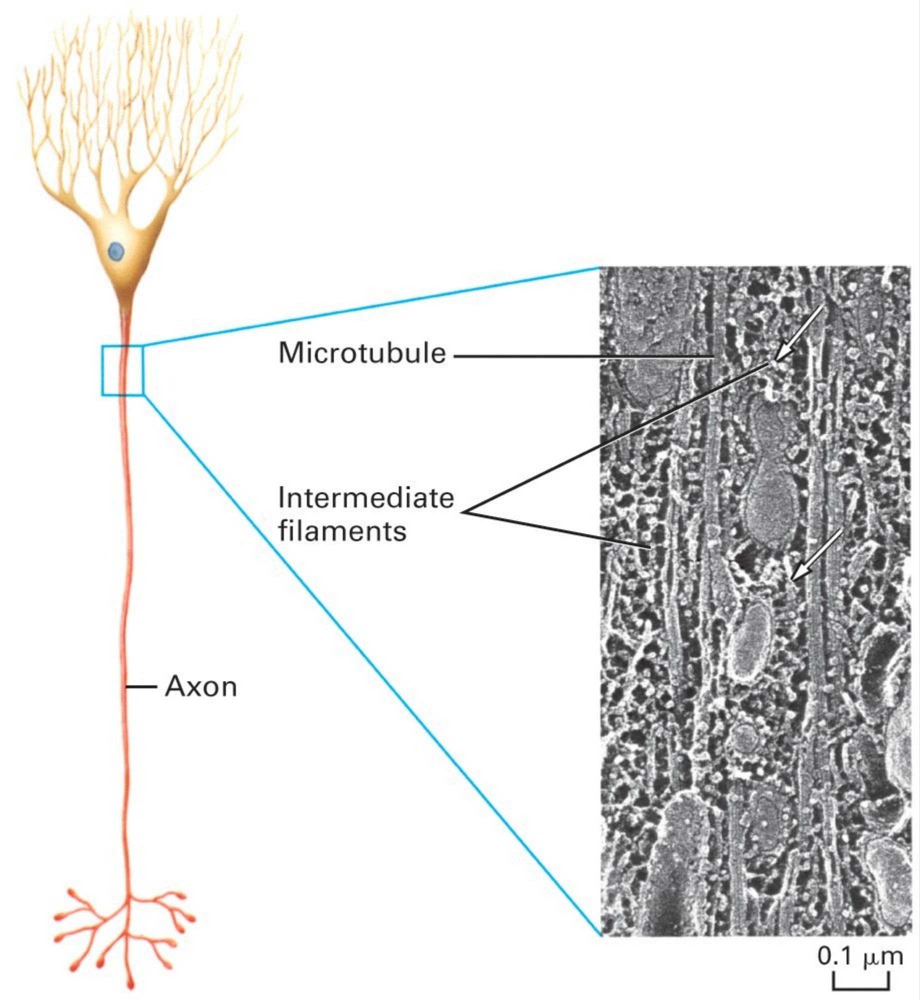
- Continue with looking at molecules that help set up potentials
- Look at other electrically active tissue
- Discuss the mechanisms by which muscles create force

Figure credits: Unless mentioned, all jpeg images are from the site of *Molecular Cell Biology* by Lodish et al., published by W H Freeman & Co

Measuring potential



Neuron structure revisited



Transport across membranes

TABLE 7-1 Mechanisms for Transporting Ions and Small Molecules Across Cell Membranes

	Transport Mechanism			
Property	**Passive Diffusion**	**Facilitated Diffusion**	**Active Transport**	**Cotransport***
Requires specific protein	−	+	+	+
Solute transported against its gradient	−	−	+	+
Coupled to ATP hydrolysis	−	−	+	−
Driven by movement of a cotransported ion down its gradient	−	−	−	+
Examples of molecules transported	O_2, CO_2, steroid hormones, many drugs	Glucose and amino acids (uniporters); ions and water (channels)	Ions, small hydrophilic molecules, lipids (ATP-powered pumps)	Glucose and amino acids (symporters); various ions and sucrose (antiporters)

*Also called *secondary active transport*.

Ionic concentrations

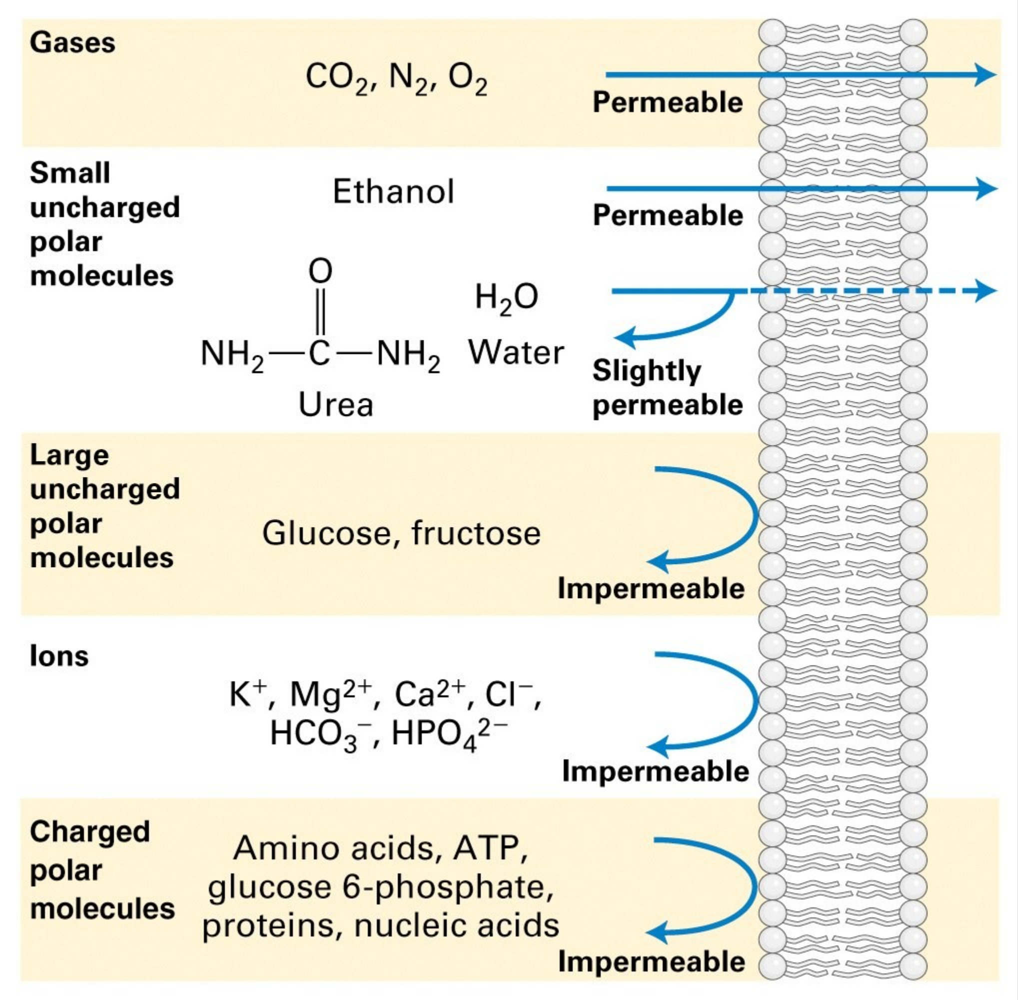
TABLE 7-2 Typical Intracellular and Extracellular Ion Concentrations

Ion	Cell (mM)	Blood (mM)
MAMMALIAN CELL (VERTEBRATE)		
K^+	139	4
Na^+	12	145
Cl^-	4	116
HCO_3^-	12	29
X^-	138	9
Mg^{2+}	0.8	1.5
Ca^{2+}	<0.0002	1.8

*The large nerve axon of the squid has been widely used in studies of the mechanism of conduction of electric impulses.

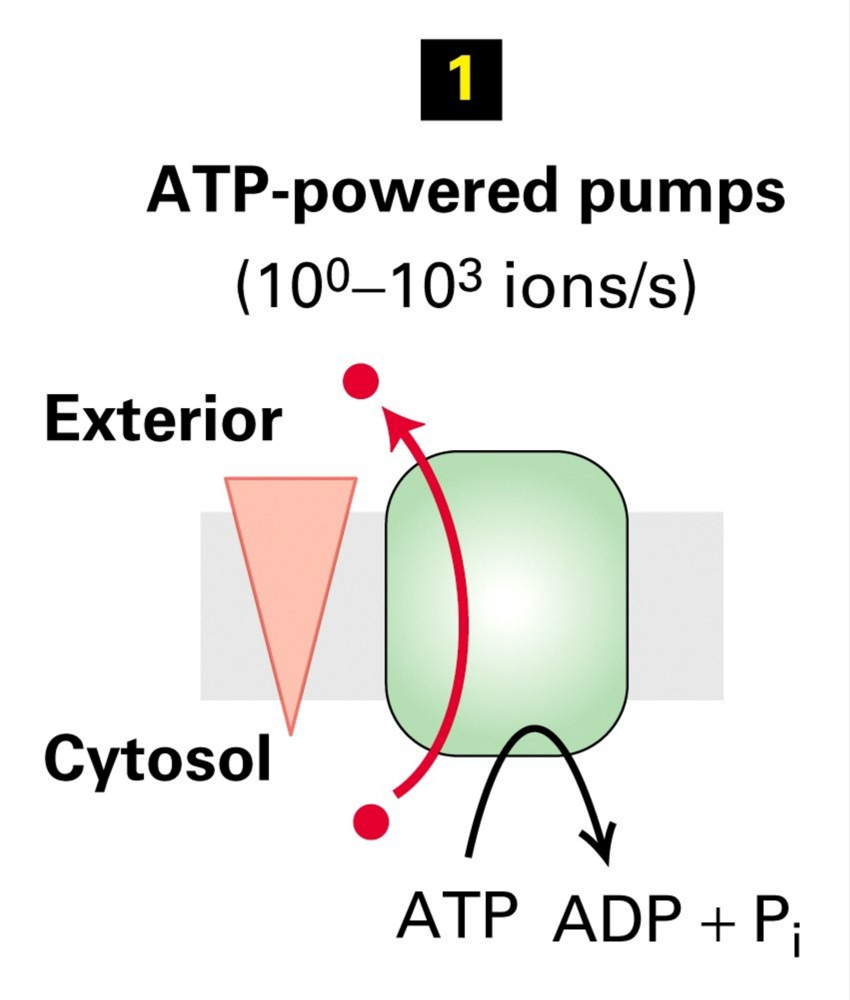
†X^- represents proteins, which have a net negative charge at the neutral pH of blood and cells.

How does the cell maintain potential?



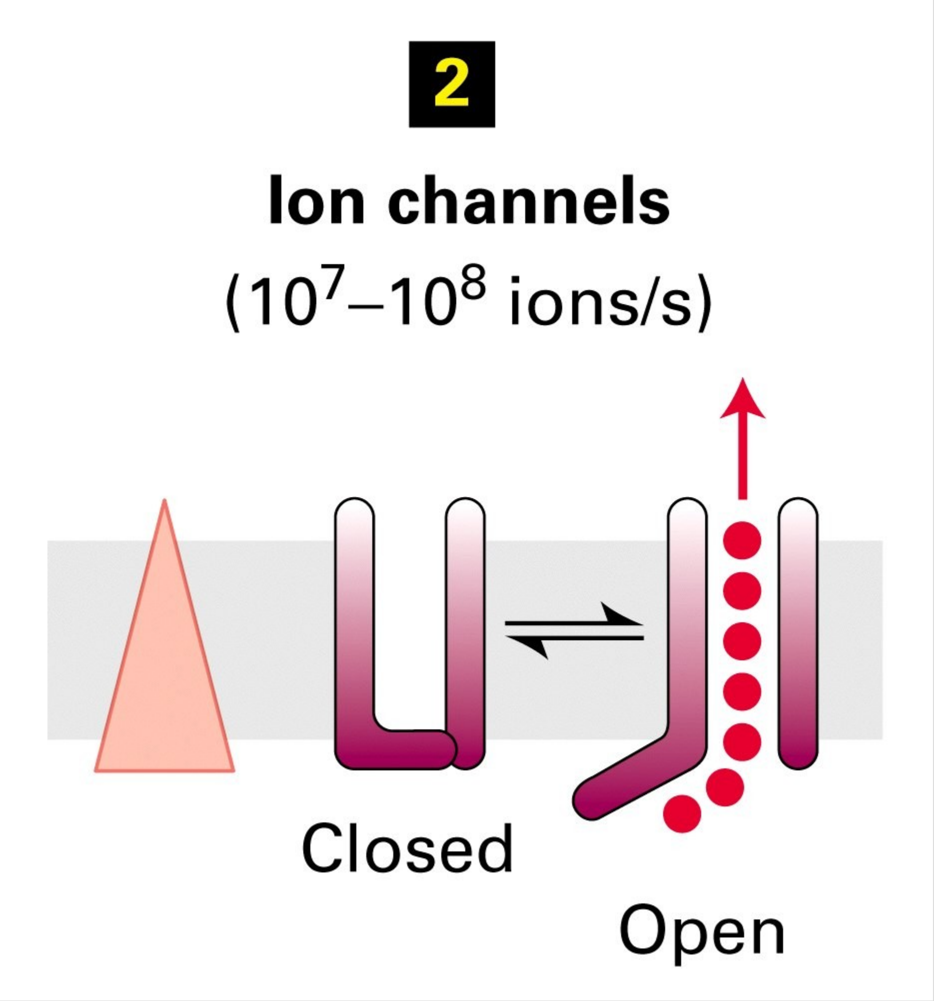
Proteins that enable molecular transport

Pumps



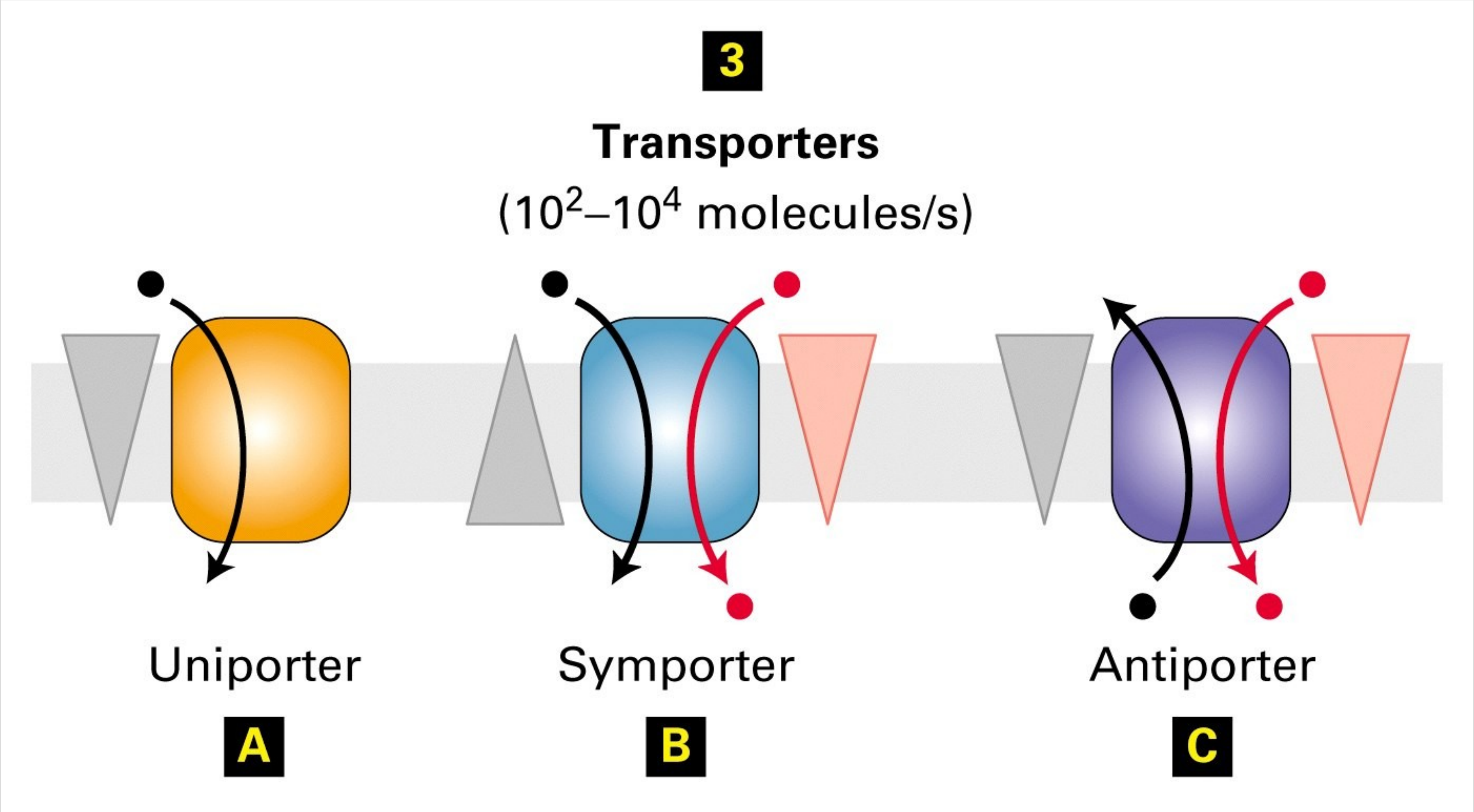
Proteins that enable molecular transport

Channels

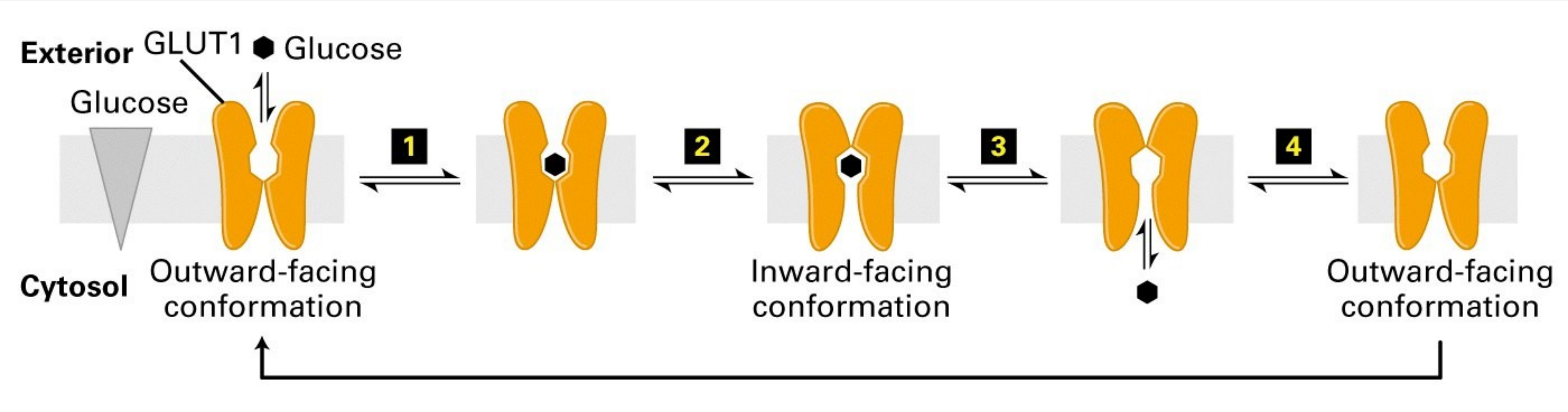


Proteins that enable molecular transport

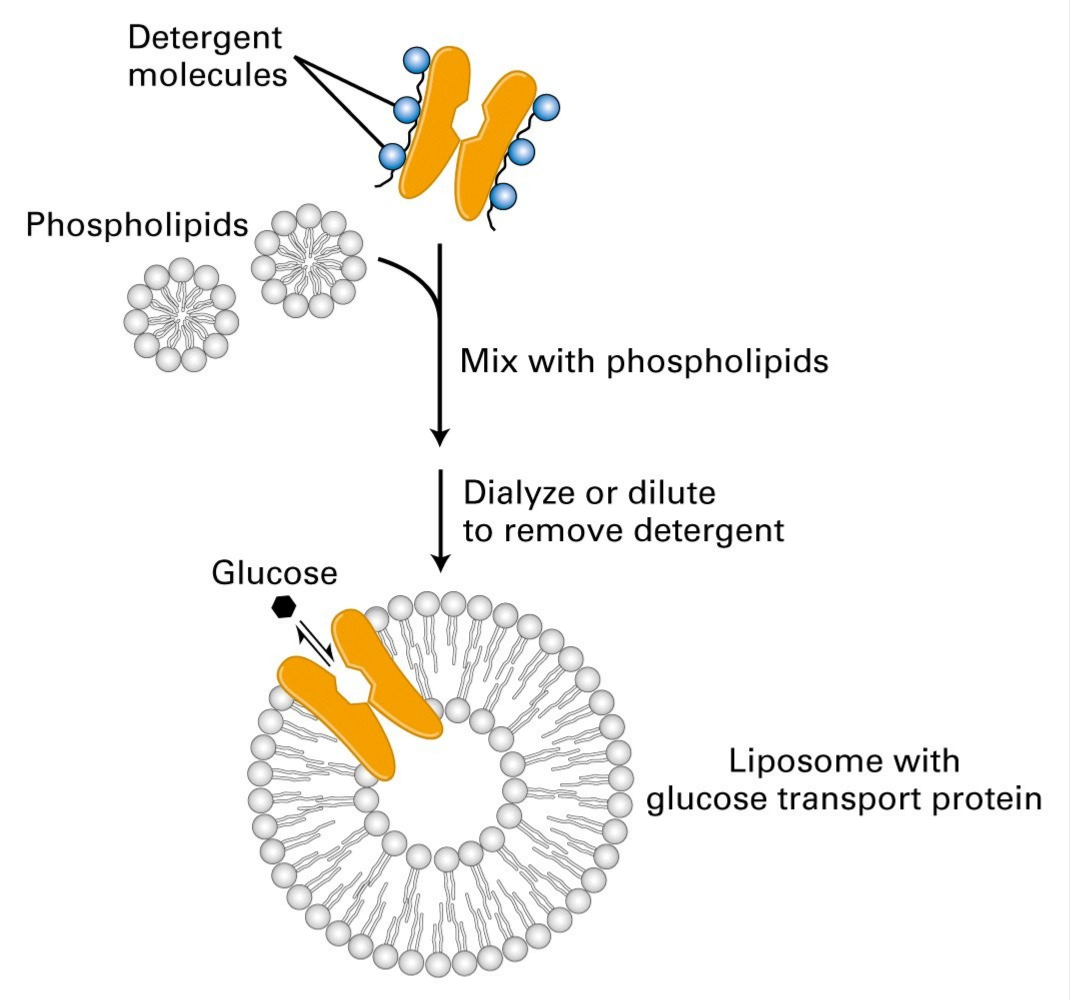
Transporters



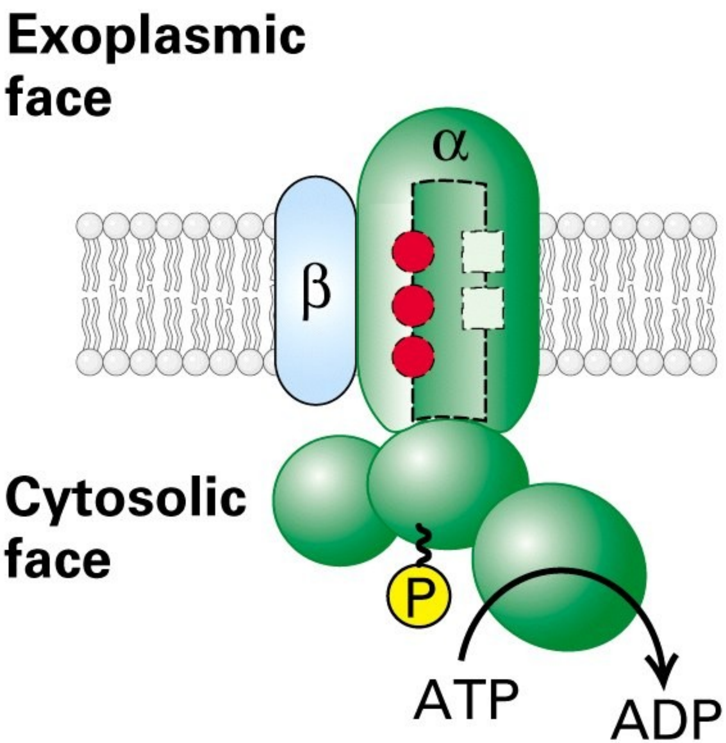
Glucose transport



How does one check these things out?



Ion pump



P-class pumps

Plasma membrane of plants, fungi, bacteria (H^+ pump)

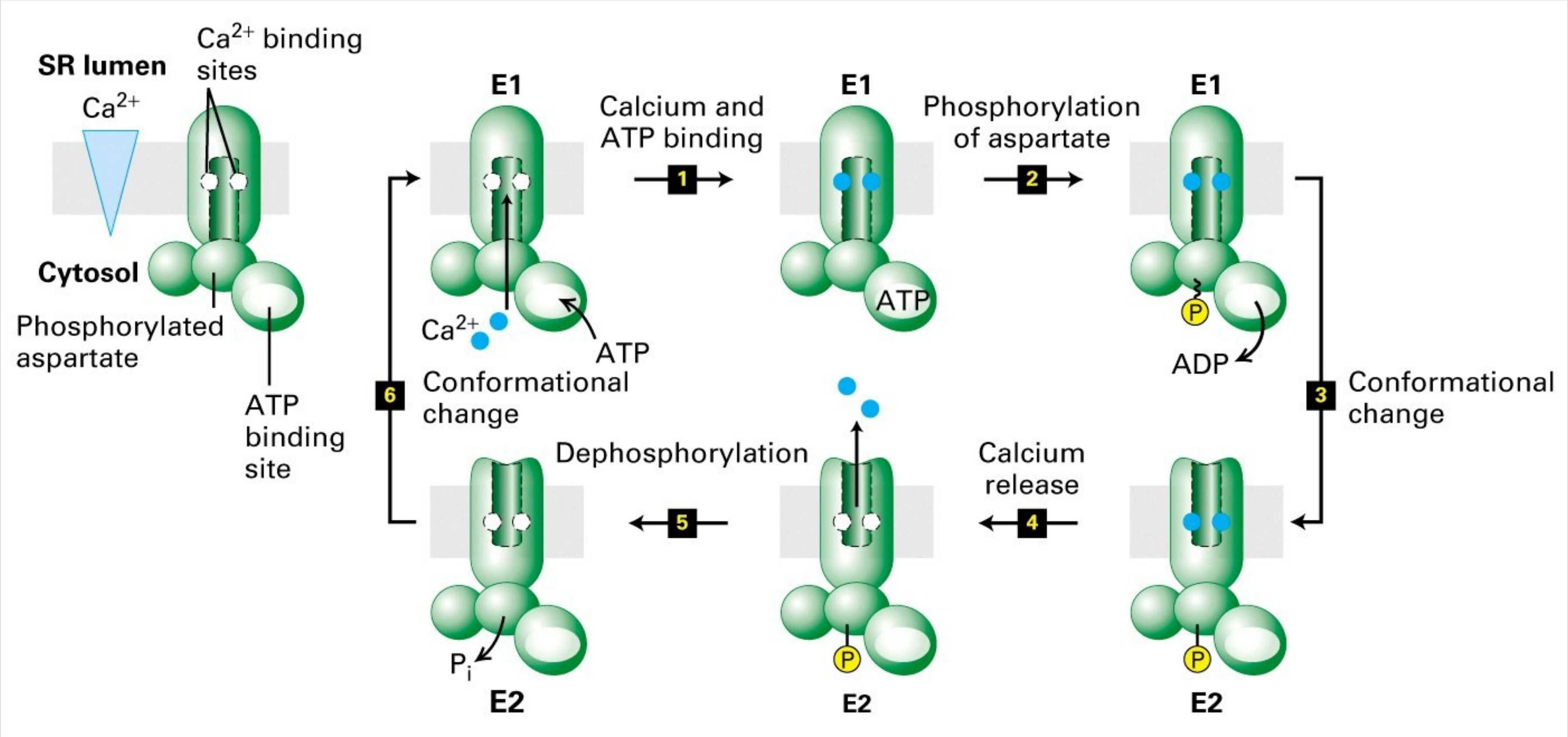
Plasma membrane of higher eukaryotes (Na^+/K^+ pump)

Apical plasma membrane of mammalian stomach (H^+/K^+ pump)

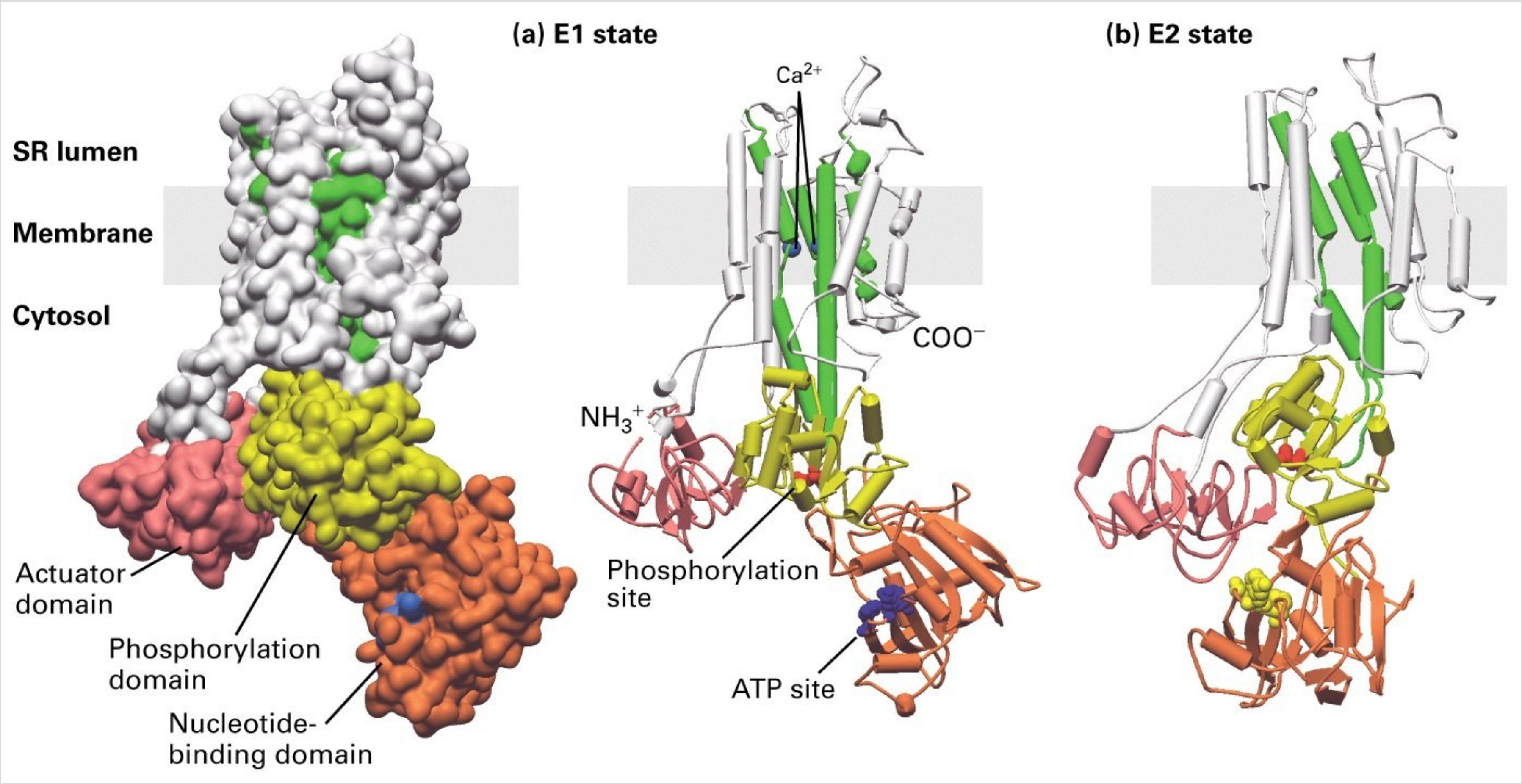
Plasma membrane of all eukaryotic cells (Ca^{2+} pump)

Sarcoplasmic reticulum membrane in muscle cells (Ca^{2+} pump)

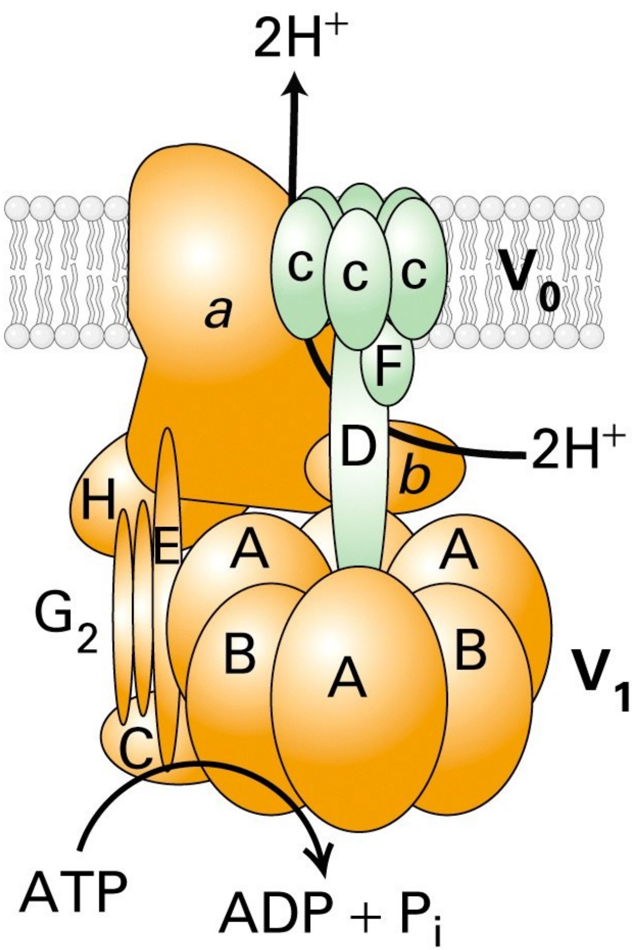
Calcium pump



Molecular picture



Proton pumps



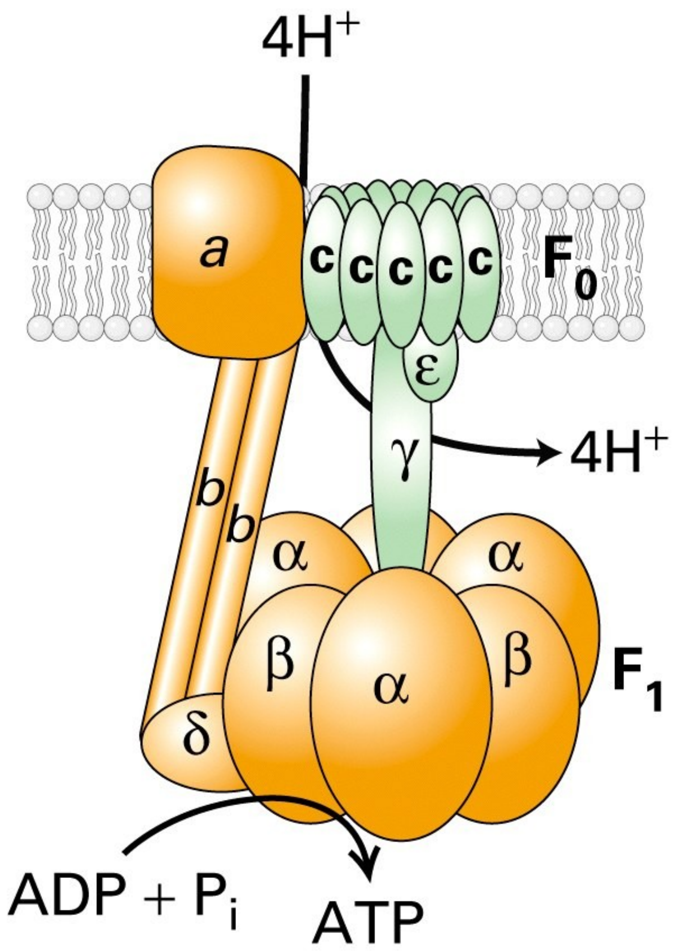
V-class proton pumps

Vacuolar membranes in plants, yeast, other fungi

Endosomal and lysosomal membranes in animal cells

Plasma membrane of osteoclasts and some kidney tubule cells

Proton pumps



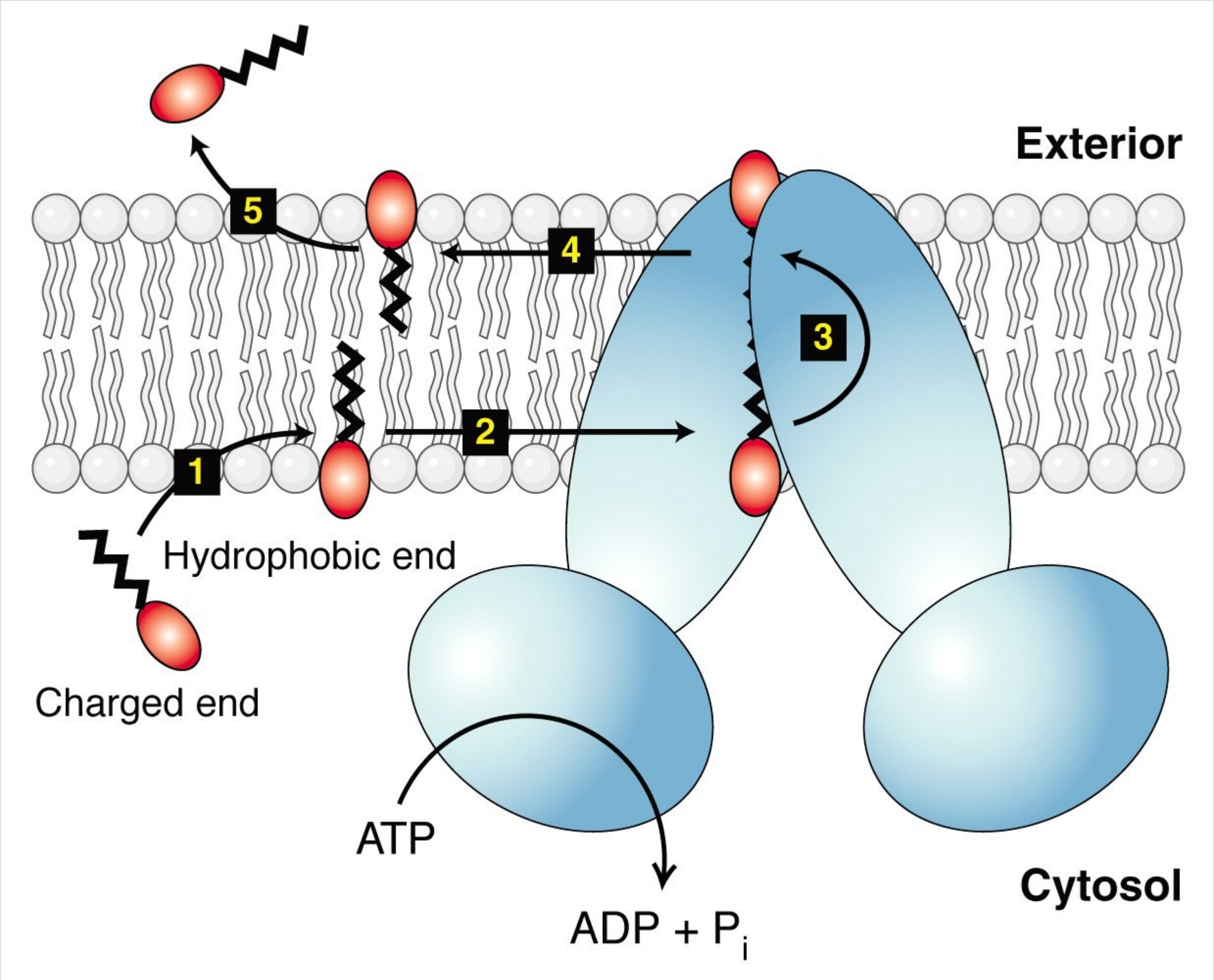
F-class proton pumps

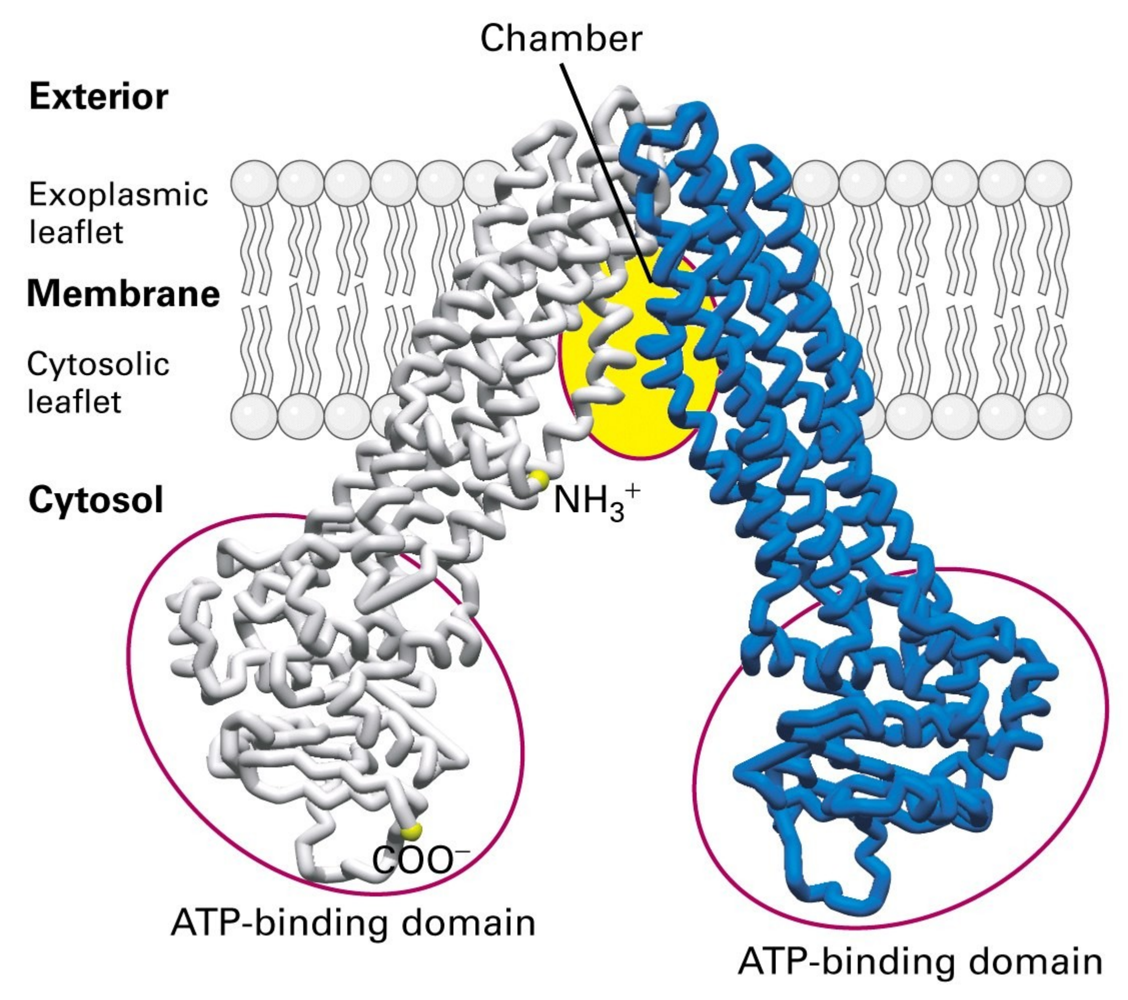
Bacterial plasma membrane

Inner mitochondrial membrane

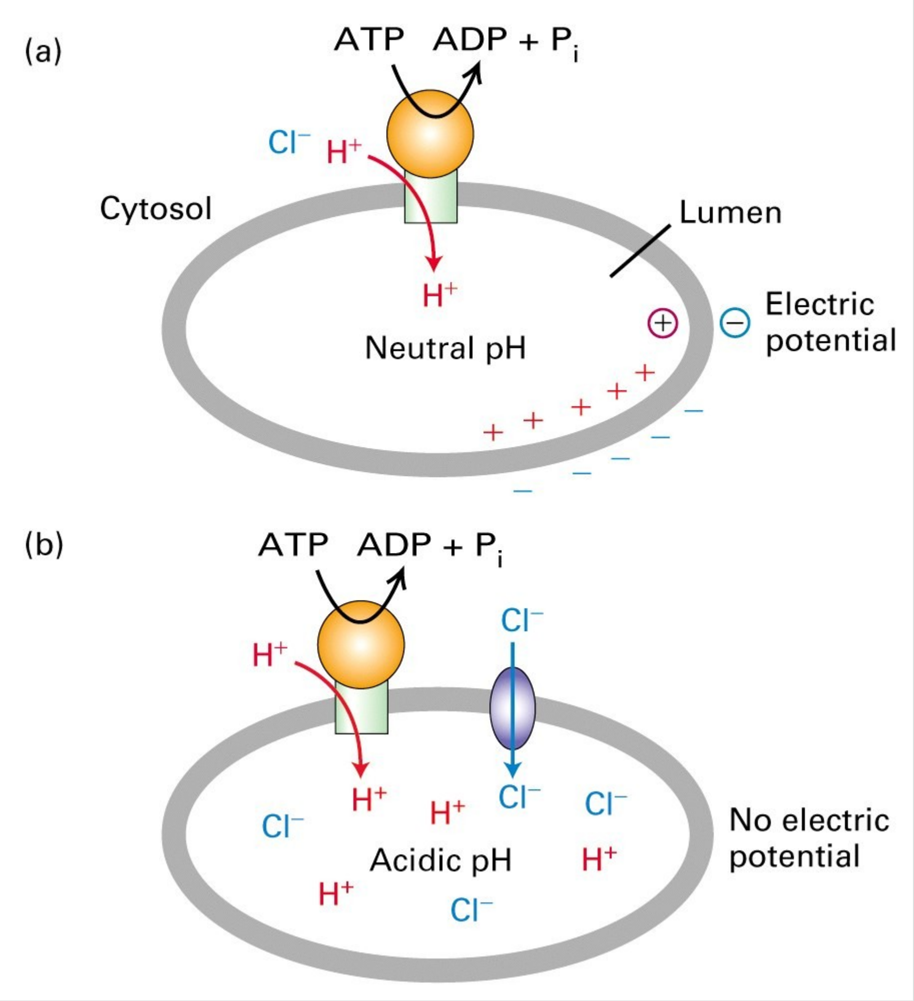
Thylakoid membrane of chloroplast

Transport of molecules with hydrophobic and hydrophilic parts

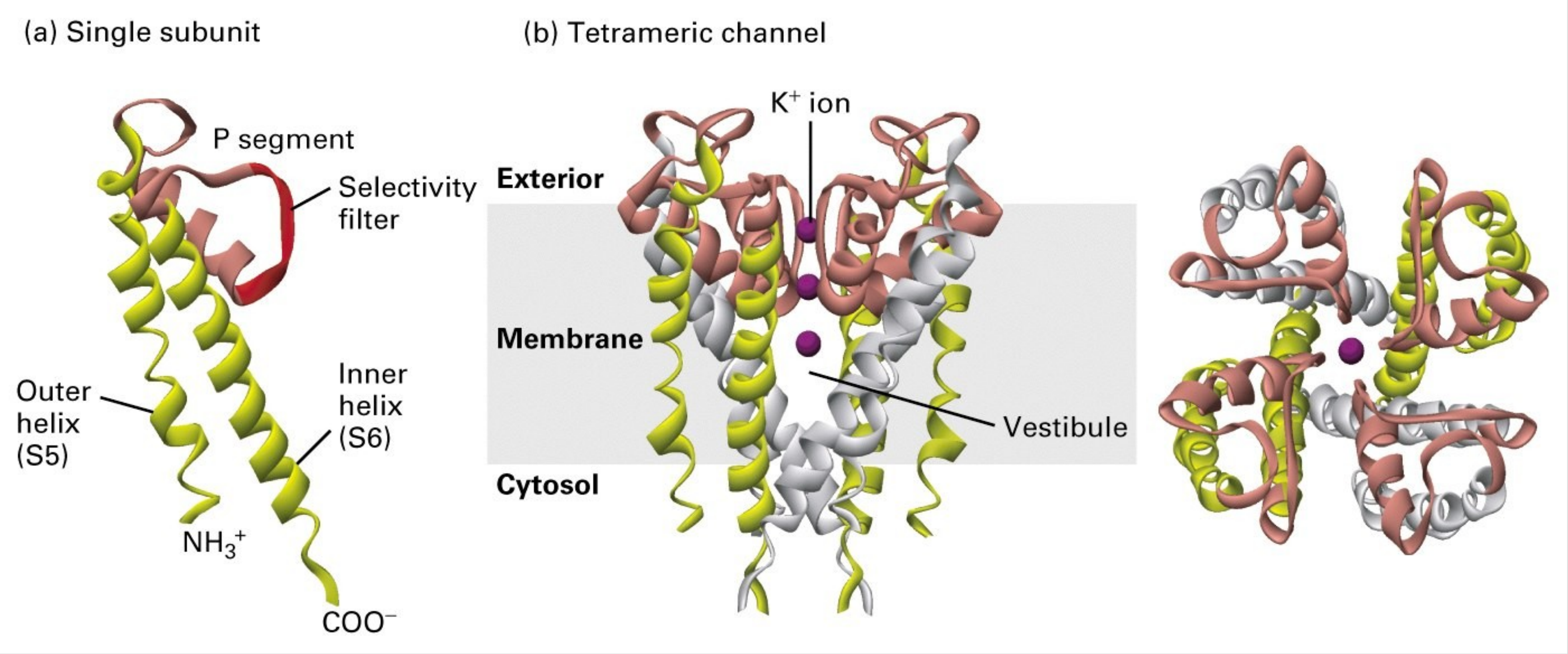



Chamber
Exterior
Exoplasmic
leaflet
Membrane
Cytosolic
leaflet
Cytosol
NH_3^+
COO^-
ATP-binding domain
ATP-binding domain

Charge neutrality

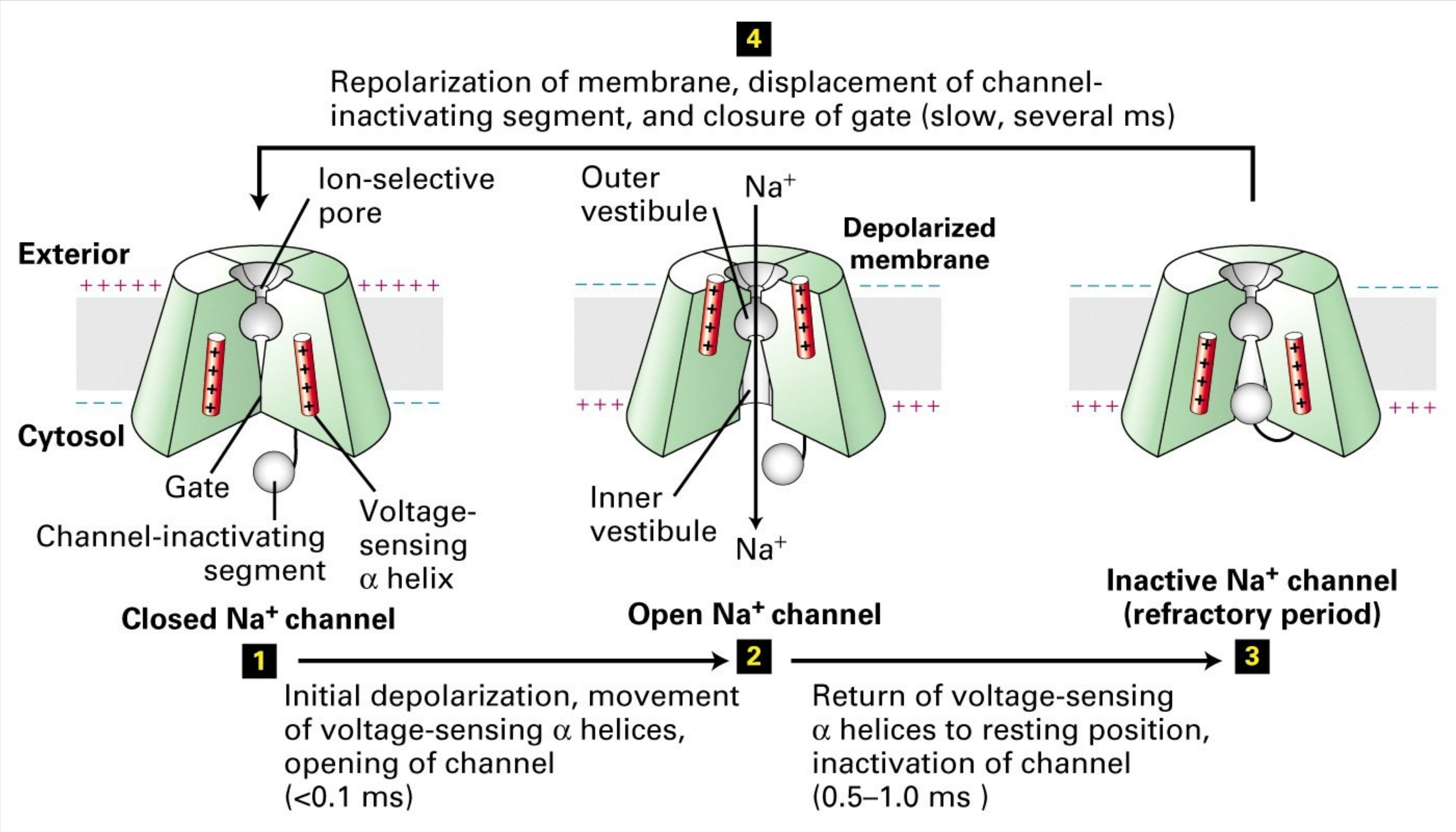


Channels

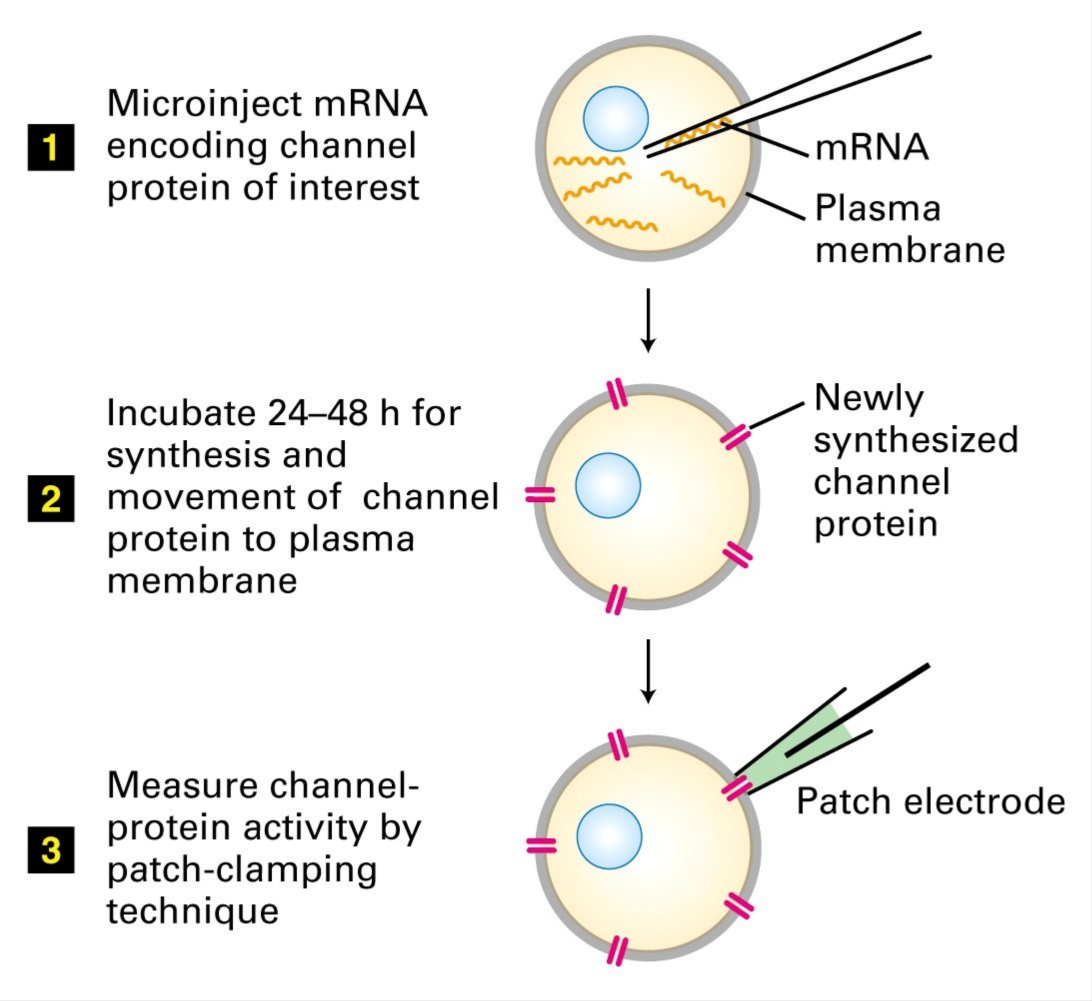


(a) Single subunit
(b) Tetrameric channel
P segment
Selectivity filter
Outer helix (S5)
Inner helix (S6)
NH3+
COO−
K+ ion
Exterior
Membrane
Cytosol
Vestibule

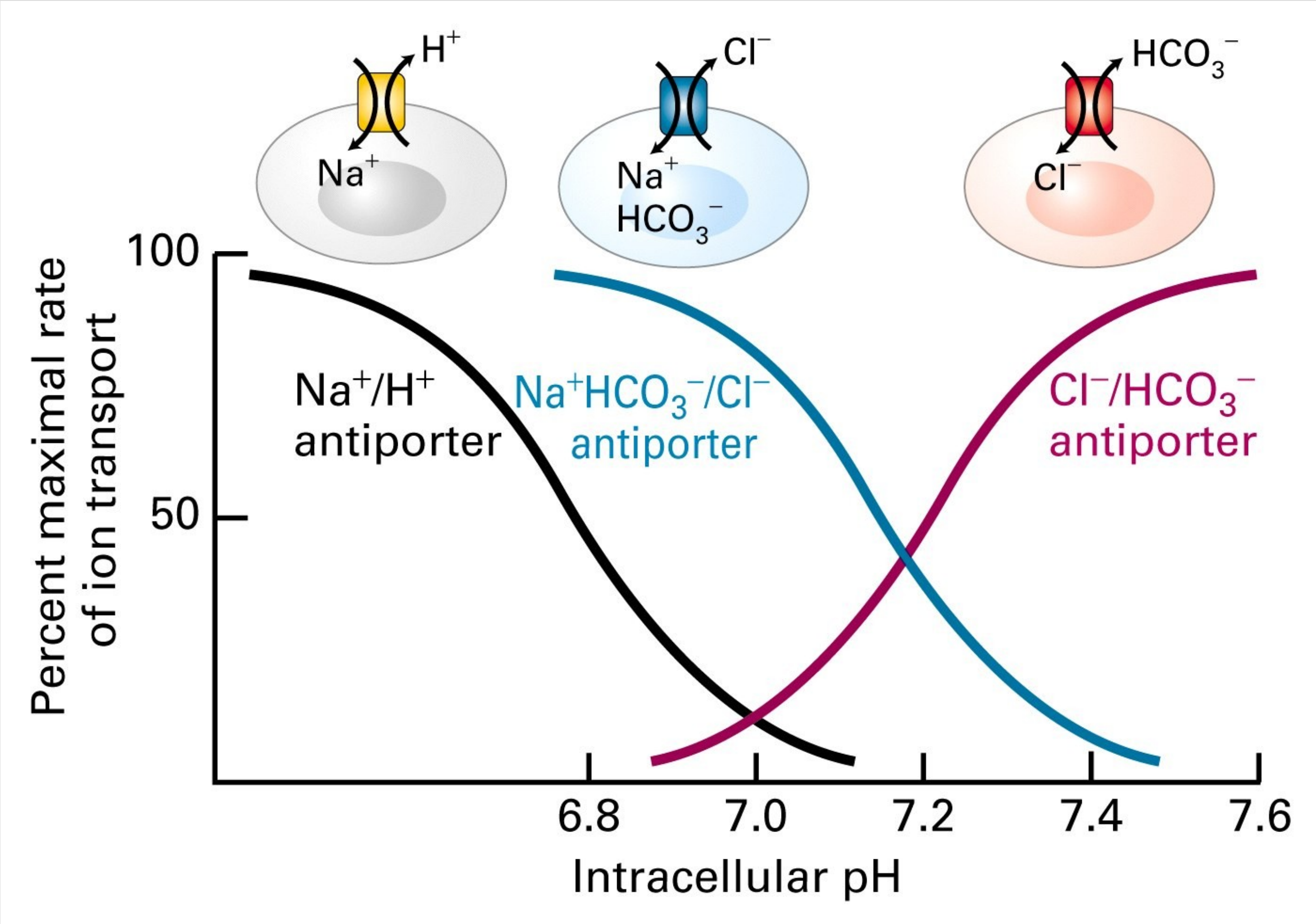
Gated channels



How channel proteins studied

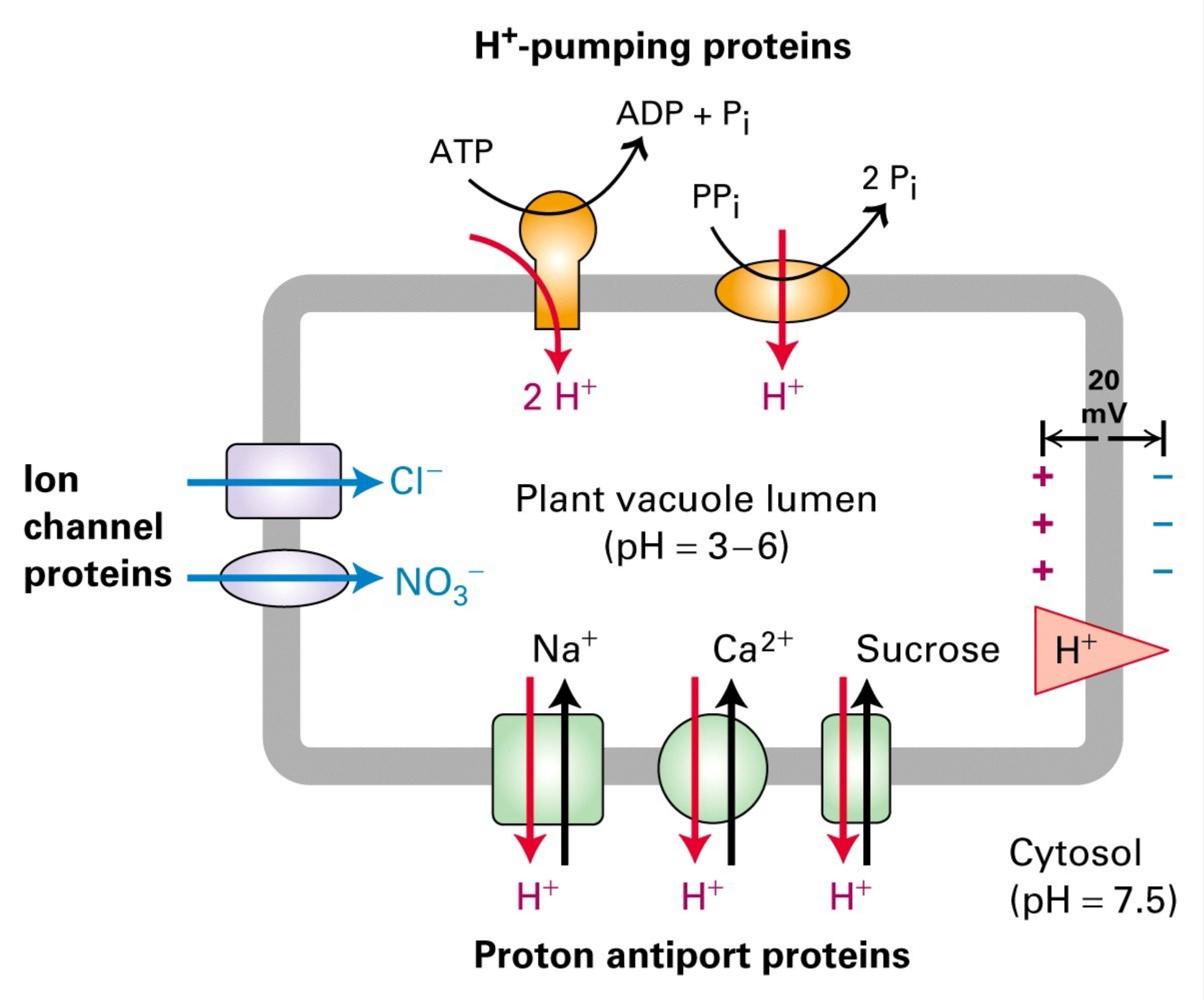


Antiporter

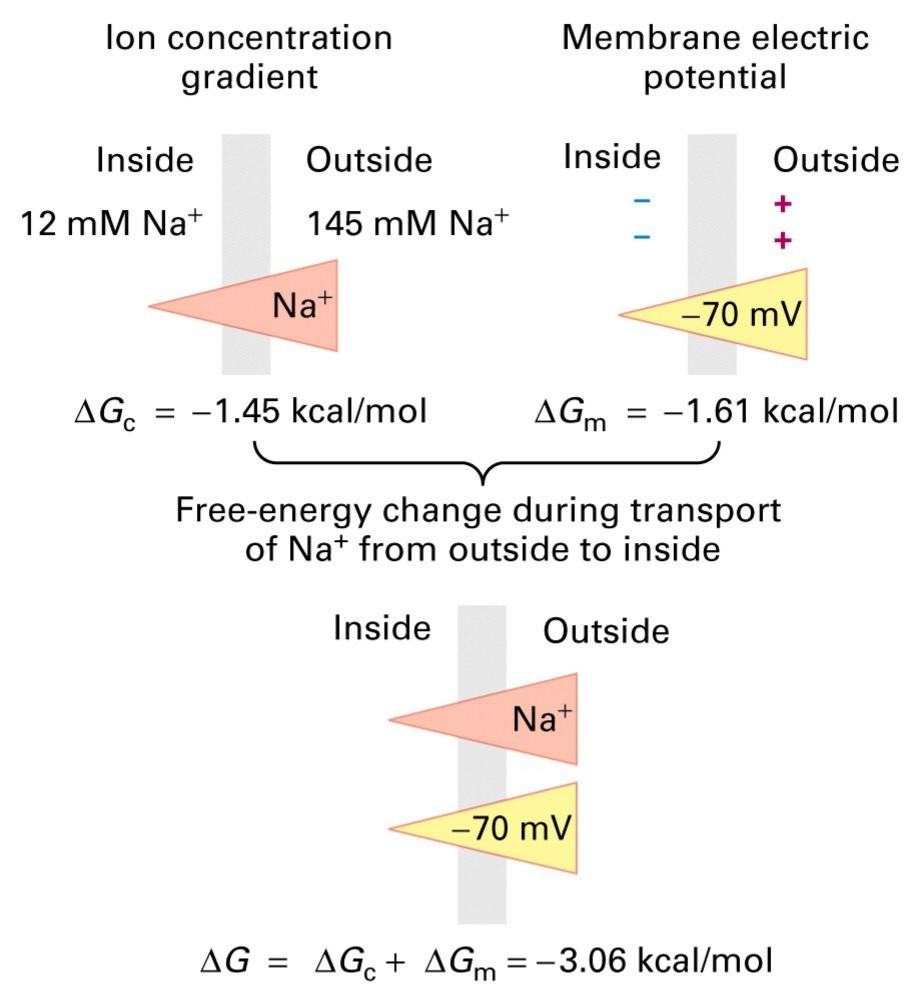


H+
Na+
Cl−
Na+
HCO3−
HCO3−
Cl−
100
50
Percent maximal rate of ion transport
Na+/H+ antiporter
Na+HCO3−/Cl− antiporter
Cl−/HCO3− antiporter
6.8
7.0
7.2
7.4
7.6
Intracellular pH

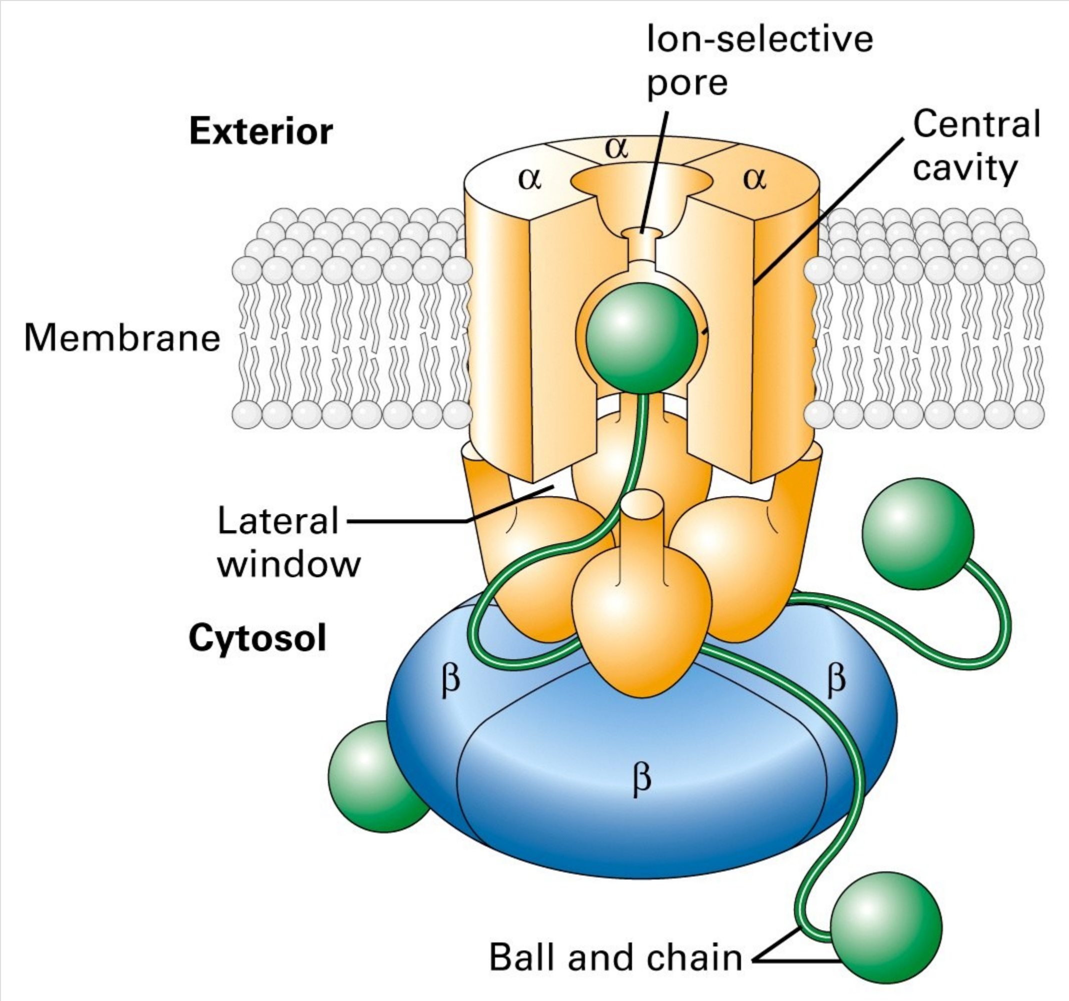
Non-electrically excitable tissue also could have some internal potential



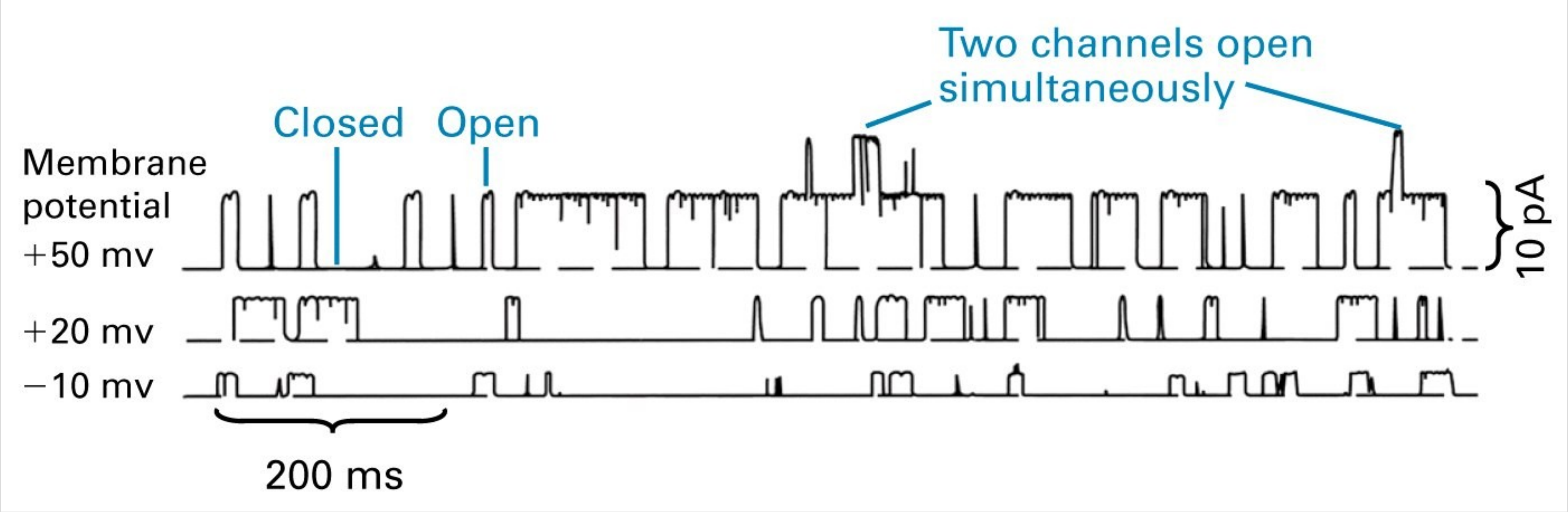
Energy from ionic gradient important in many situations including photosynthesis



Gated channels

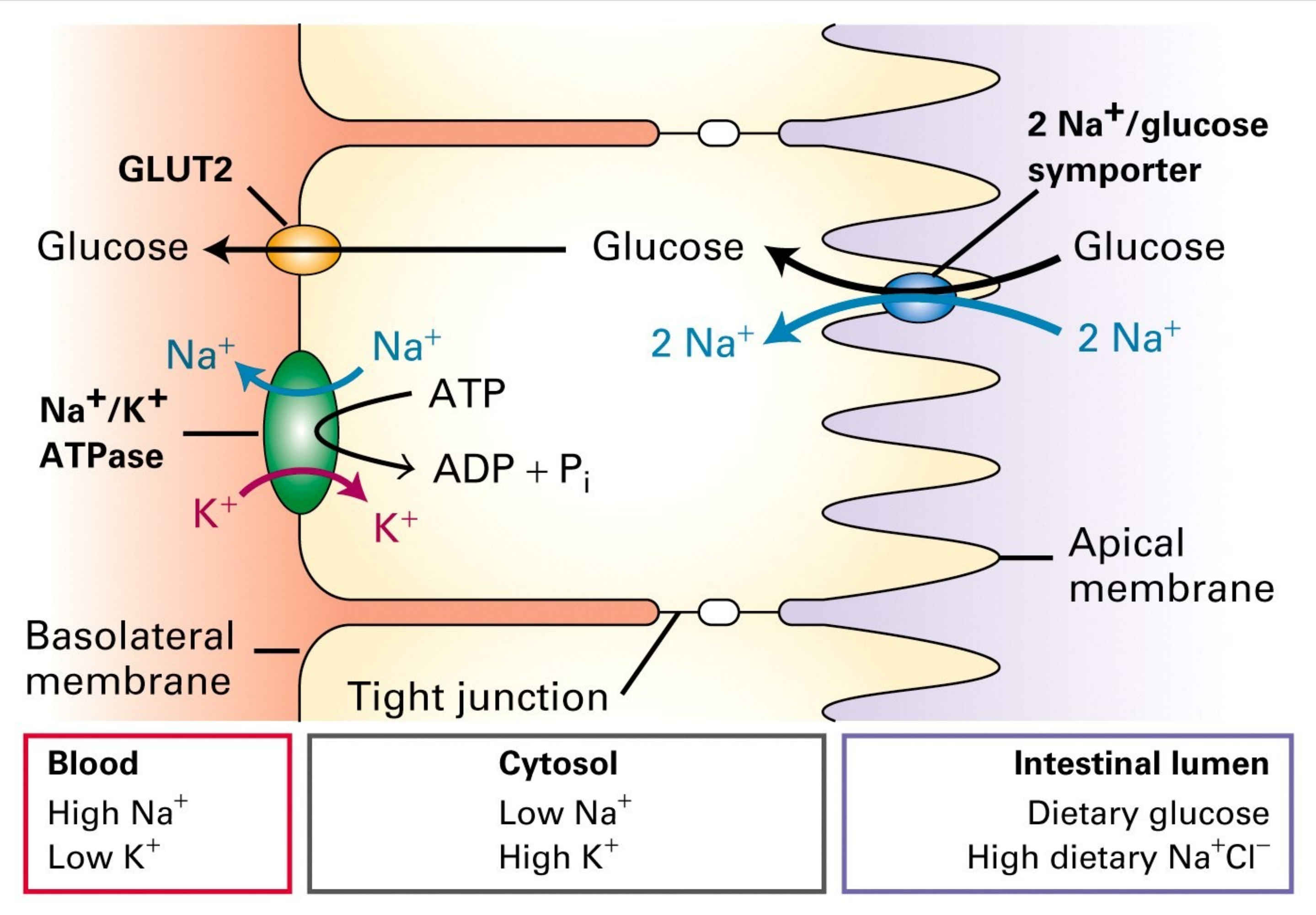


Random Telegraph Signals

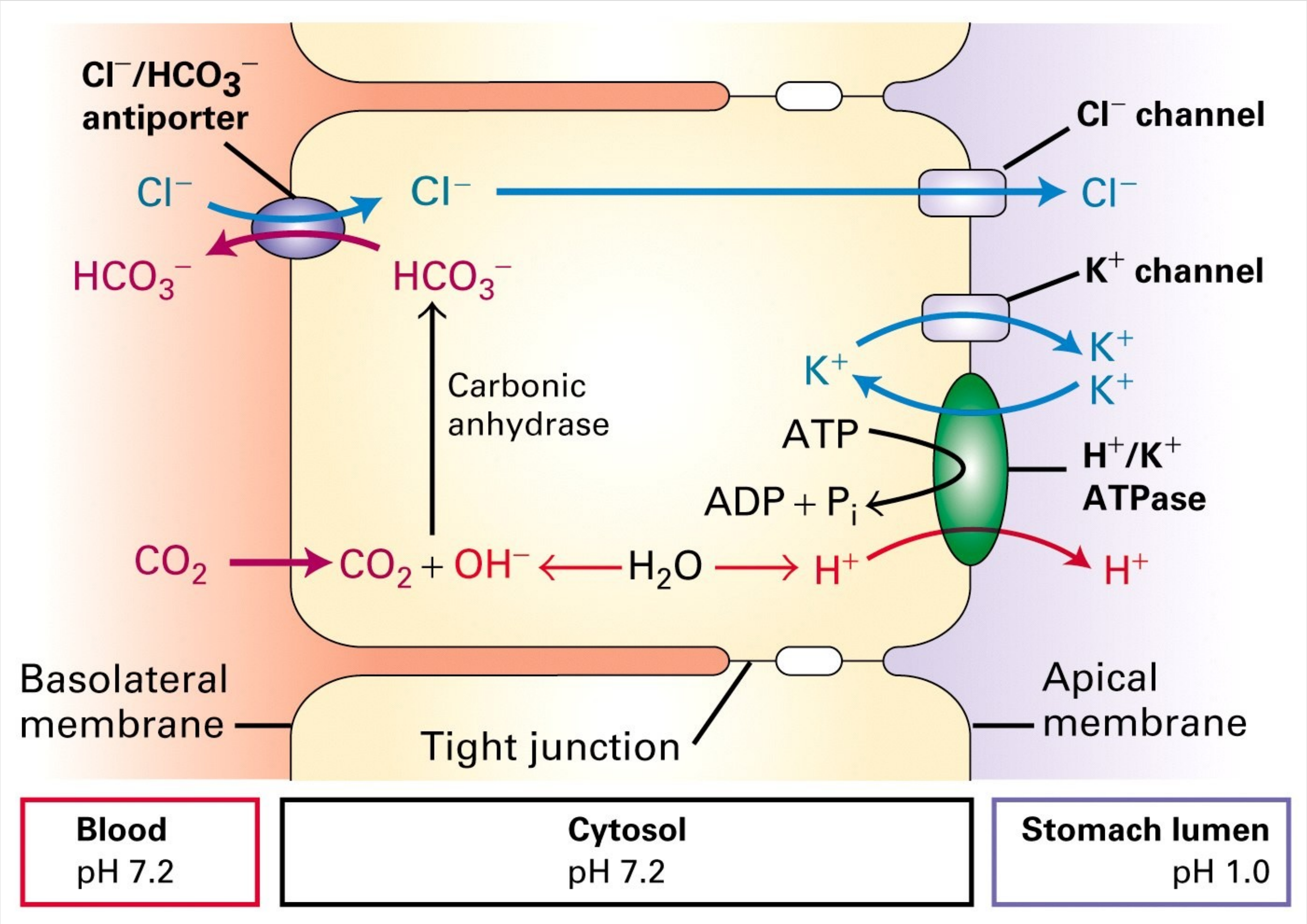


Ion pumps in other tissue

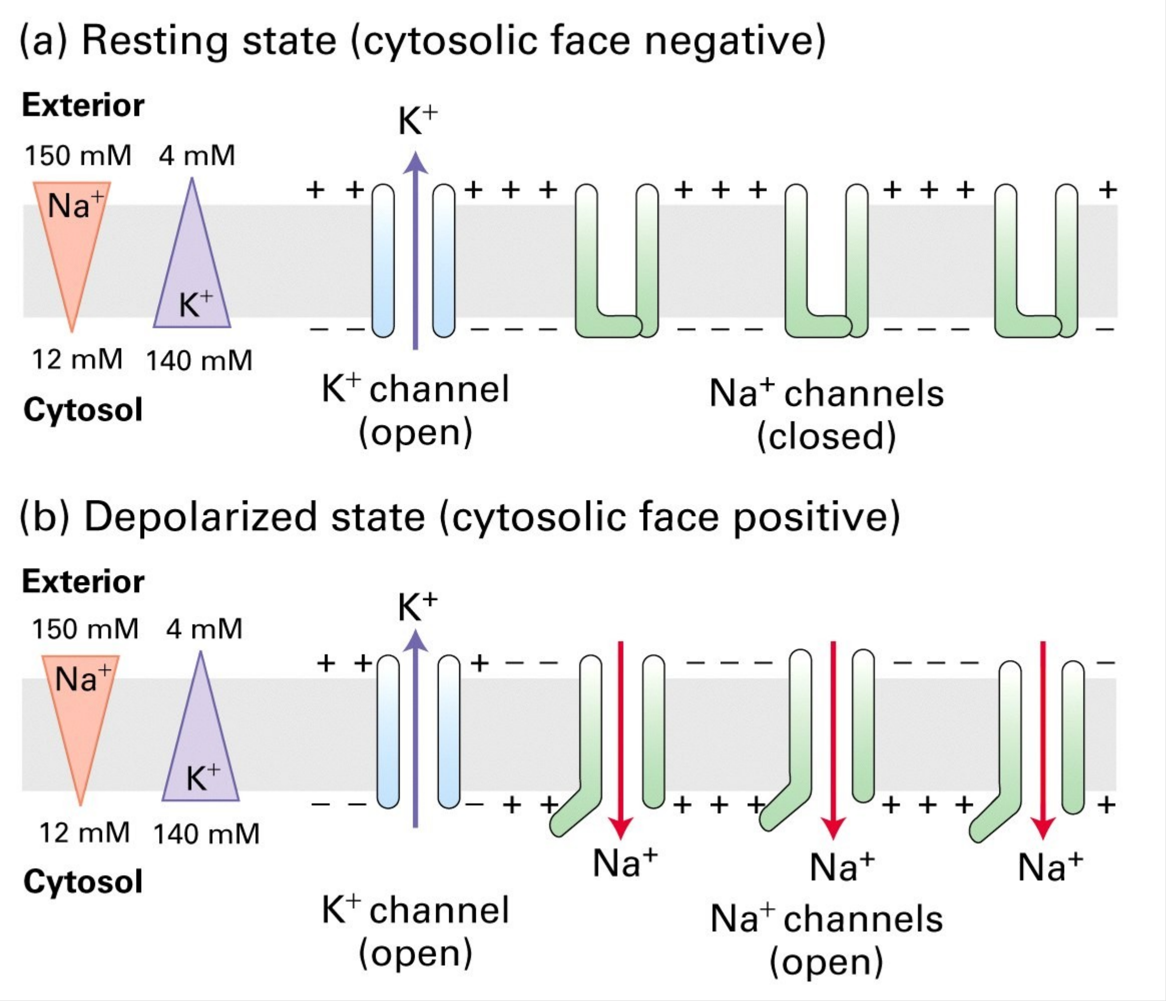
Glucose intake



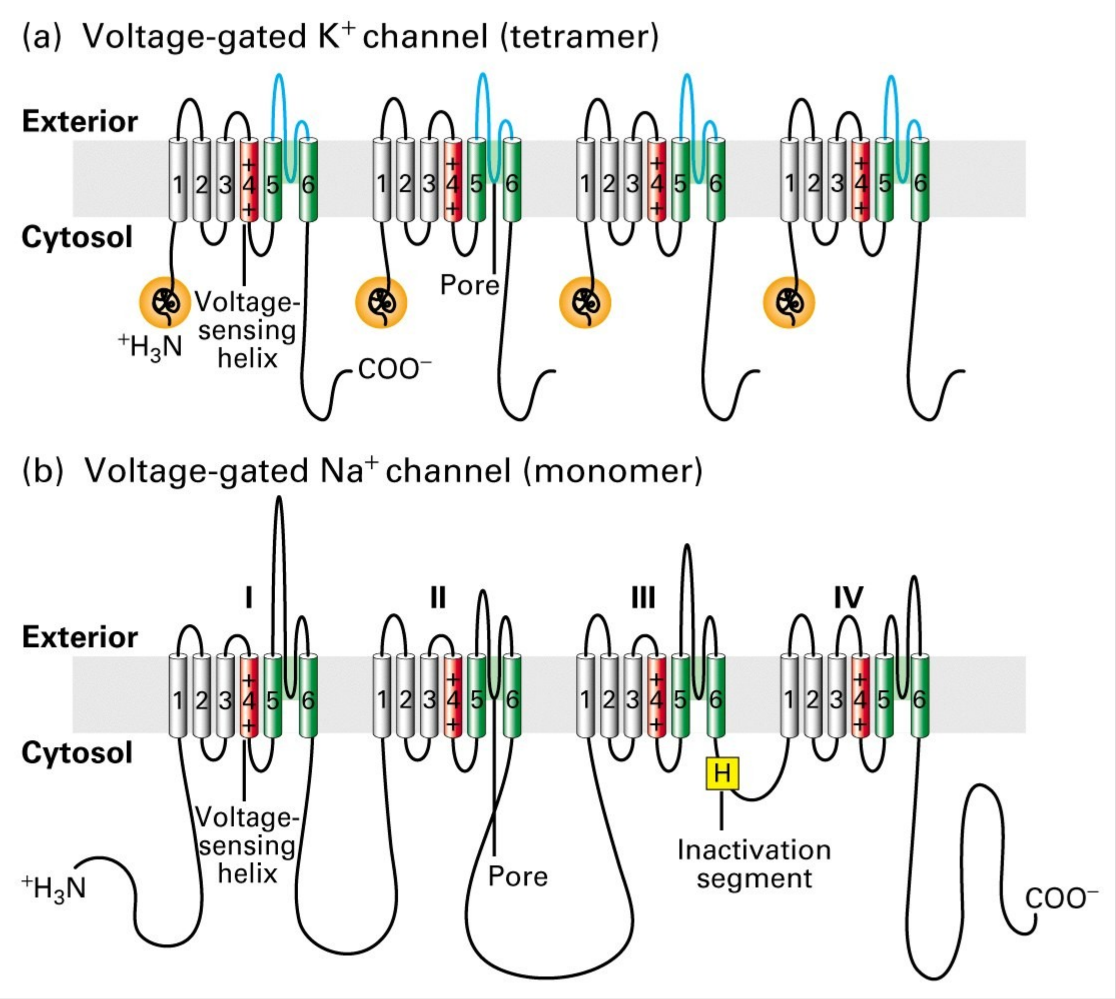
Ion pumps in other tissue



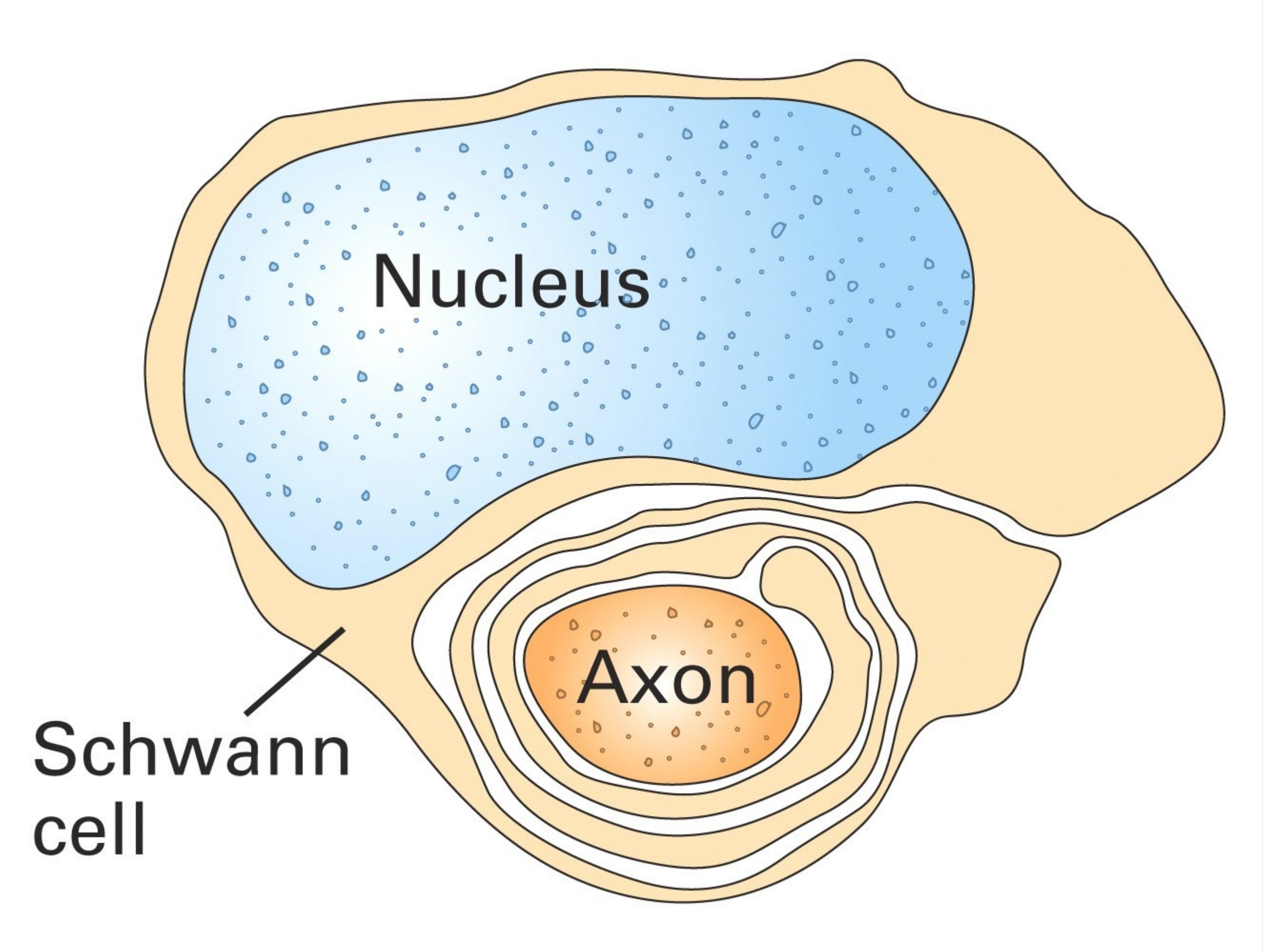
Gated channels



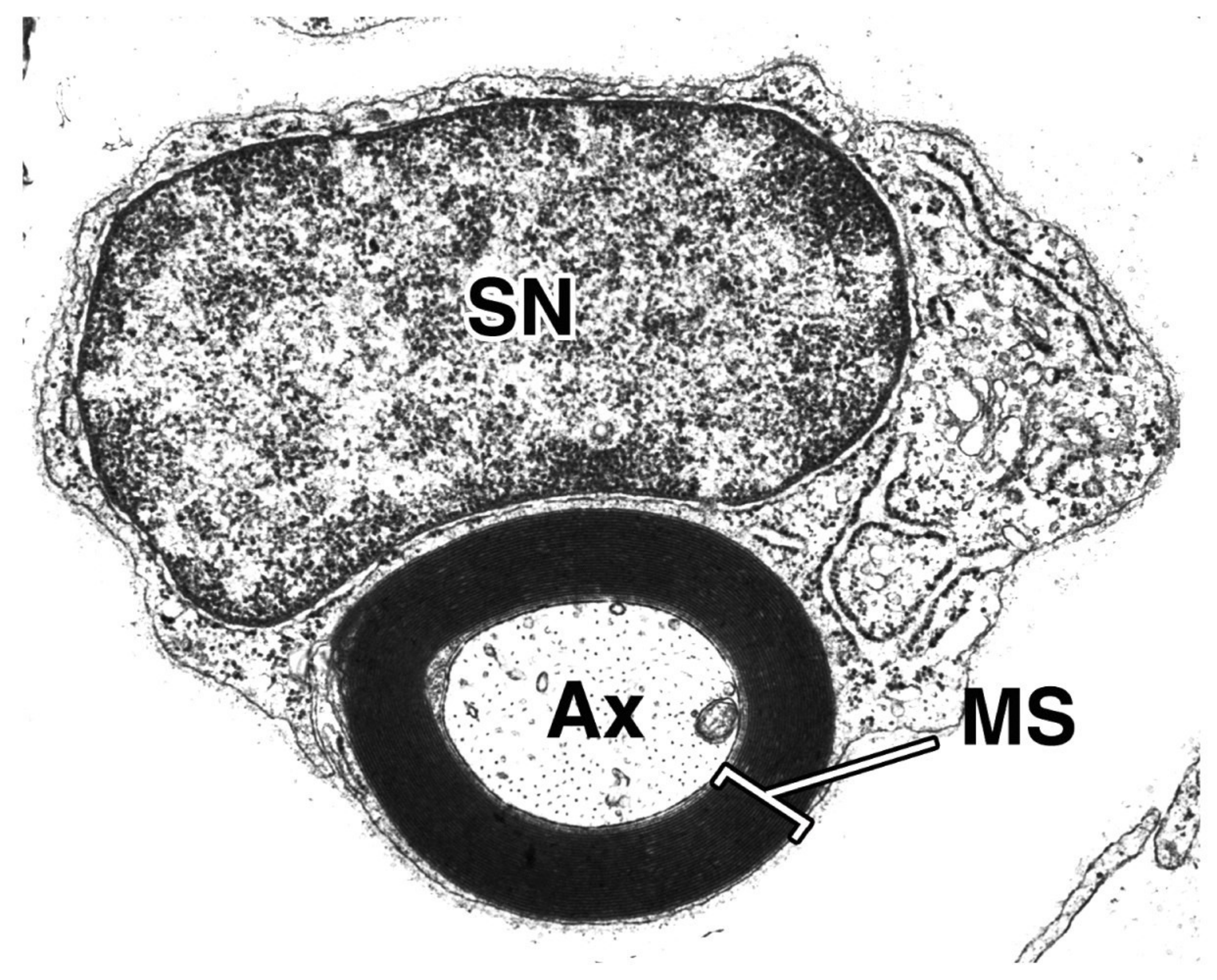
Gated channels



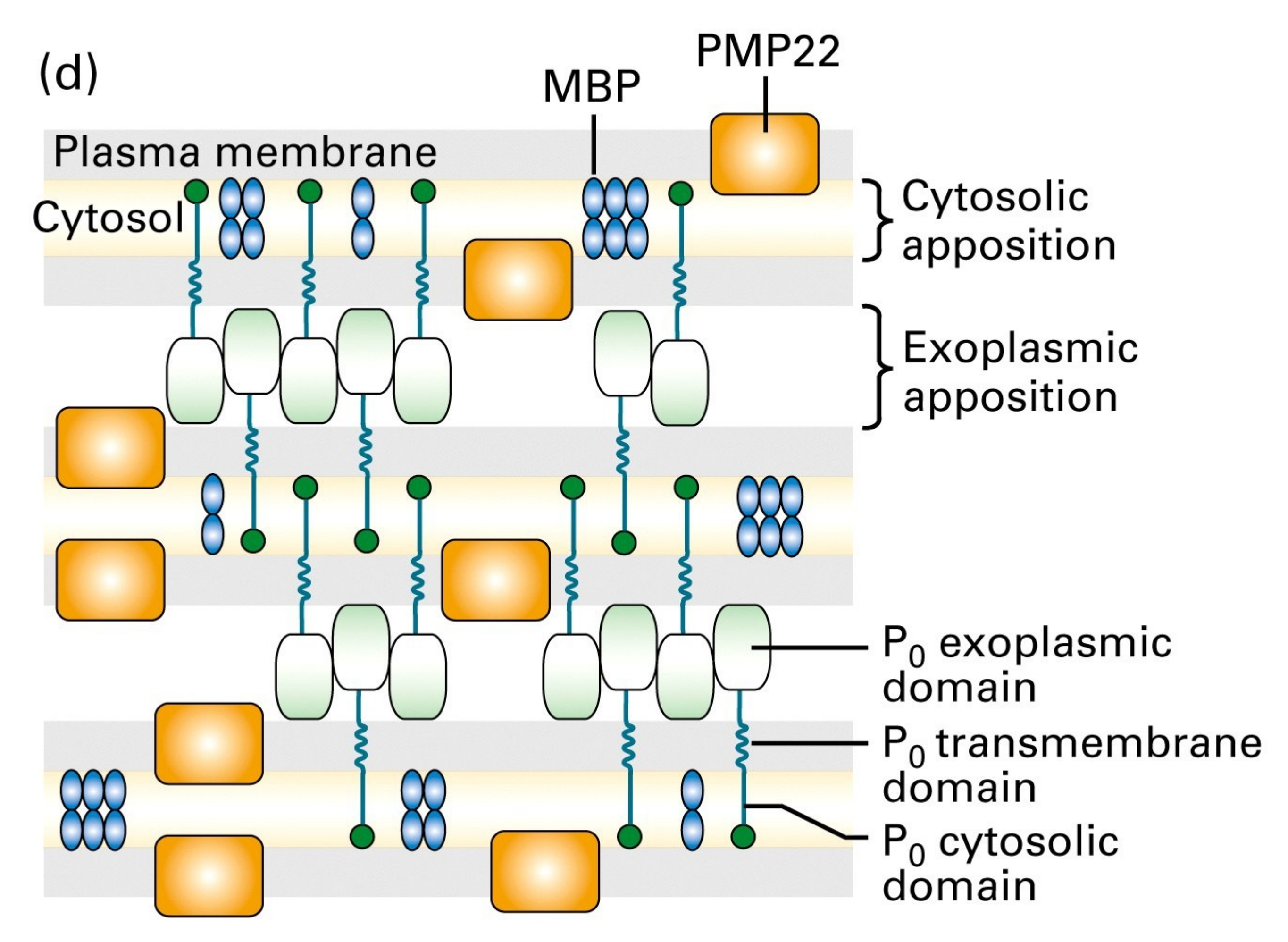
Schwann cells



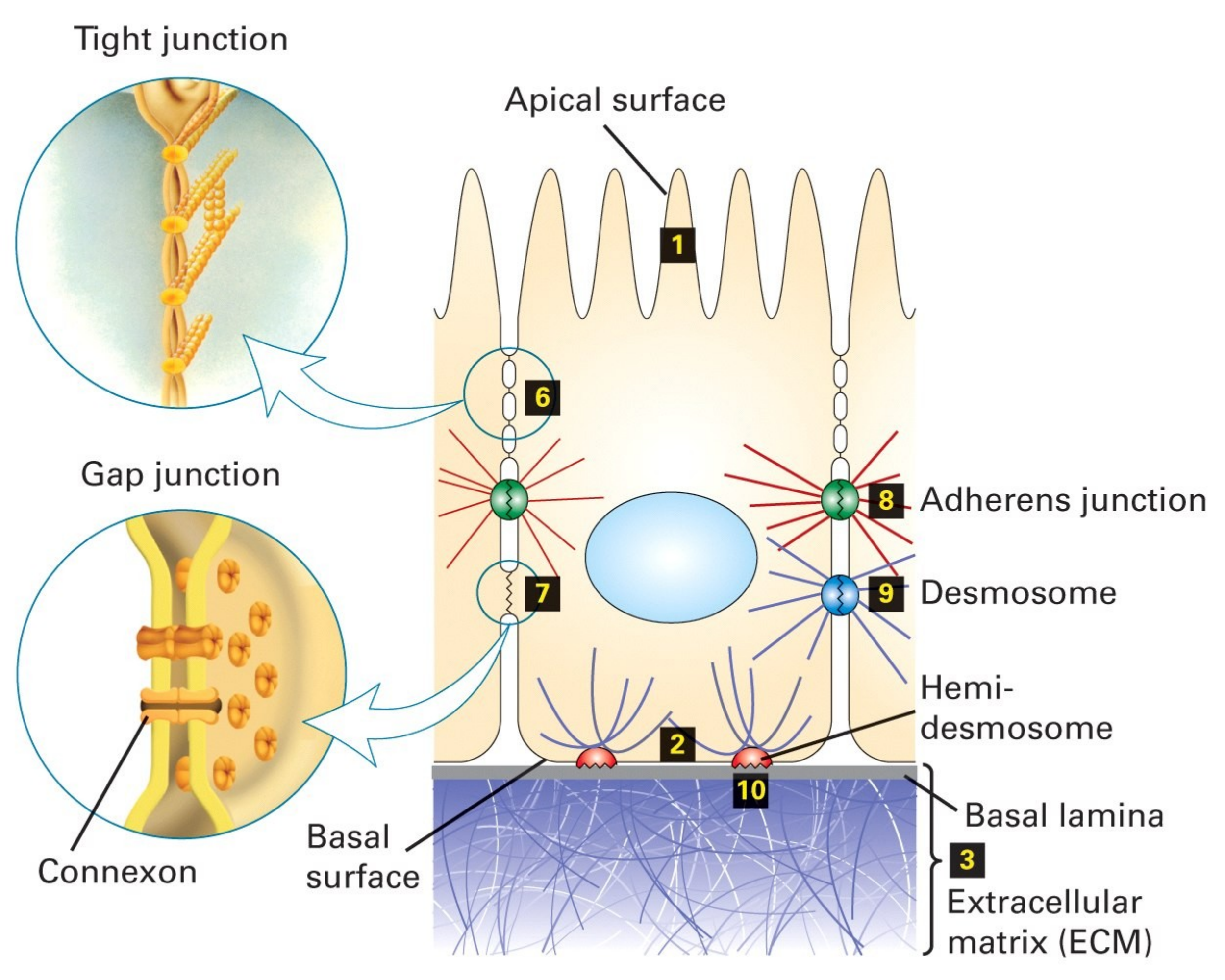
Schwann cells



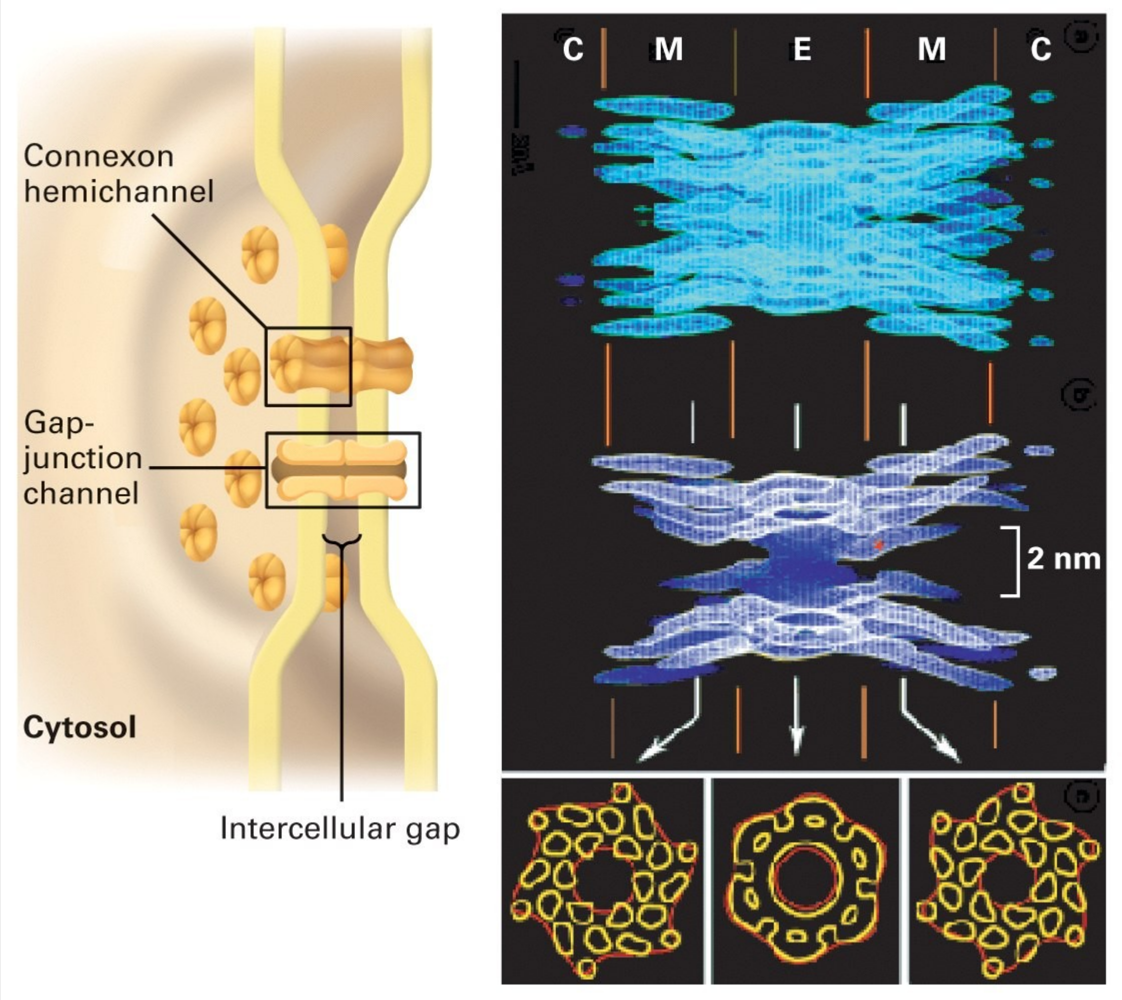
Schwann cells



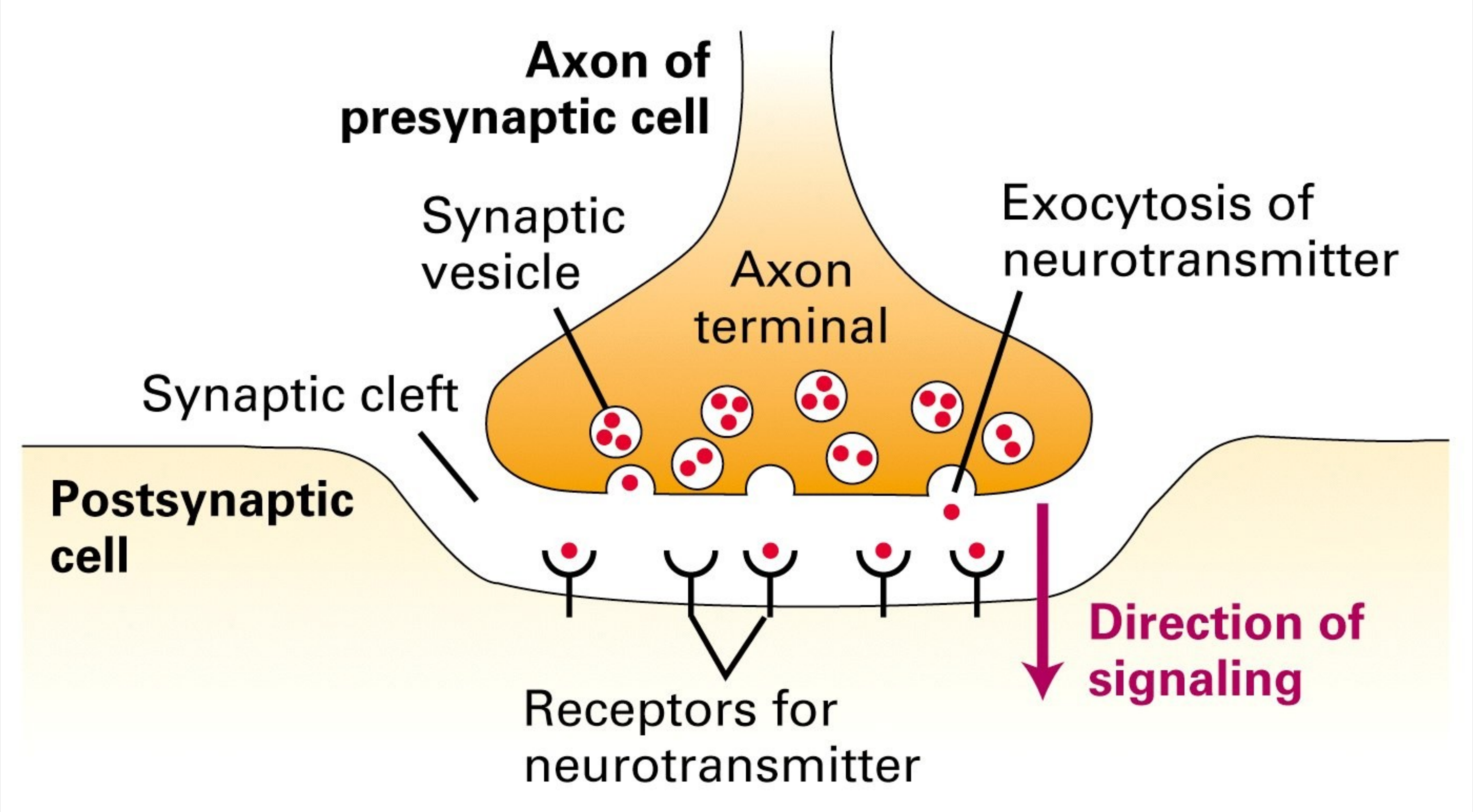
Types of junctions



Connections

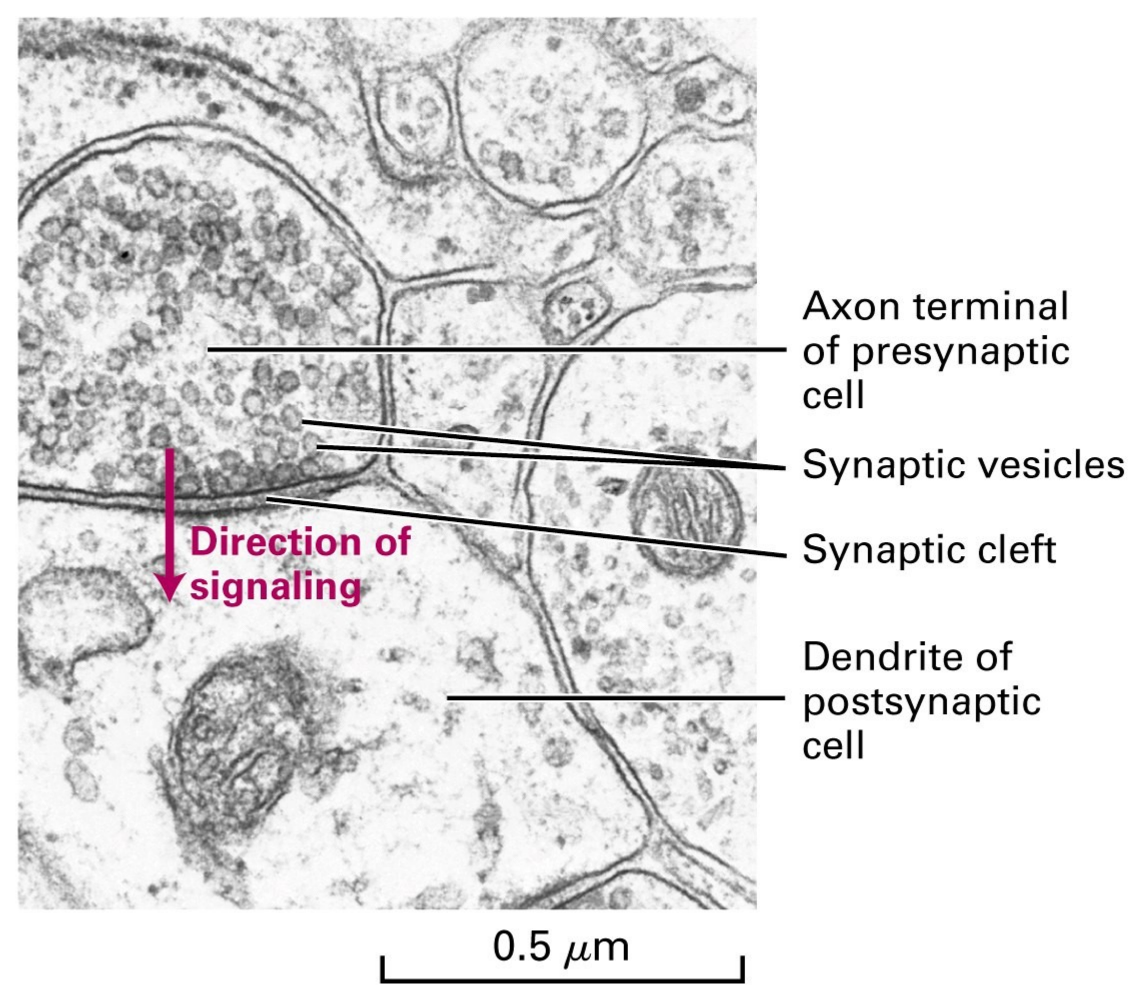


Chemical synapse

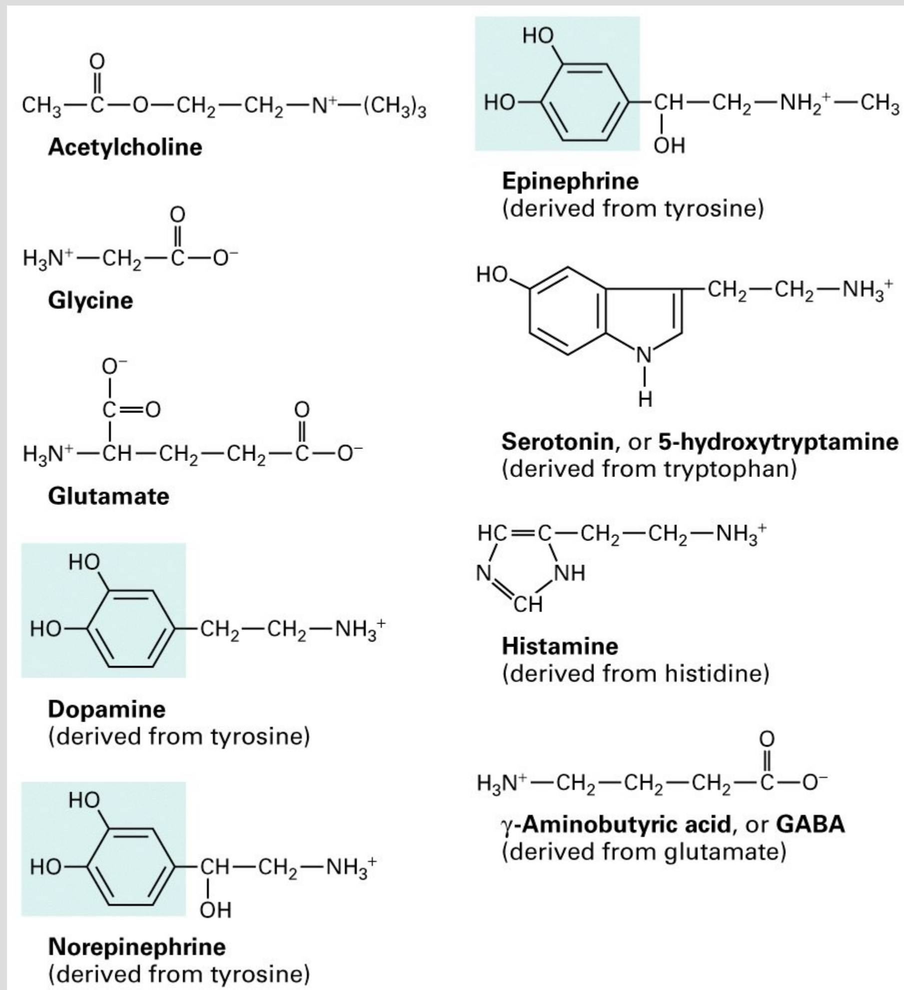


About 10^{16} synapses in the brain of children!

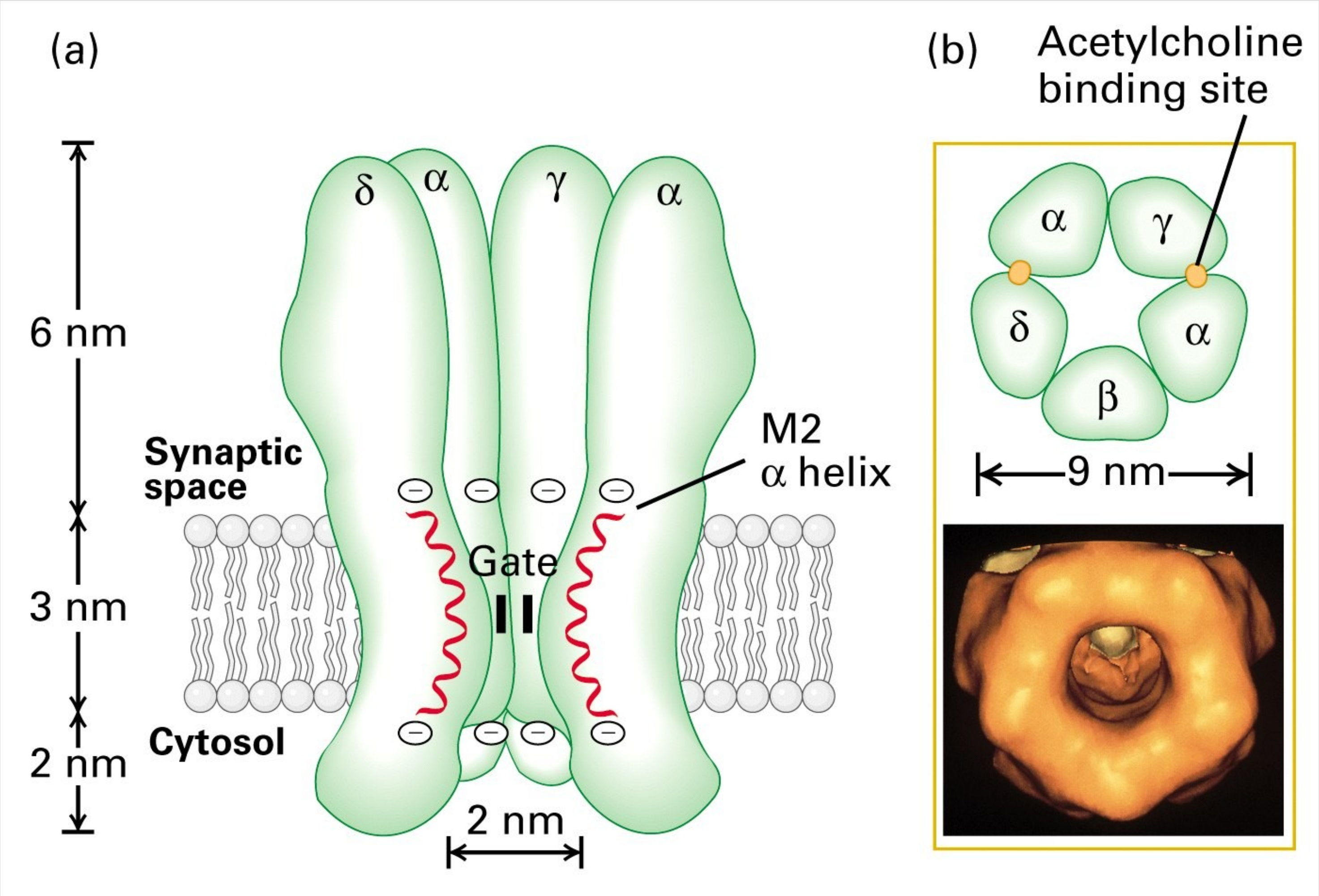
Synapse: Electron Image



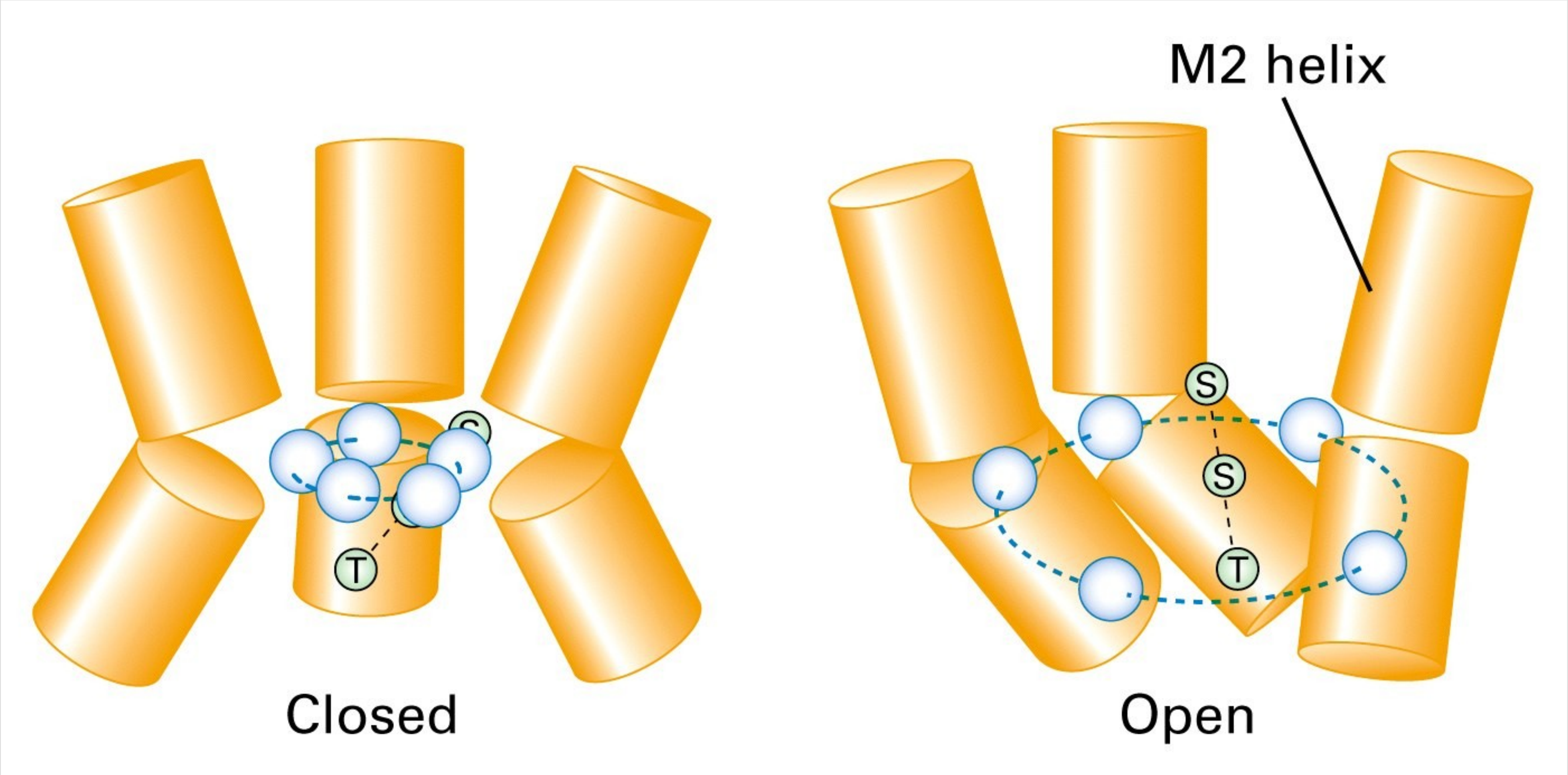
Transmitters



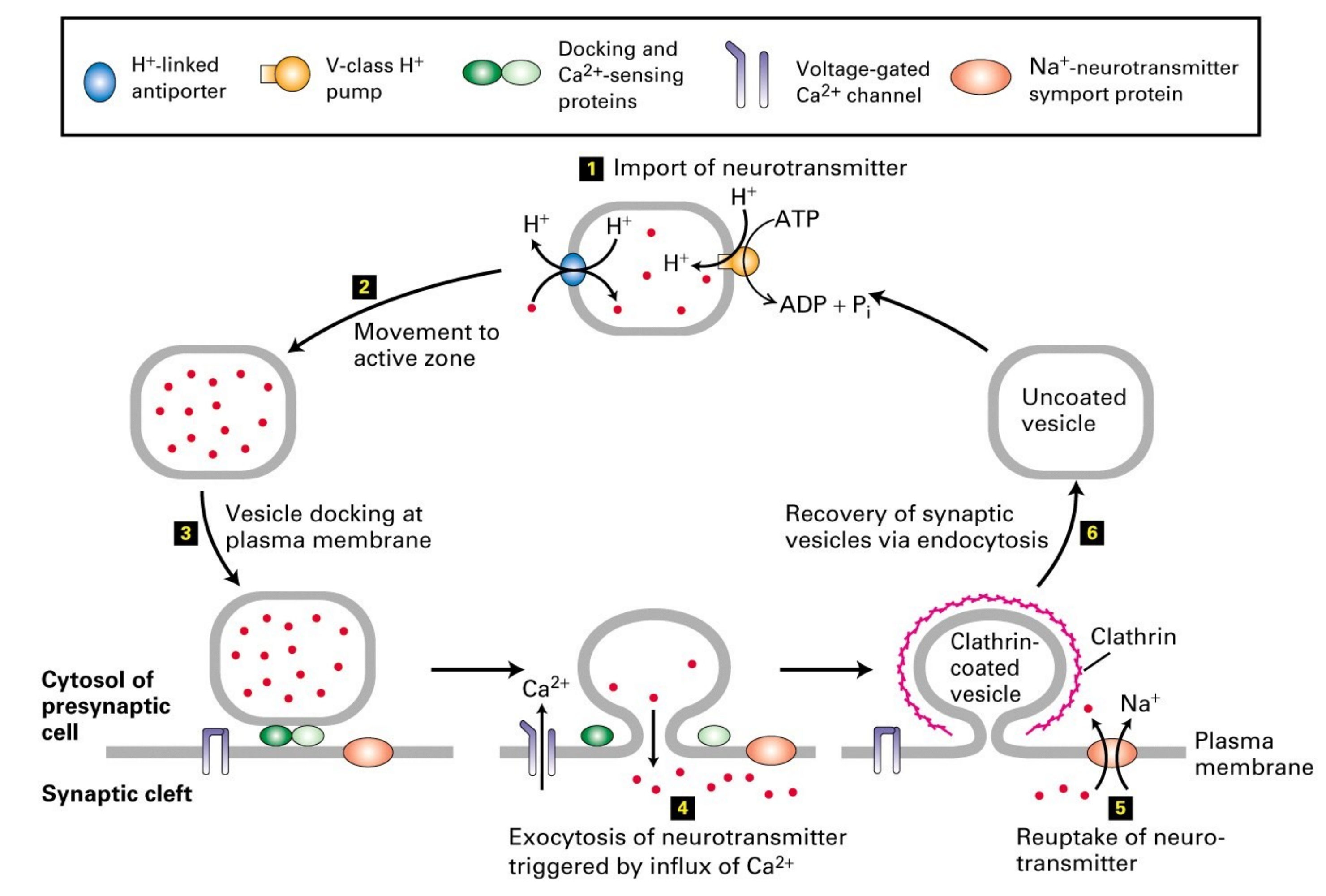
Neuro-transmitter action



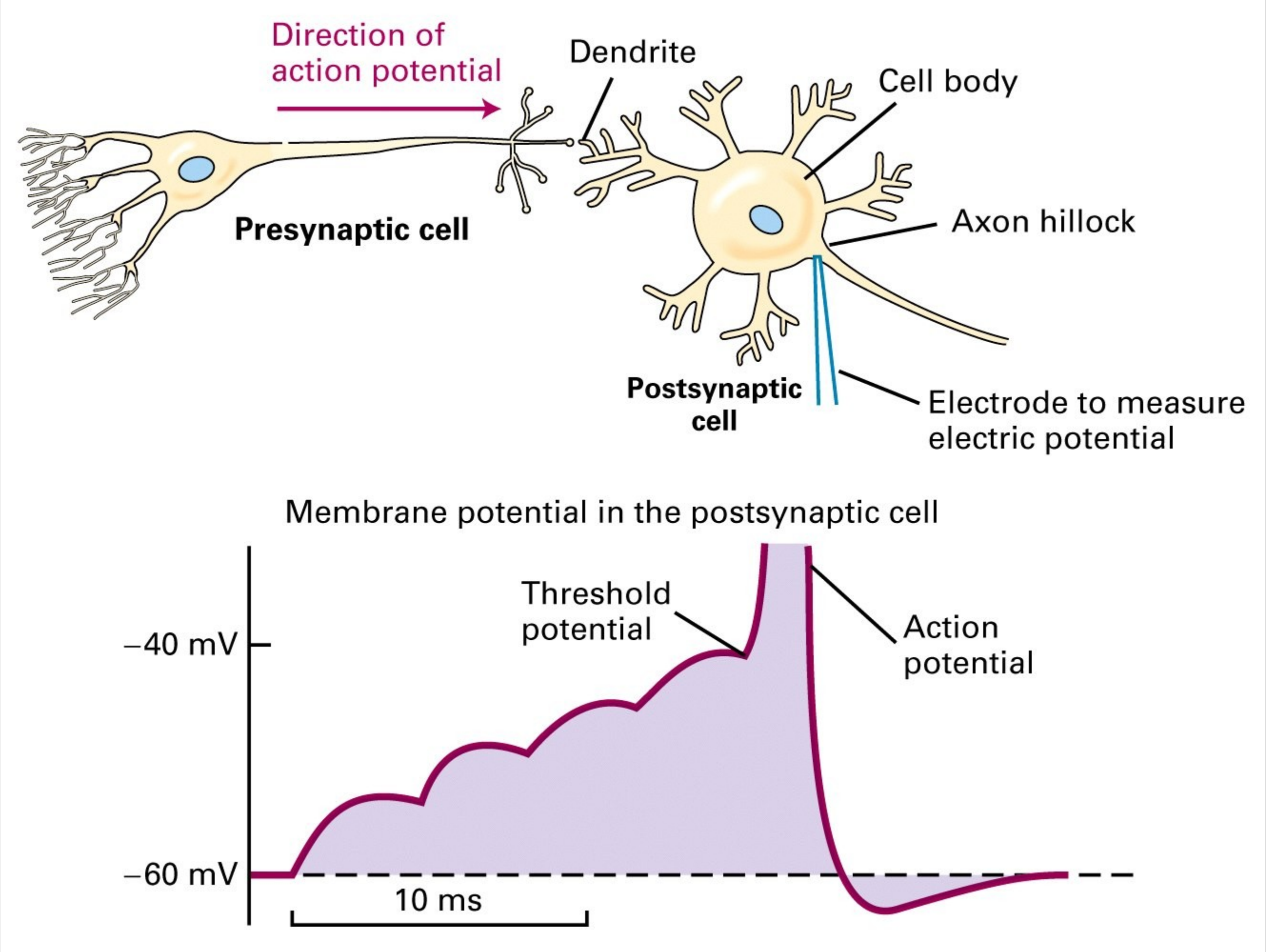
Neurotransmitter action



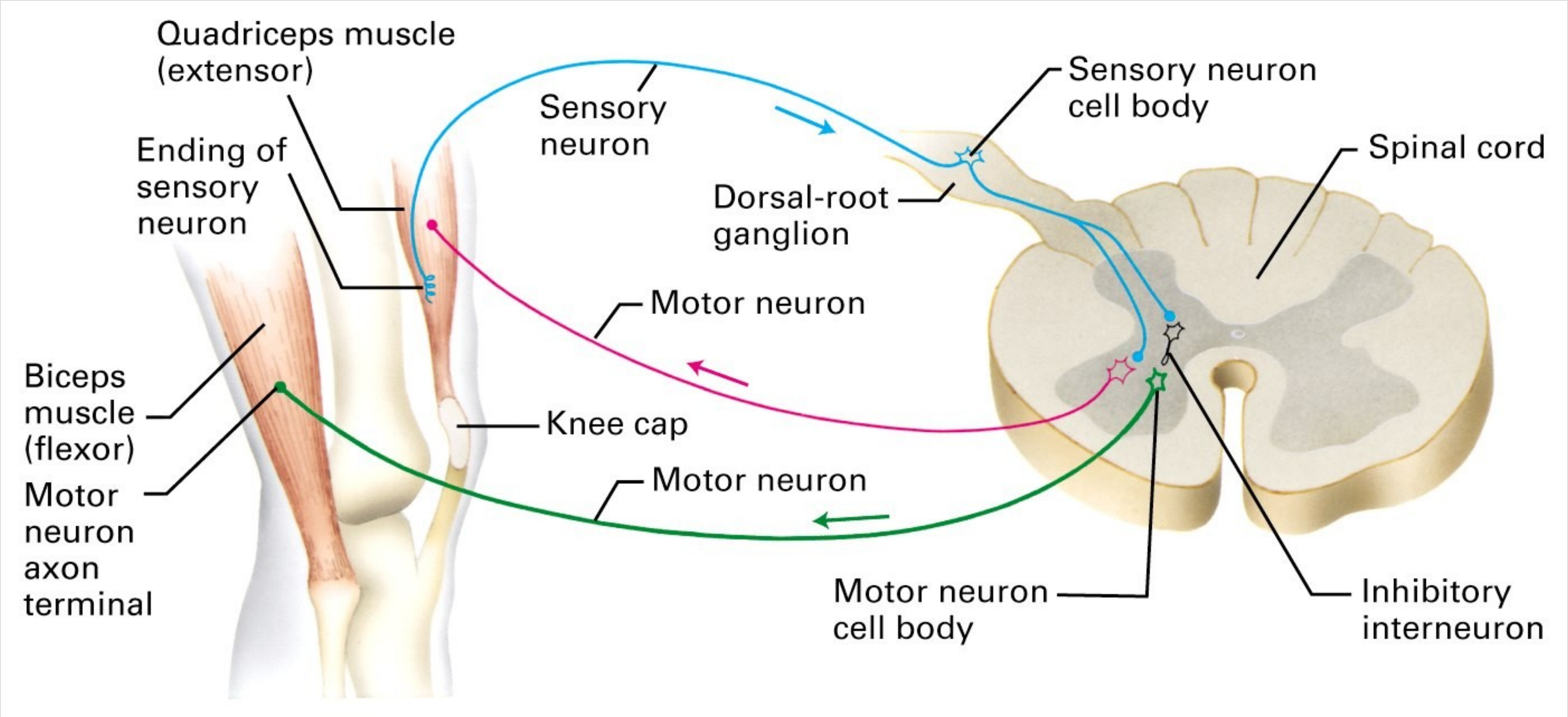
Vesicle cycle



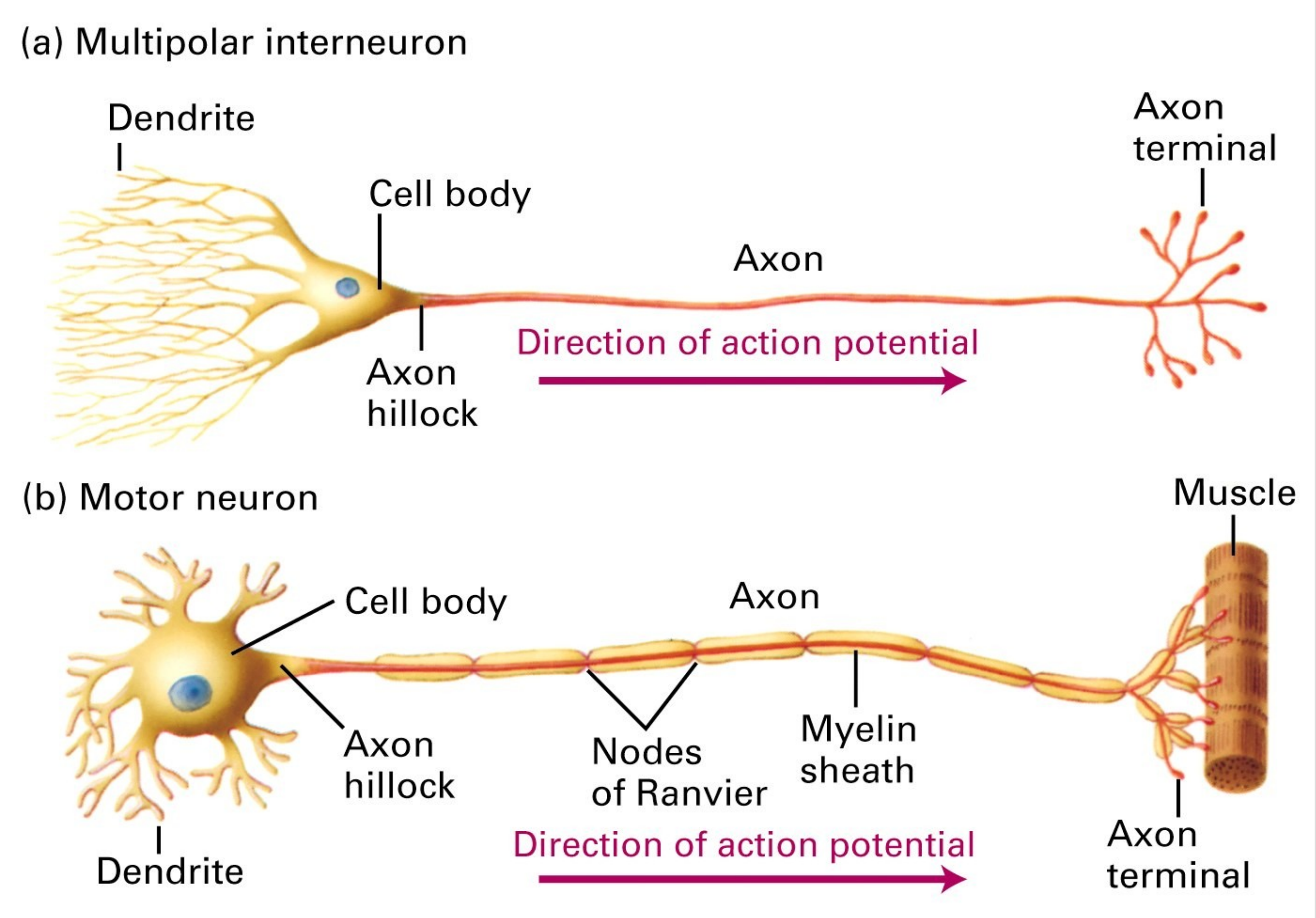
Summing of synaptic signals



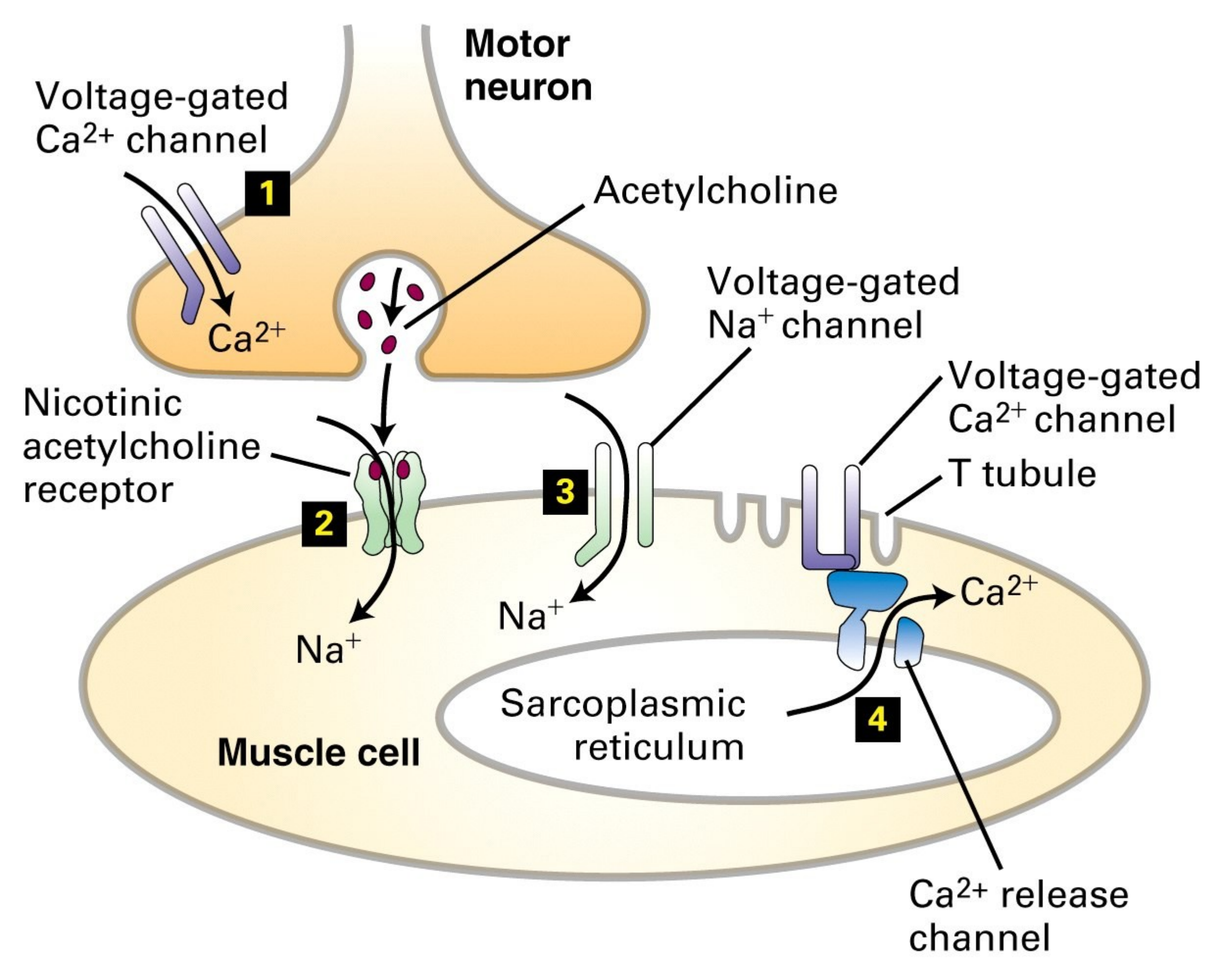
Nervous system to effector organs



Neuron to muscle



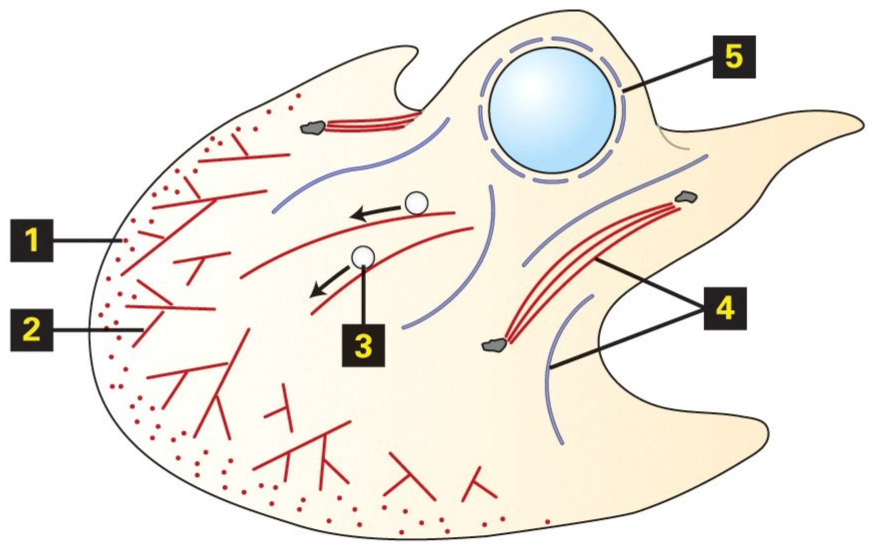
Neuron to muscle cell



Types of muscle cells

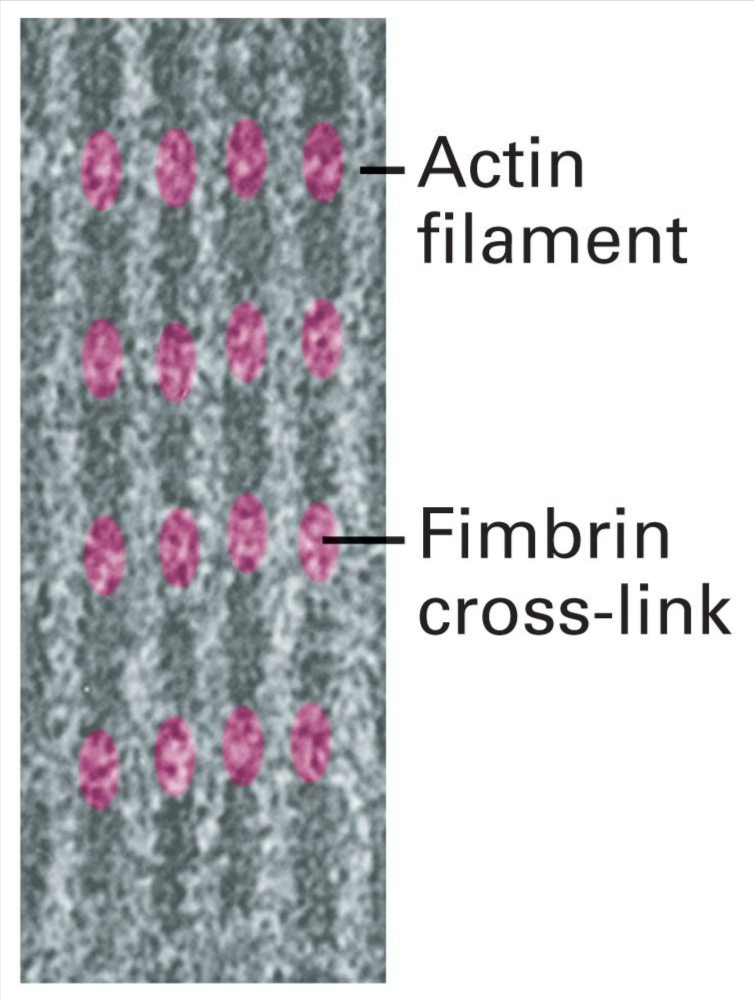
- Striated
- Cardiac
- Smooth

Cell cytoskeleton

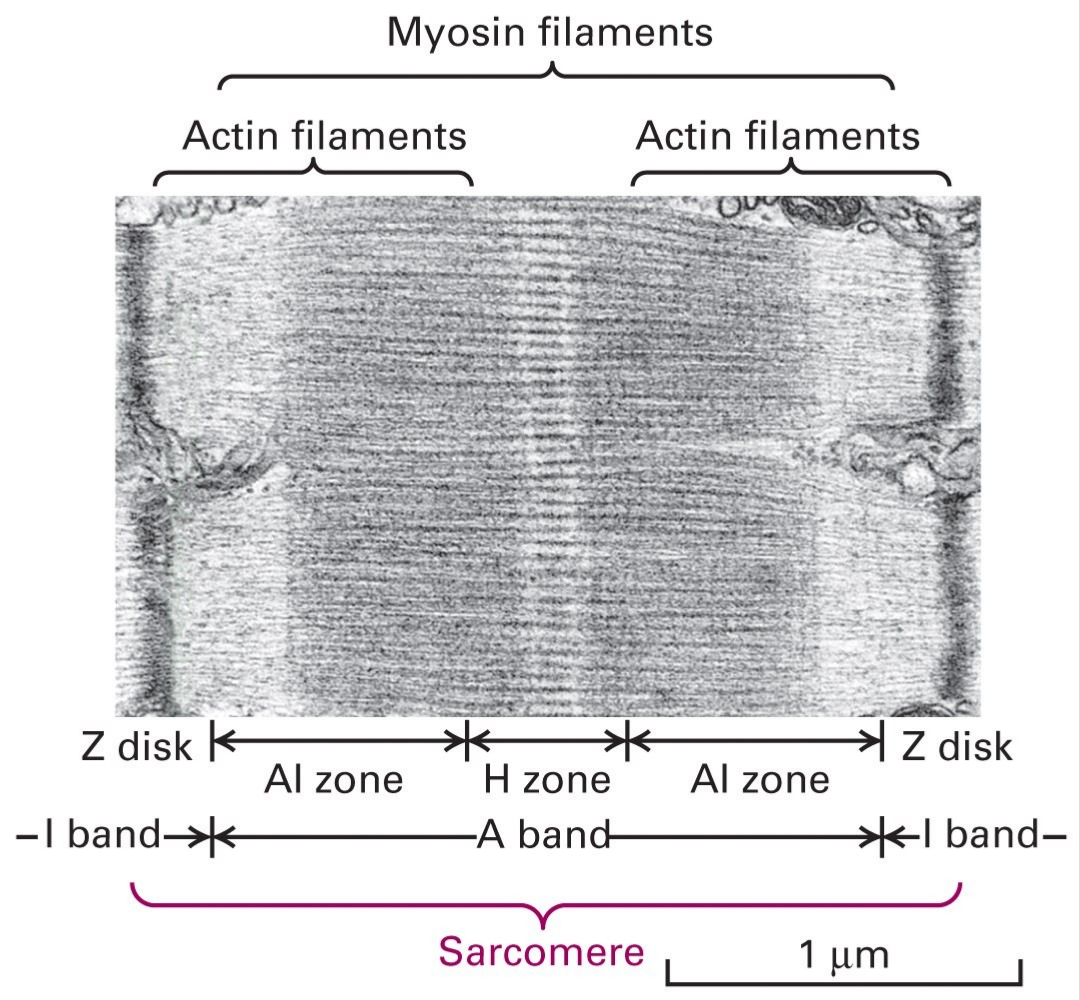


	CYTOSKELETAL COMPONENT	CELL FUNCTION
1	Actin dynamics	Membrane extension
2	Filament networks: bundles	Cell structure
3	Myosin motors	Contractility and vesicle transport
4	Actin bundles and intermediate filaments	Cell adhesion
5	Lamin network	Nuclear structure

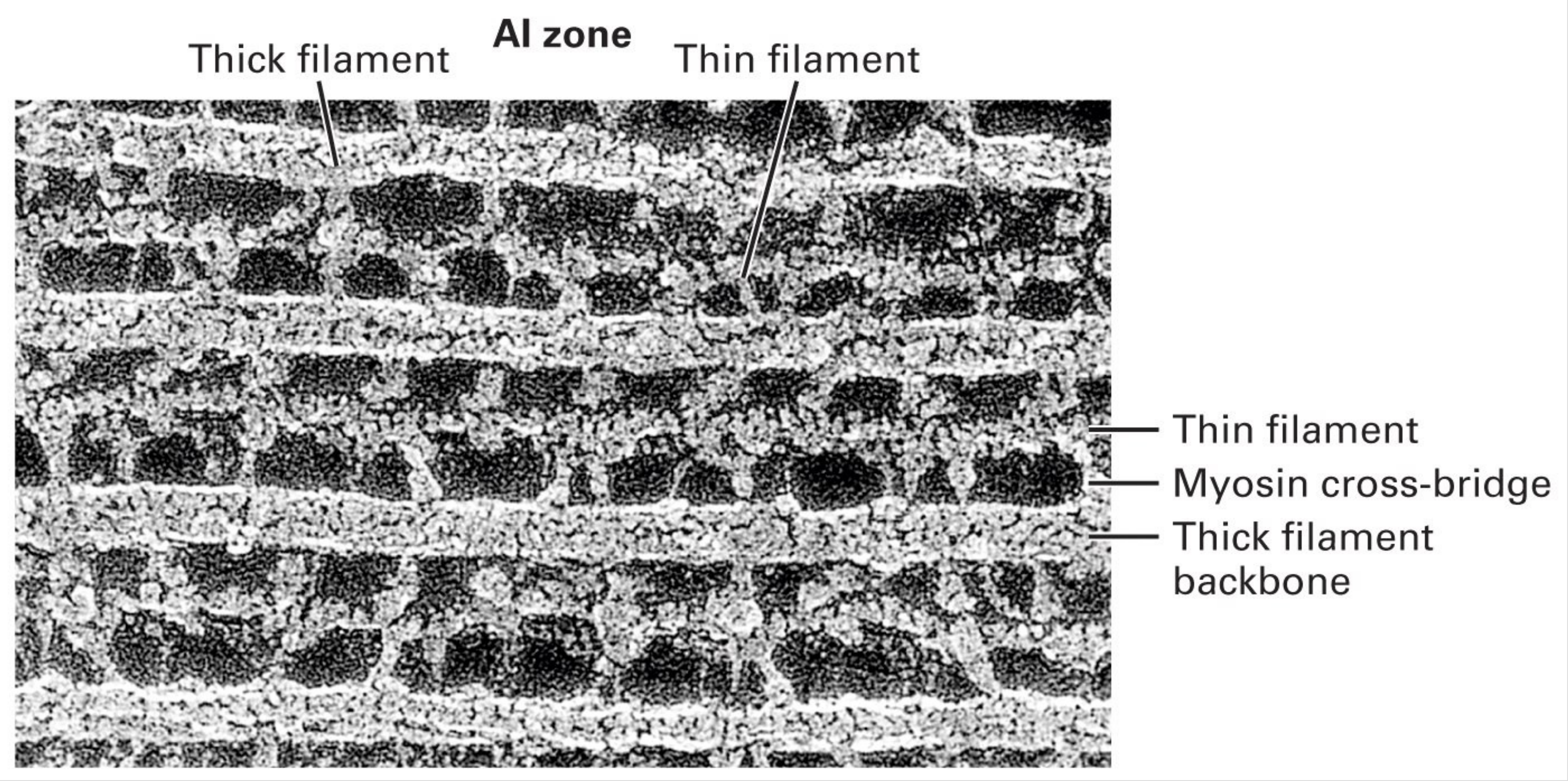
Striated muscle



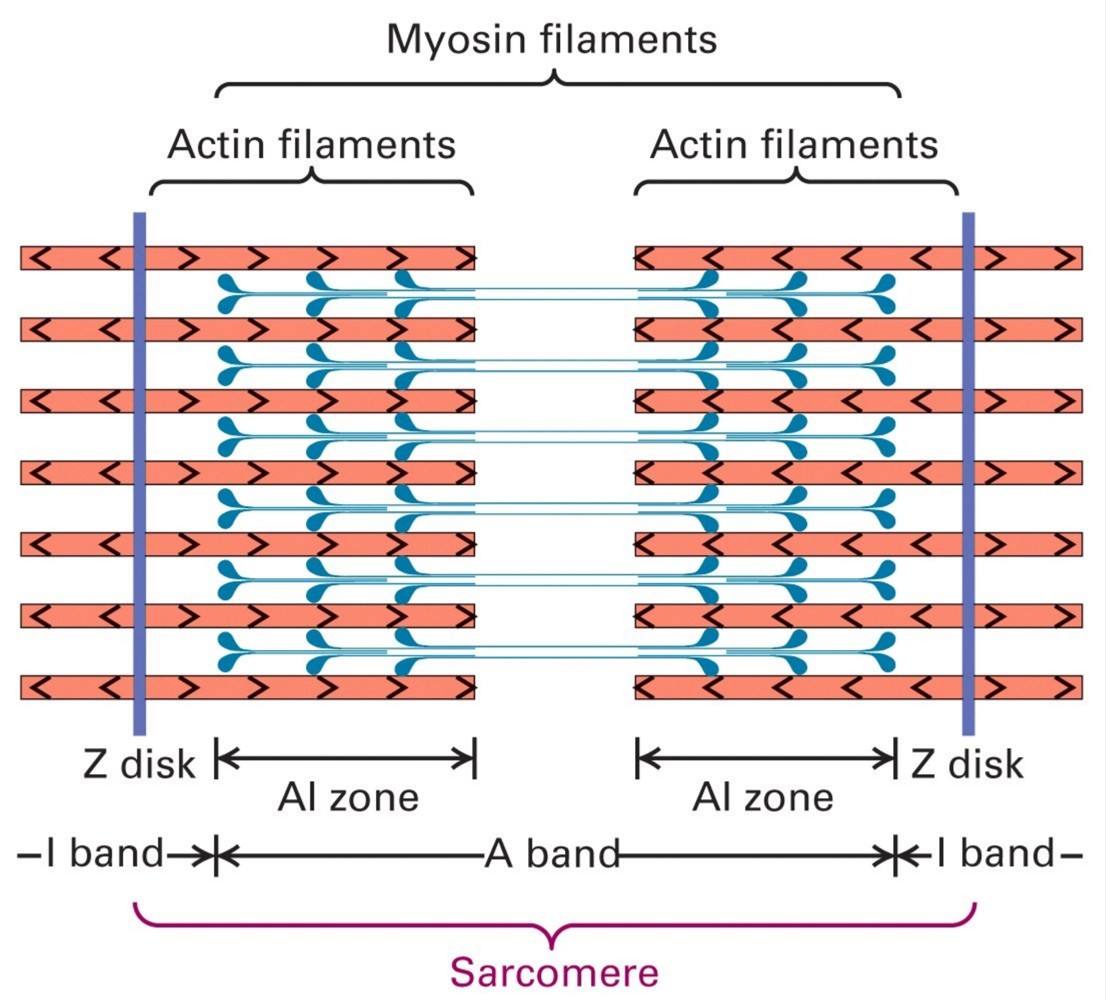
Striated muscle structure



Structure


AI zone
Thick filament
Thin filament
Thin filament
Myosin cross-bridge
Thick filament backbone

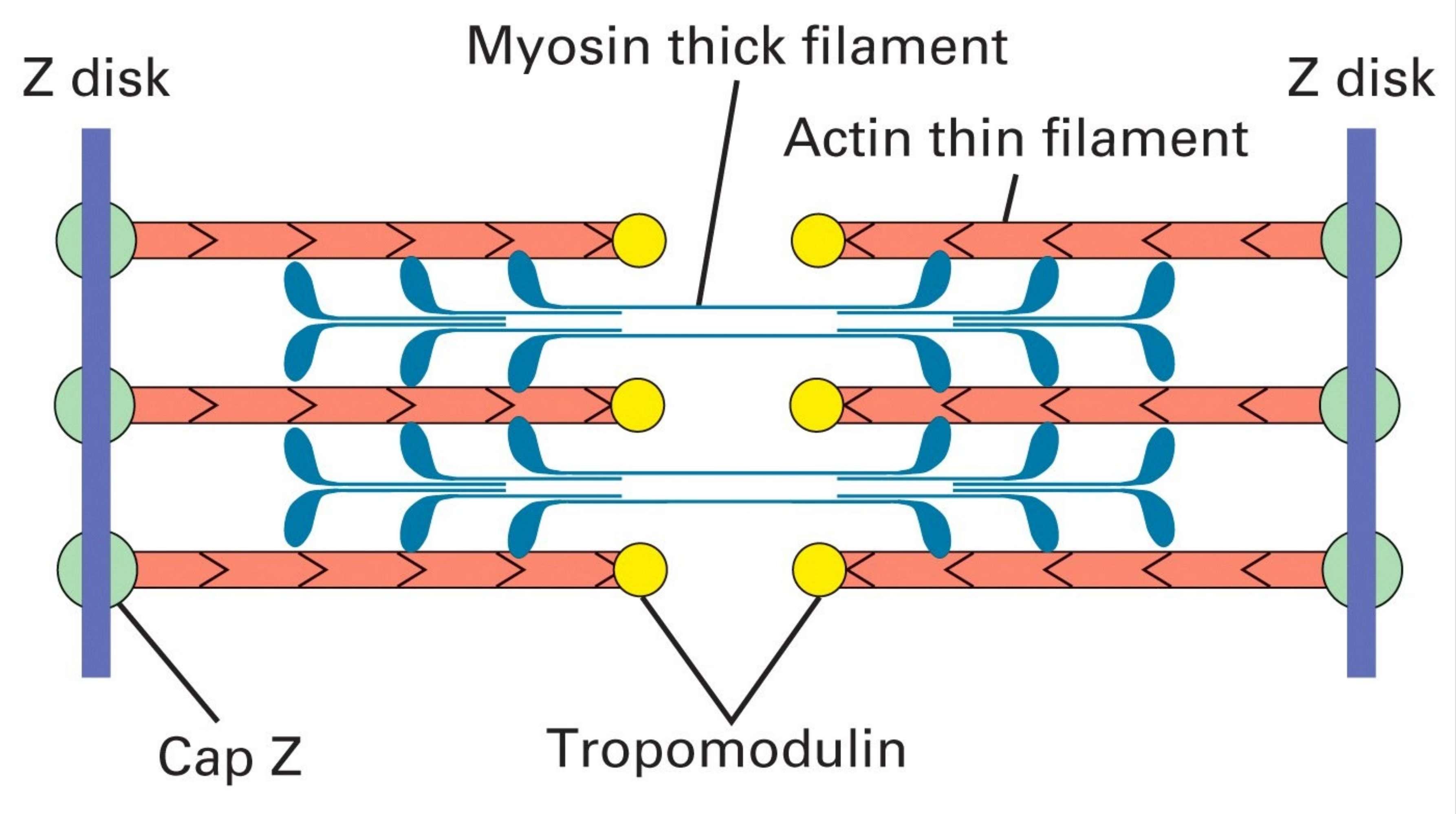
Structure sketch



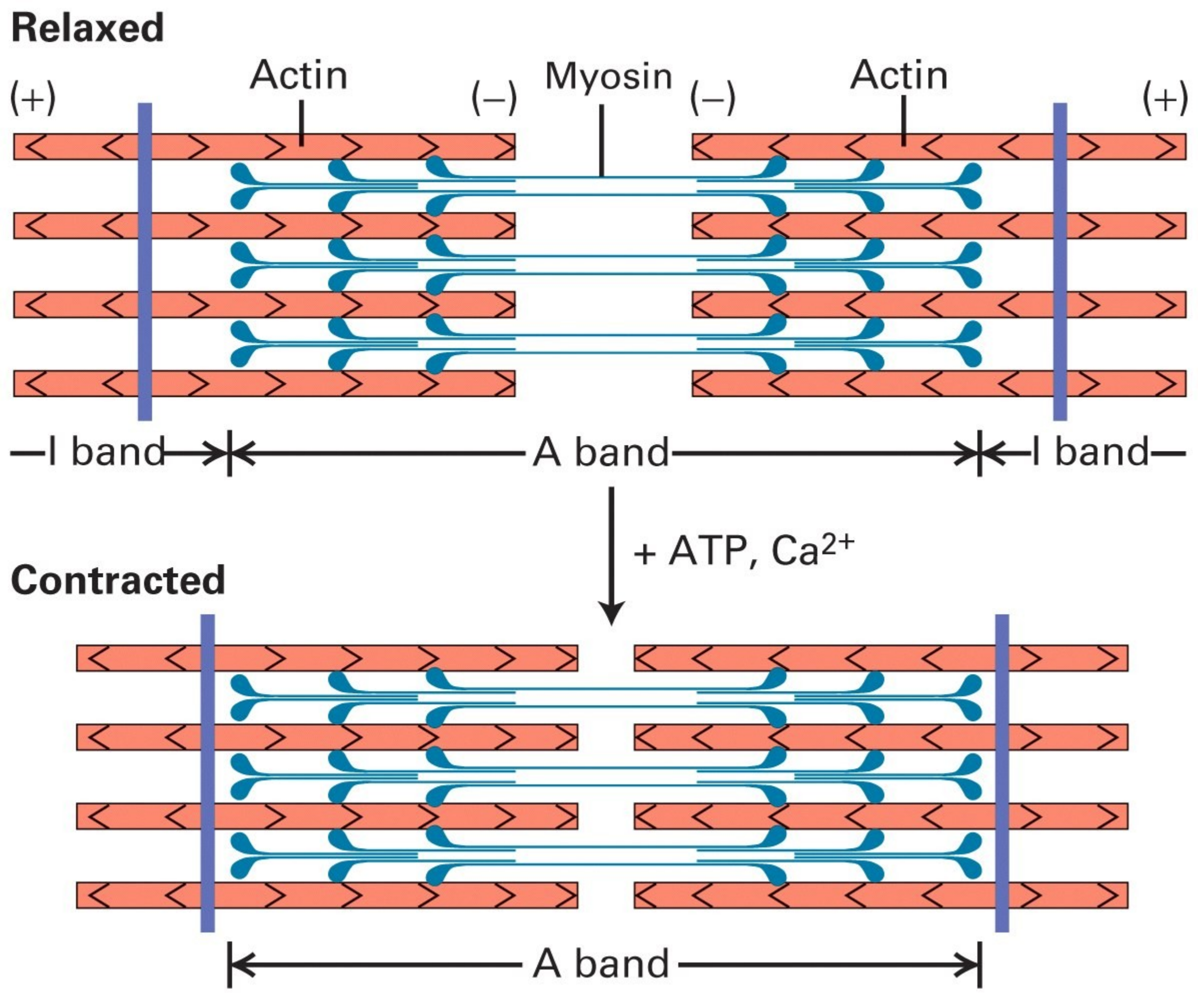
How do muscles contract

- No change of fibril length
- I band width changes

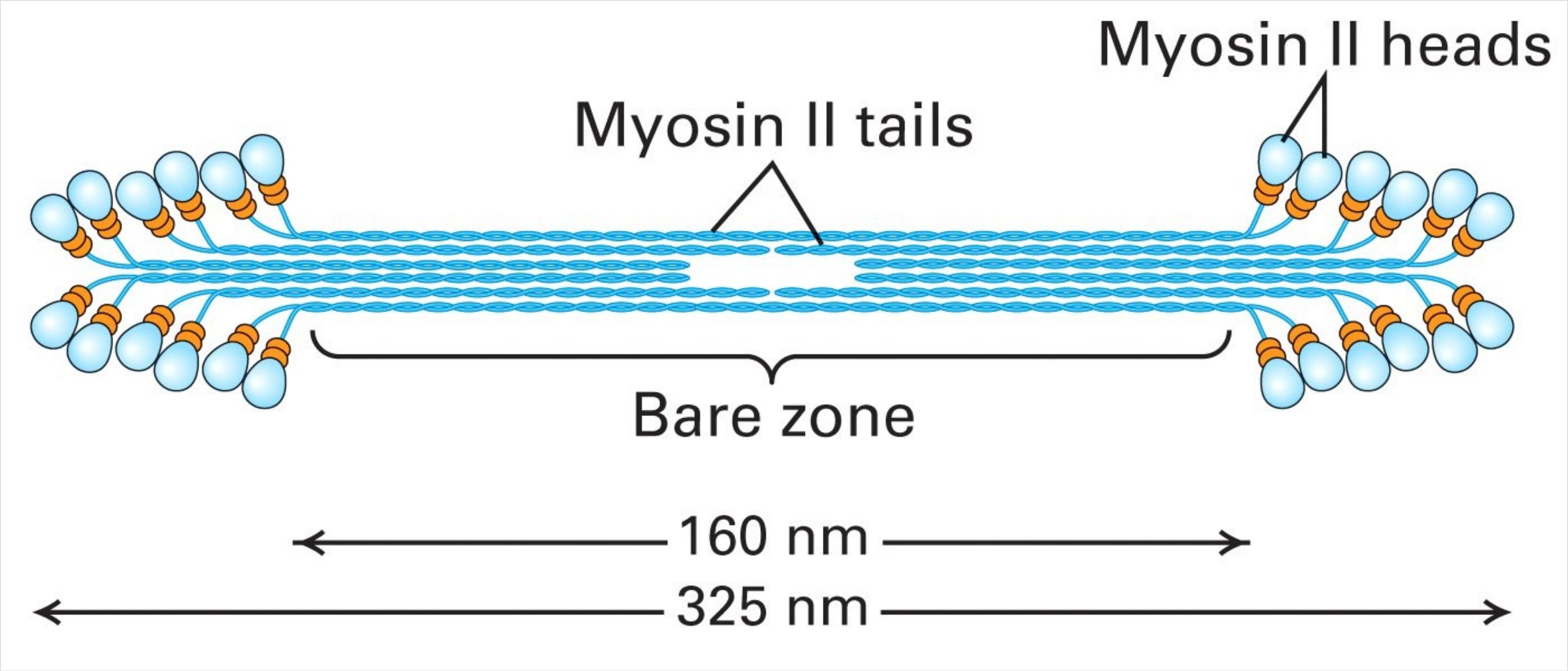
Motor structure



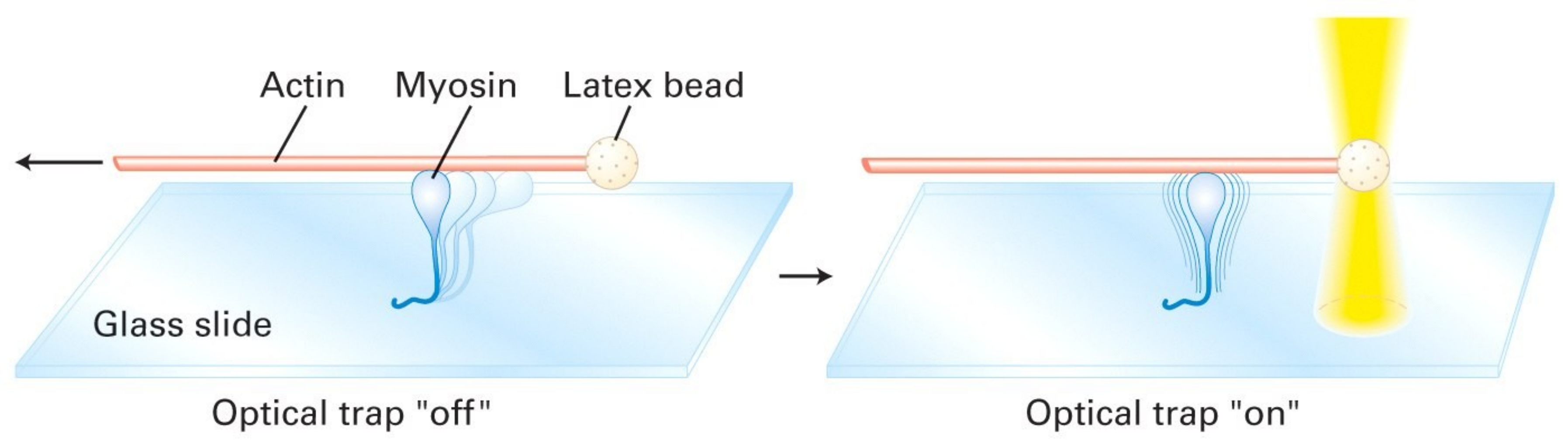
Contraction



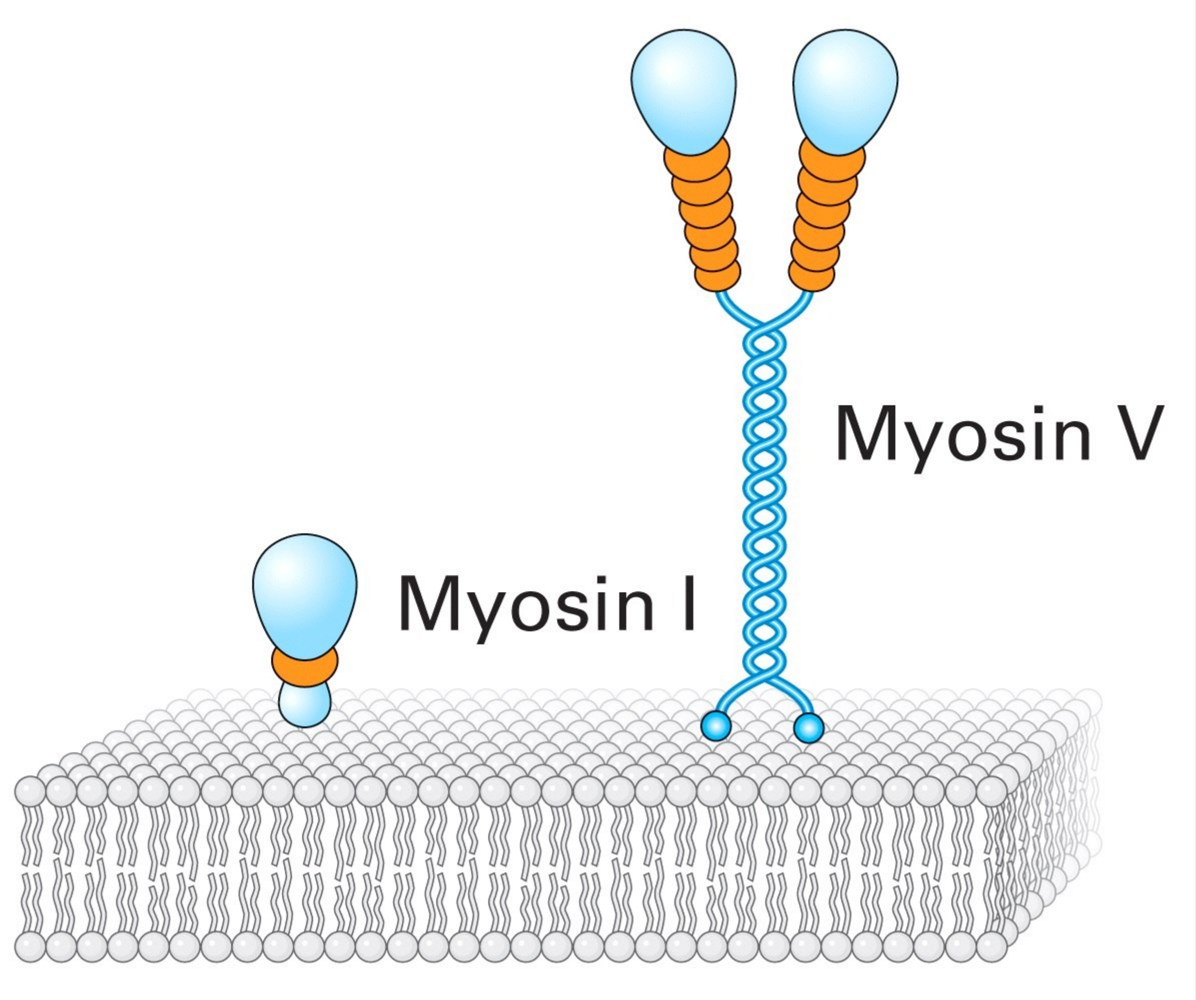
Cartoon of muscle cell structure



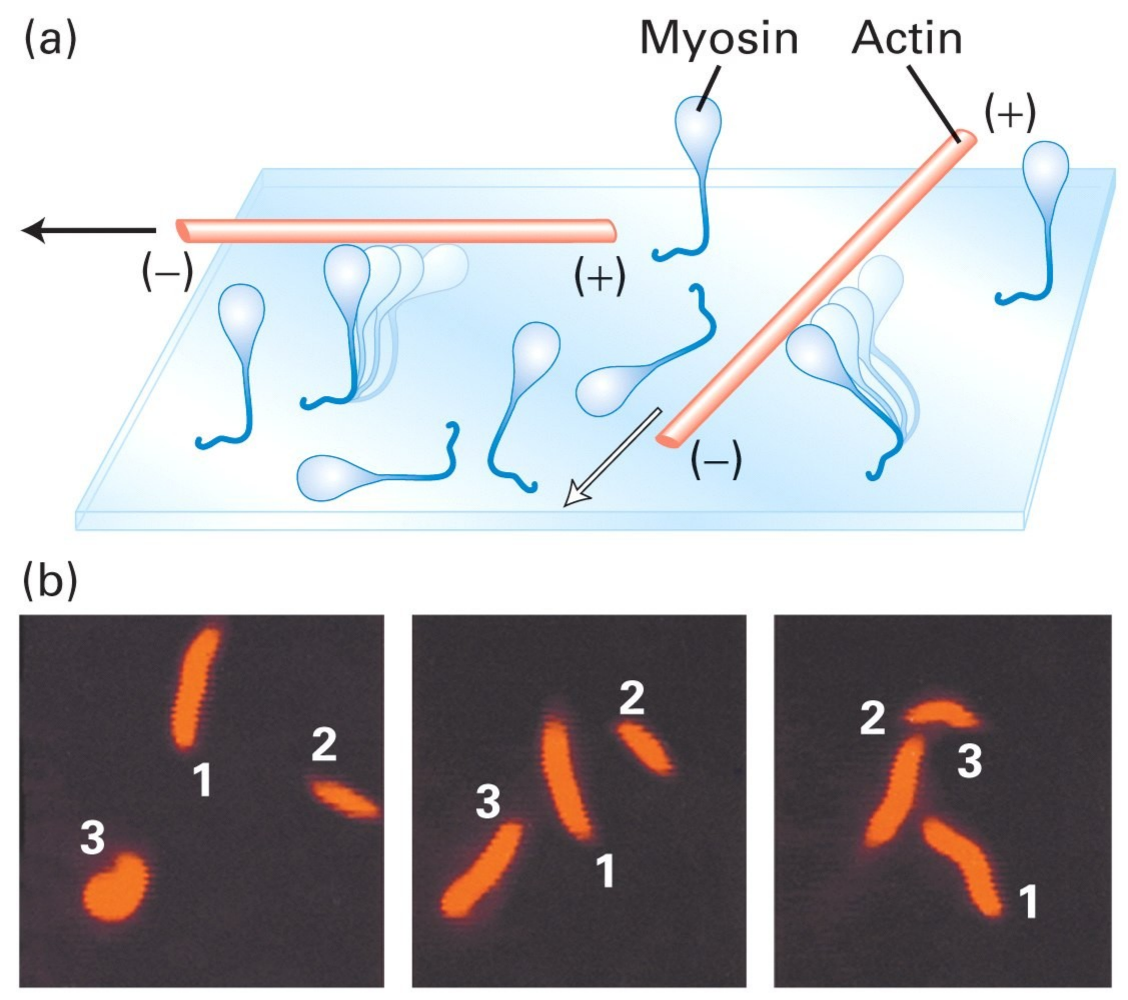
Basic action



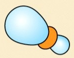
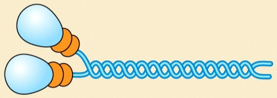
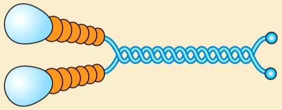
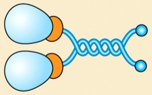
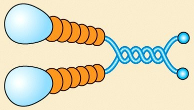
Cartoon of muscle cell



Actin-myosin action



Myosins

TABLE 19-3 Myosins				
Type	Heavy Chain (MW)	Structure	Step Size (nm)	Activity
I	110,000–150,000		10–14	Membrane binding, endocytic vesicles
II	220,000		5–10	Filament sliding
V	170,000–220,000		36	Vesicle transport
VI	140,000		30	Endocytosis
XI	170,000–260,000		35	Cytoplasmic streaming

Summary

- Several types of membrane proteins involved in molecule and ion transport across cell membranes
- Several of them have their conductances modulated by either potential or the attachment of a ligand & serve in modifying the potential setup by other membrane proteins that set up ionic gradients
- Reception a nerve impulse in a muscle cell at a sarcoplasmic reticulum releases calcium ion that causes a sarcomere to shorten as myosin ratchets against actin with energy from ATP