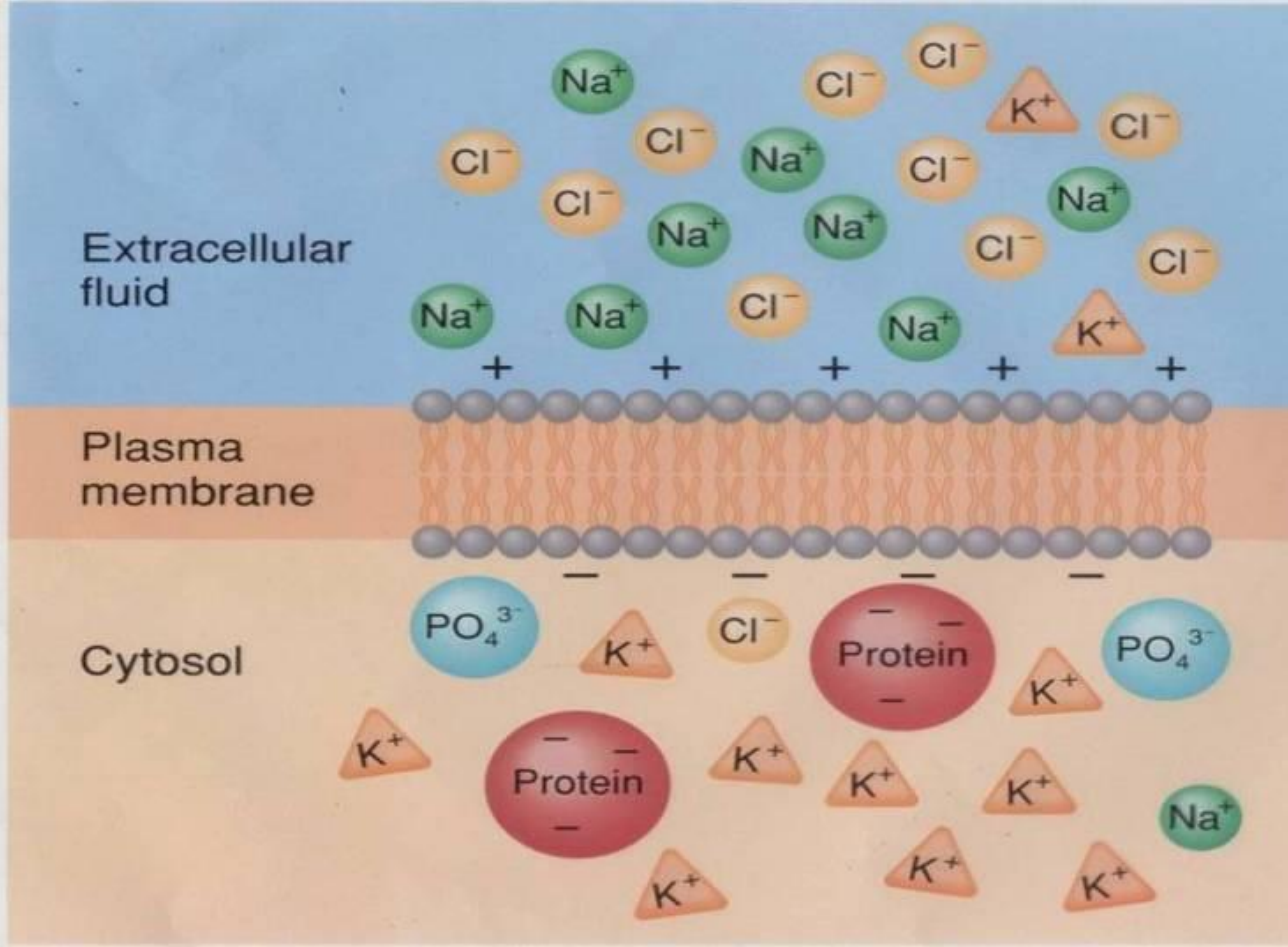


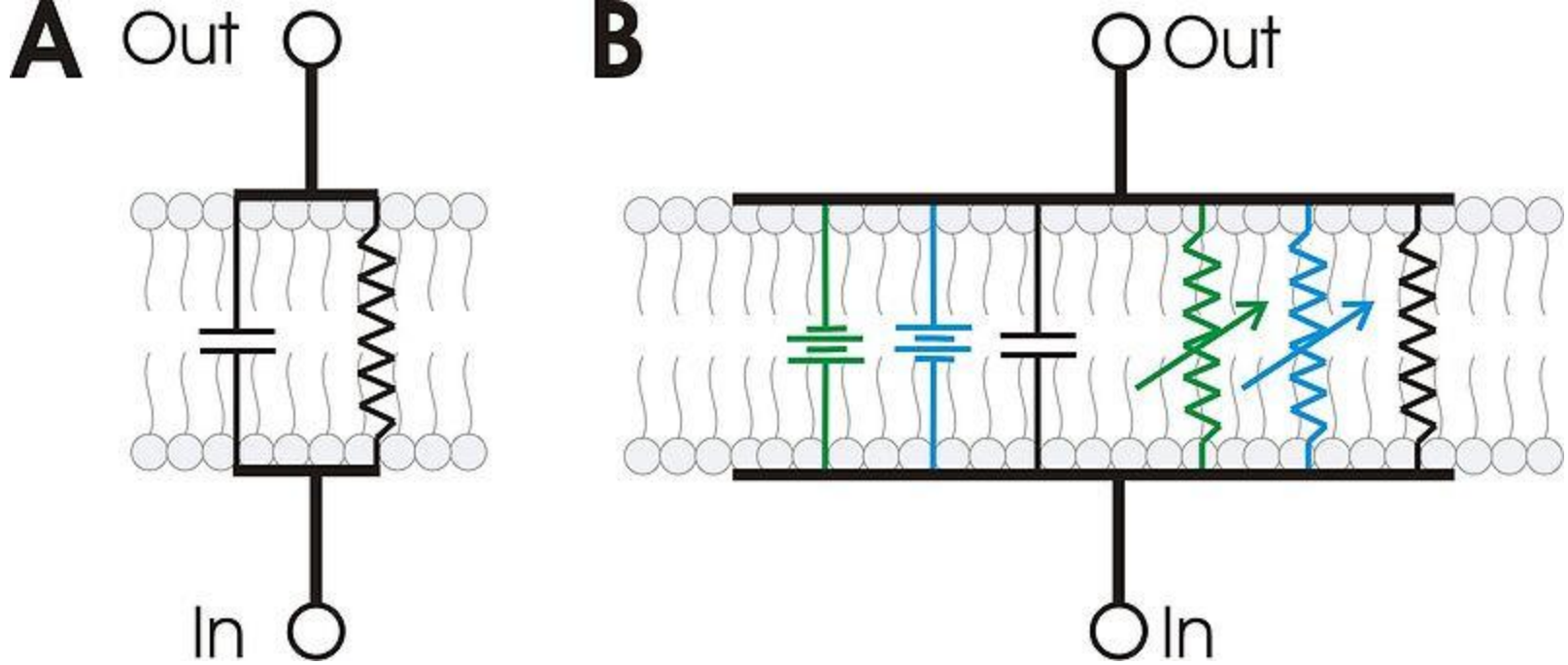
Transport of ions across plasma membranes

Plasma Membranes of Excitable tissues

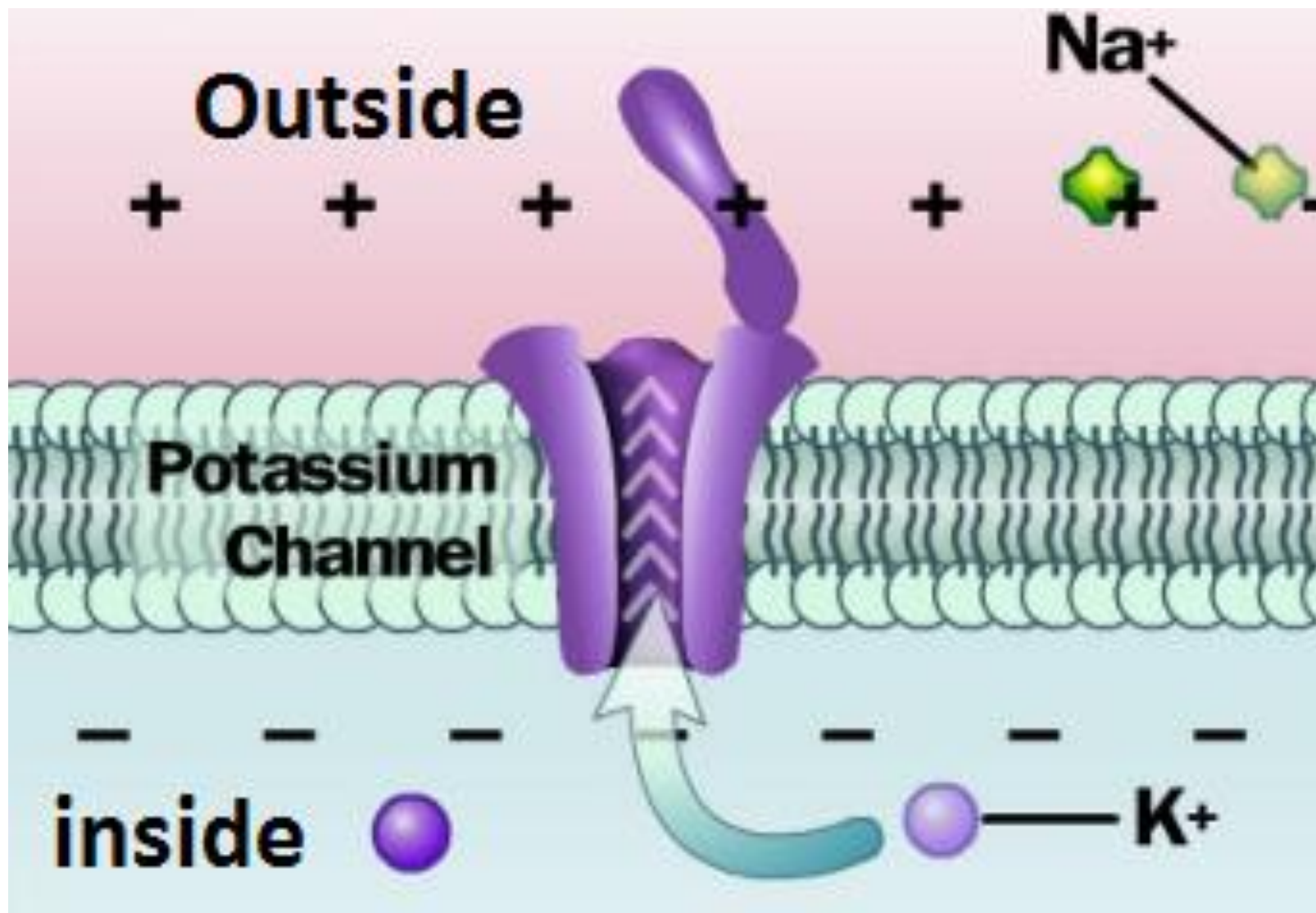
Ref: Guyton, 13th ed: pp: 61-71. 12th ed: pp: 57-69. 11th ed: p**57-71**,

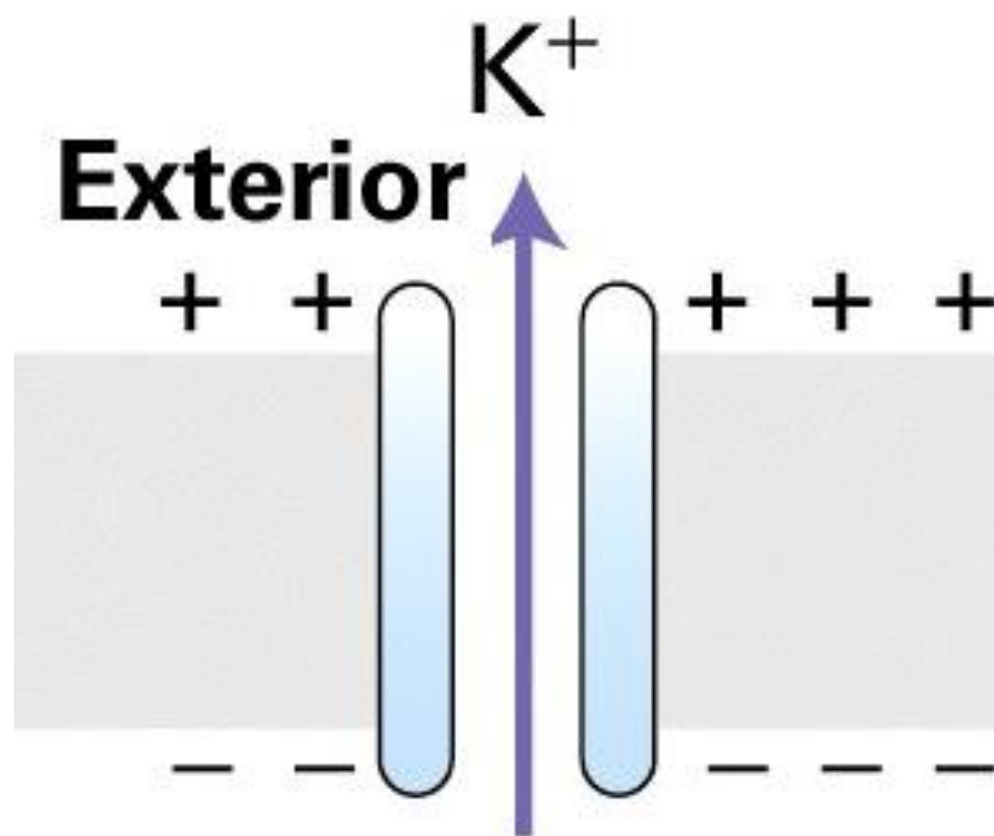


Electrical properties of plasma membranes



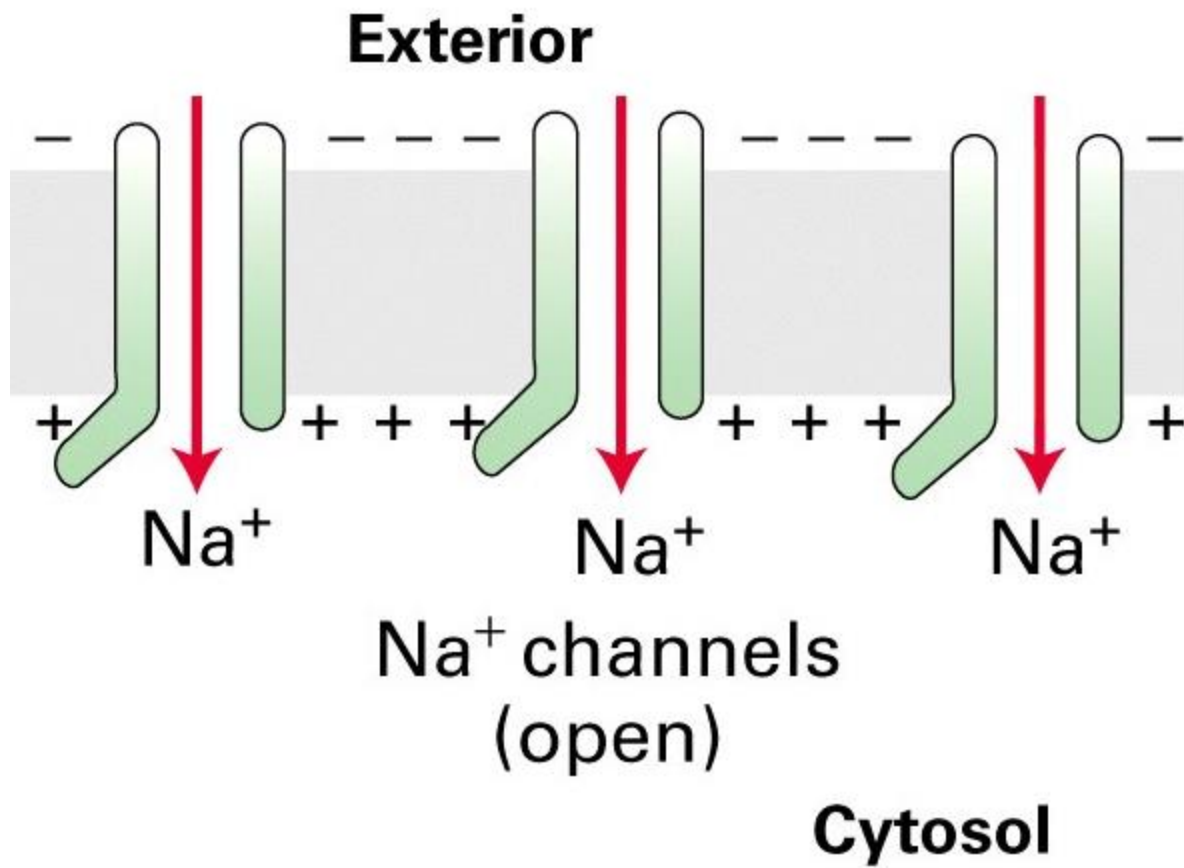
- Part A:** A basic [en:RC circuit](#), superimposed on an image of a membrane bilayer to show the relationship between the two. **Part B:** A more elaborate [en:RC circuit](#), superimposed on an image of a membrane bilayer. This RC circuit represents the electrical characteristics of a minimal patch of membrane containing at least one Na and two K channels. Elements shown are the transmembrane voltages produced by concentration gradients in potassium (green) and sodium (blue), The voltage-dependent ion channels that cross the membrane ([variable resistors](#); K=green, Na=blue), the non-voltage-dependent K channel (black), and the membrane capacitance.





K^+ channel
(open)

Cytosol



Nernst equation

$$E = \frac{RT}{ZF} \ln \frac{[C]_{out}}{[C]_{in}}$$

R (Gas Constant) = 8.314472 (J/K·mol)

T (Absolute Temperature) = t °C +
273.15 (°K)

Z (Valence)

F (Faraday's Constant) = 9.6485309×10⁴
(C/mol)

[C]_{out} (Outside Concentration, mM)

[C]_{in} (Inside Concentration, mM)

Electro-chemical Equilibrium

$$\Delta G_{\text{conc}} + \Delta G_{\text{volt}} = 0$$

$$zFV - RT \ln \frac{C_o}{C_i} = 0$$

$$V = \frac{RT}{zF} \ln \frac{C_o}{C_i} = 2.3 \frac{RT}{zF} \log_{10} \frac{C_o}{C_i}$$

$$E_{K^+}$$

$$E_{eq, K^+} = 61.54 mV \log \frac{[K^+]_o}{[K^+]_i}$$

$$E \text{ (mV)} = - 61. \log (C_i/C_o)$$

E = Equilibrium potential for a univalent ion

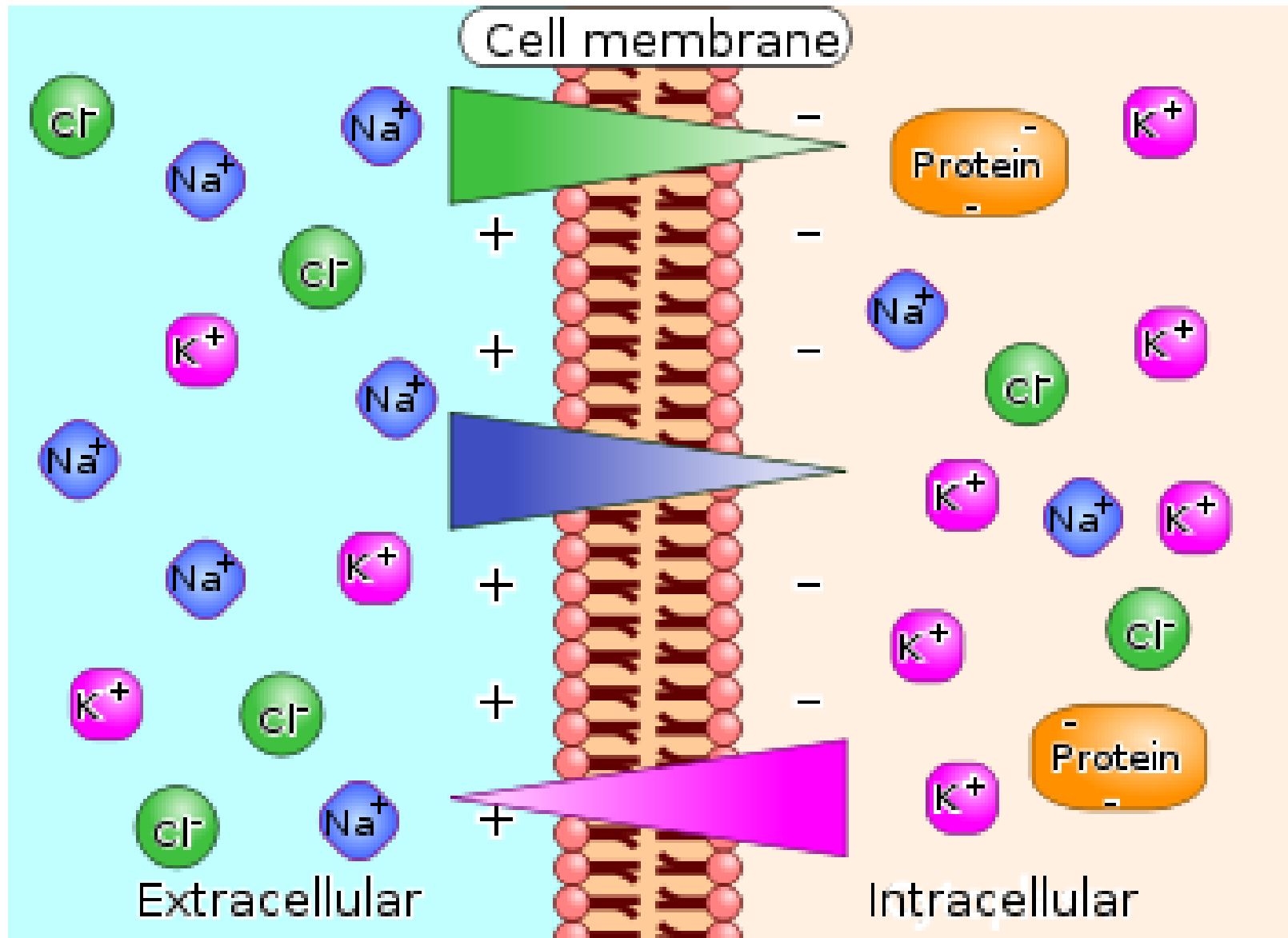
C_i = conc. inside the cell.

C_o = conc. outside the cell.

Concentration of Ions

Ion	Extracellular (mM)	Intracellular (mM)	Nernst Potential (mV)
Na ⁺	145	15	60
Cl ⁻	100	5	-80
K ⁺	4.5	160	-95
Ca ²⁺	1.8	10 ⁻⁴	130

Membrane permeability



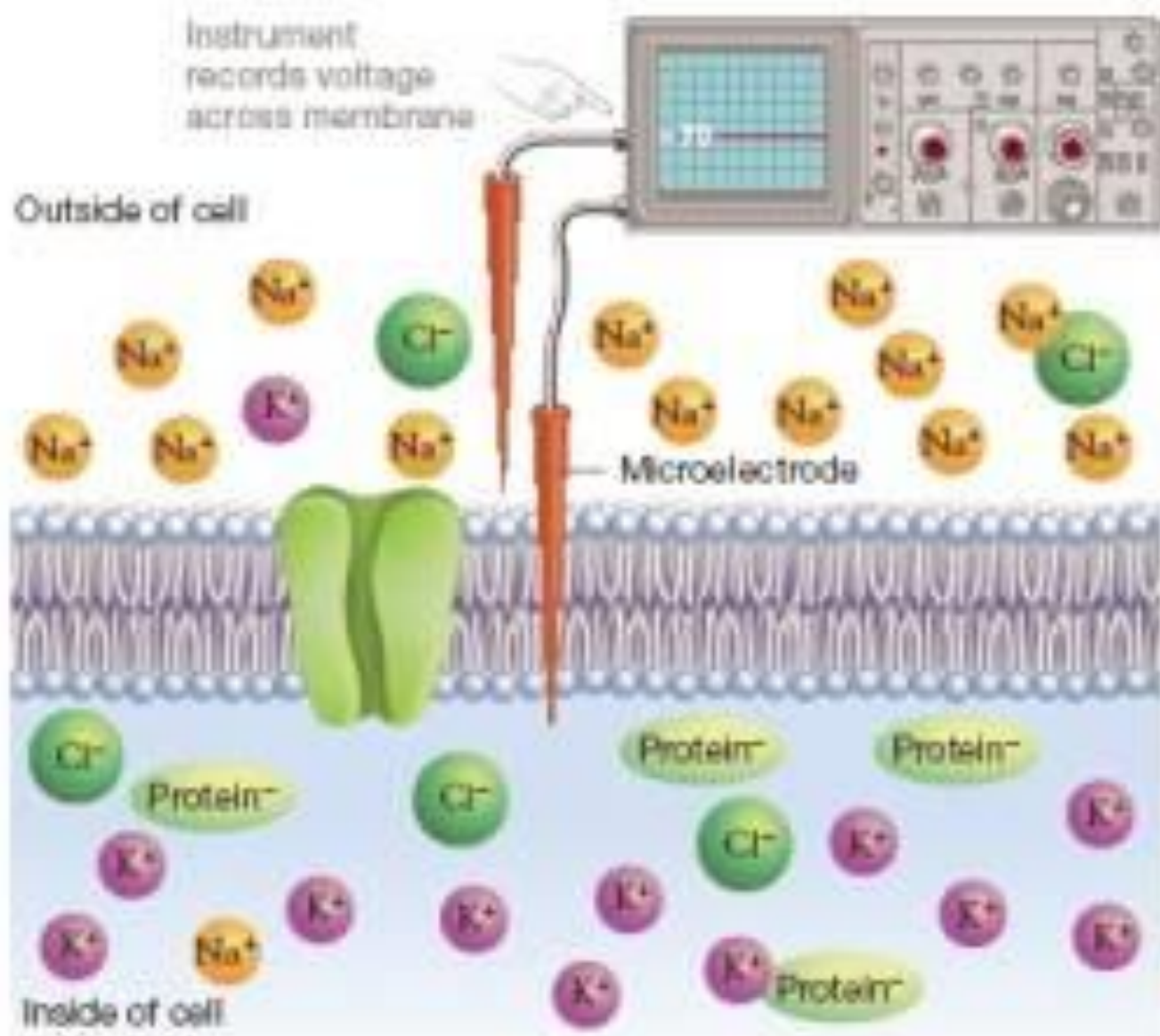
Goldman Hodgkin Katz equation

$$E_m = \frac{RT}{F} \ln \left(\frac{P_{Na^+} [Na^+]_o + P_{K^+} [K^+]_o + P_{Cl^-} [Cl^-]_i}{P_{Na^+} [Na^+]_i + P_{K^+} [K^+]_i + P_{Cl^-} [Cl^-]_o} \right)$$

i = Conc. inside

O = Conc. outside

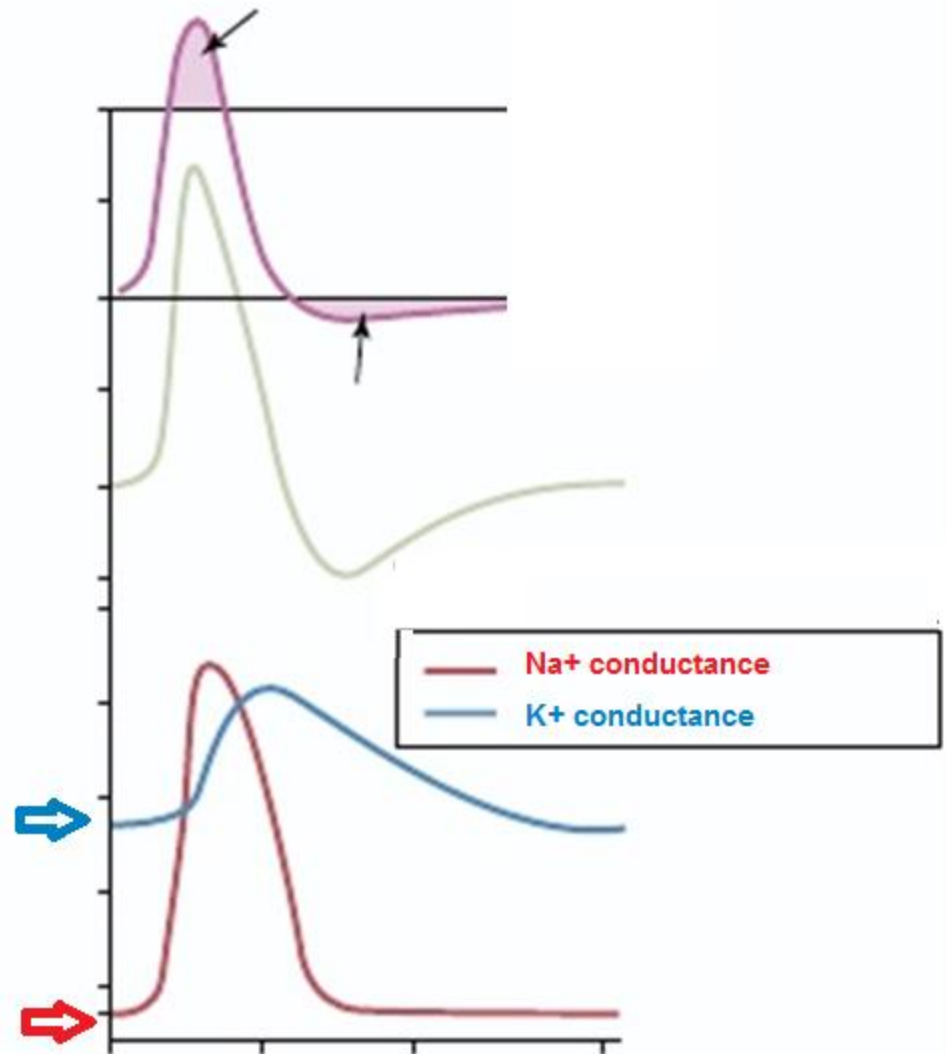
P = permeability of the membrane to that ion.



Resting membrane potential

- Activity K⁺ channels
- Activity of Na⁺ channels
- Na⁺/K⁺ pumps

- Na⁺ and K⁺ conductance at resting potentials



Conductance of plasma membrane (Ohm's Law)

- $I = \Delta V/R$
- G (conductance) = $1/R$
- $I = G \cdot \Delta V$

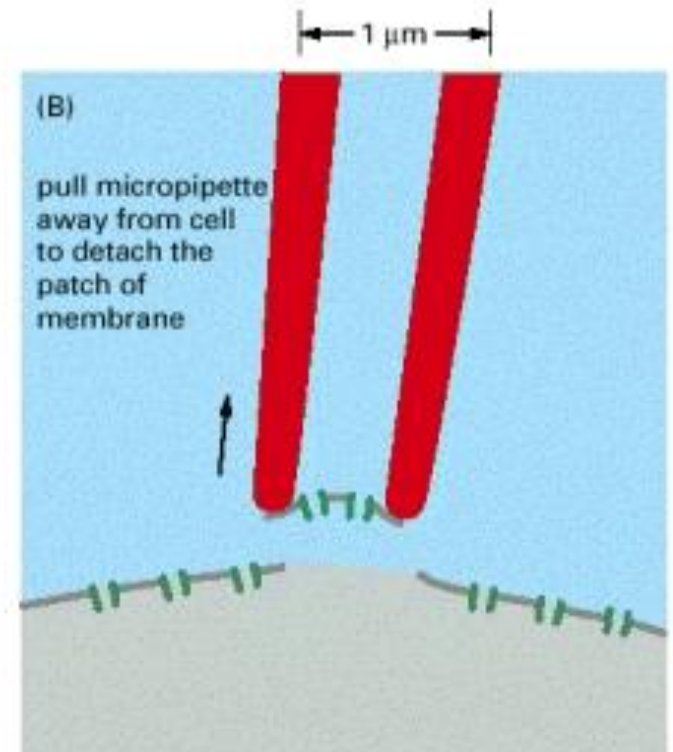
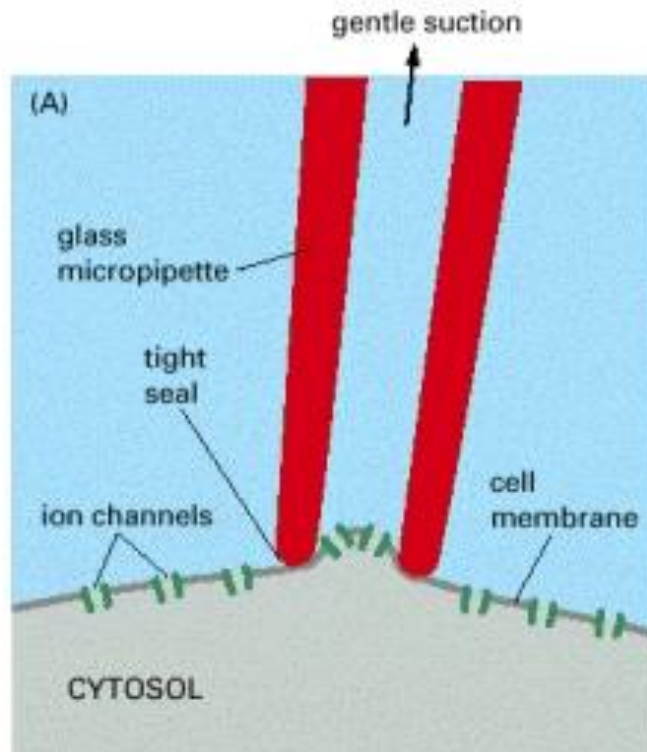
The chord Conductance equation describes the contributions of permeant ions to the resting membrane potential

$$V_m = \frac{g_K}{g_{tot}} E_K + \frac{g_{Na}}{g_{tot}} E_{Na} + \frac{g_{Cl}}{g_{tot}} E_{Cl}$$

Measuring Currents at specific
membrane potential

Patch Clamp

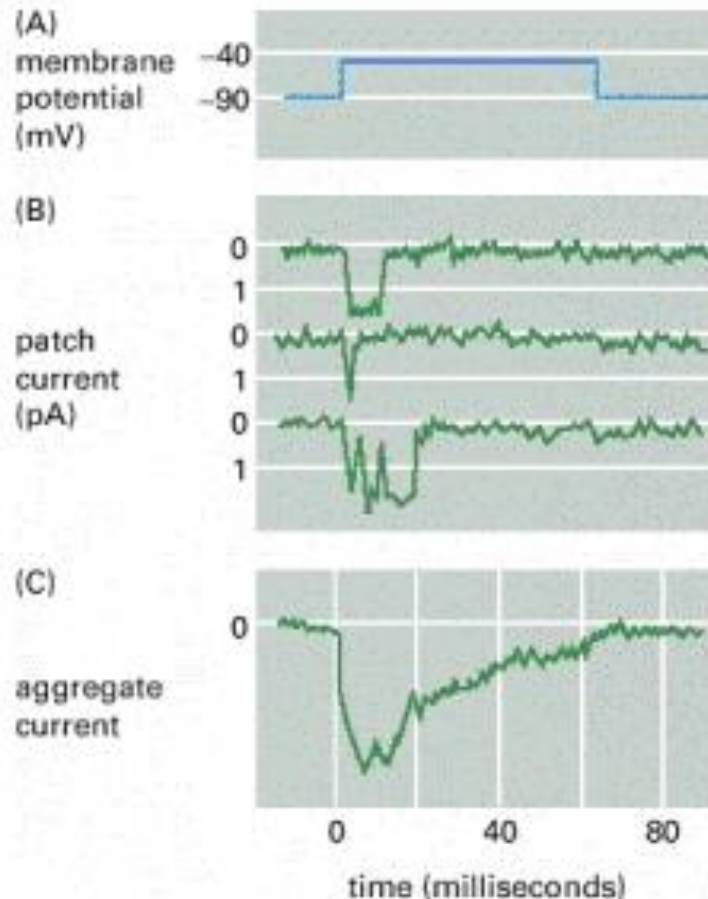
- Patch still attached to the rest of the cell, as in (A), or detached, as in (B).



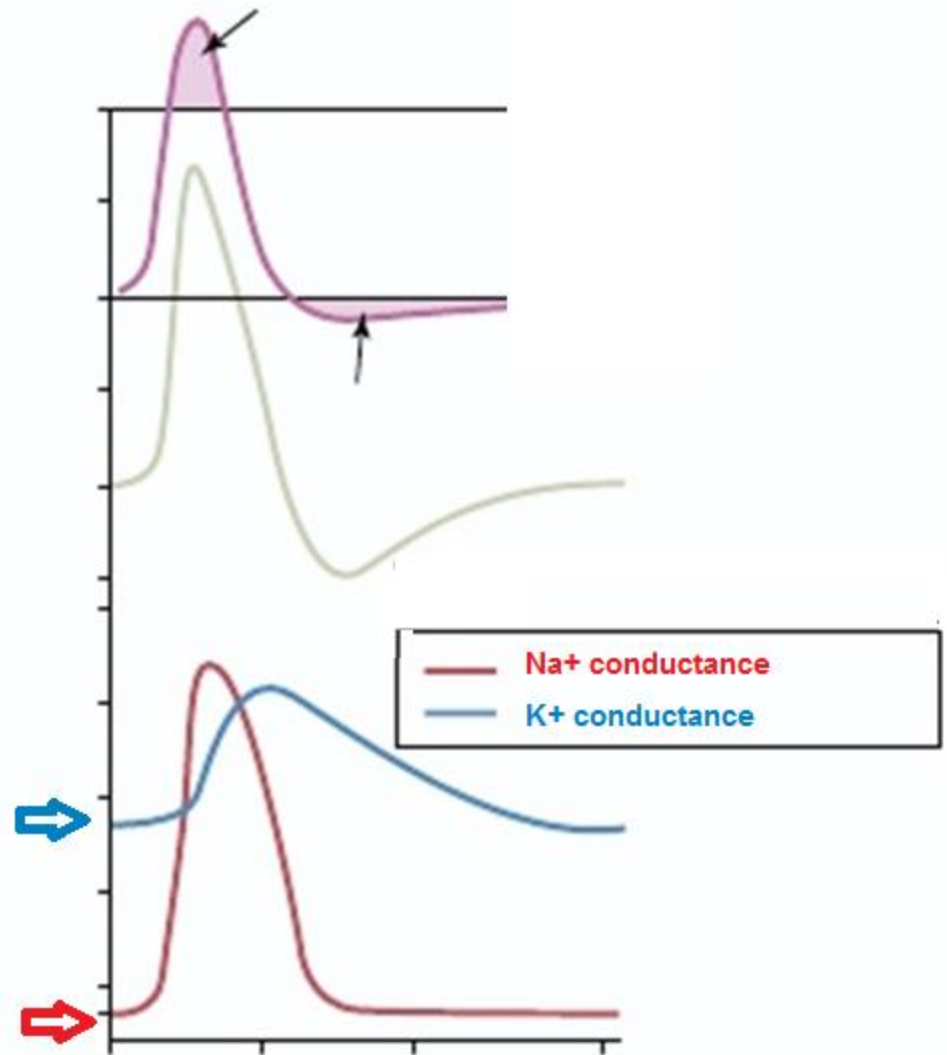
Patch Clamp

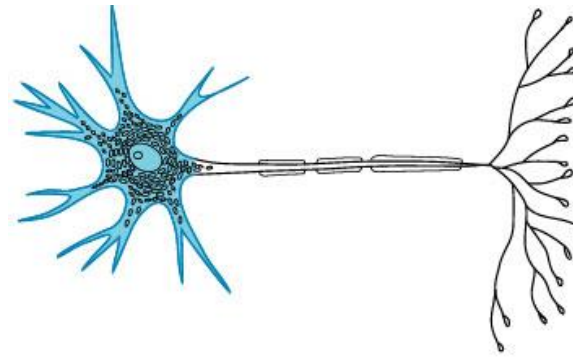
- electronic device is employed to maintain, or “clamp,” the membrane potential at a set value
- recording the ionic current through individual channels

Recording of currents in Patch Clamp

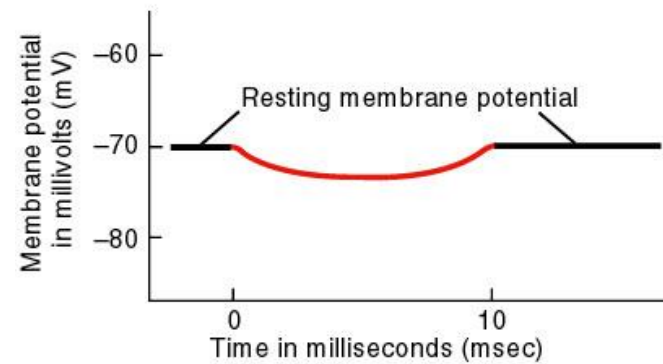


- Na⁺ and K⁺ conductance at resting potentials

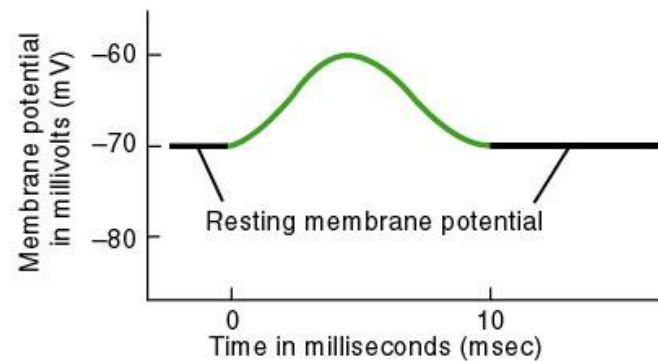




- Changes in Resting membrane potential



(a) Hyperpolarizing graded potential

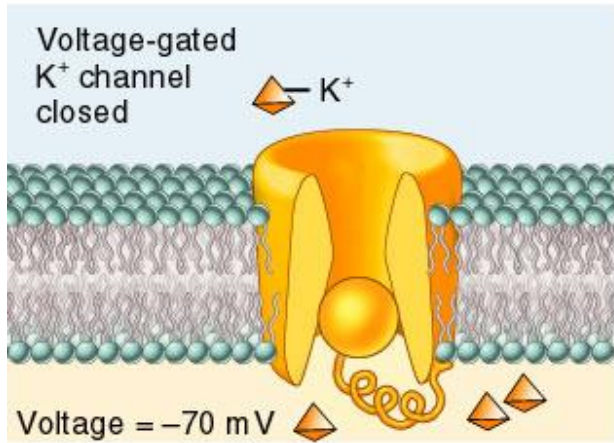


(b) Depolarizing graded potential

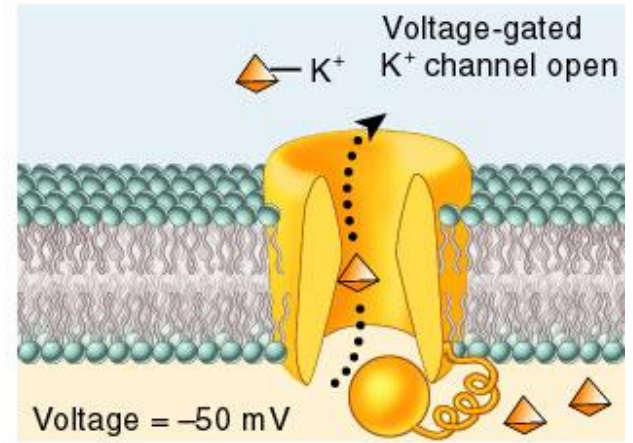
□ Extracellular fluid

■ Plasma membrane

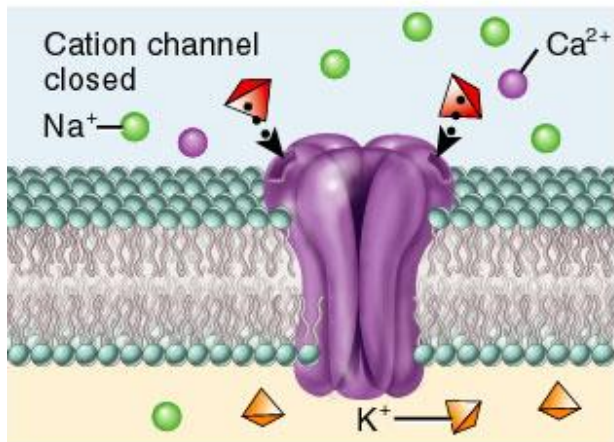
□ Cytosol



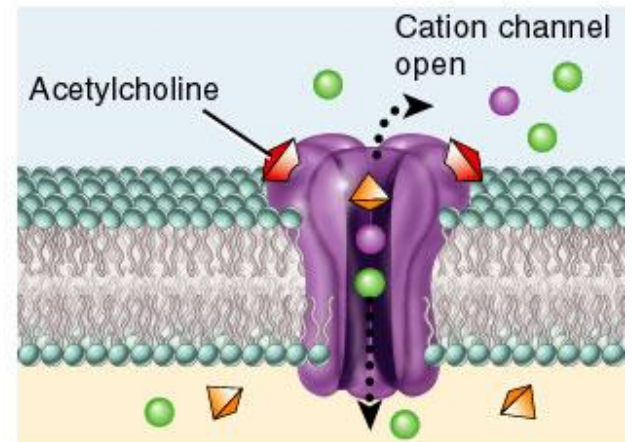
Change in membrane potential opens the channel



(a) Voltage-gated channel

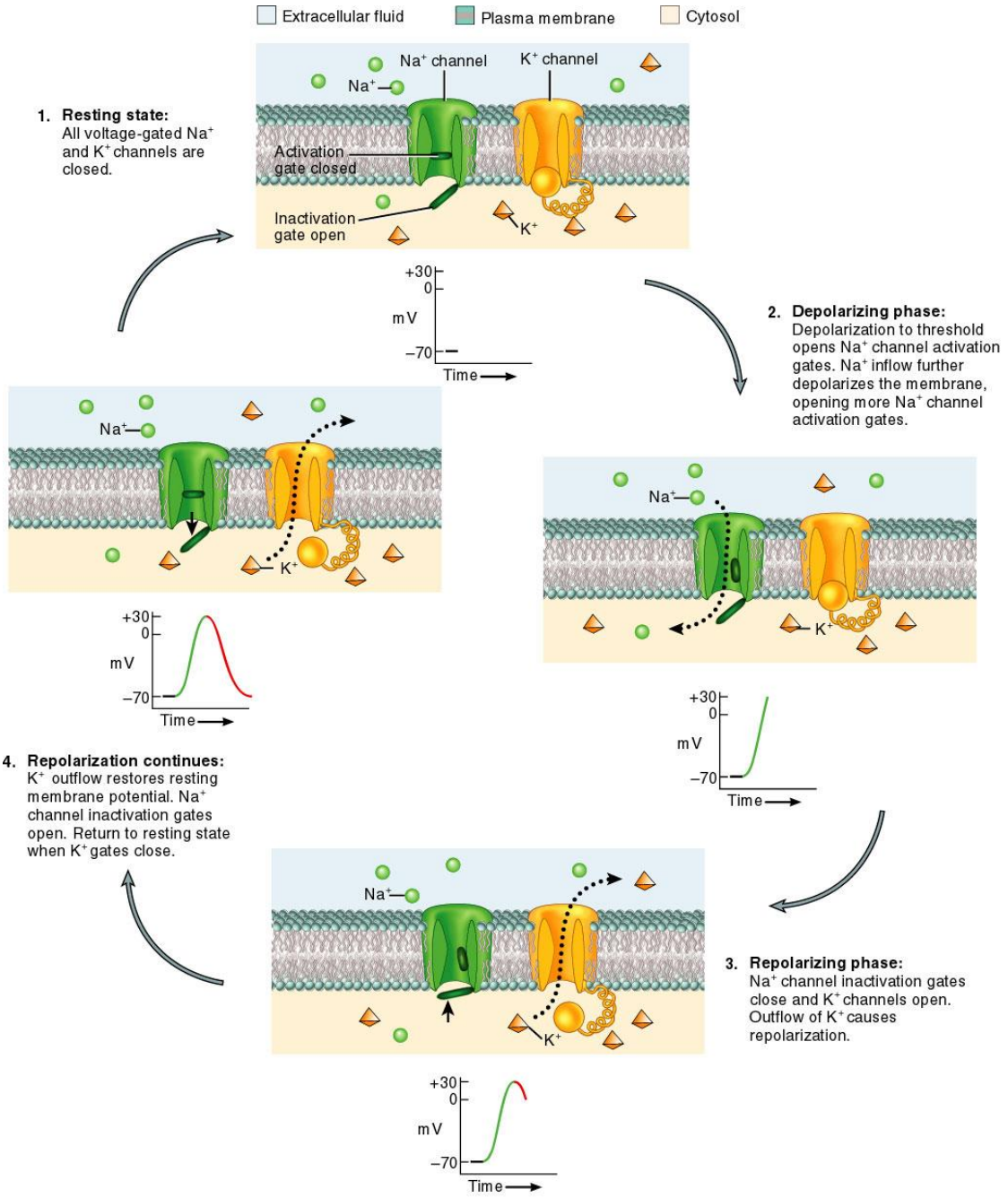


Chemical stimulus opens the channel



(b) Ligand-gated channel

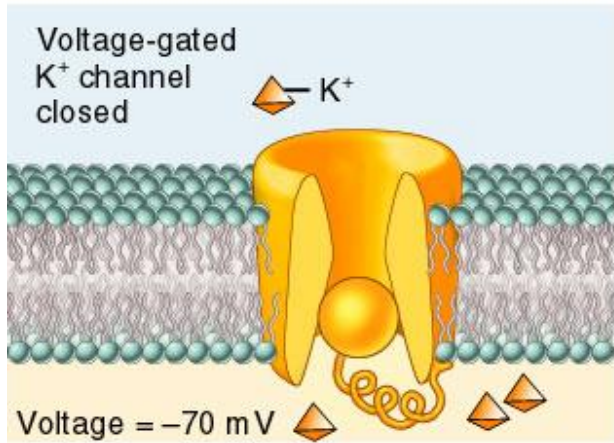
- Changes in Channels activity results in action potential



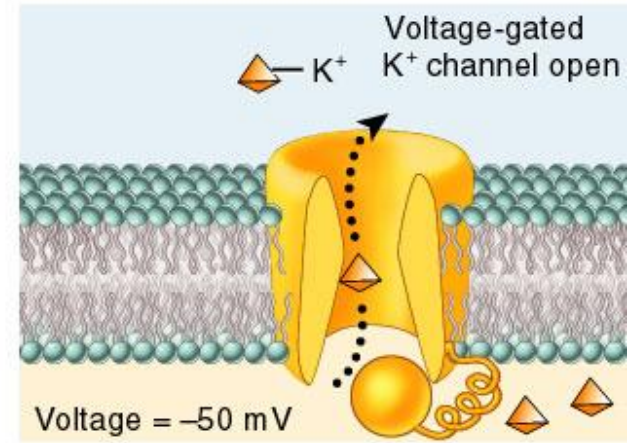
□ Extracellular fluid

■ Plasma membrane

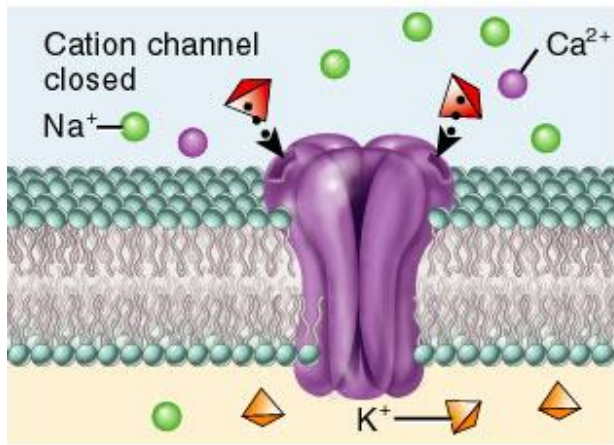
□ Cytosol



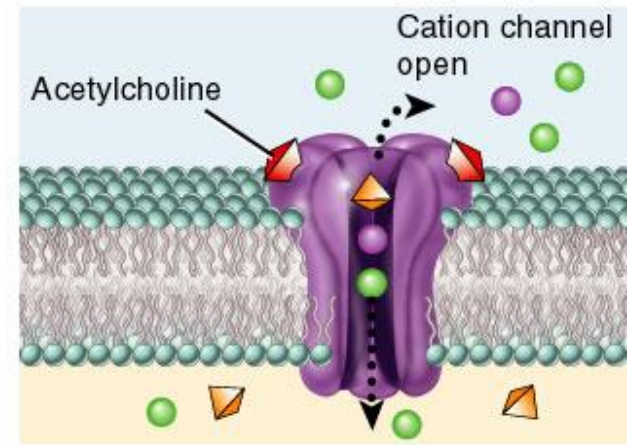
Change in membrane potential opens the channel



(a) Voltage-gated channel



Chemical stimulus opens the channel



(b) Ligand-gated channel

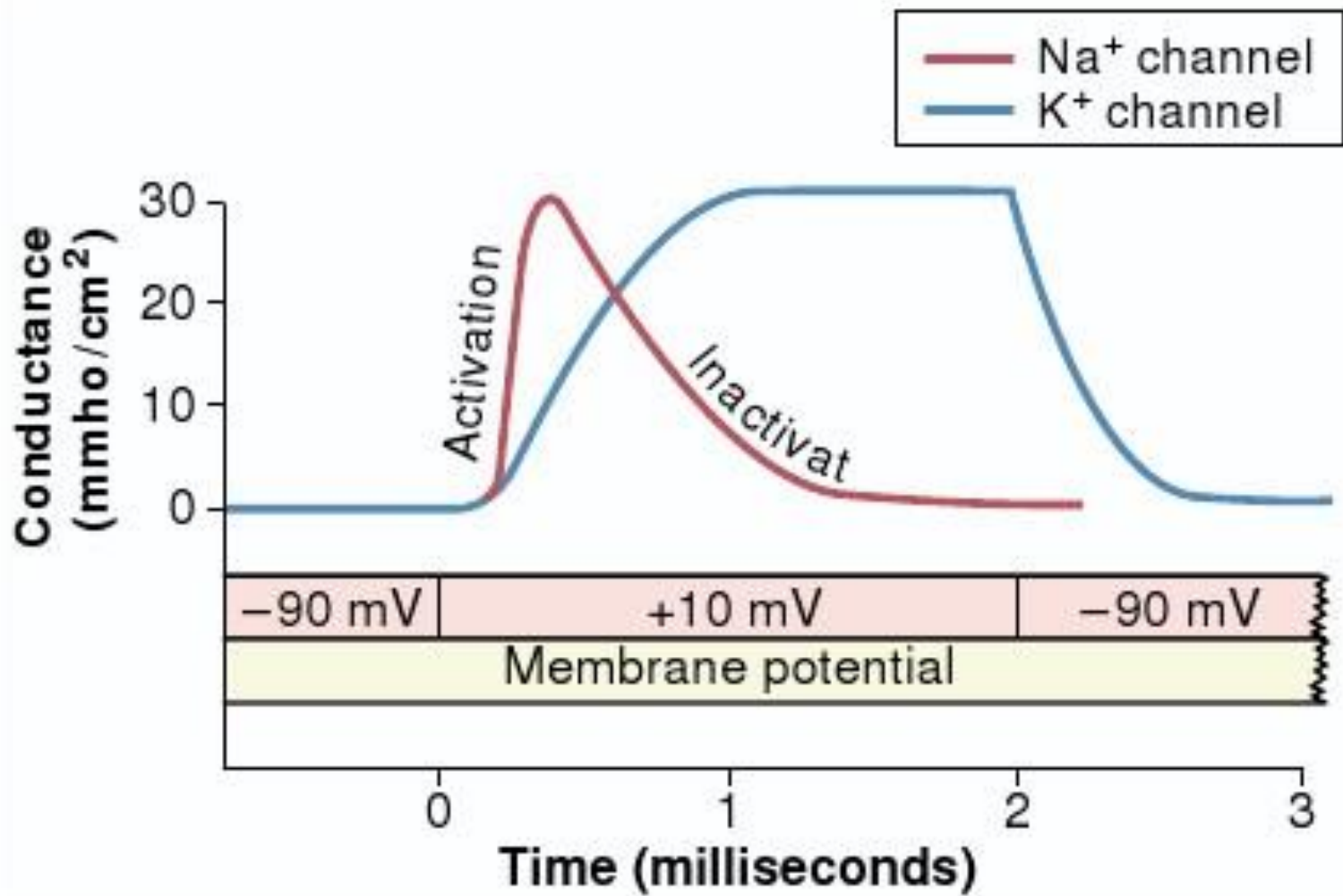
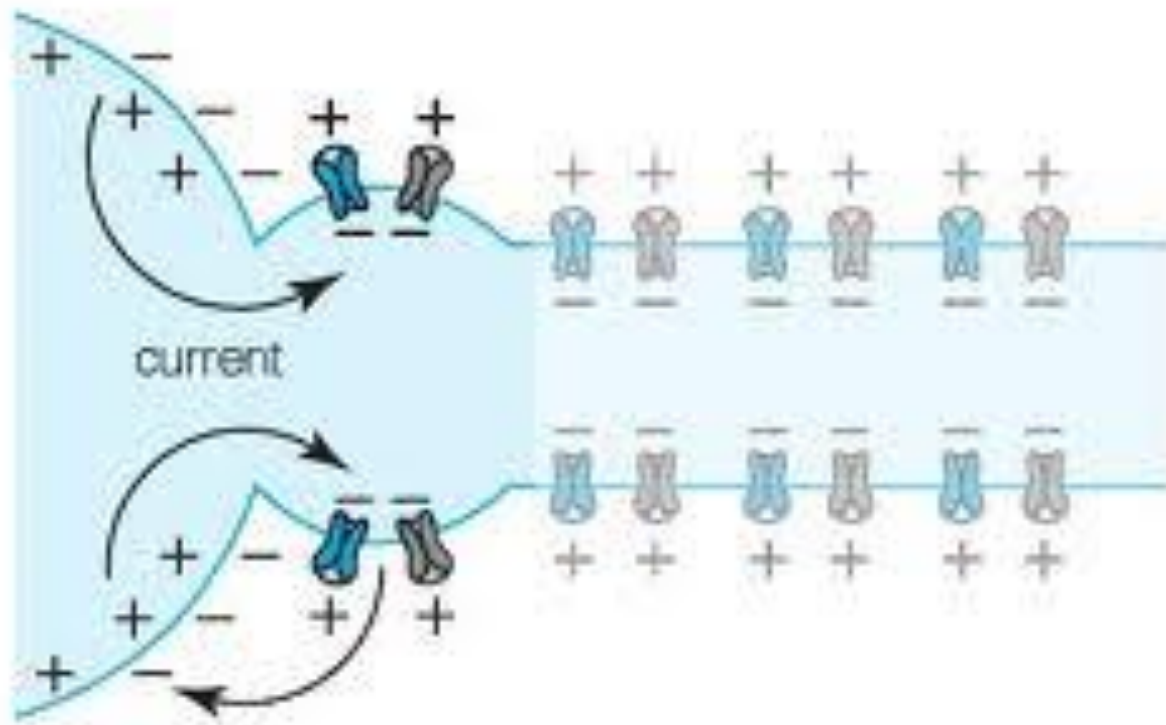


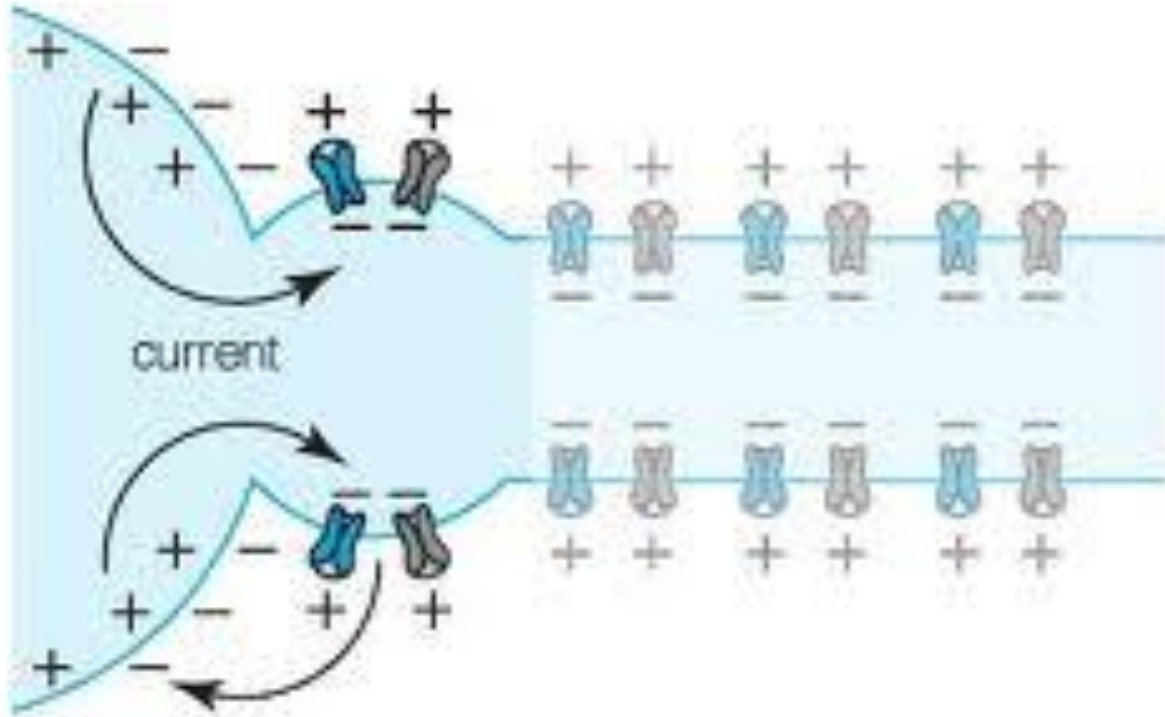
Figure 5-9

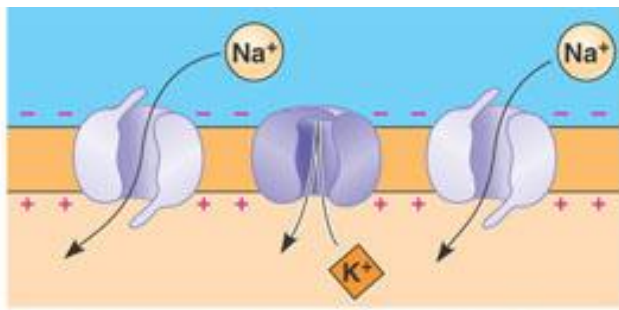
Ionic currents cause depolarization



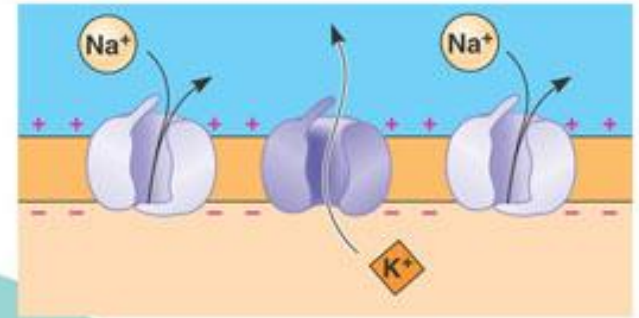
Resistance to ionic currents and activation of channels

Action potentials

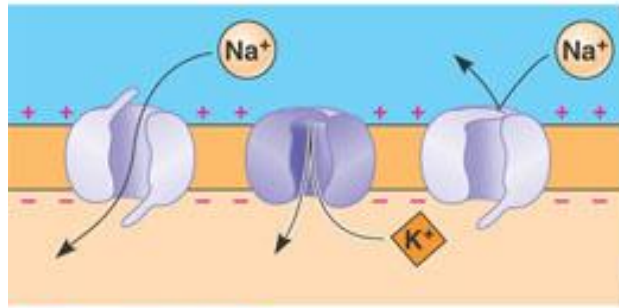




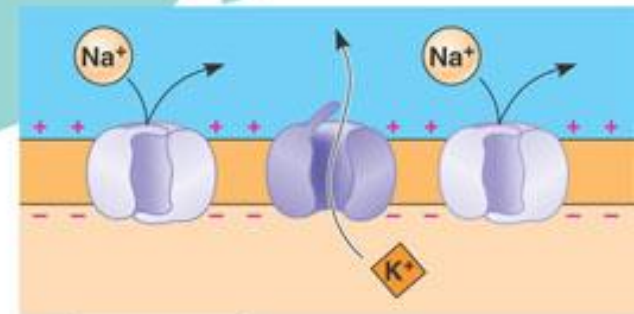
3 Rising phase of the action potential



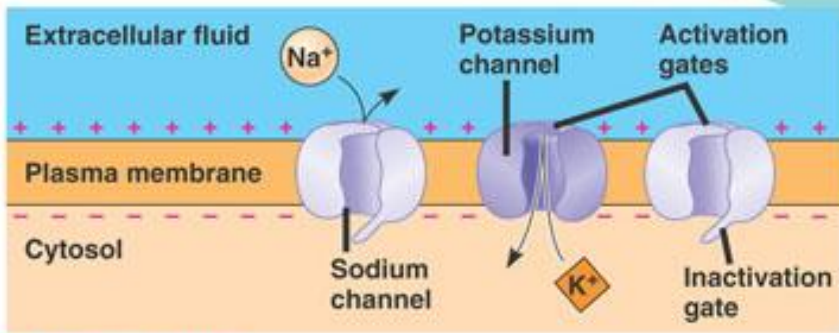
4 Falling phase of the action potential



2 Depolarization

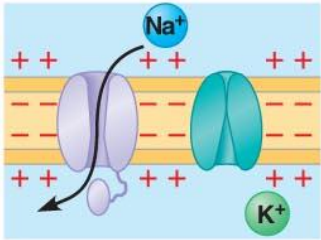


5 Undershoot

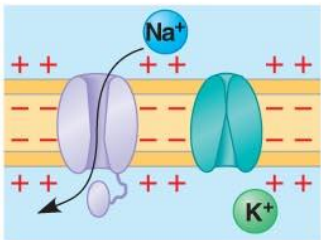


1 Resting state

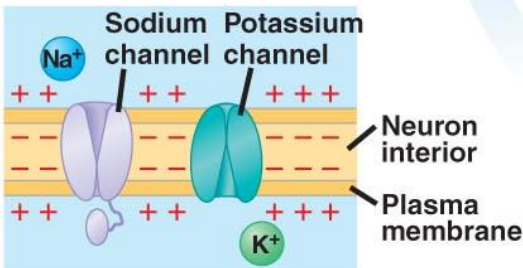
Generation of action potentials



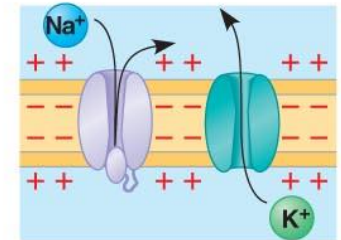
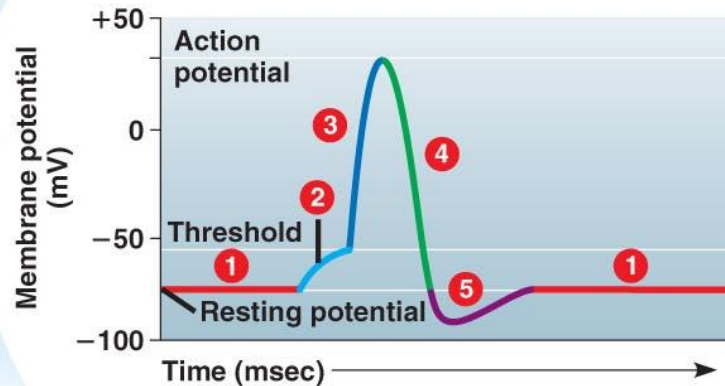
- 3** Additional Na⁺ channels open, K⁺ channels are closed; interior of cell becomes more positive.



- 2** A stimulus opens some Na⁺ channels; if threshold is reached, action potential is triggered.

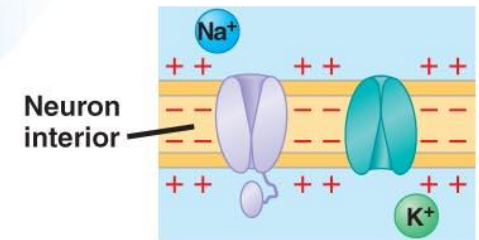


- 1** Resting state: voltage-gated Na⁺ and K⁺ channels closed; resting potential is maintained.



- 4** Na⁺ channels close and inactivate. K⁺ channels open, and K⁺ rushes out; interior of cell more negative than outside.

- 5** The K⁺ channels close relatively slowly, causing a brief undershoot.



- 1** Return to resting state.

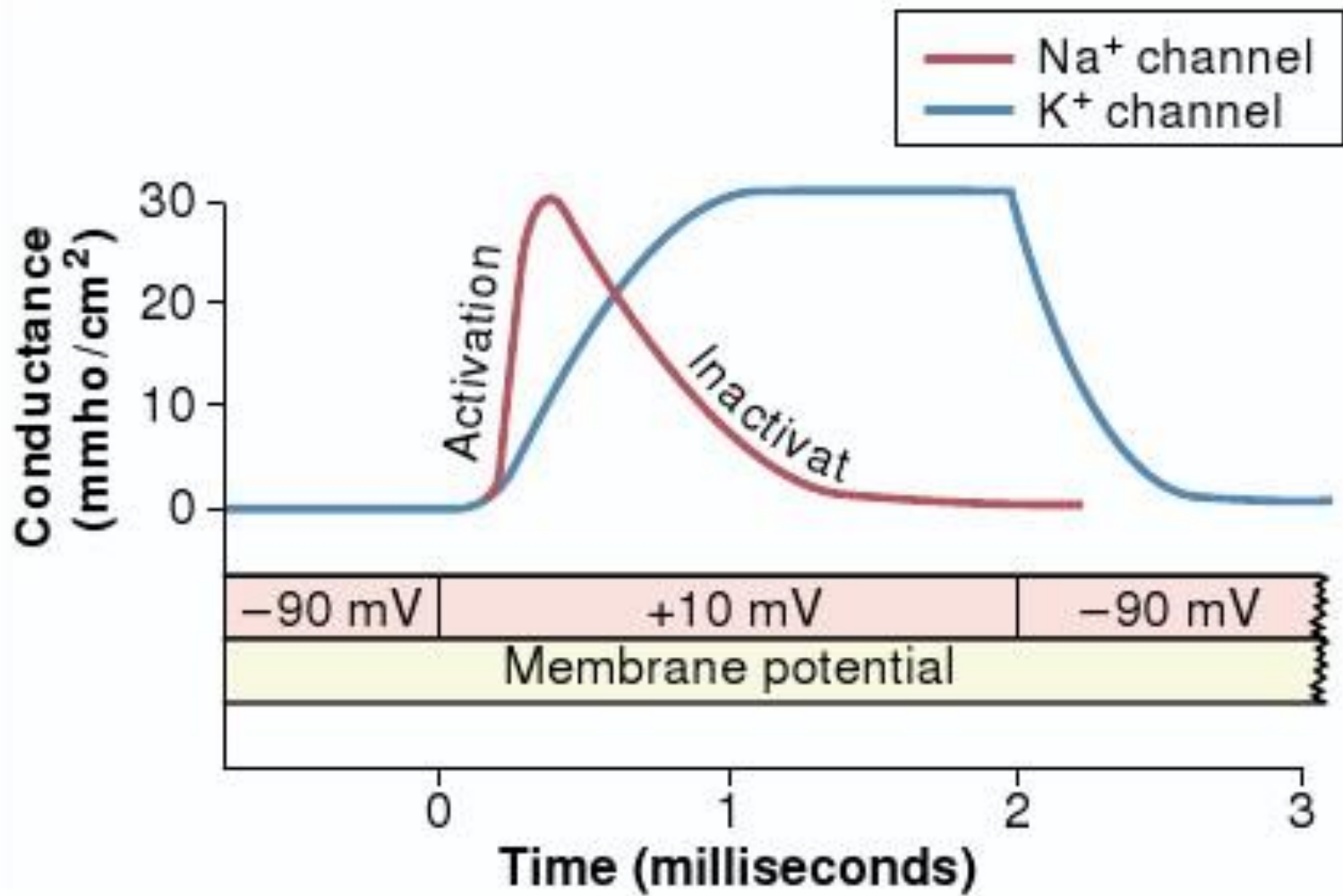
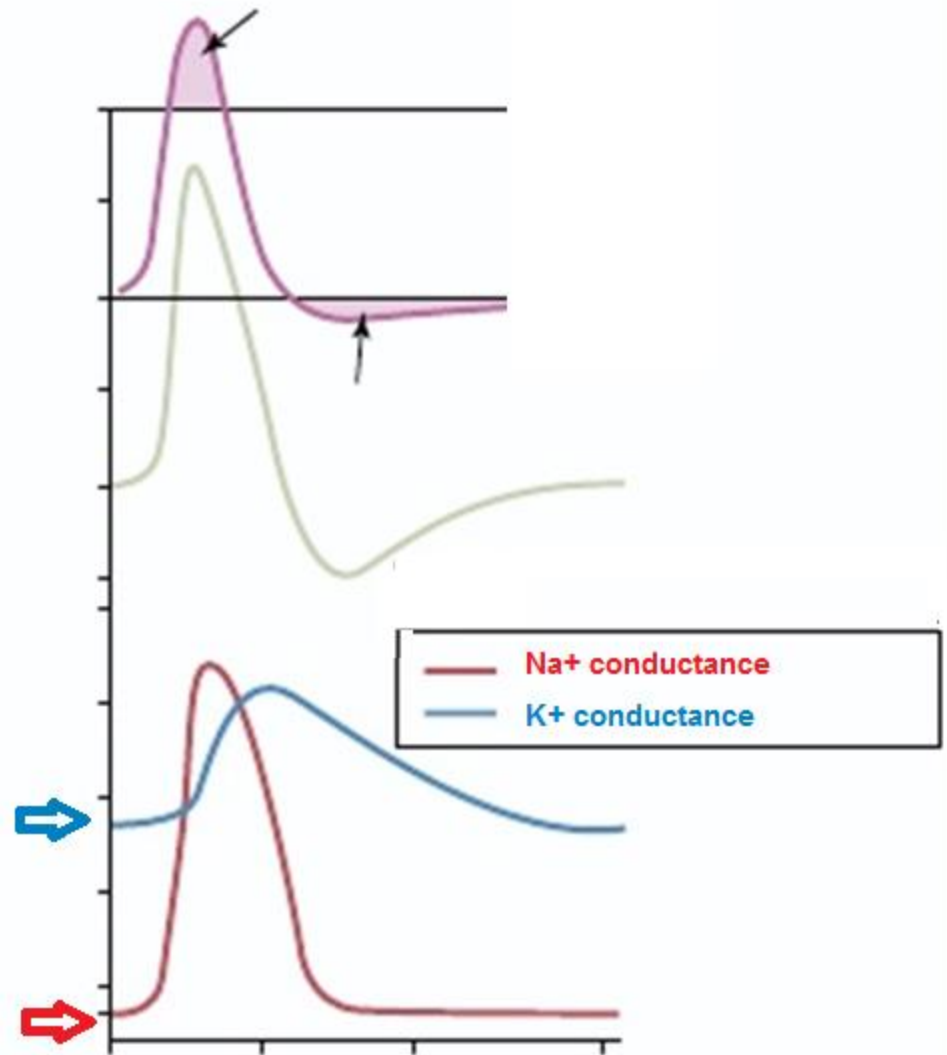
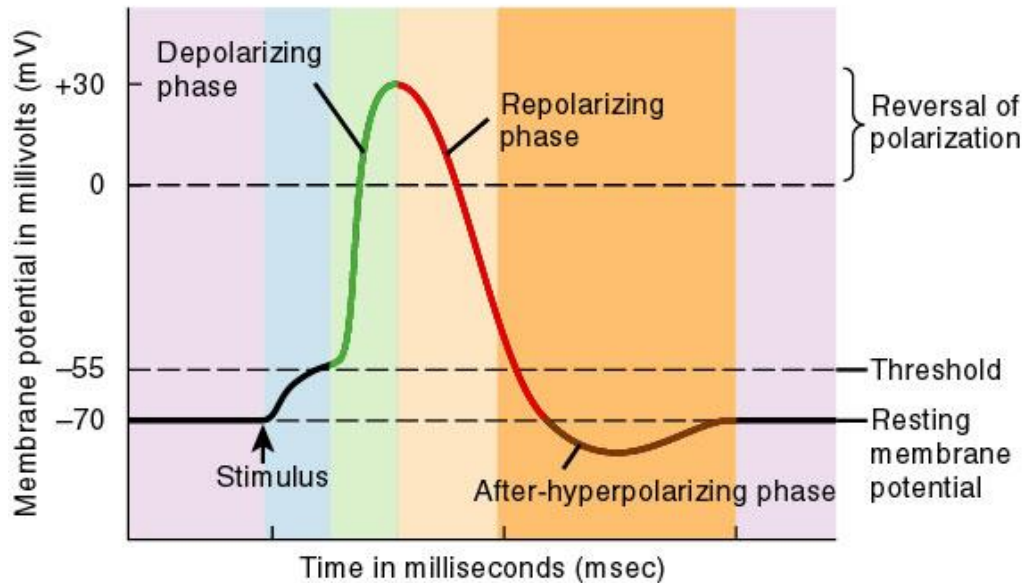
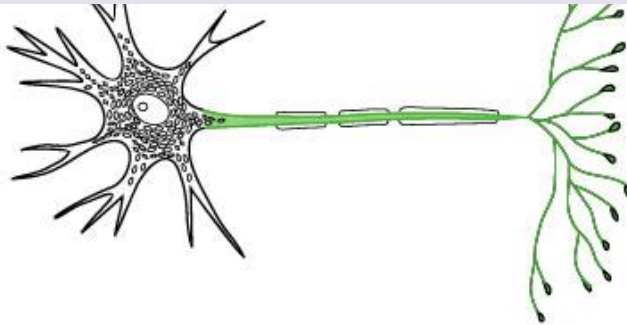


Figure 5-9

- Na⁺ and K⁺ conductance at resting potentials



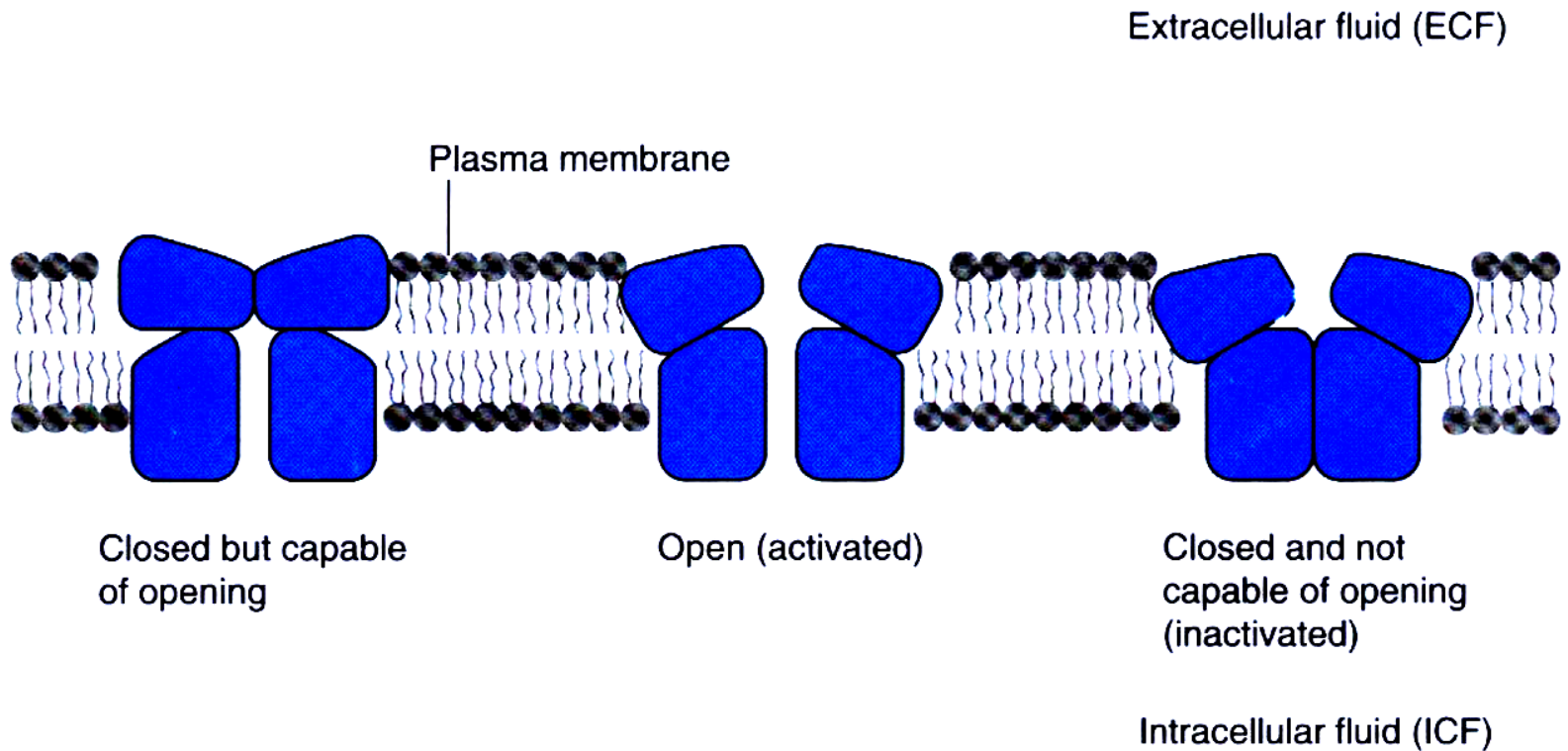
Refractory periods



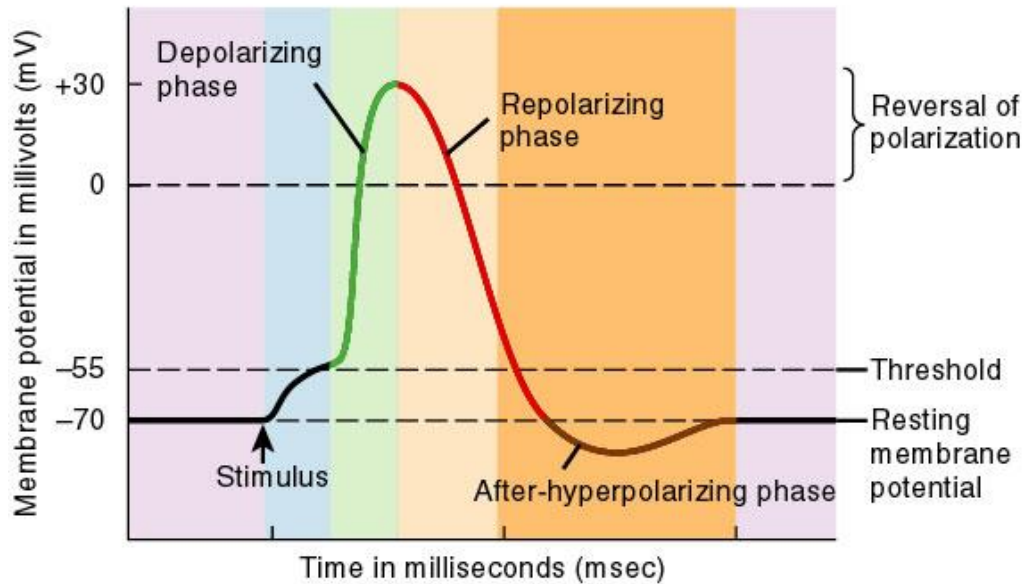
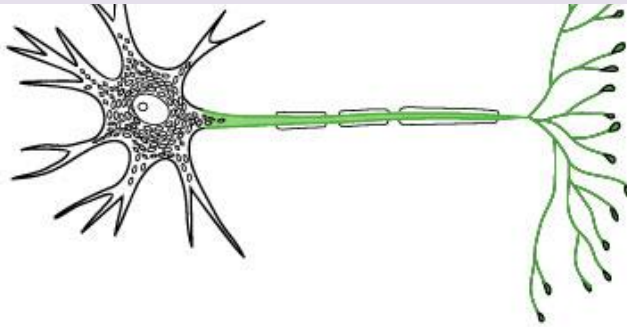
Key:

- Resting membrane potential: Voltage-gated Na^+ channels are in the resting state and voltage-gated K^+ channels are closed
 - Stimulus causes depolarization to threshold
 - Voltage-gated Na^+ channel activation gates are open
 - Voltage-gated K^+ channels are open; Na^+ channels are inactivating
 - Voltage-gated K^+ channels are still open; Na^+ channels are in the resting state
- } Absolute refractory period
- } Relative refractory period

Refractory periods and Na⁺ Channels



Refractory periods

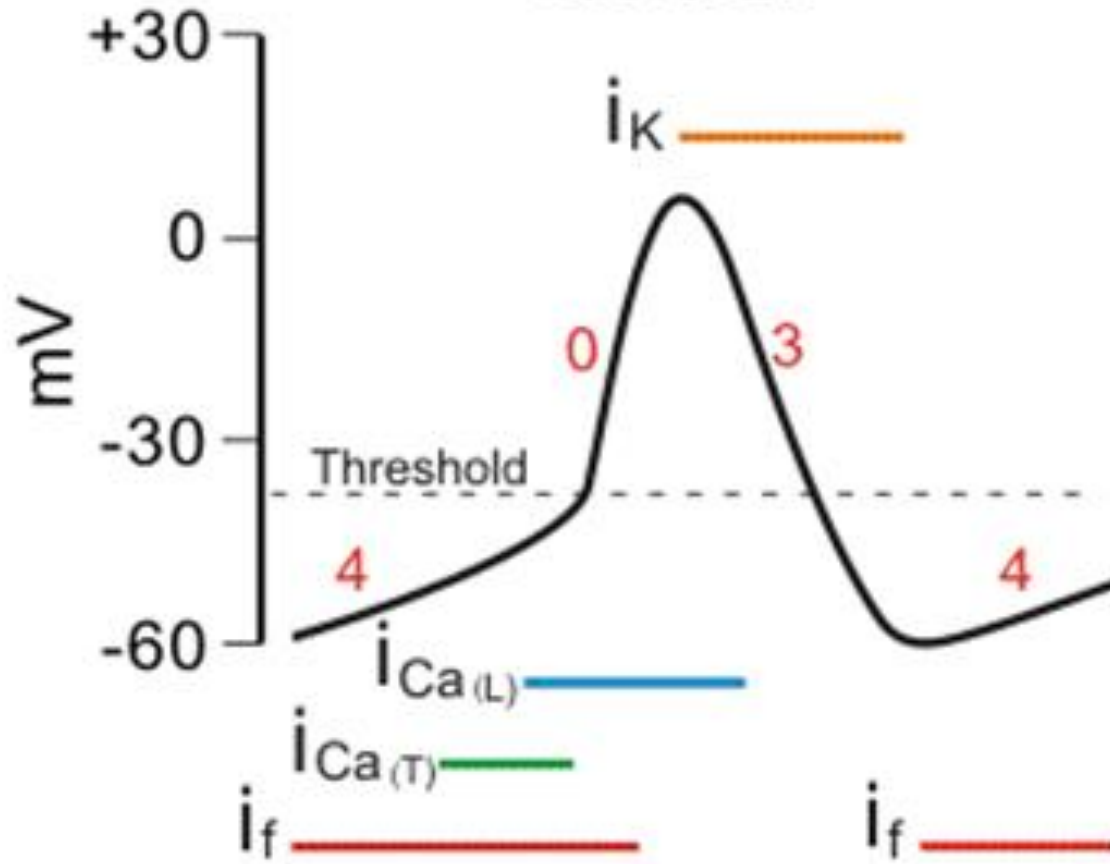


Key:

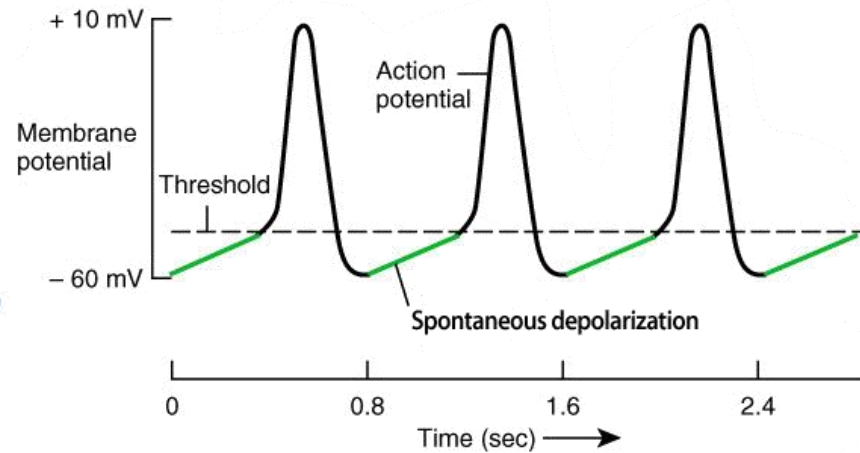
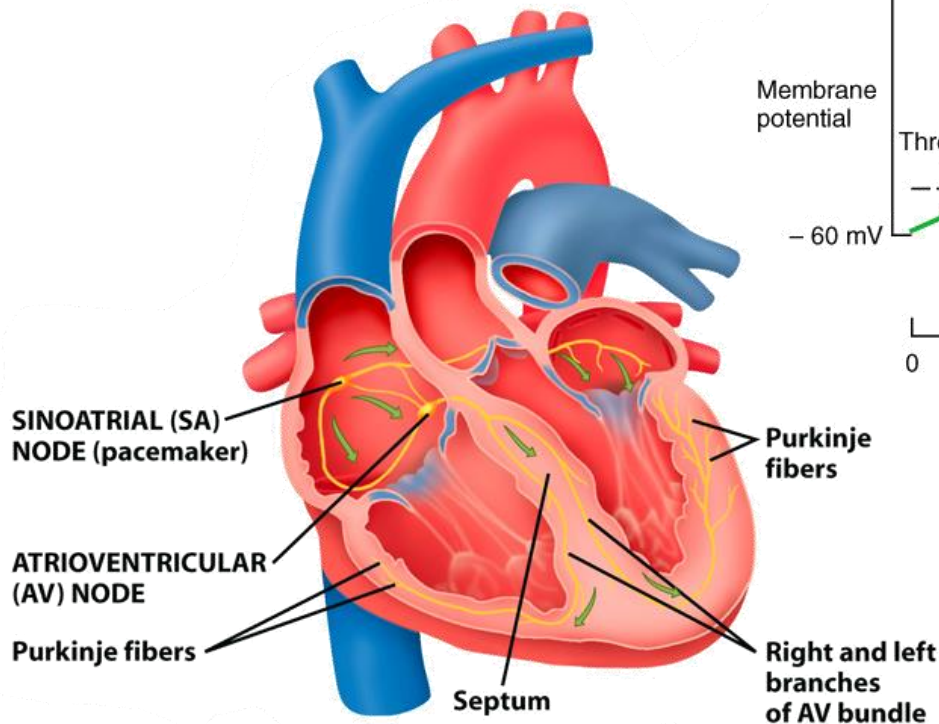
- Resting membrane potential: Voltage-gated Na^+ channels are in the resting state and voltage-gated K^+ channels are closed
 - Stimulus causes depolarization to threshold
 - Voltage-gated Na^+ channel activation gates are open
 - Voltage-gated K^+ channels are open; Na^+ channels are inactivating
 - Voltage-gated K^+ channels are still open; Na^+ channels are in the resting state
- } Absolute refractory period
- } Relative refractory period

Involvement of other Ions in Action potential

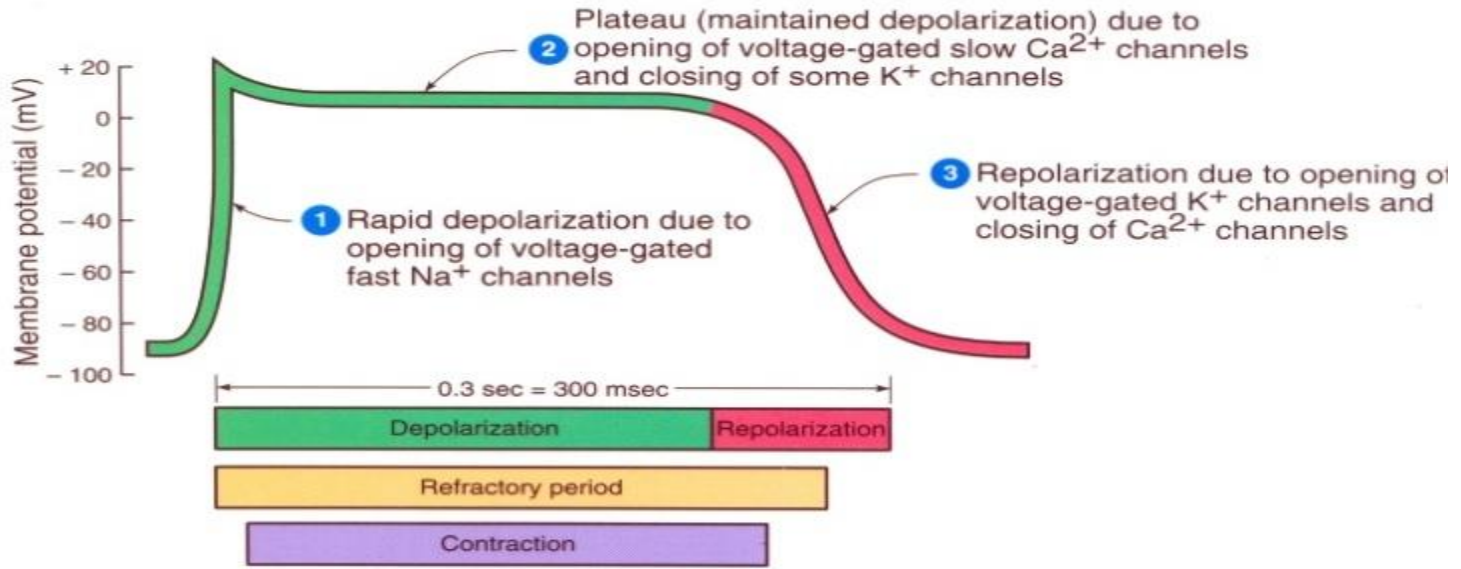
SA Node



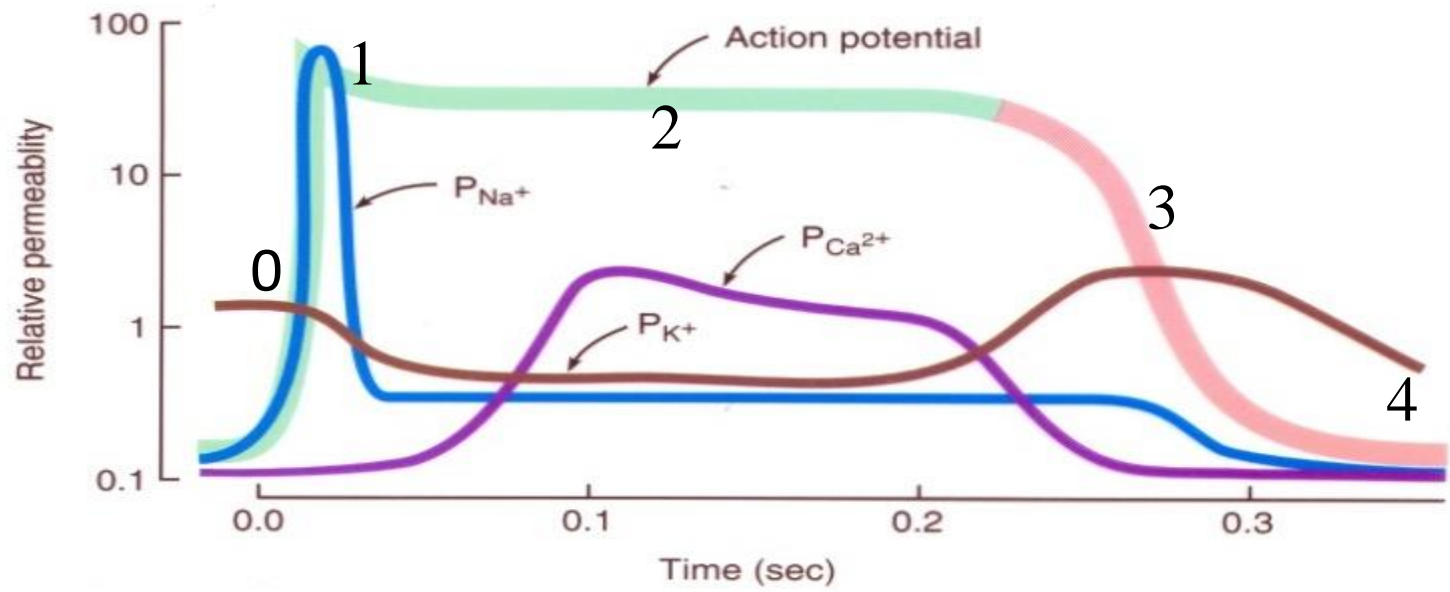
Cardiac Conduction



Generation of Action potential every 0.8 seconds, or 75 action potentials per minute at the SA node (**Pacemaker of the heart**)

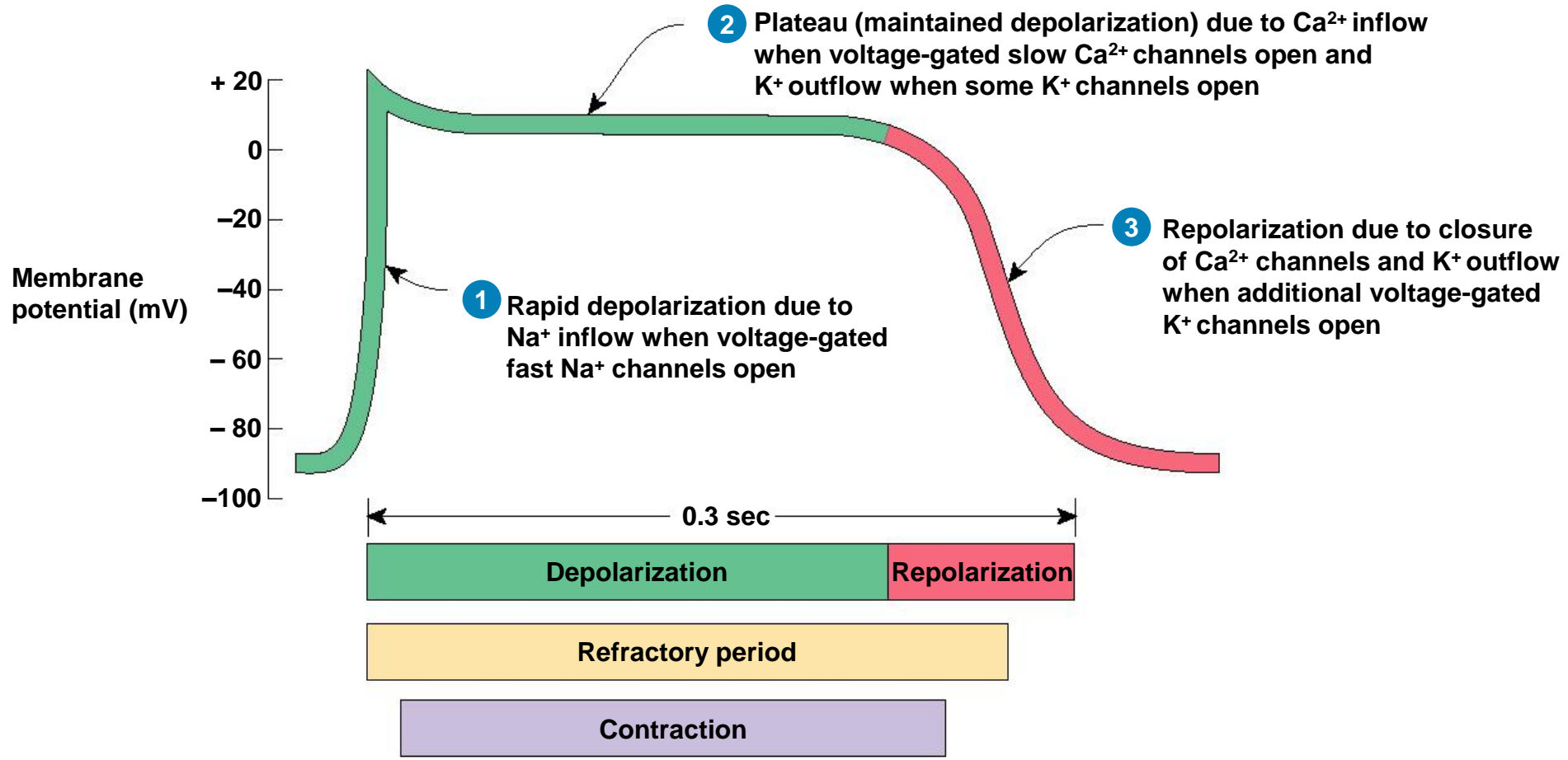


(a) Action potential, refractory period, and contraction

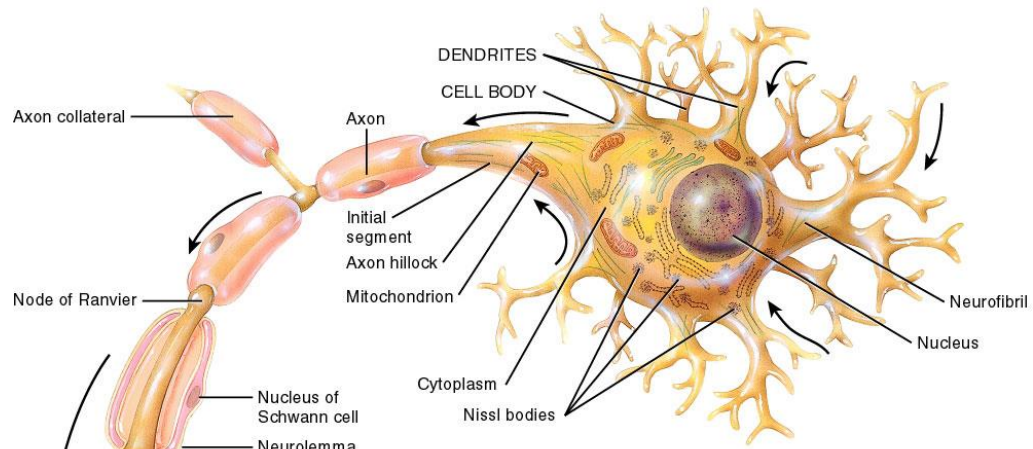


(b) Membrane permeability (P) changes

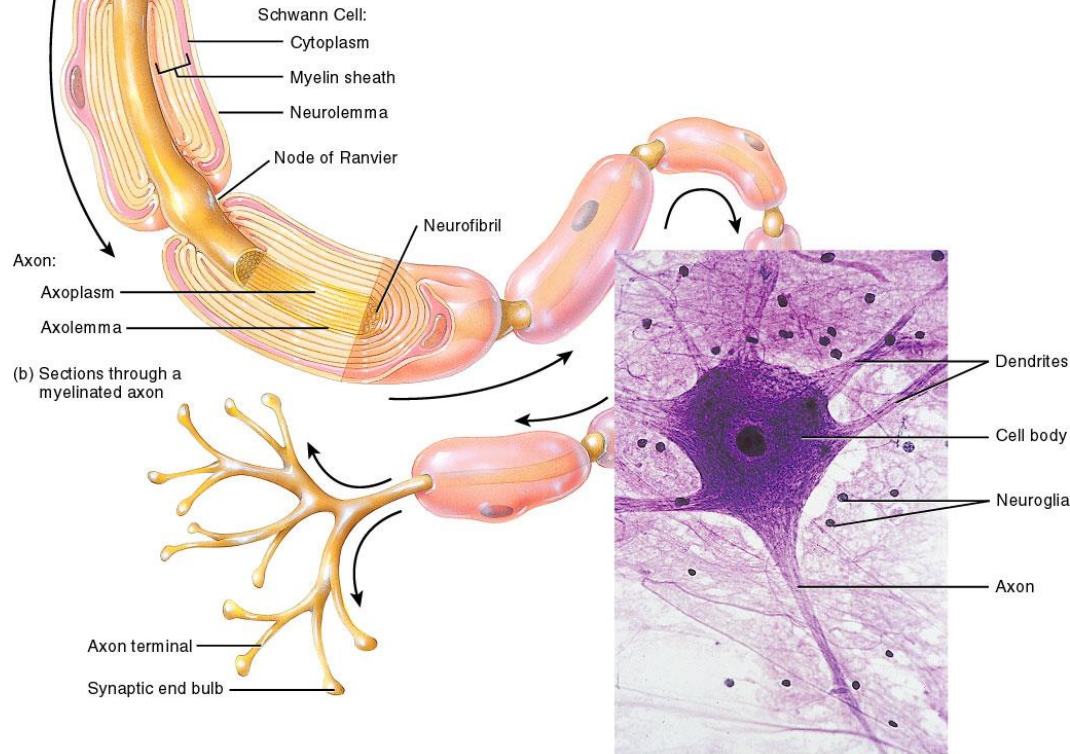
Cardiac Muscle Action Potential



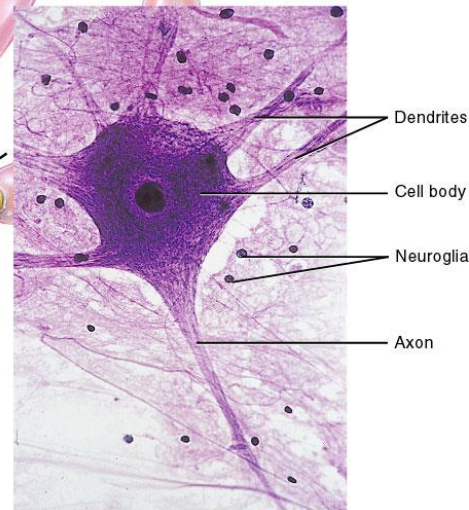
Generation of action potential at Neural cells



(a) Parts of a motor neuron



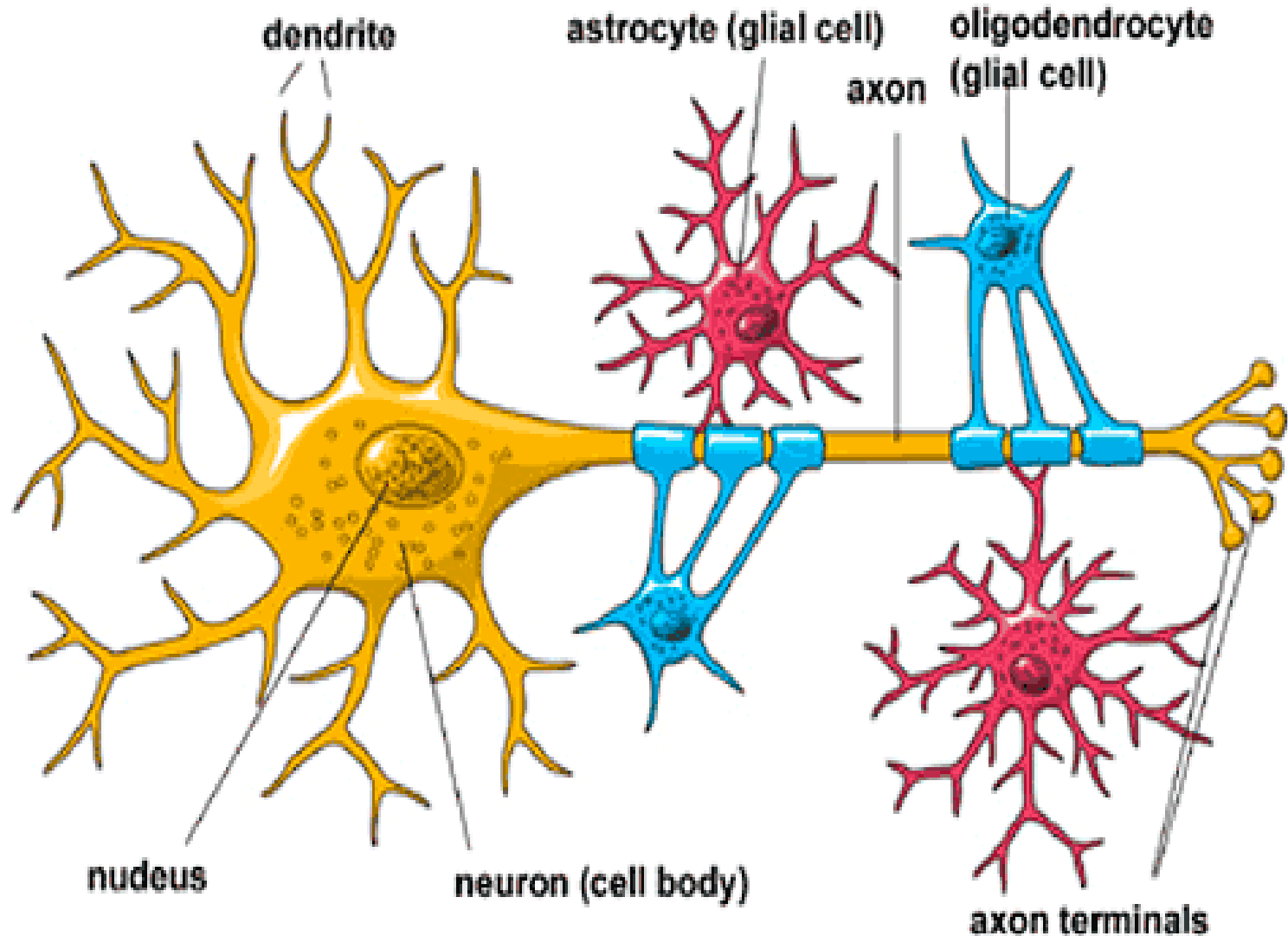
(b) Sections through a myelinated axon



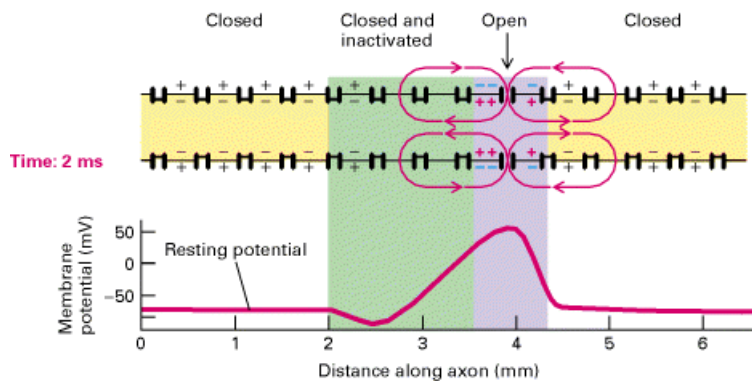
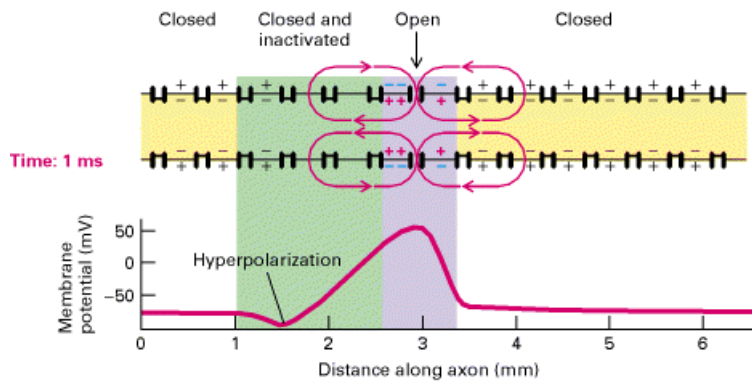
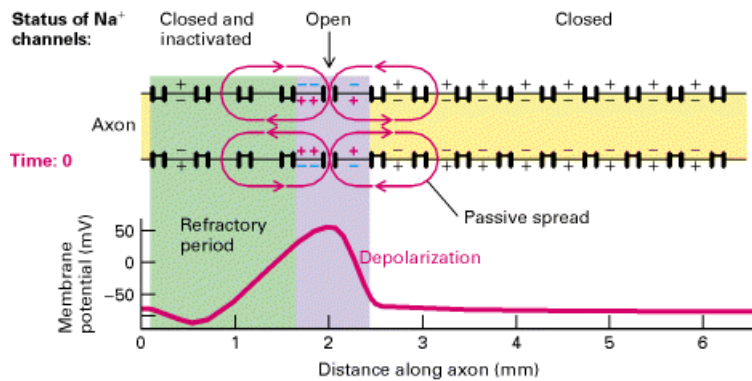
LM 430x

(c) Motor neuron

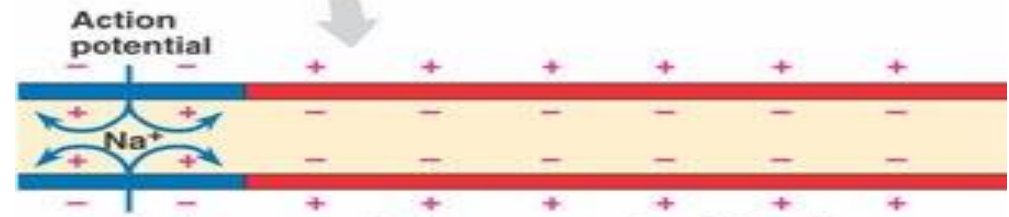
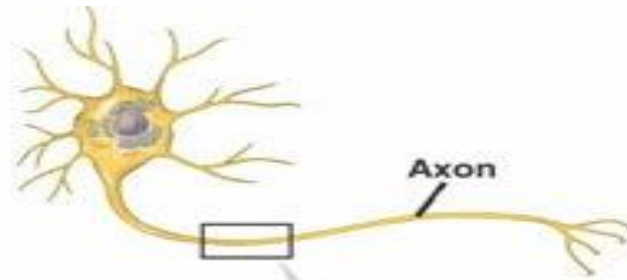
Supportive cells



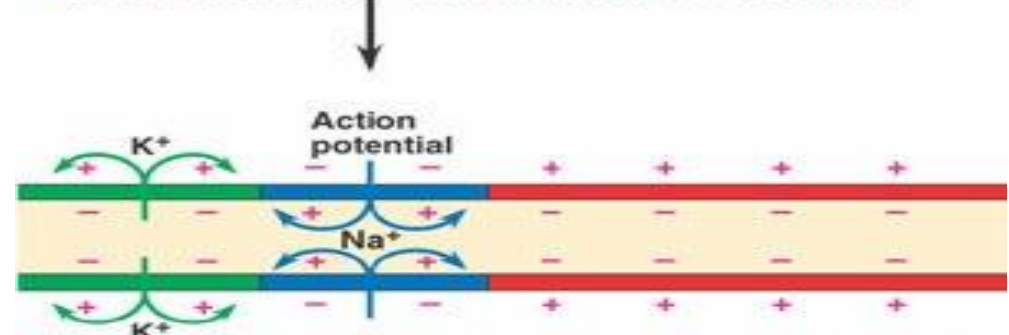
Conduction of impulse



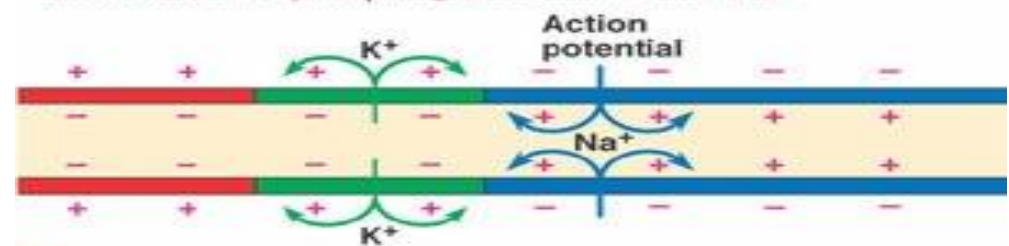
- Continuous Conduction in Unmyelinated axons



1 An action potential is generated as Na^+ flows inward across the membrane at one location.

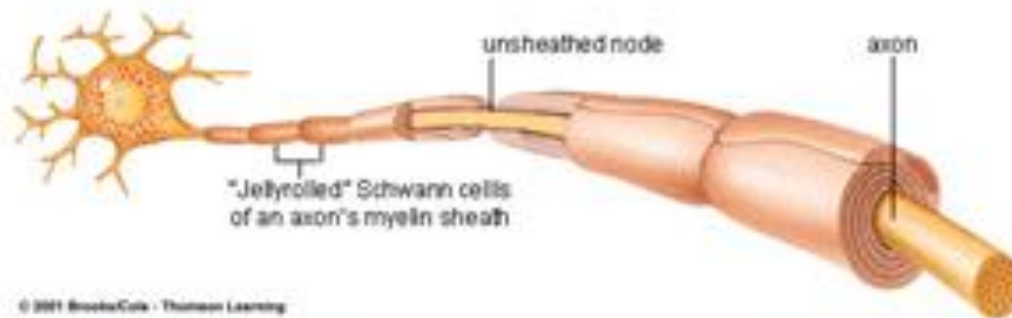


2 The depolarization of the action potential spreads to the neighboring region of the membrane, re-initiating the action potential there. To the left of this region, the membrane is repolarizing as k^+ flows outward.



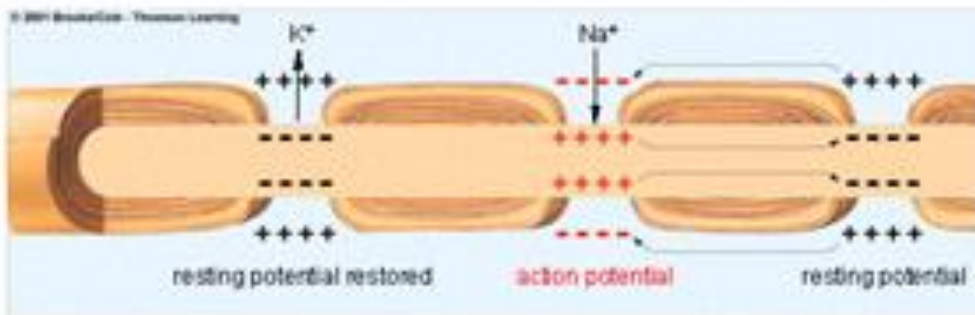
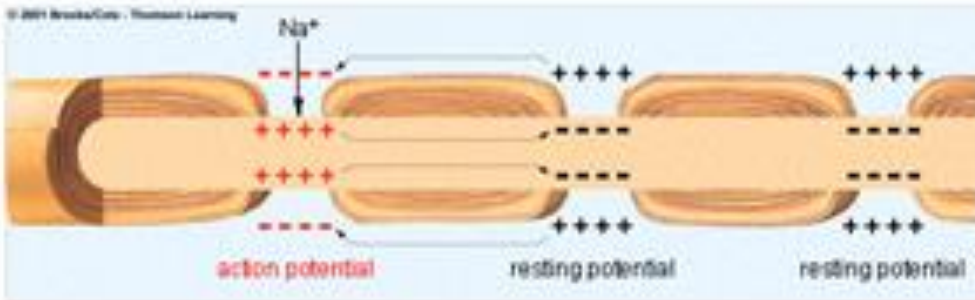
3

- Continuous Conduction in Unmyelinated axons



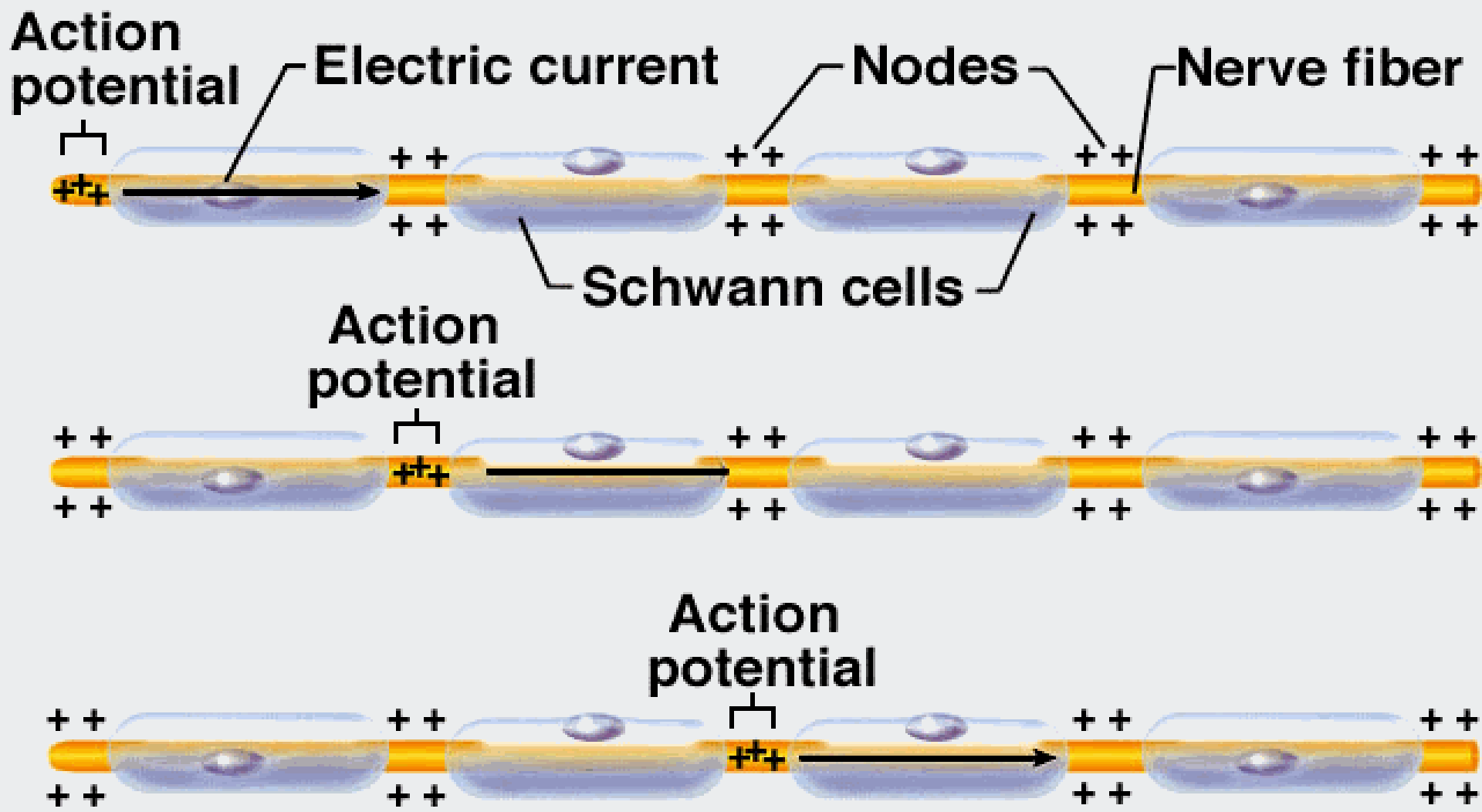
Myelin Sheath

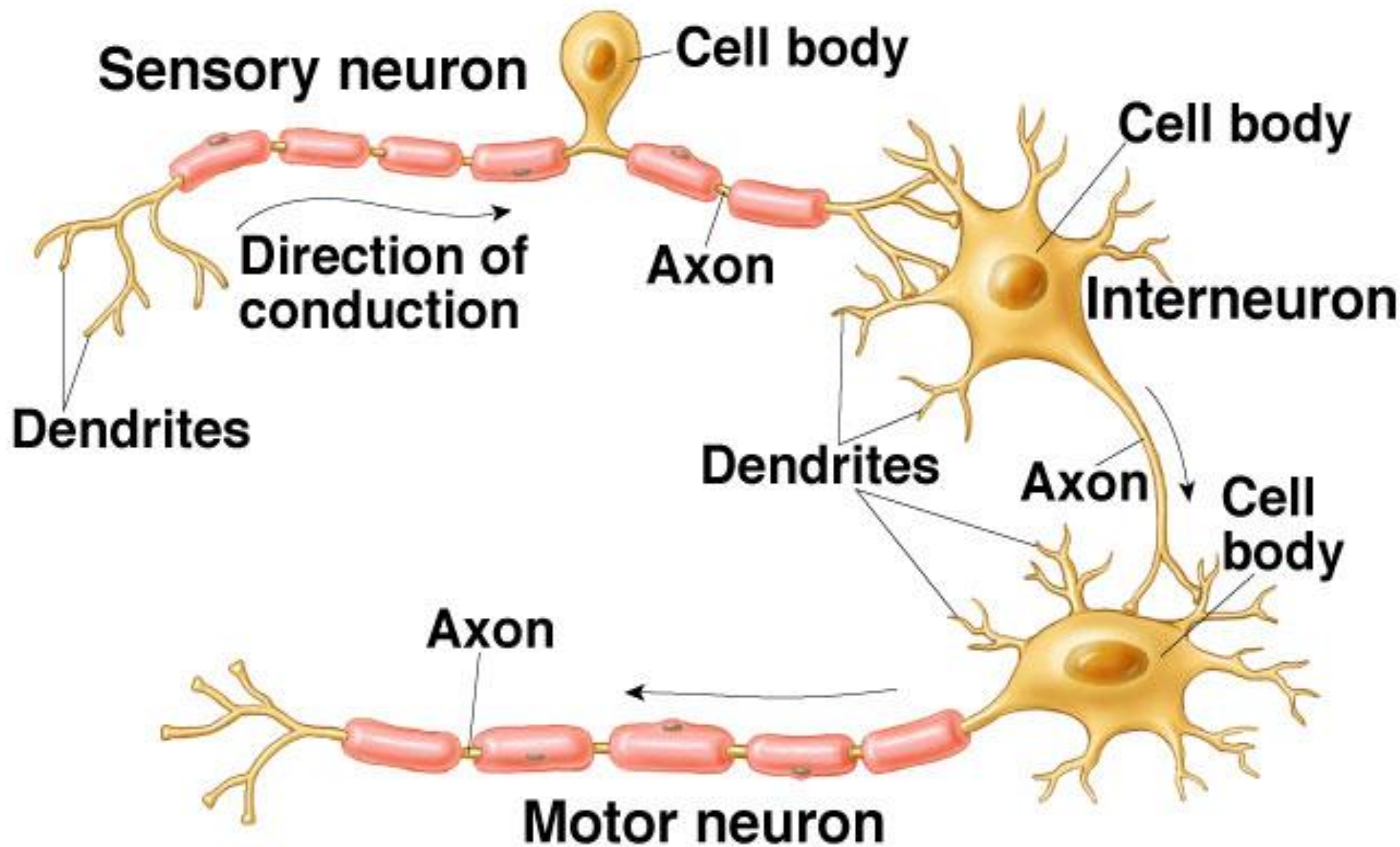
© 2011 Brooks/Cole - Thomson Learning

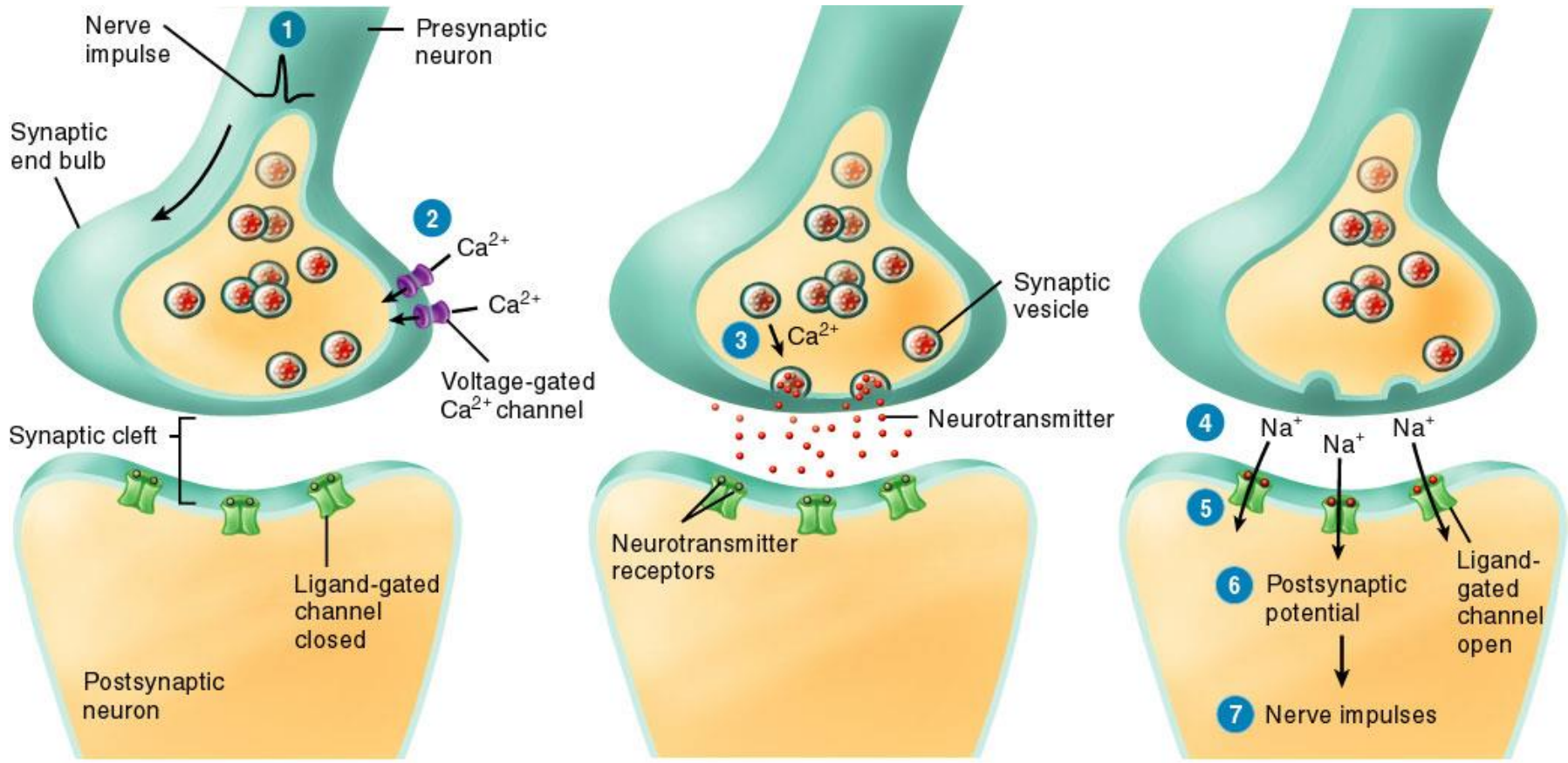


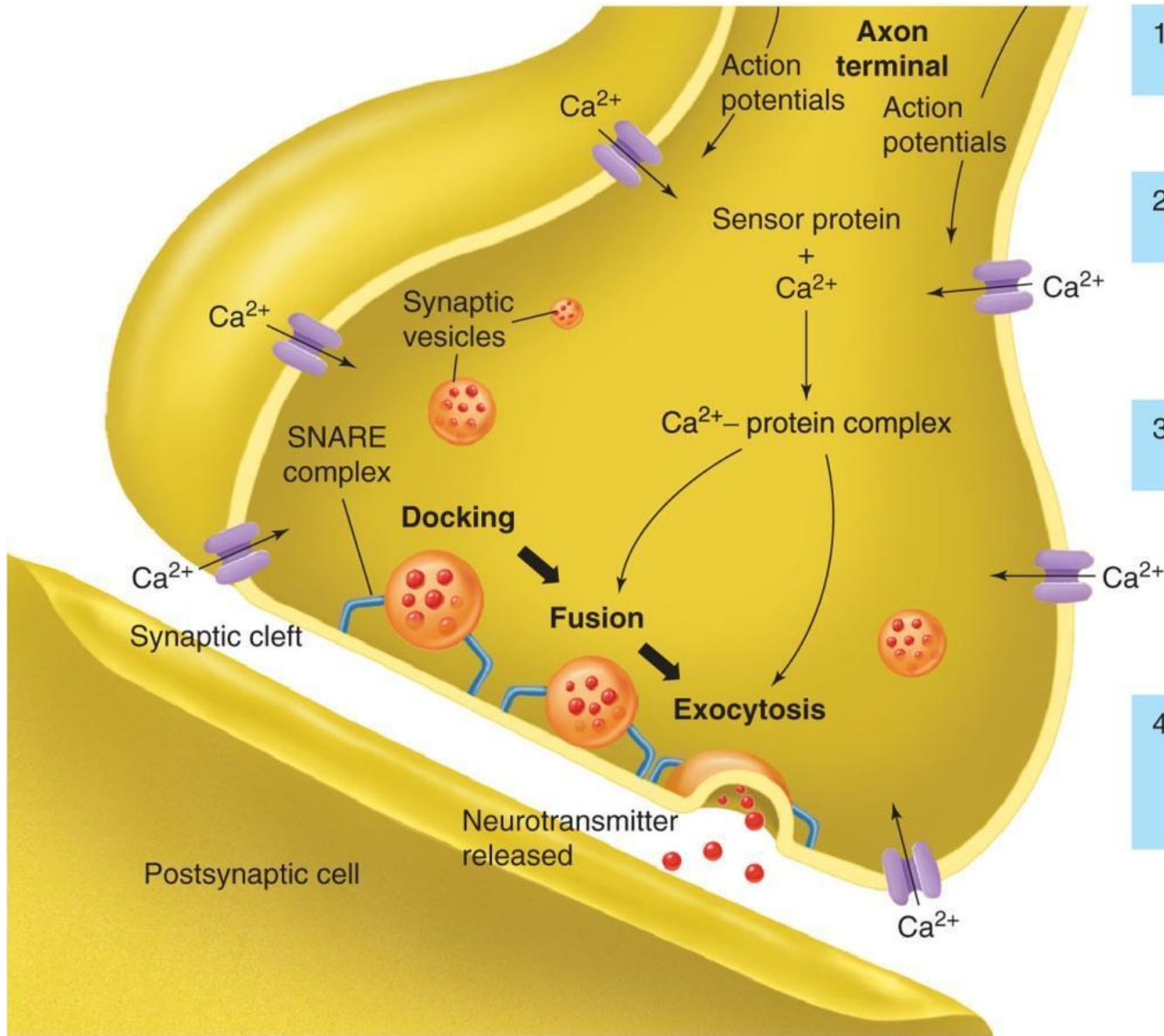
Saltatory
Conduction in
Myelinated
axons

Nerve Impulse on Myelinated Fiber







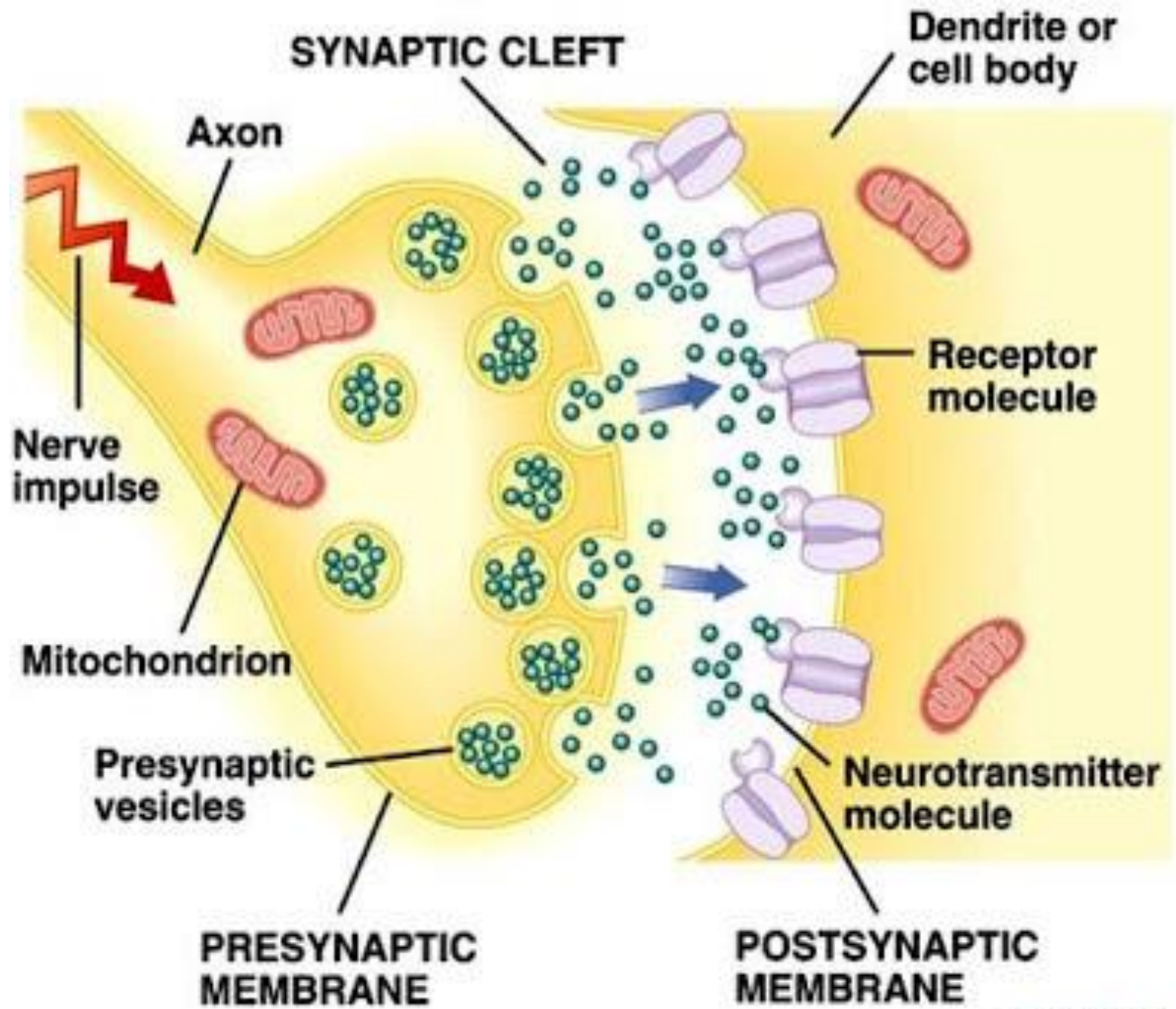


1. Action potentials reach axon terminals

2. Voltage-gated Ca^{2+} channels open

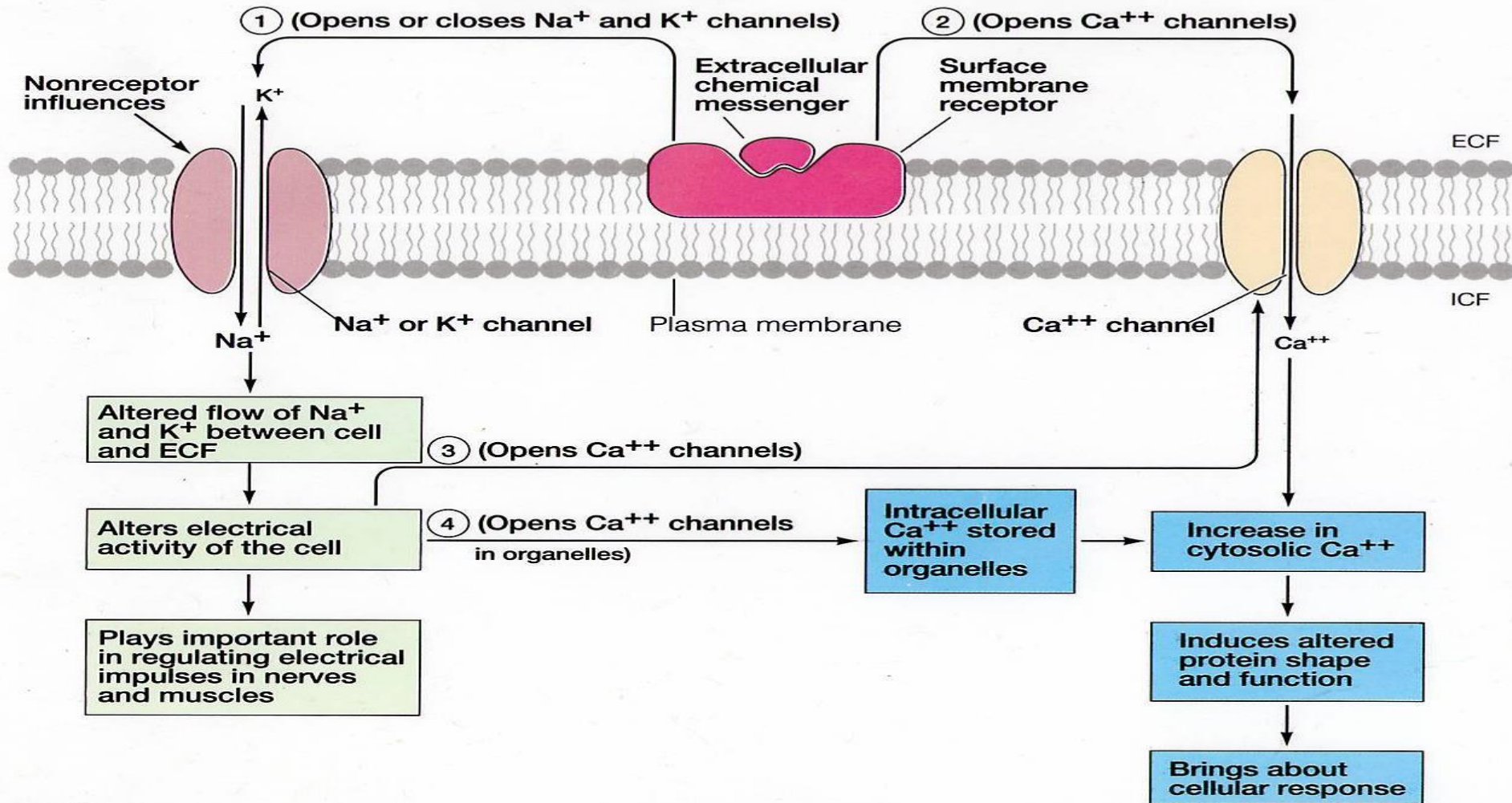
3. Ca^{2+} binds to sensor protein in cytoplasm

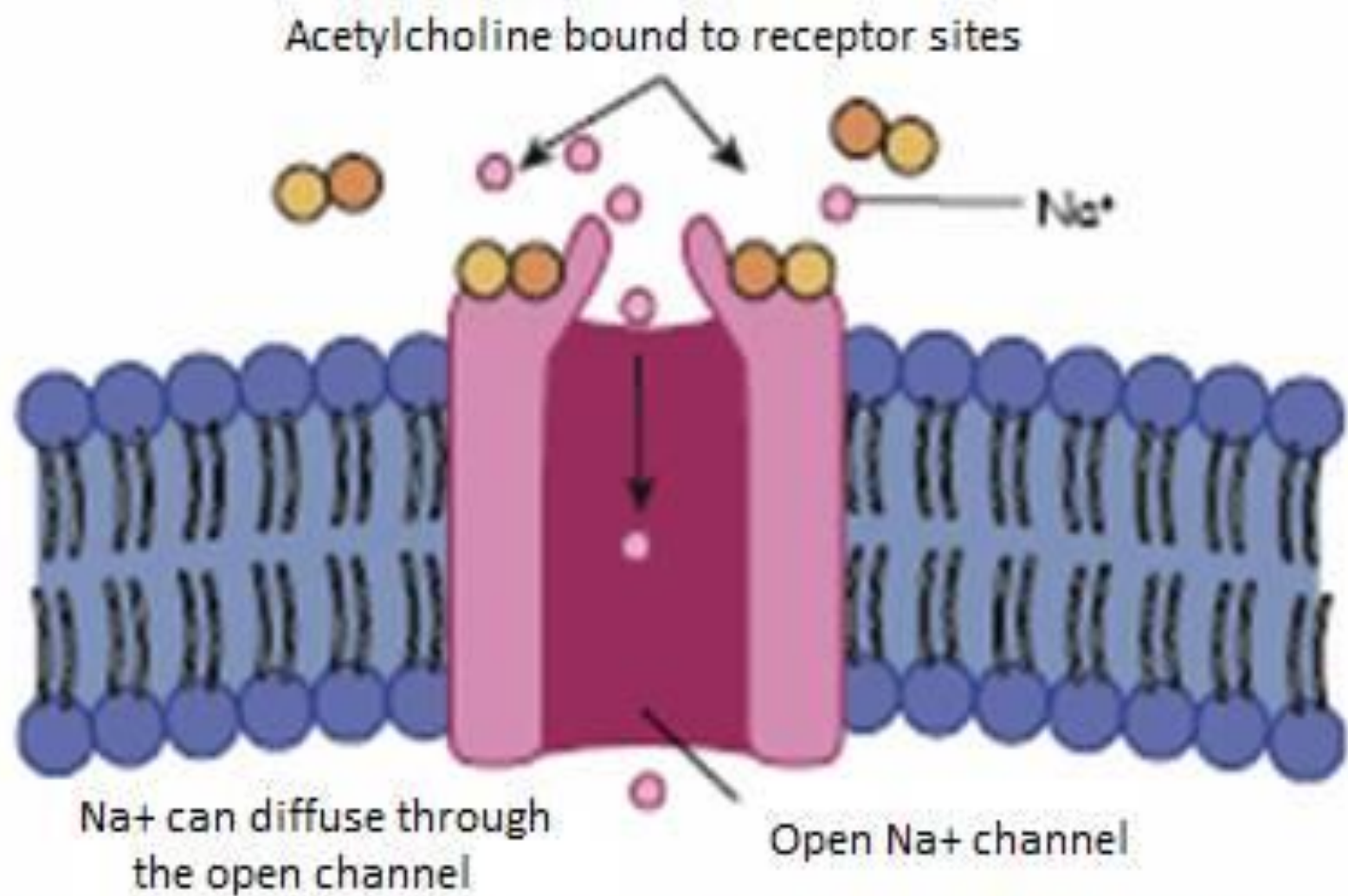
4. Ca^{2+} -protein complex stimulates fusion and exocytosis of neurotransmitter



Chemical gated Channels

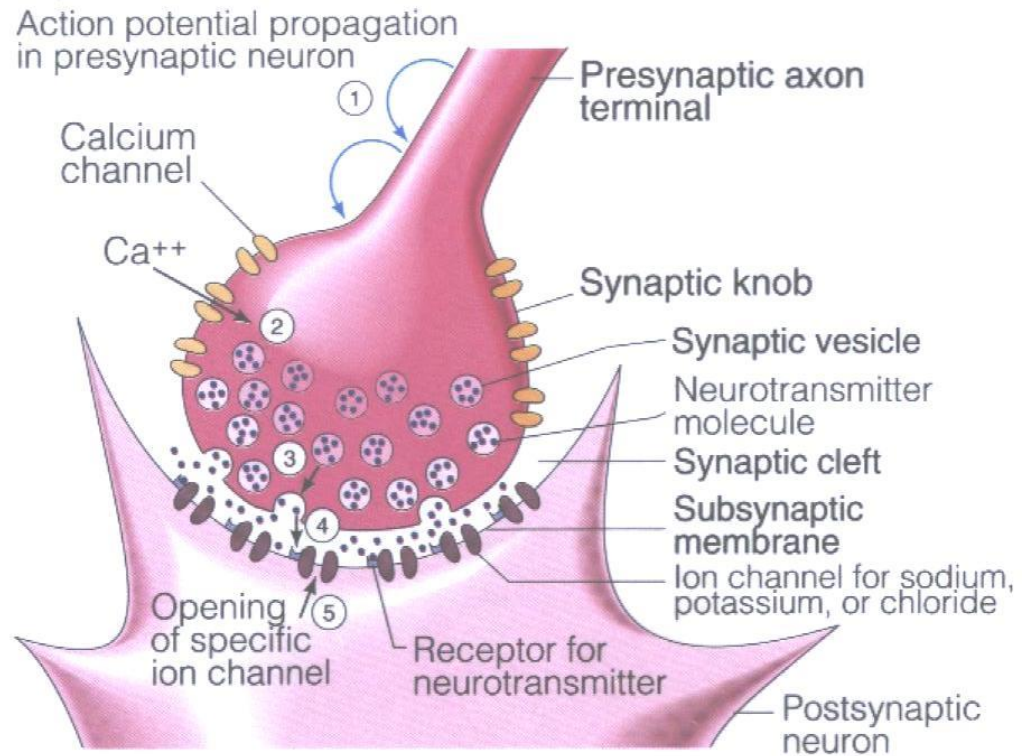
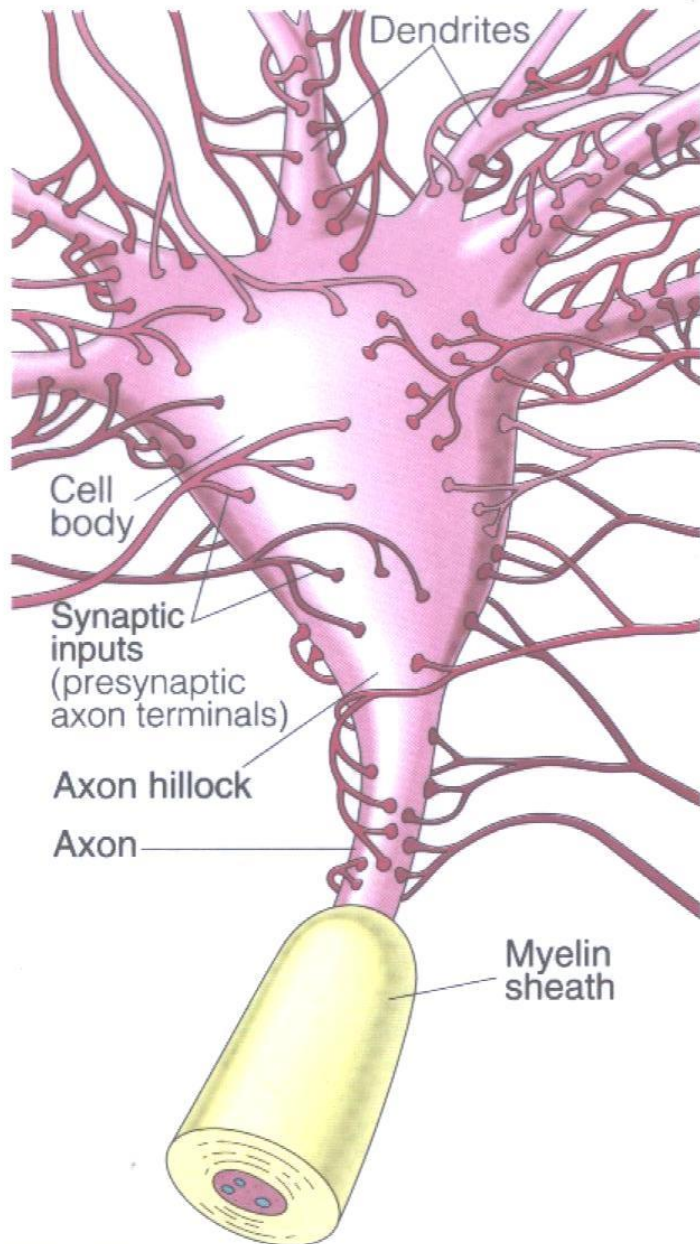
Postreceptor Event: Channel Regulation

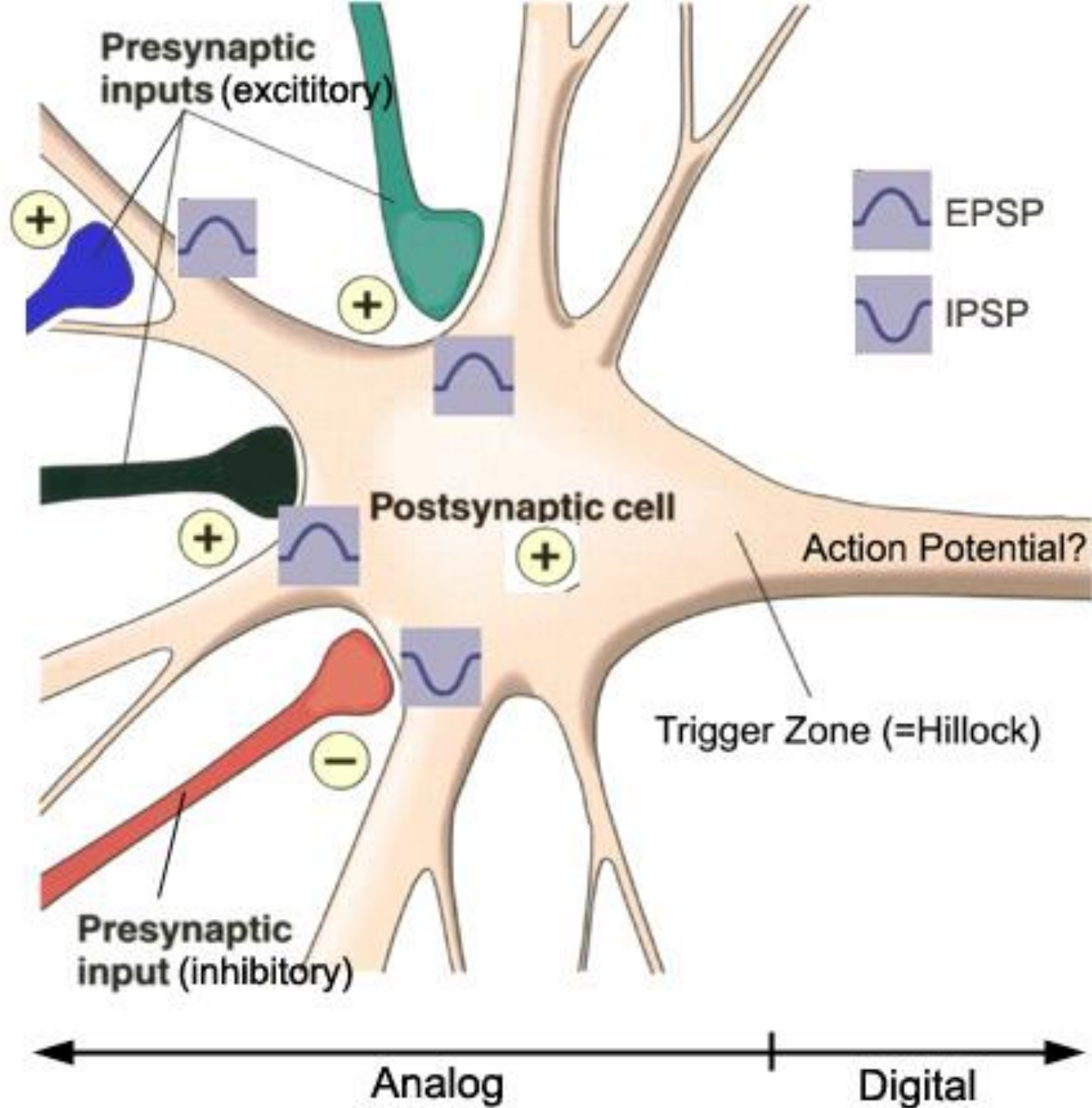


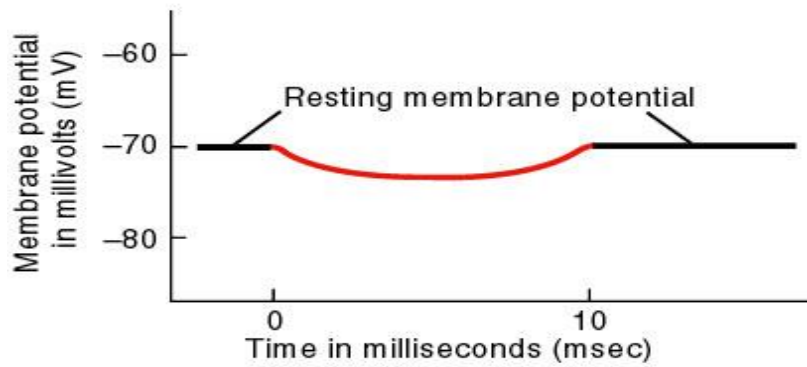
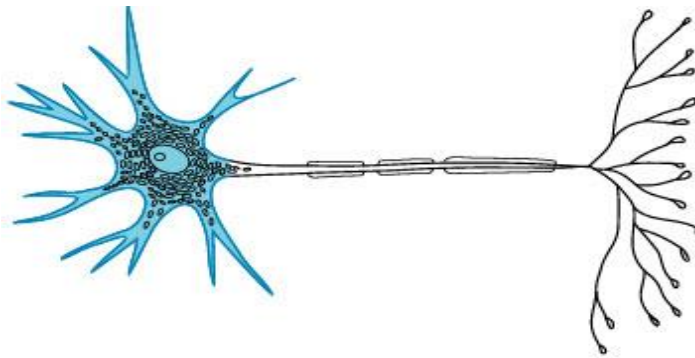


When 2 acetylcholine molecules bind to their receptor sites on the Na⁺ channel, the channel opens to allow Na⁺ to diffuse through the channel into the cell

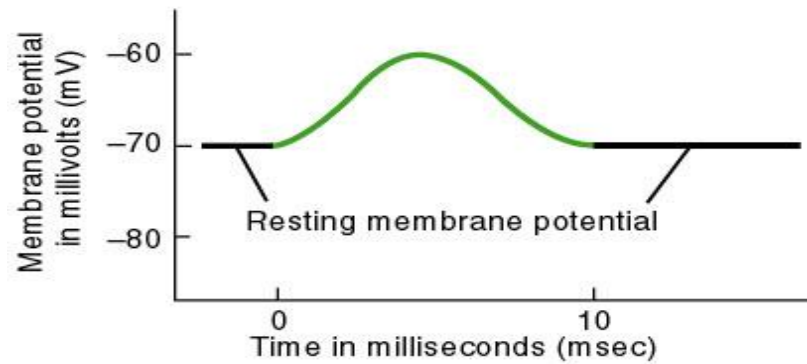
Synaptic Structure and Function





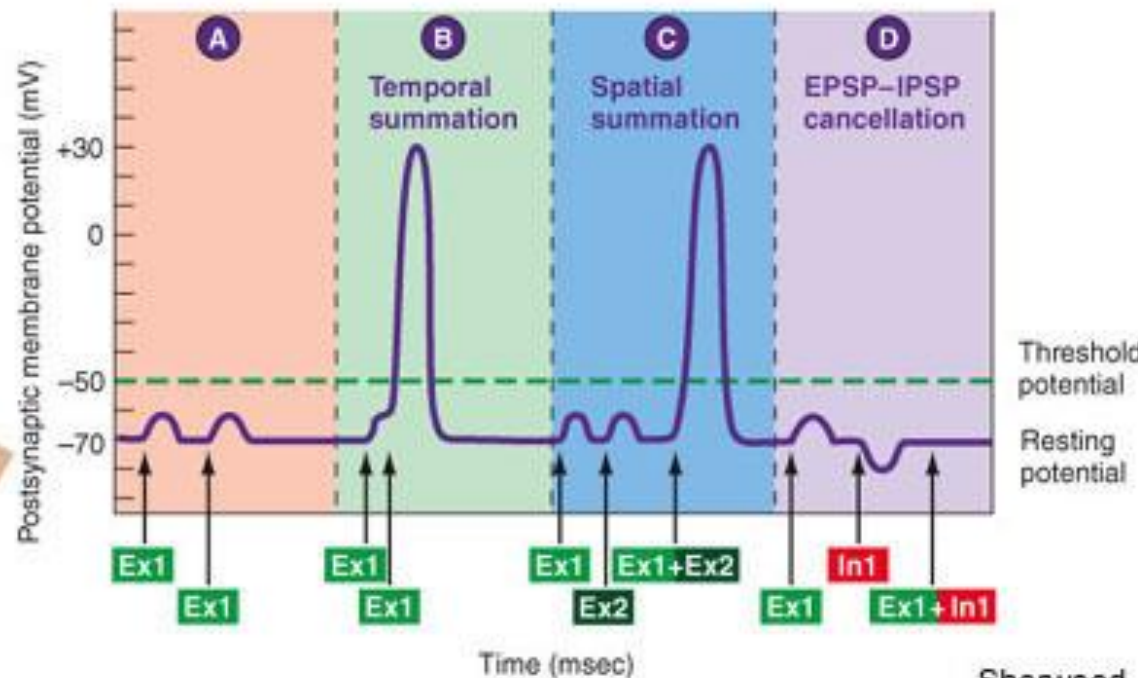
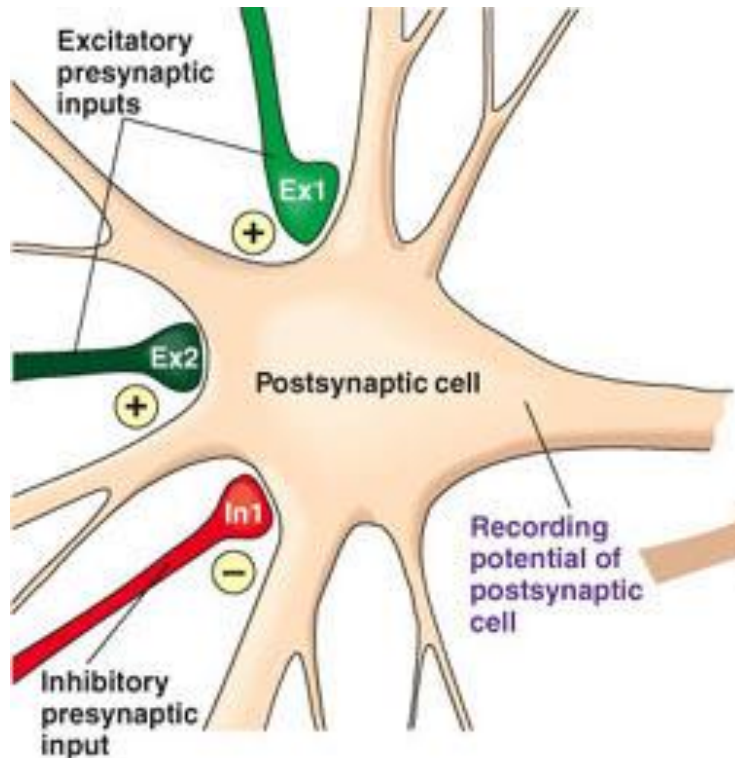


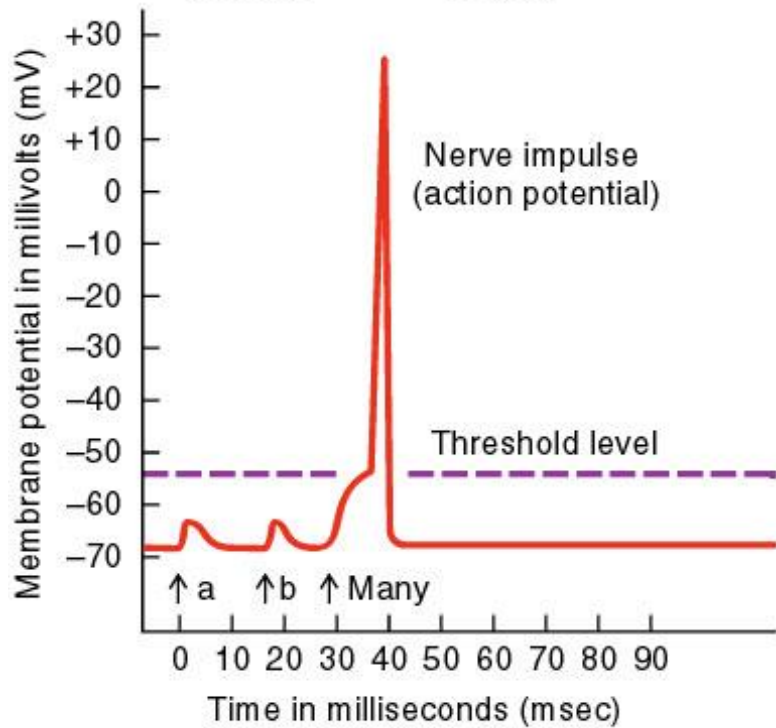
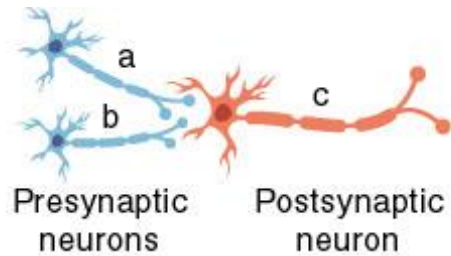
(a) Hyperpolarizing graded potential



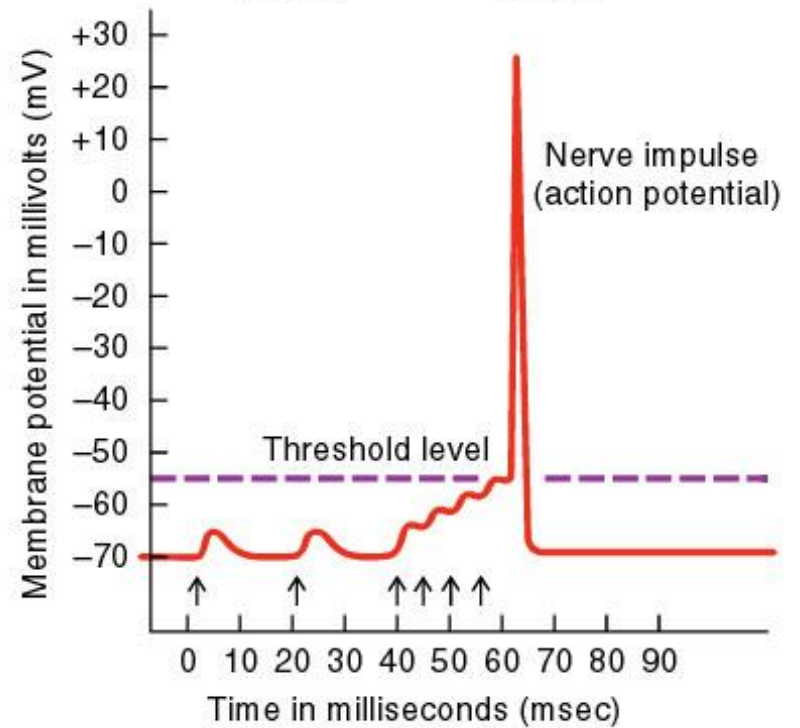
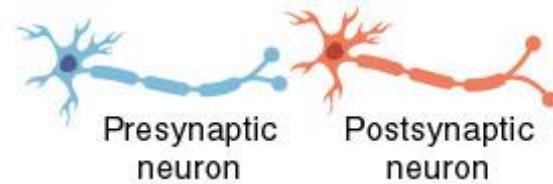
(b) Depolarizing graded potential

Summation of postsynaptic potentials

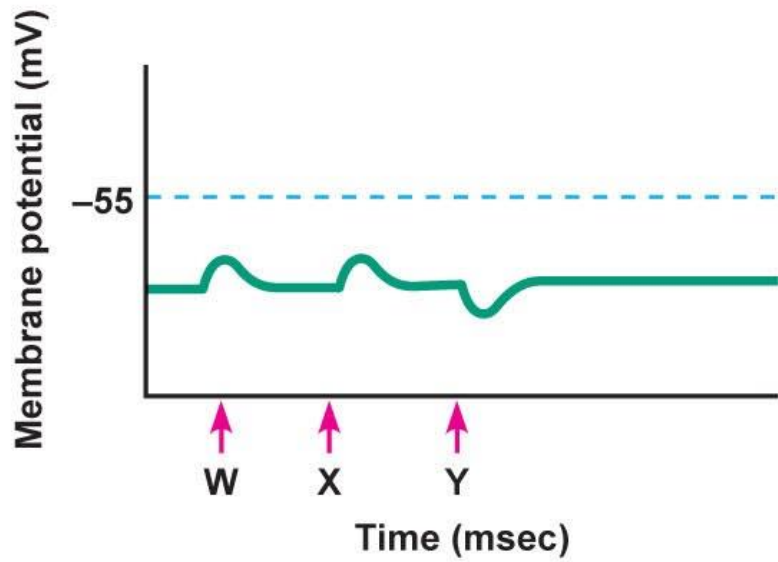




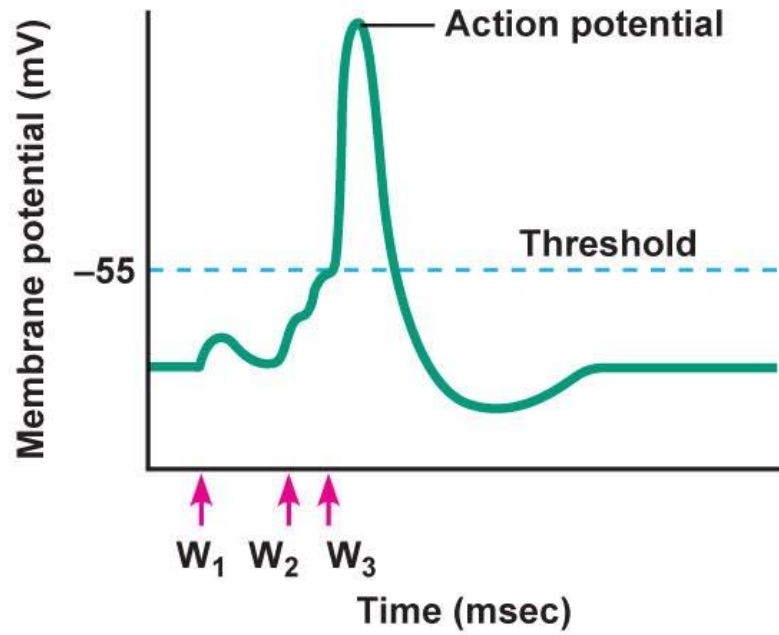
(a) Spatial summation



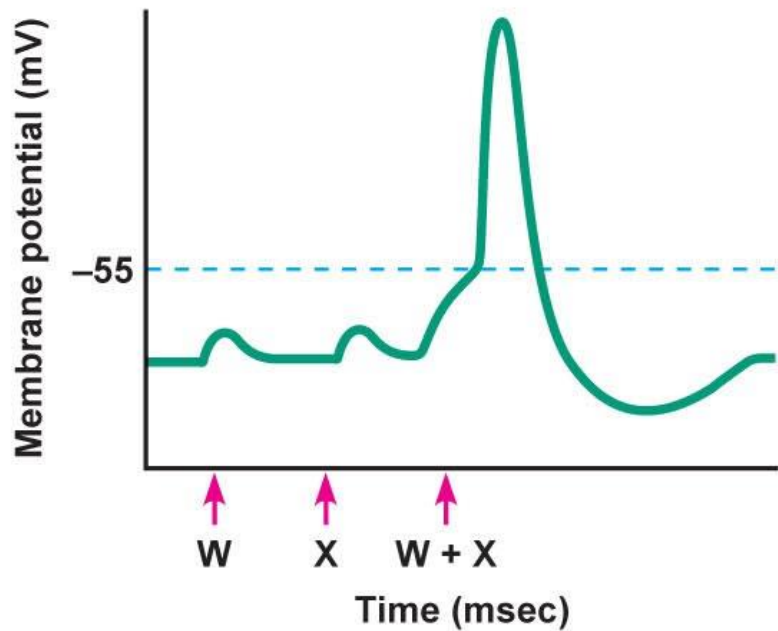
(b) Temporal summation



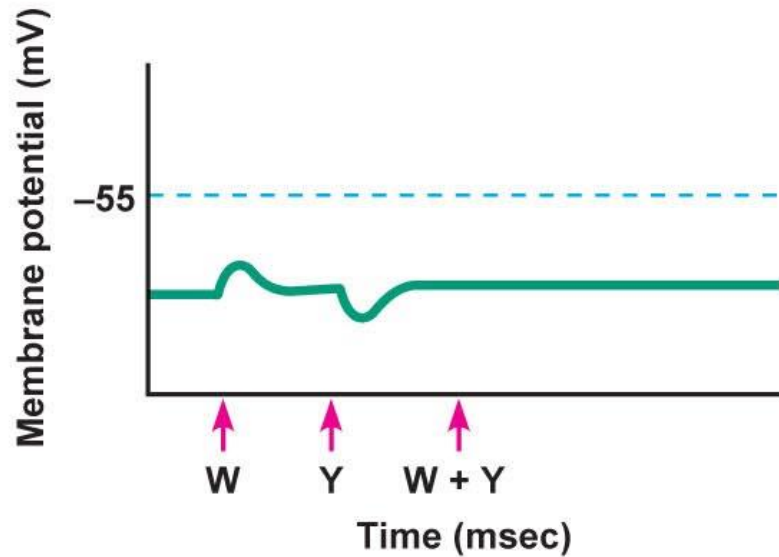
(a)



(b)

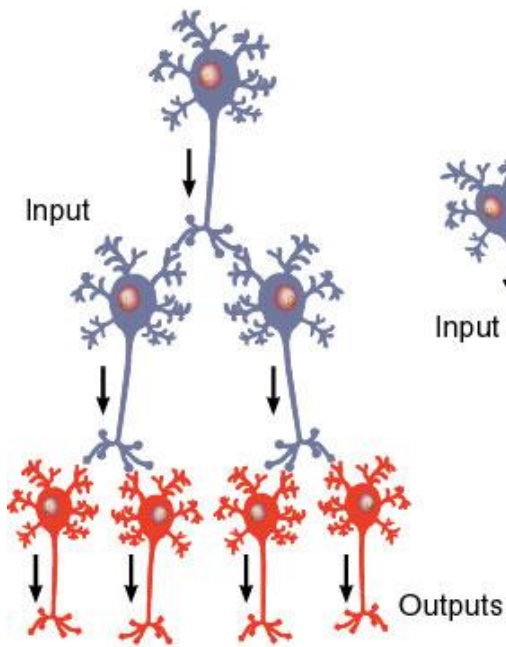


(c)

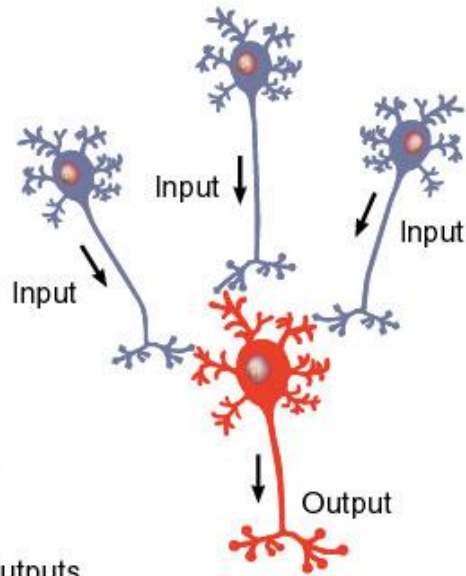


(d)

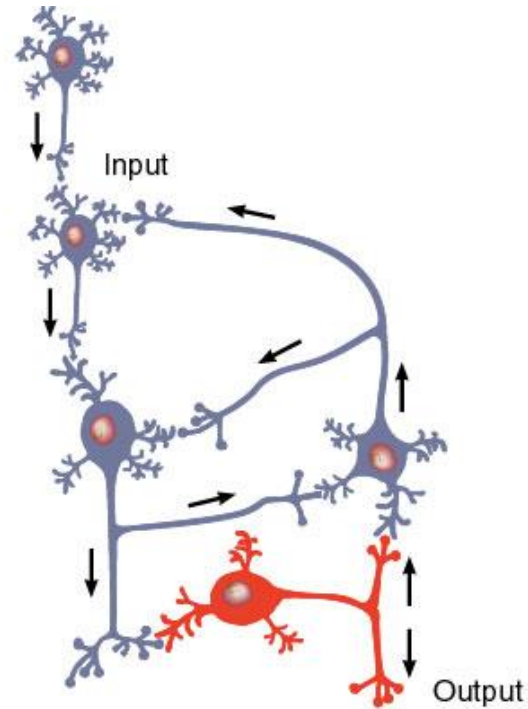
Synaptic organization



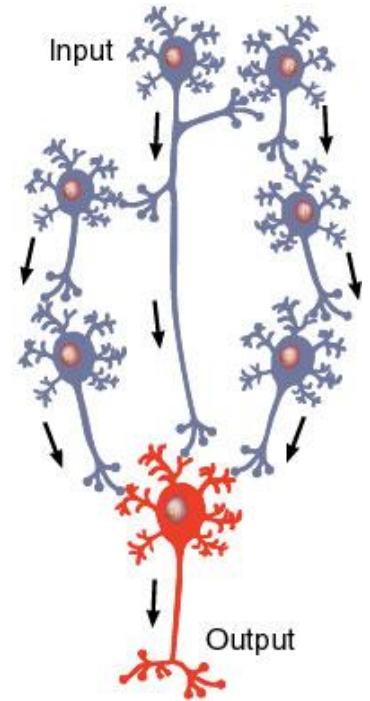
(a) Diverging circuit



(b) Converging circuit



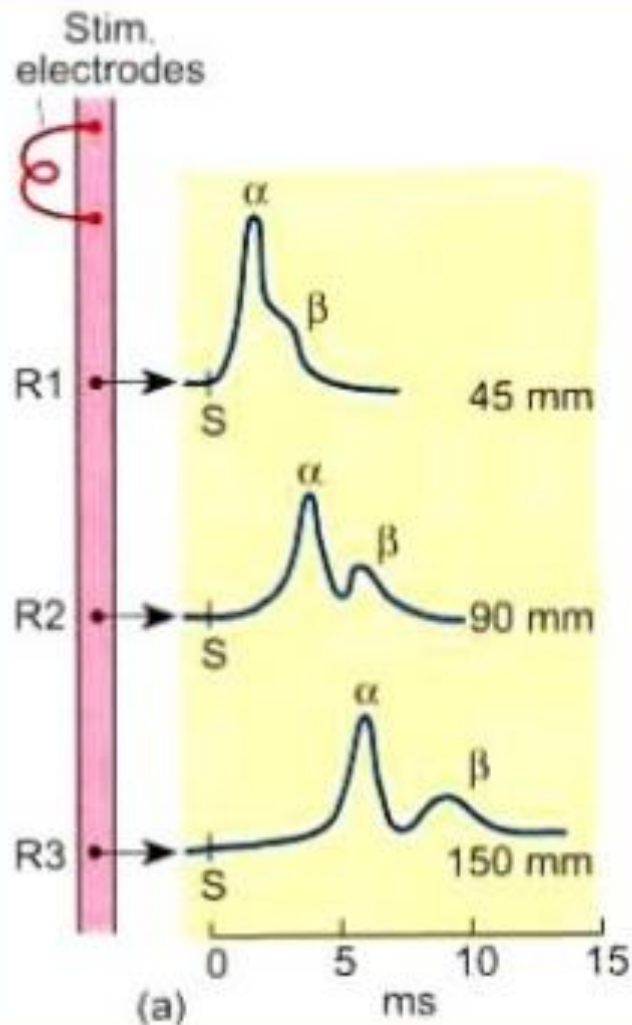
(c) Reverberating circuit



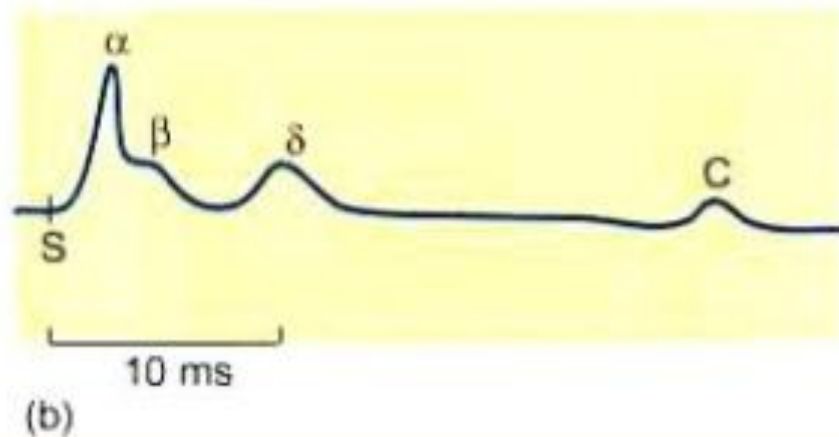
(d) Parallel after-discharge circuit

Monophasic action potential Vs Biphasic action potentials

A compound action potential recorded at different points along an intact nerve

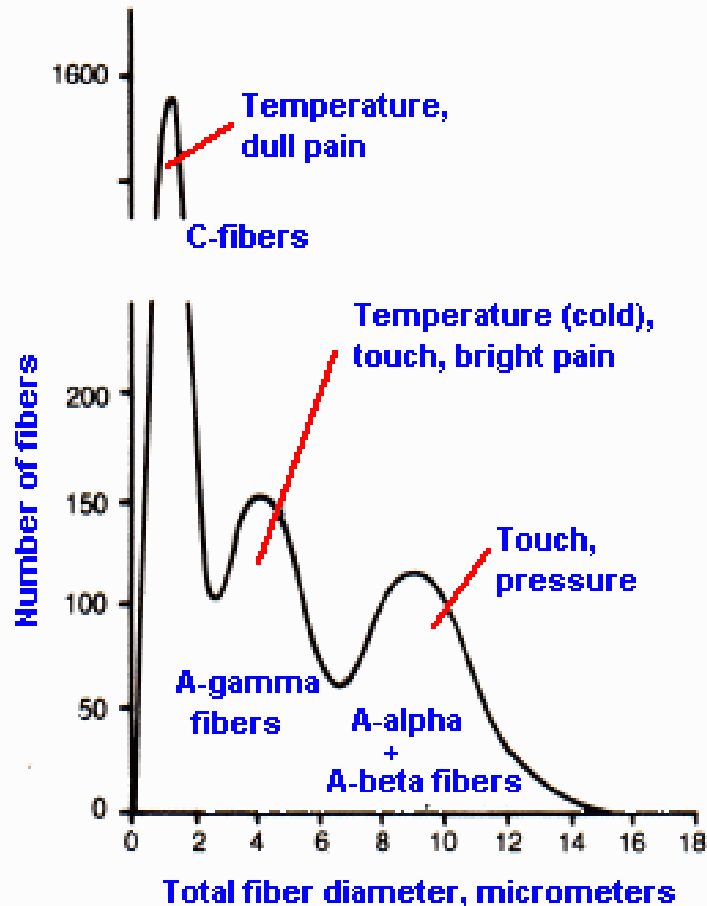


Each wave reflects the activity of a group of fibers with a similar conduction velocity.



Compound action potentials

A. Cutaneous nerve



B. Muscle nerve

