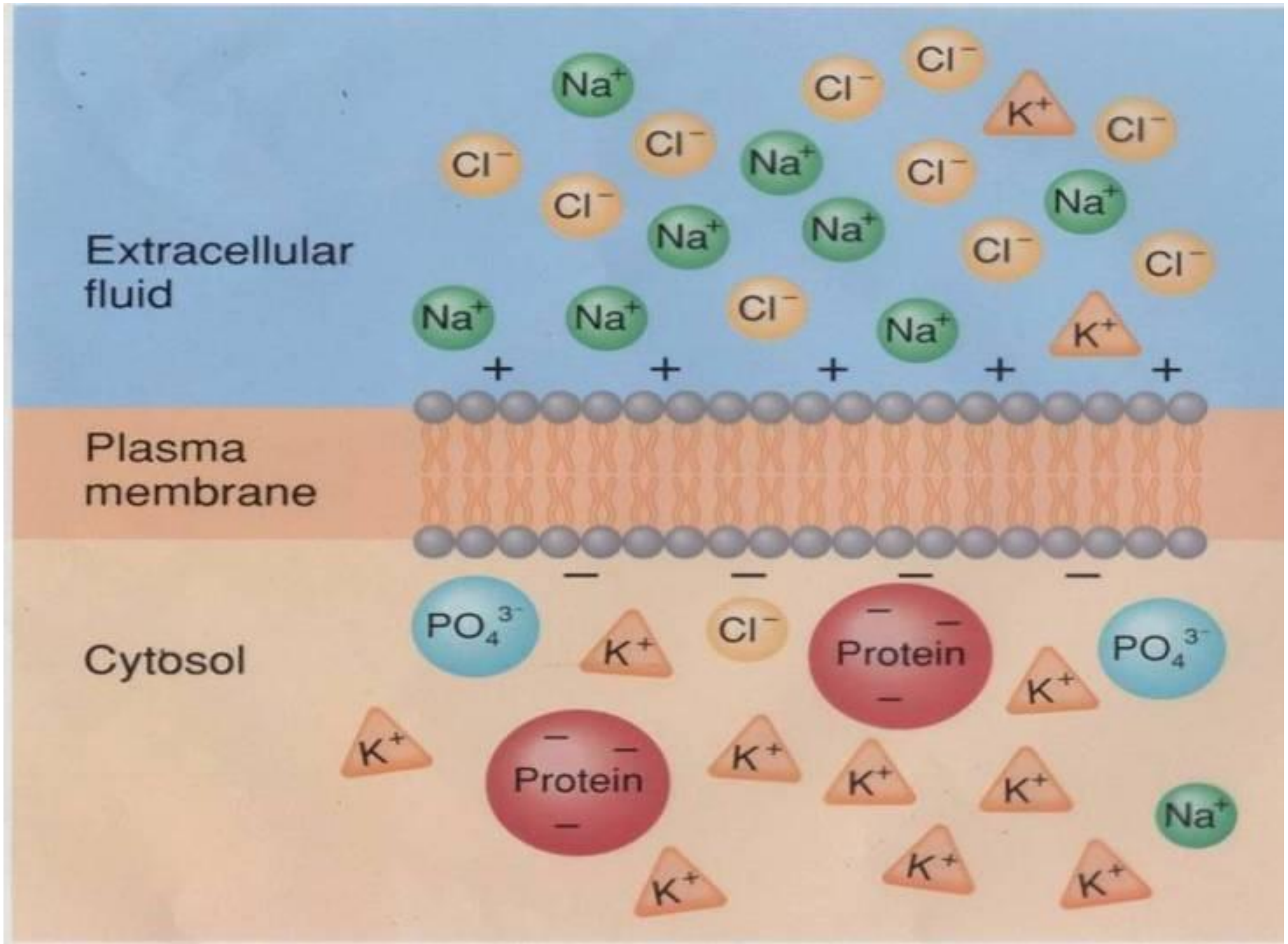
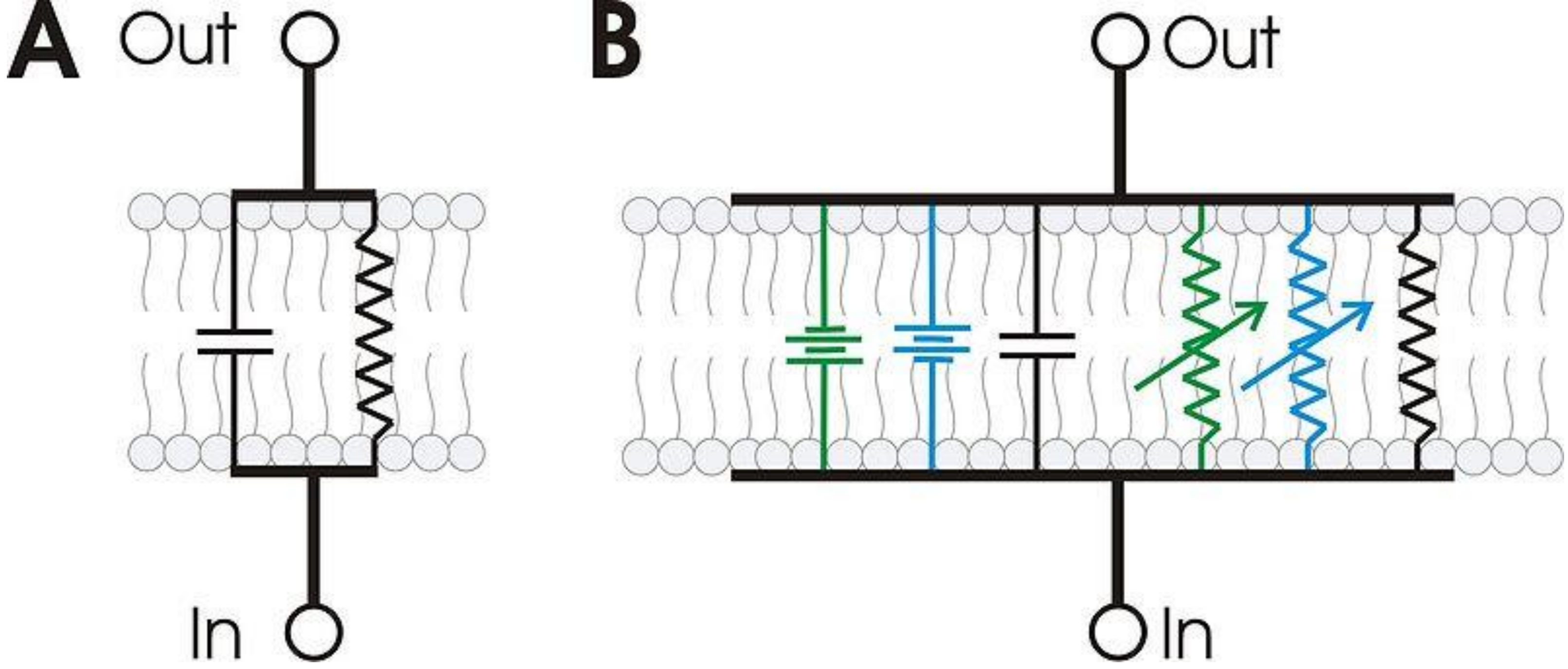
# Transport of ions across plasma membranes

## Plasma Membranes of Excitable tissues

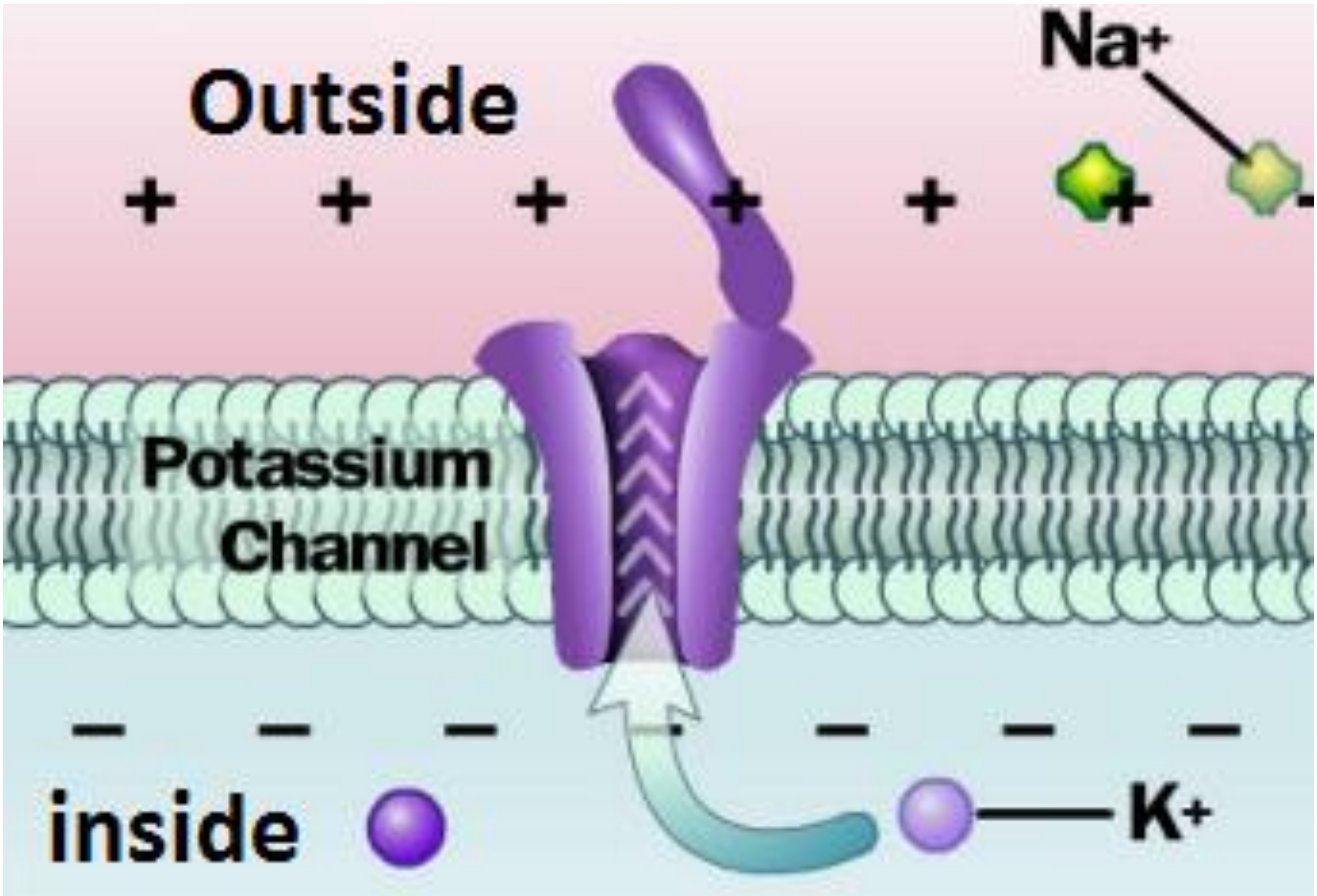
Ref: Guyton, 13th ed: pp: 61-71. 12th ed: pp: 57-69. 11th ed: **p57-71**,

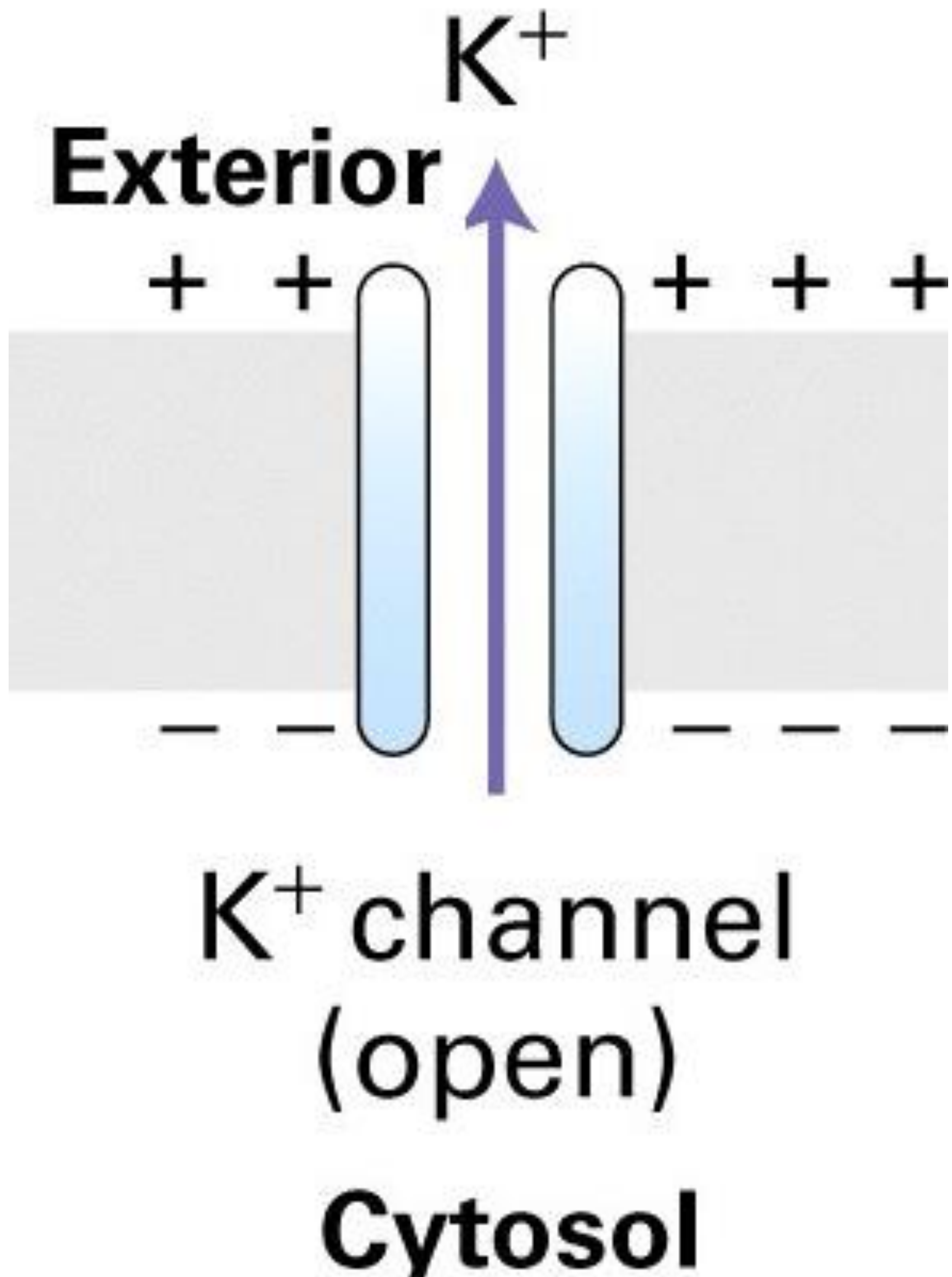

Extracellular fluid
Plasma membrane
Cytosol
Na+
Cl−
K+
PO4 3−
Protein

# Electrical properties of plasma membranes

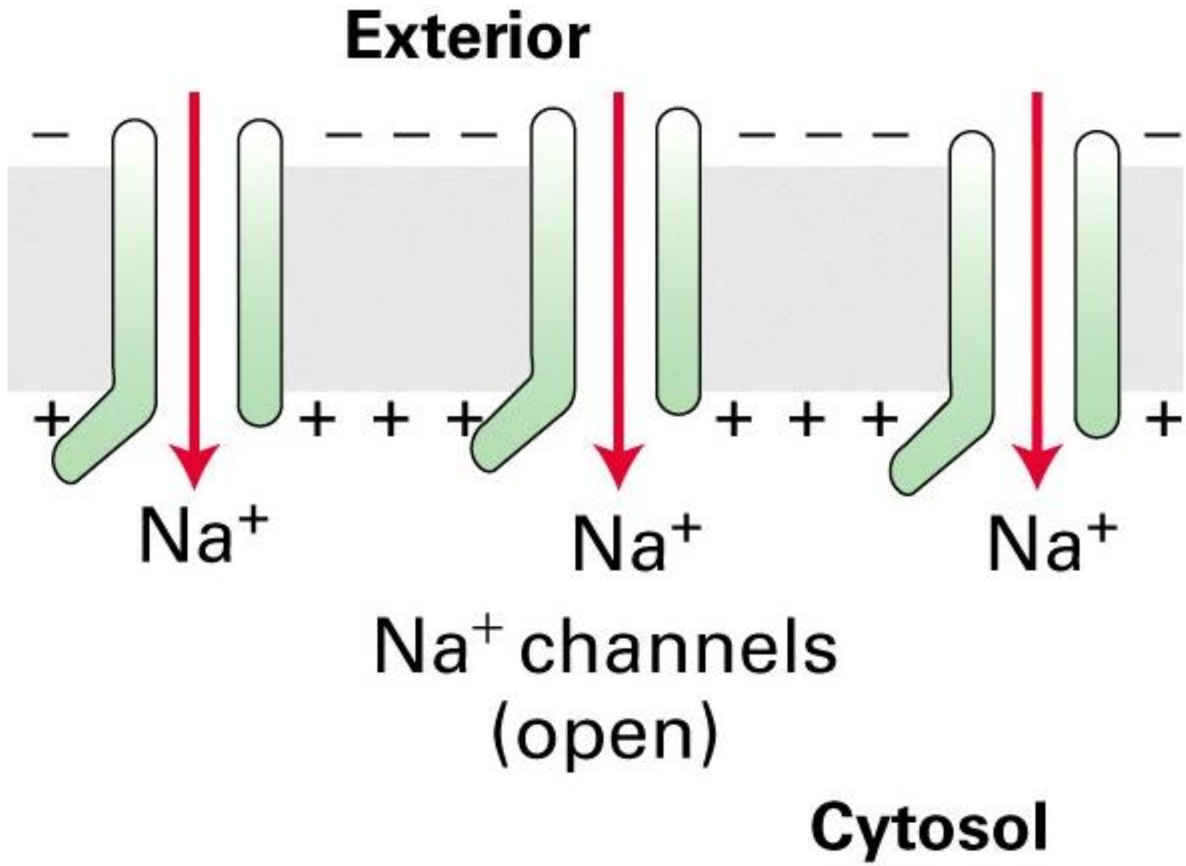



- **Part A:** A basic en:RC circuit, superimposed on an image of a membrane bilayer to show the relationship between the two. **Part B:** A more elaborate en:RC circuit, superimposed on an image of a membrane bilayer. This RC circuit represents the electrical characteristics of a minimal patch of membrane 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.


Na+
Outside
Potassium
Channel
inside
K+



K+
Exterior
+ +
+ + +
– –
– – –
K+ channel
(open)
Cytosol


Exterior
Na+
Na+
Na+
Na+ channels
(open)
Cytosol

# Nernest 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) = $9.6485309 \times 10^4$ (C/mol)

[C]out (Outside Concentration, mM)

[C]in (Inside Concentration, mM)

# Electro-chemical Equilibrium

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

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

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

# $E_{k+}$

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

**E (mV) = - 61.log (Ci/Co)**

E = Equilibrium potential for a univalent ion

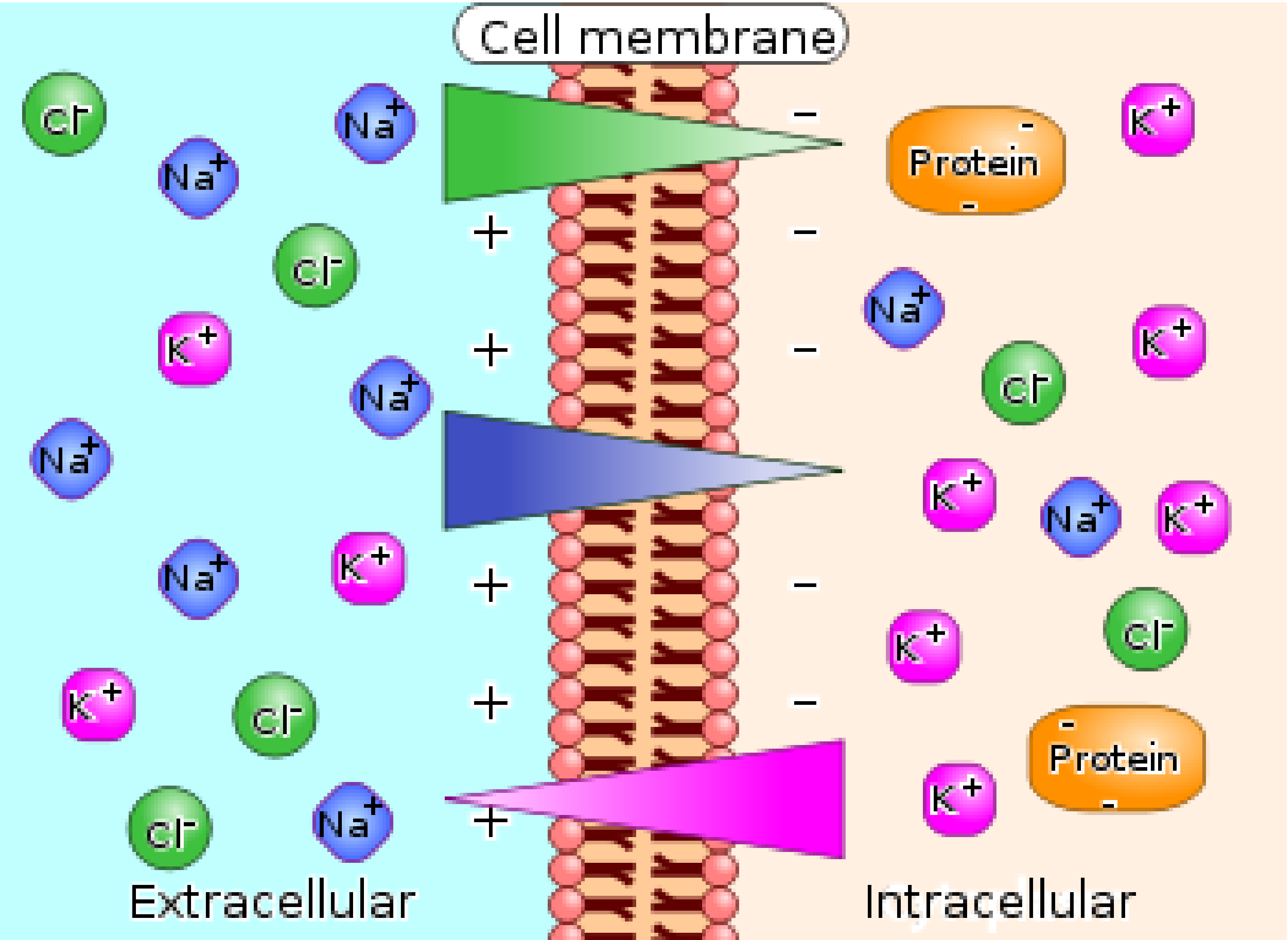
Ci = conc. inside the cell.

Co = 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



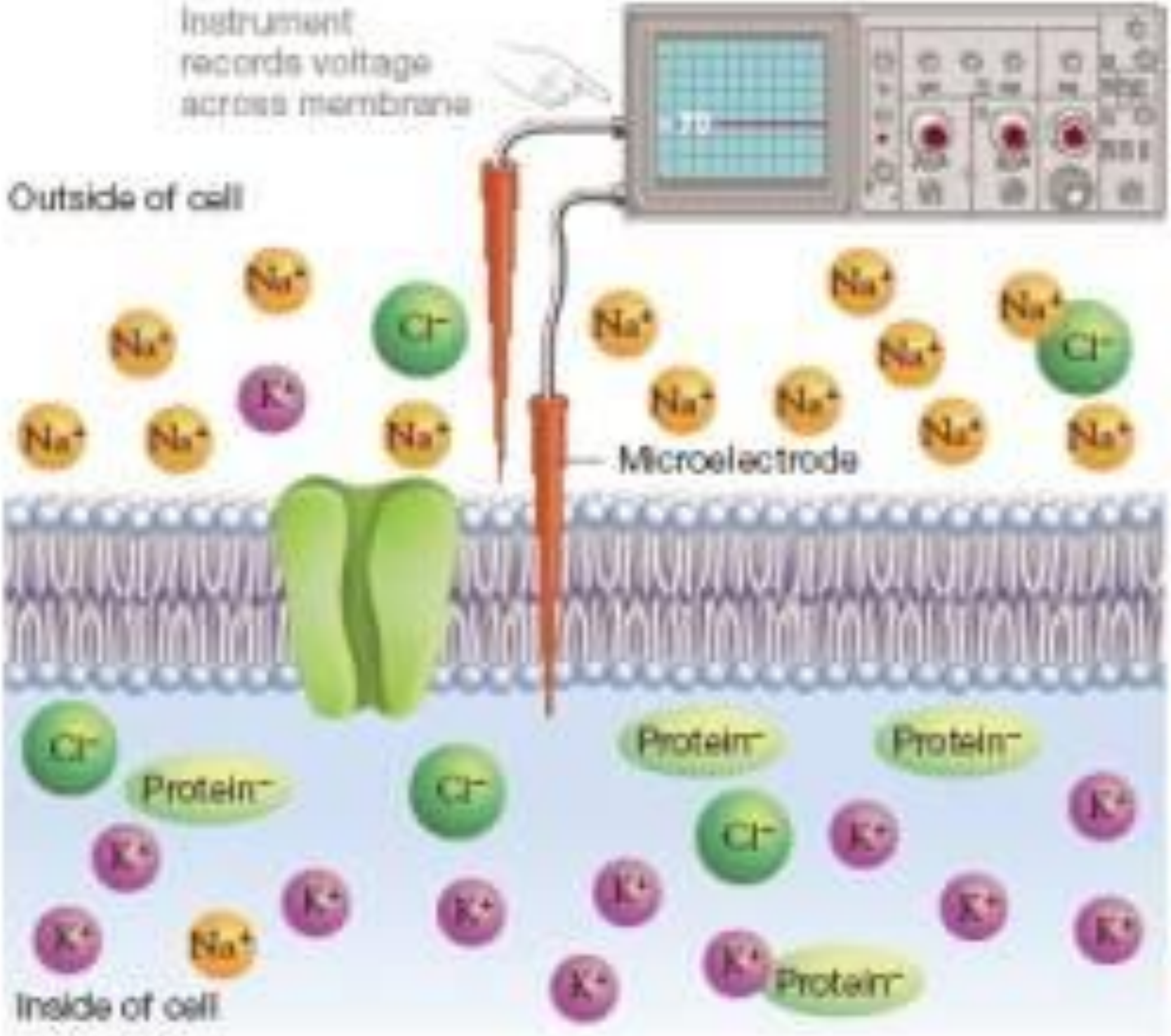
# Goldman Hodgkin Katz equation

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

i = Conc. inside

o = Conc. outside

P = permeability of the membrane to that ion.


Instrument records voltage across membrane
Outside of cell
Microelectrode
Inside of cell
Na+
K+
Cl−
Protein−

# Resting membrane potential

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

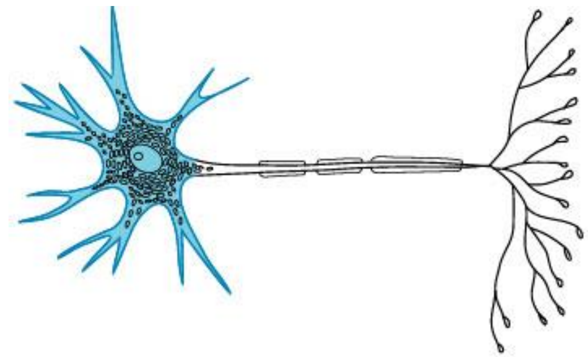
# Conductance of plasma membrane (Ohm's Law)

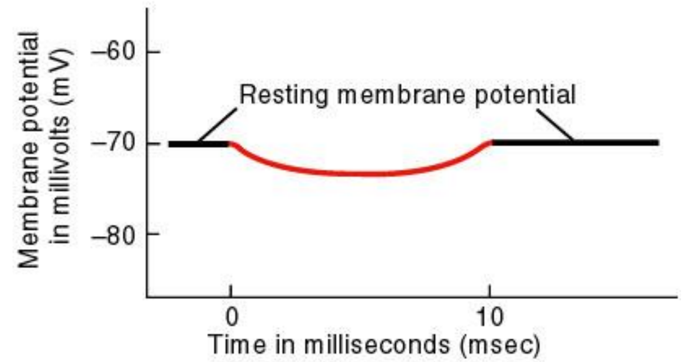
- $I = \Delta V/R$
- G (conductance)= $1/R$
- $I = G.\ \Delta V$

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

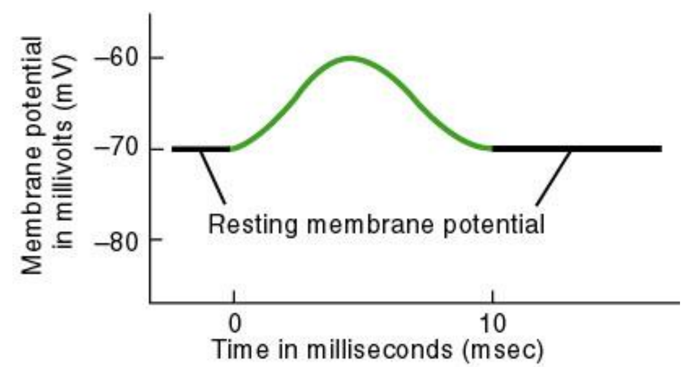
$$V_m = \frac{g_K}{g_{tot}} E_K + \frac{g_{Na}}{g_{tot}} E_{Na} + \frac{g_{Cl}}{g_{tot}} E_{Cl}$$

- Changes in Resting membrane potential



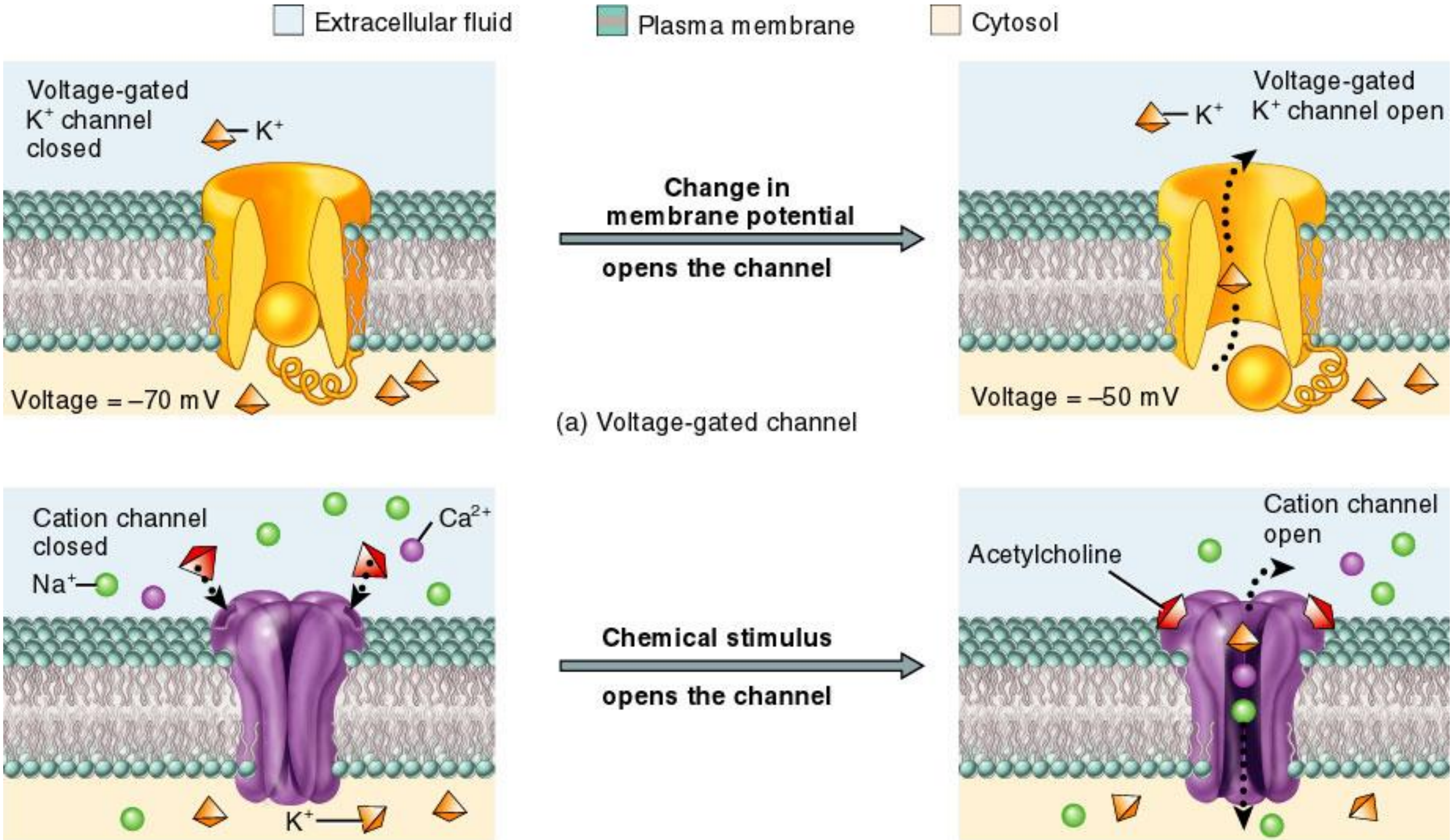



(a) Hyperpolarizing graded potential




(b) Depolarizing graded potential

12.10

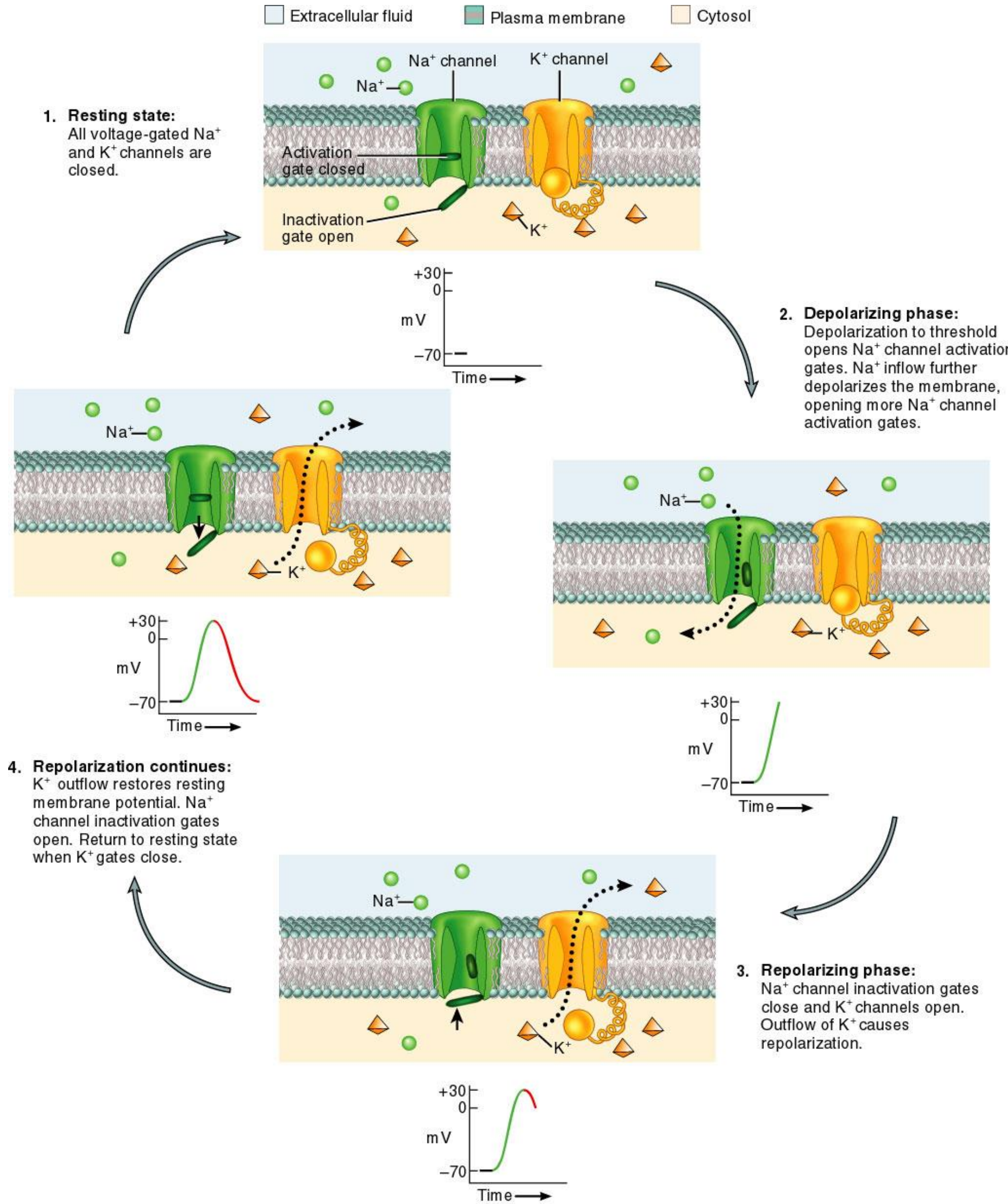



(a) Voltage-gated channel

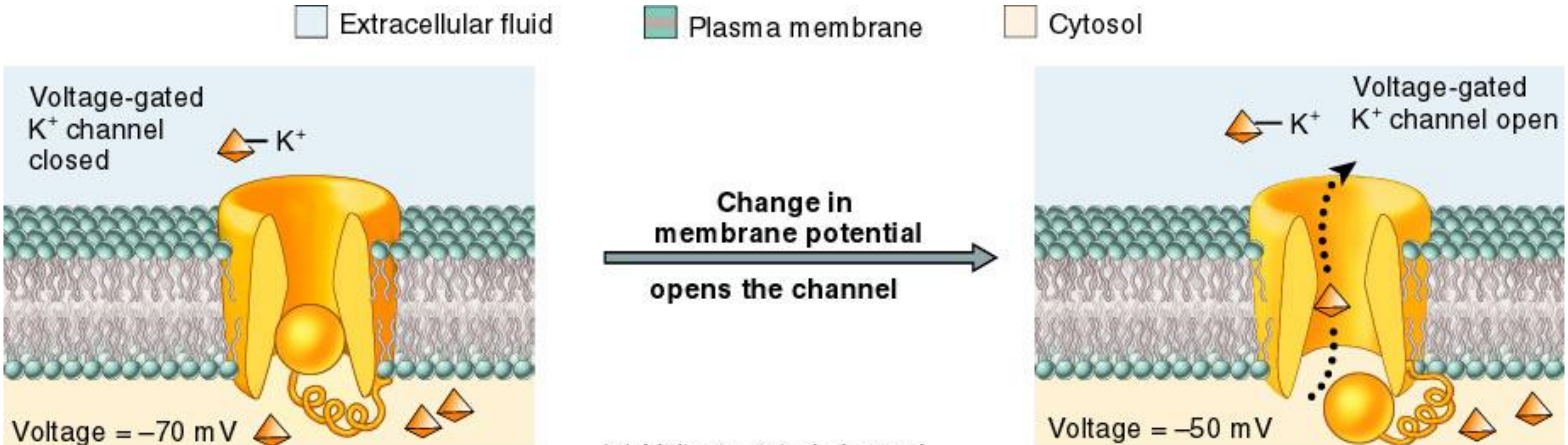
(b) Ligand-gated channel

12.08

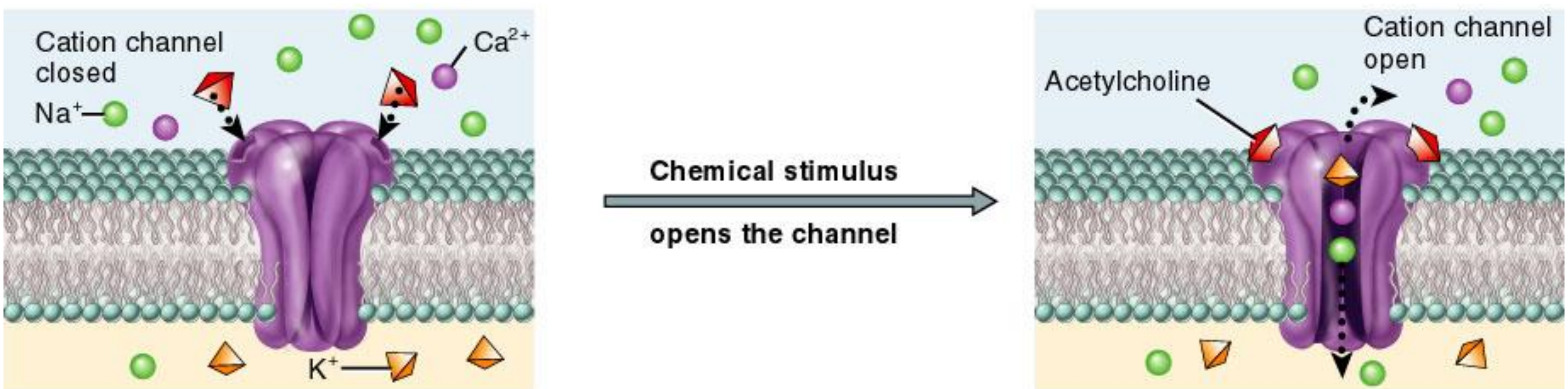
- Changes in Channels activity results in action potential




12.12



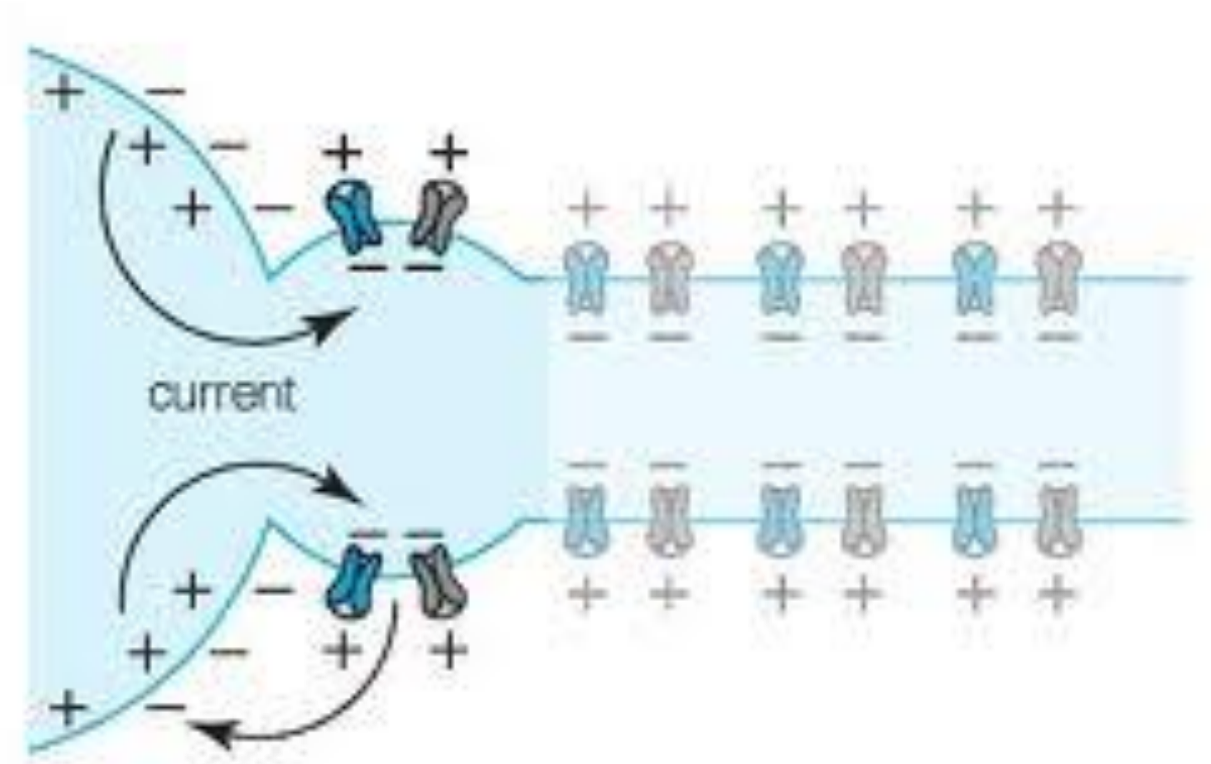
(a) Voltage-gated channel



(b) Ligand-gated channel

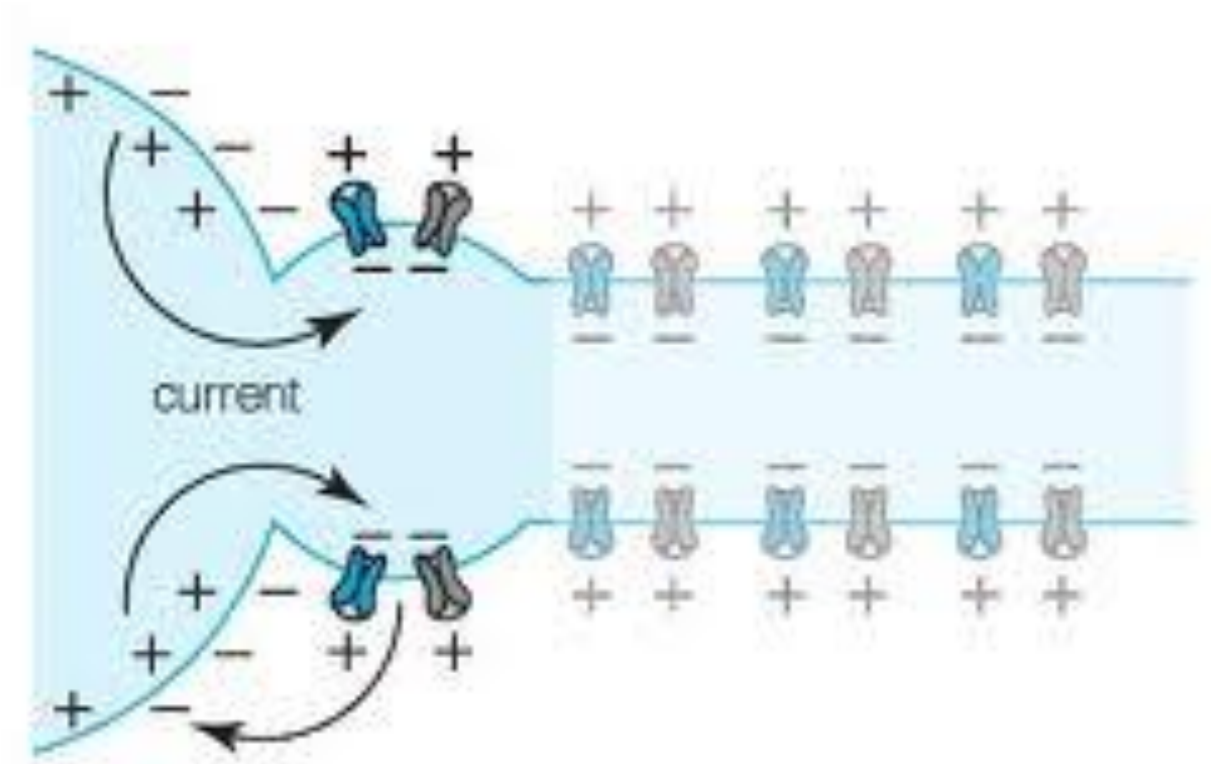
12.08

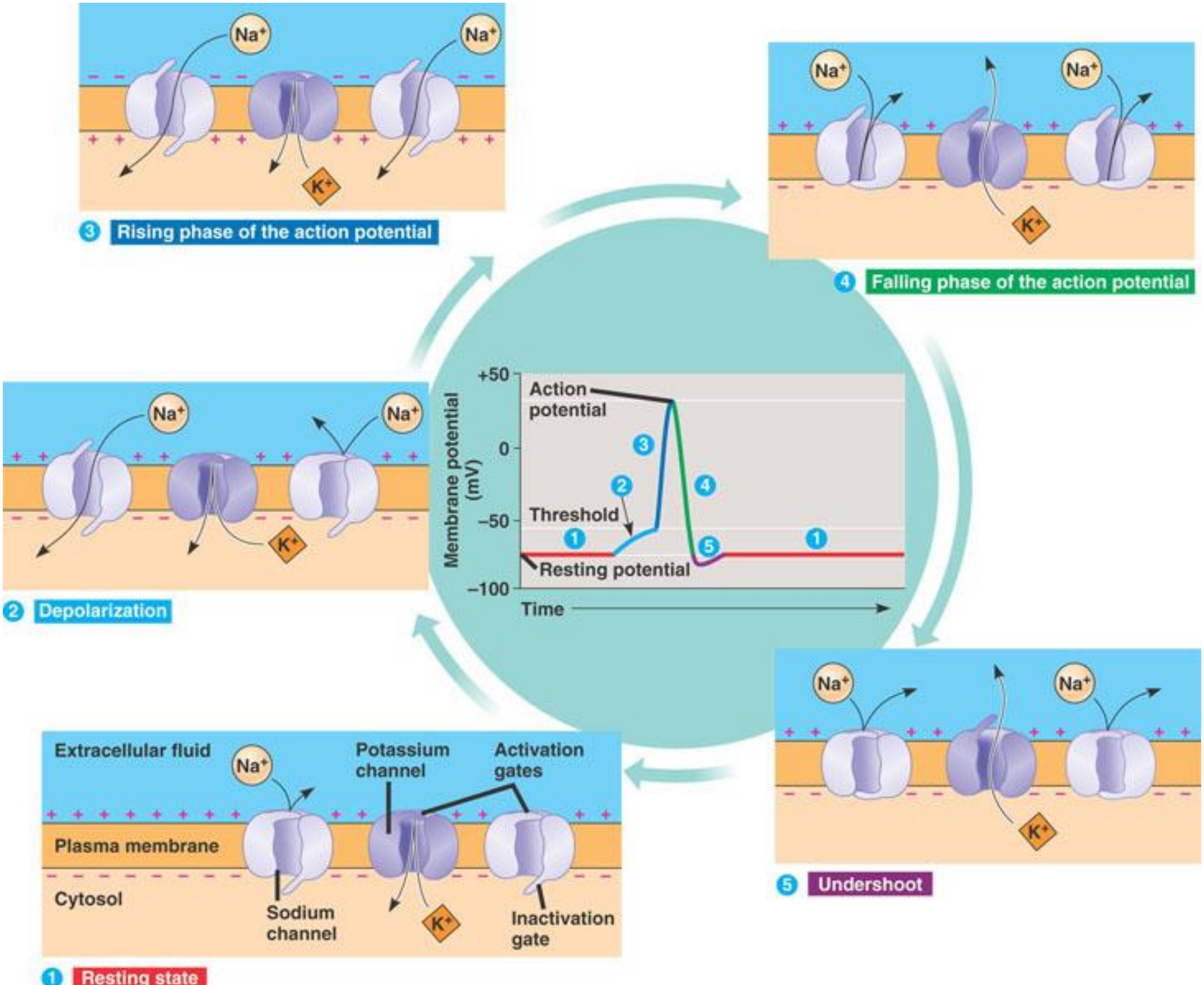
# Ionic currents cause depolarization



# Resistance to Ionic currents and activation of channels

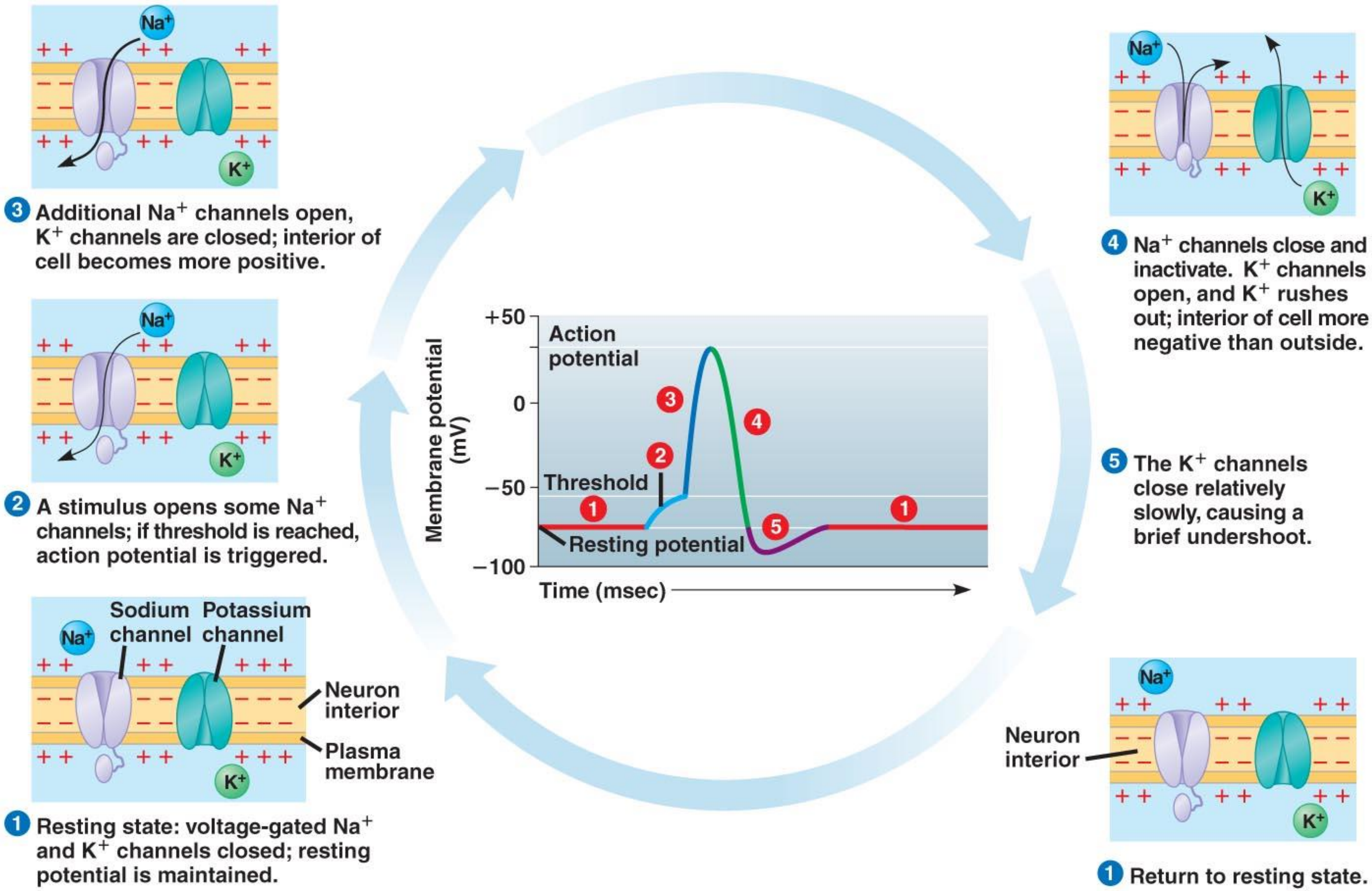
# Action potentials

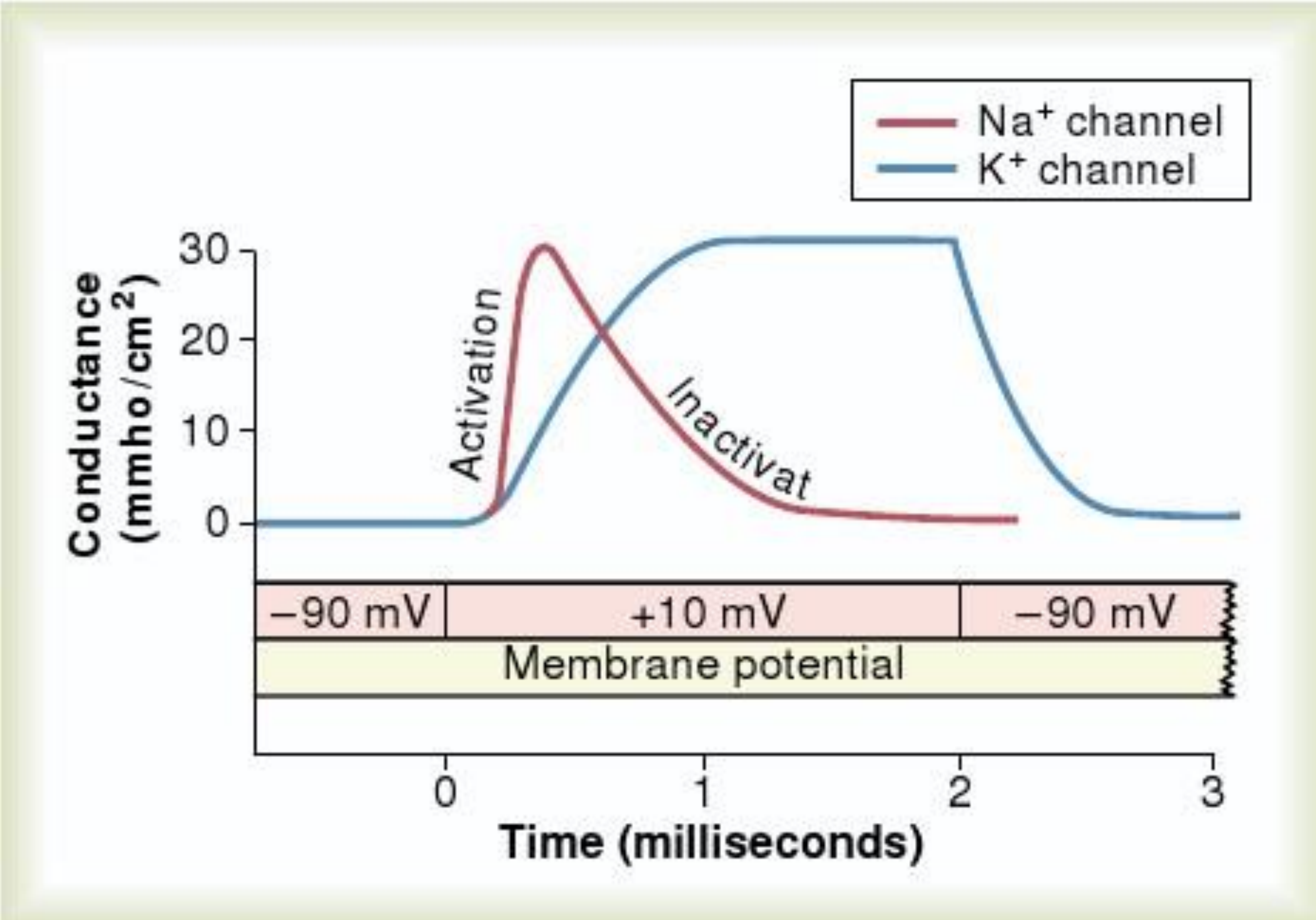




Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
2 Depolarization
5 Undershoot
Extracellular fluid
Potassium channel
Activation gates
Plasma membrane
Cytosol
Sodium channel
Inactivation gate
1 Resting state

# Generation of action potentials

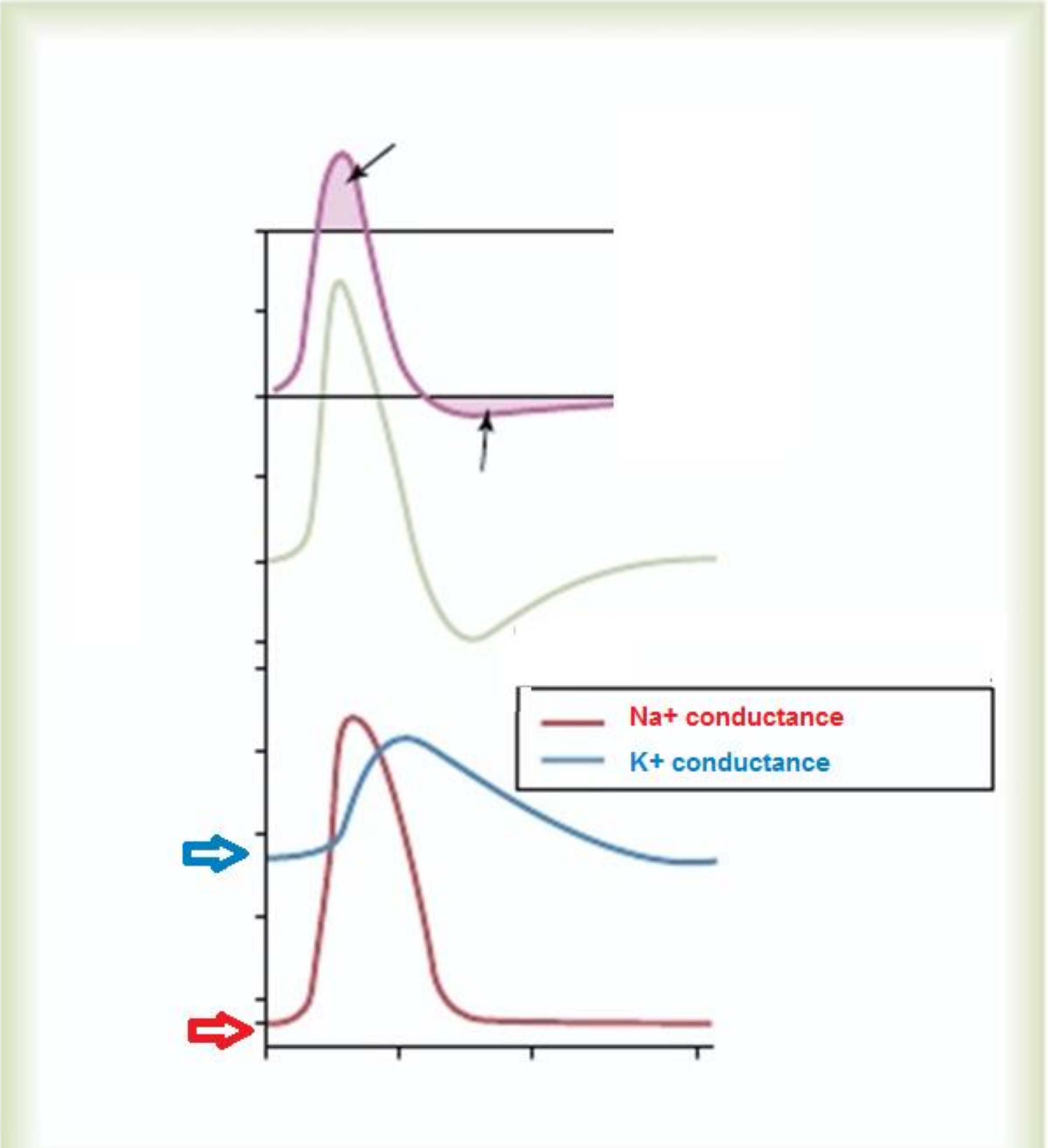




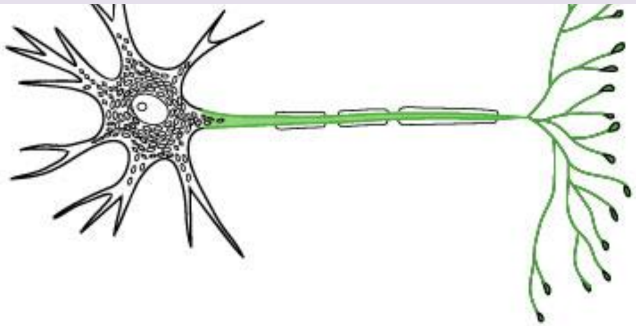
Na+ channel
K+ channel
30
20
10
0
Conductance (mmho/cm2)
Activation
Inactivat
−90 mV
+10 mV
−90 mV
Membrane potential
0
1
2
3
Time (milliseconds)

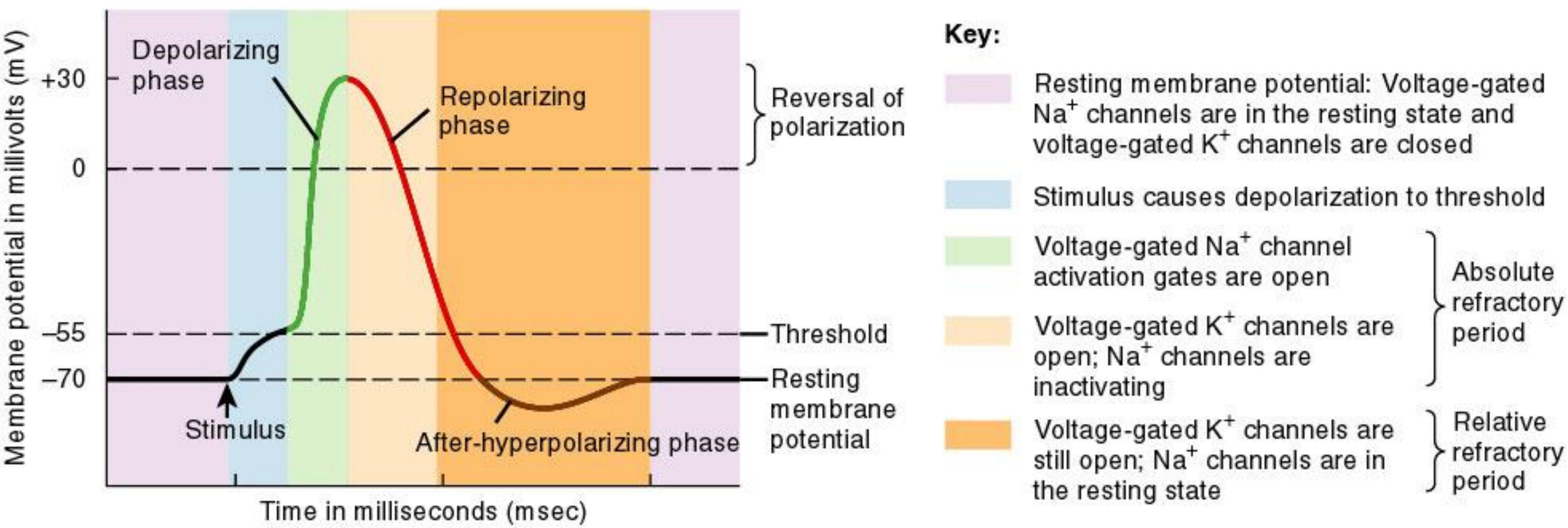

Figure 5–9

- Na+ and K+ conductance at resting potentials



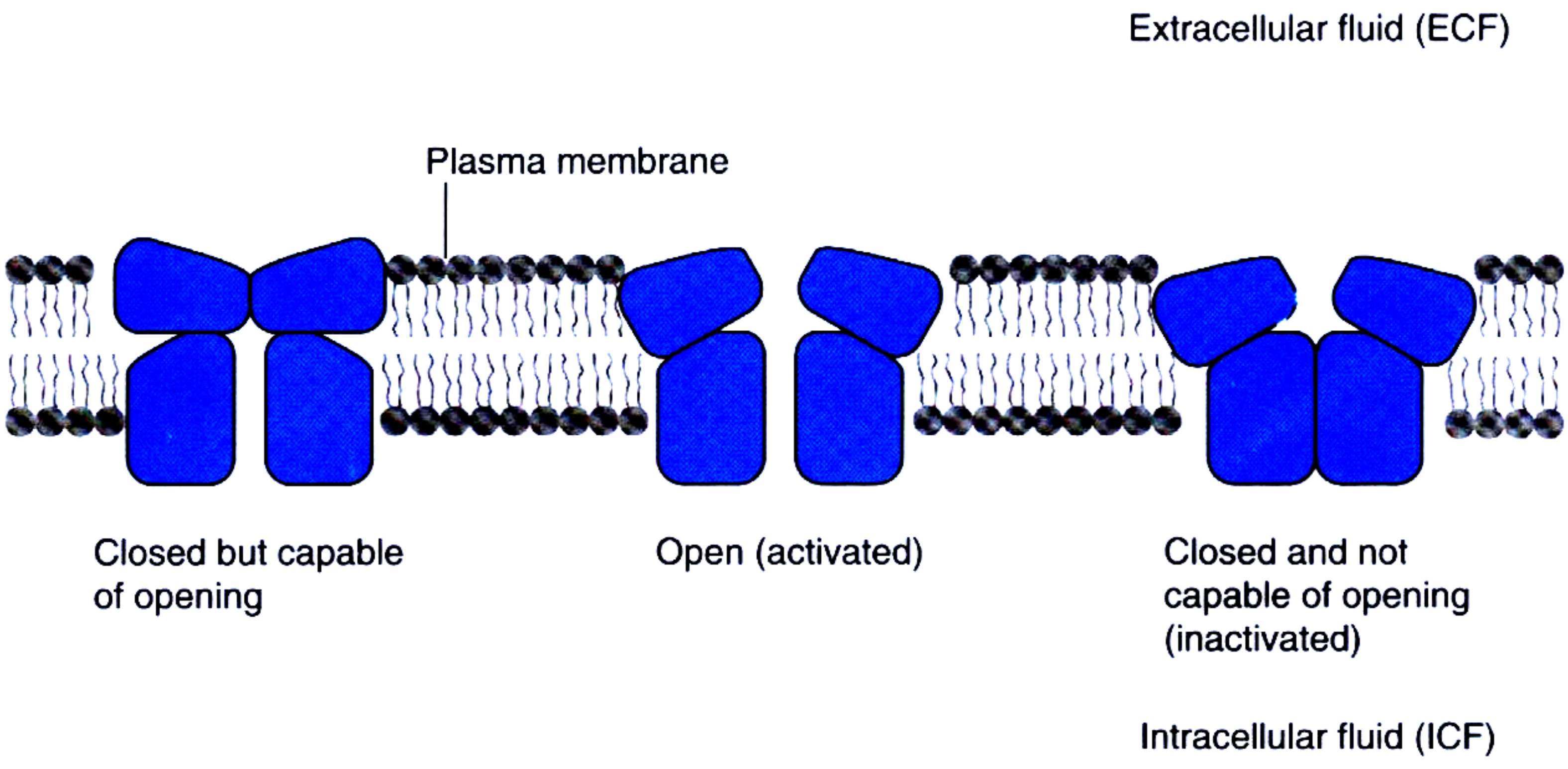
# Refractory periods



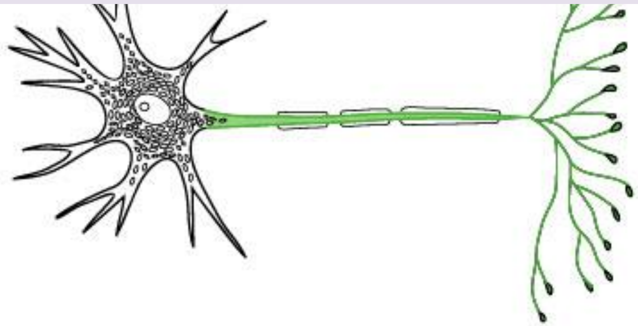


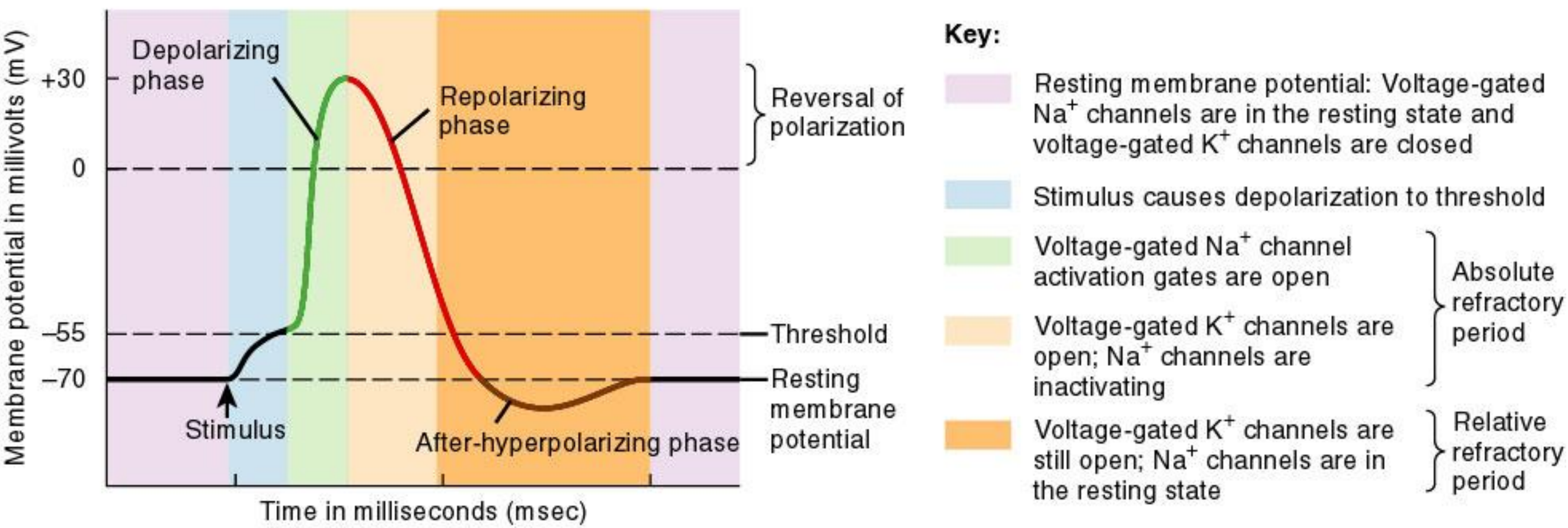

12.11

# Refractory periods and Na+ Channels



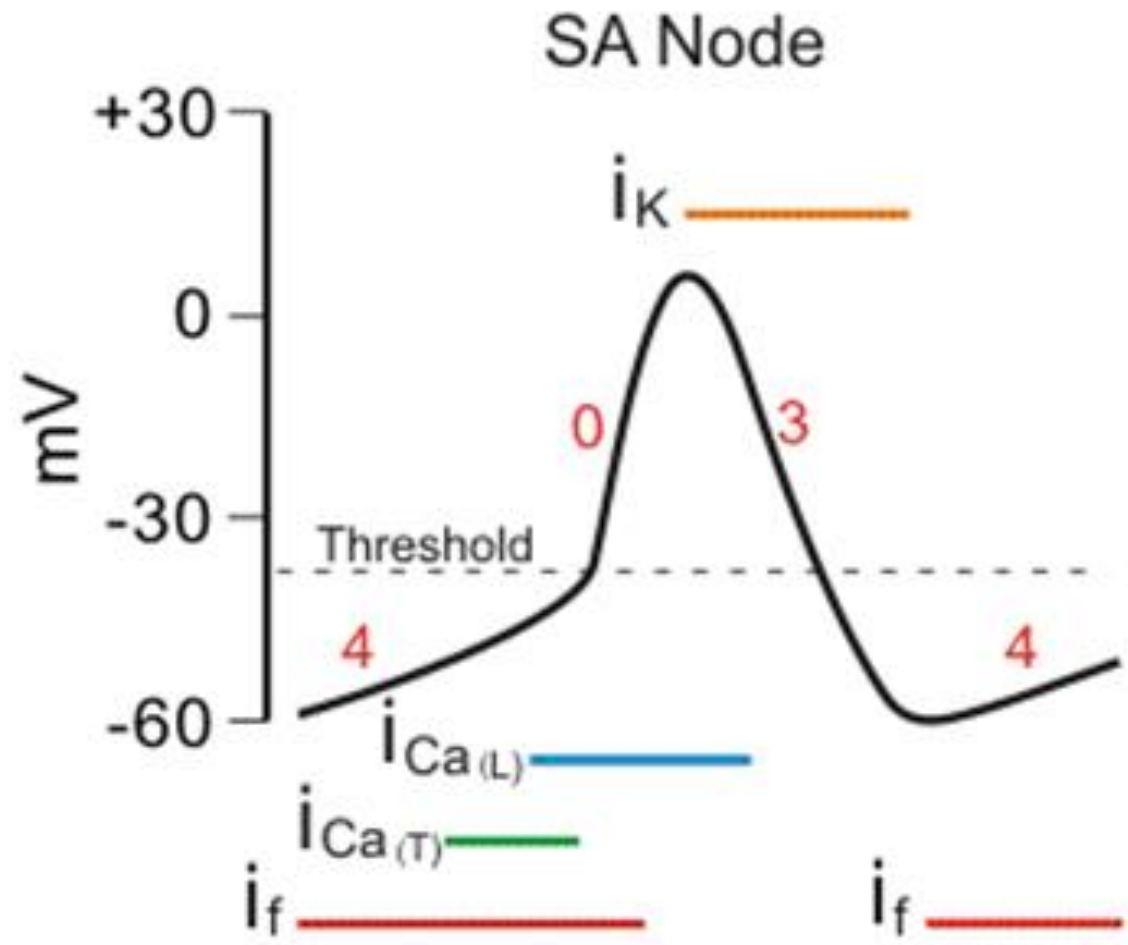
# Refractory periods



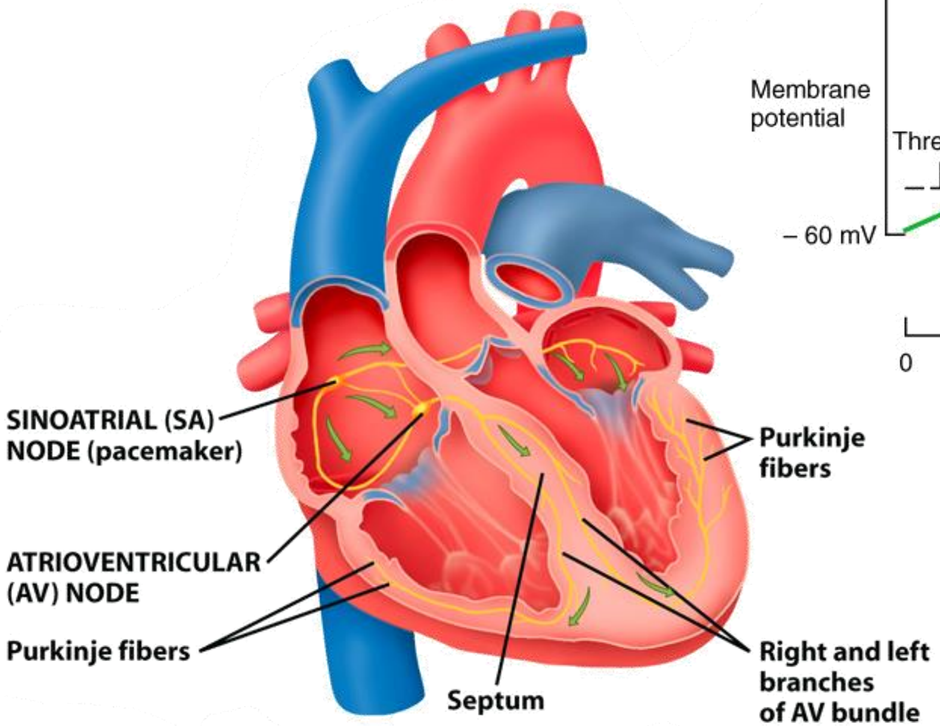


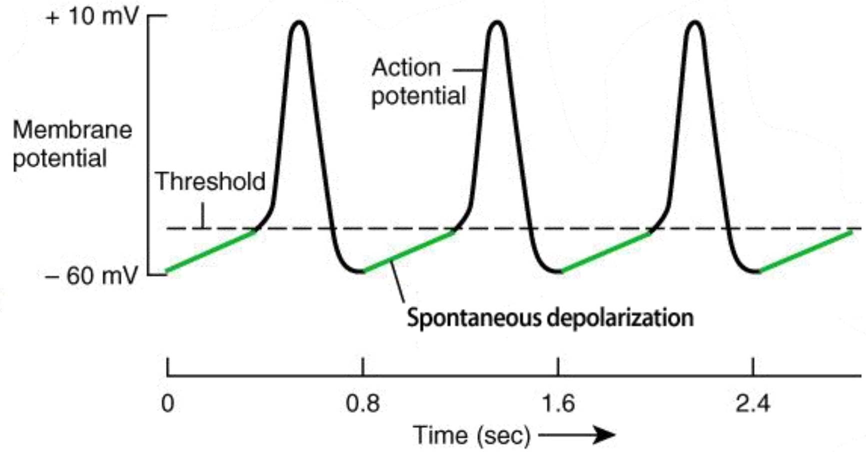

12.11

# Involvement of other Ions in Action potential

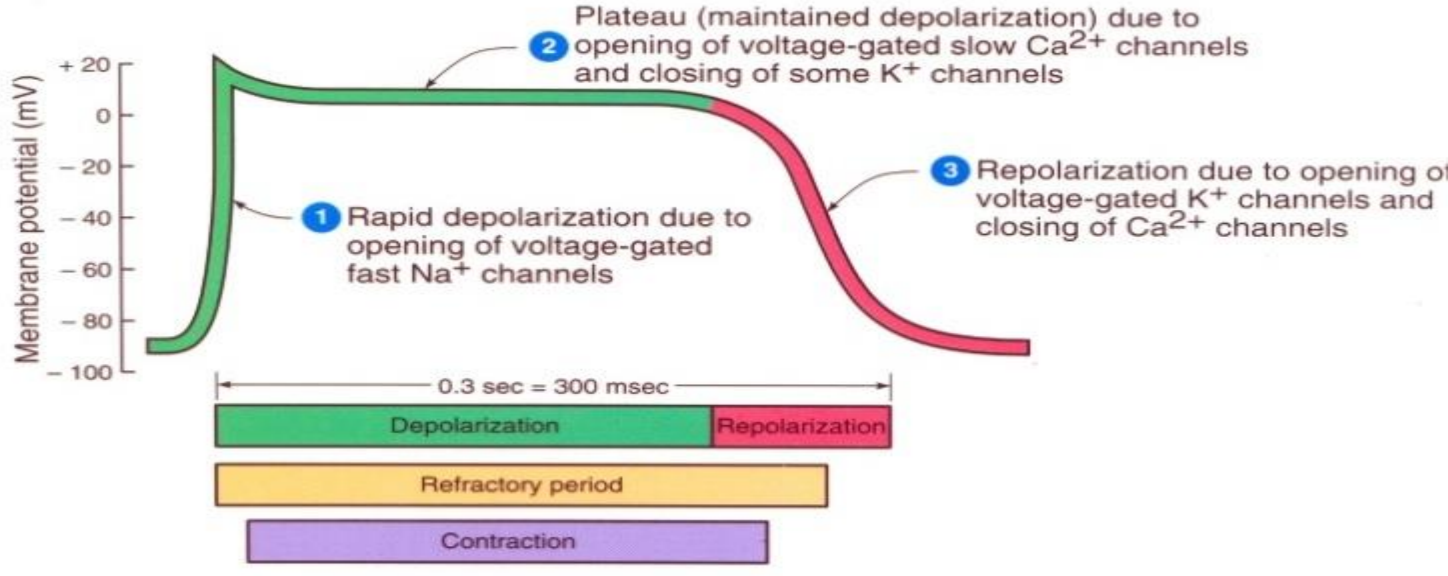

SA Node
+30
0
-30
-60
mV
Threshold
$i_K$
0
3
4
4
$i_{Ca(L)}$
$i_{Ca(T)}$
$i_f$
$i_f$

# Cardiac Conduction

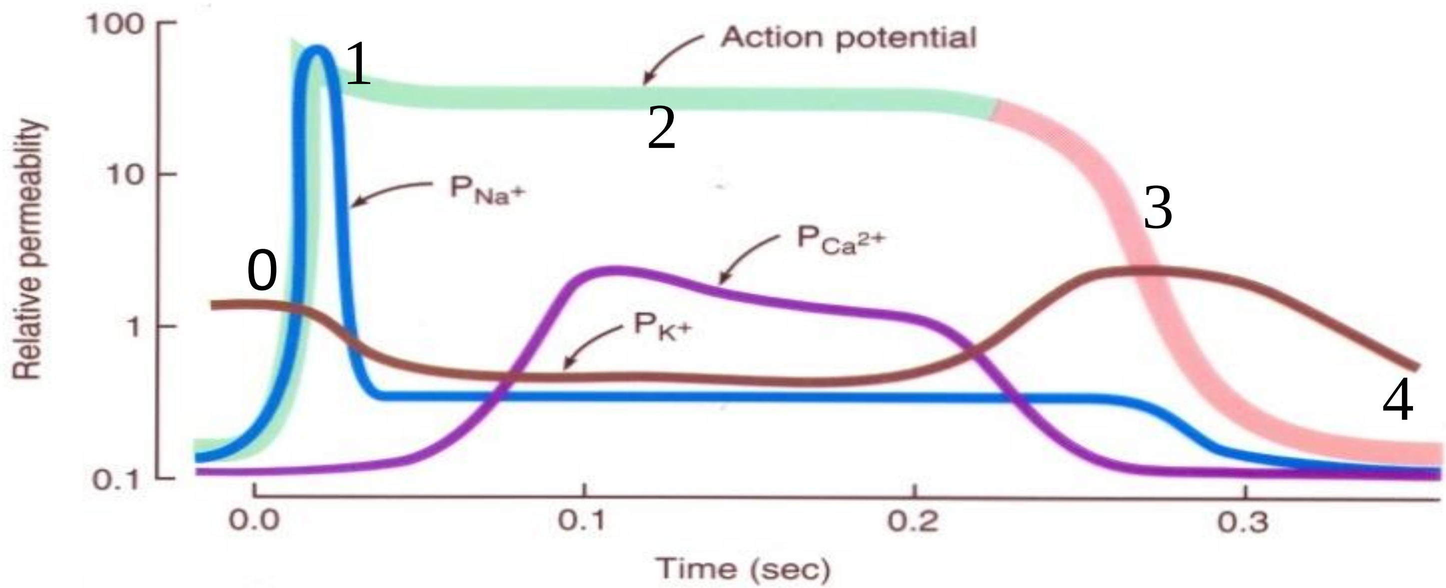



Generation of Action potential every 0.8 seconds, or 75 action potentials per minute at the SA node (Pacemaker of the heart)

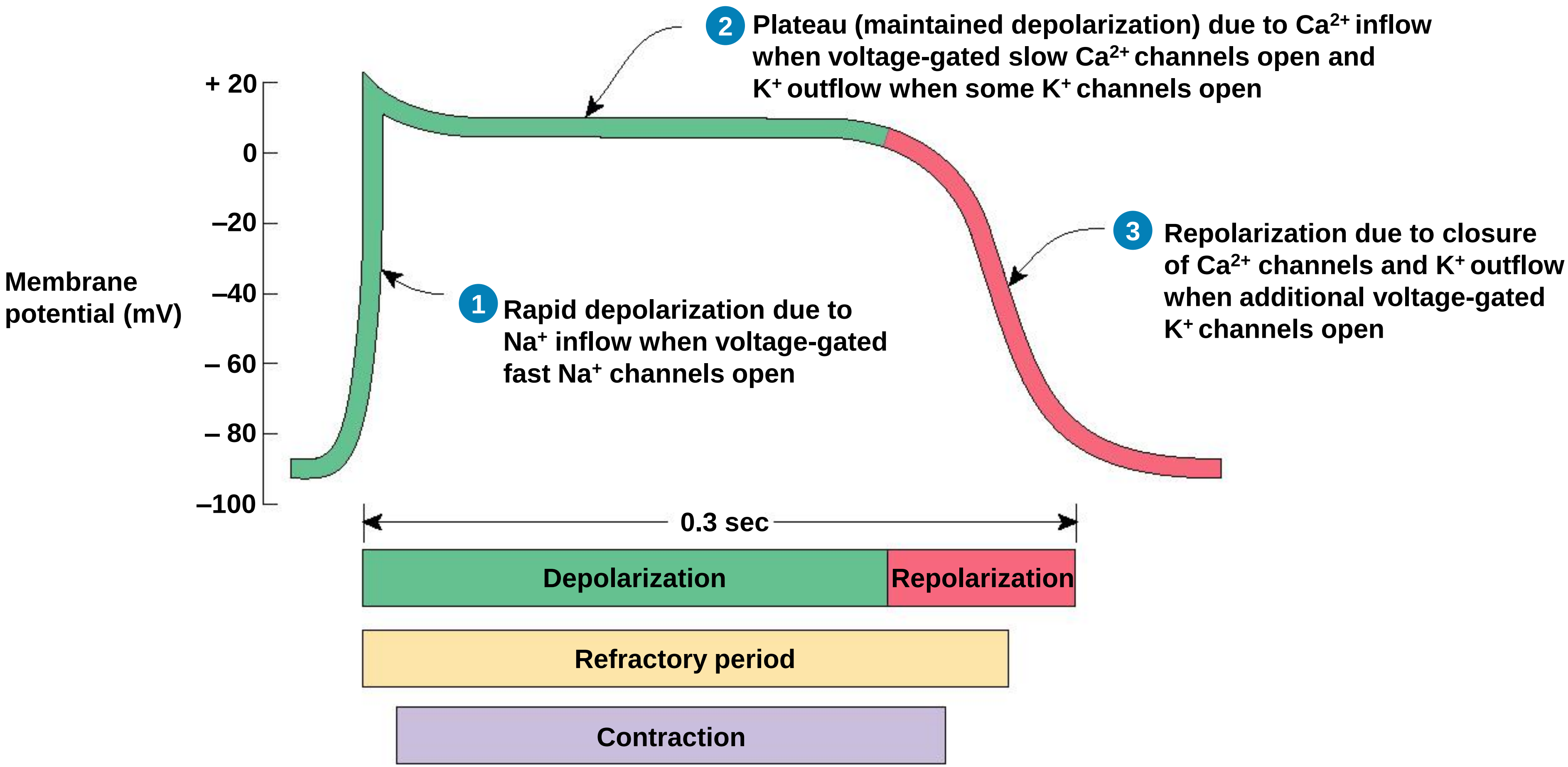


(a) Action potential, refractory period, and contraction

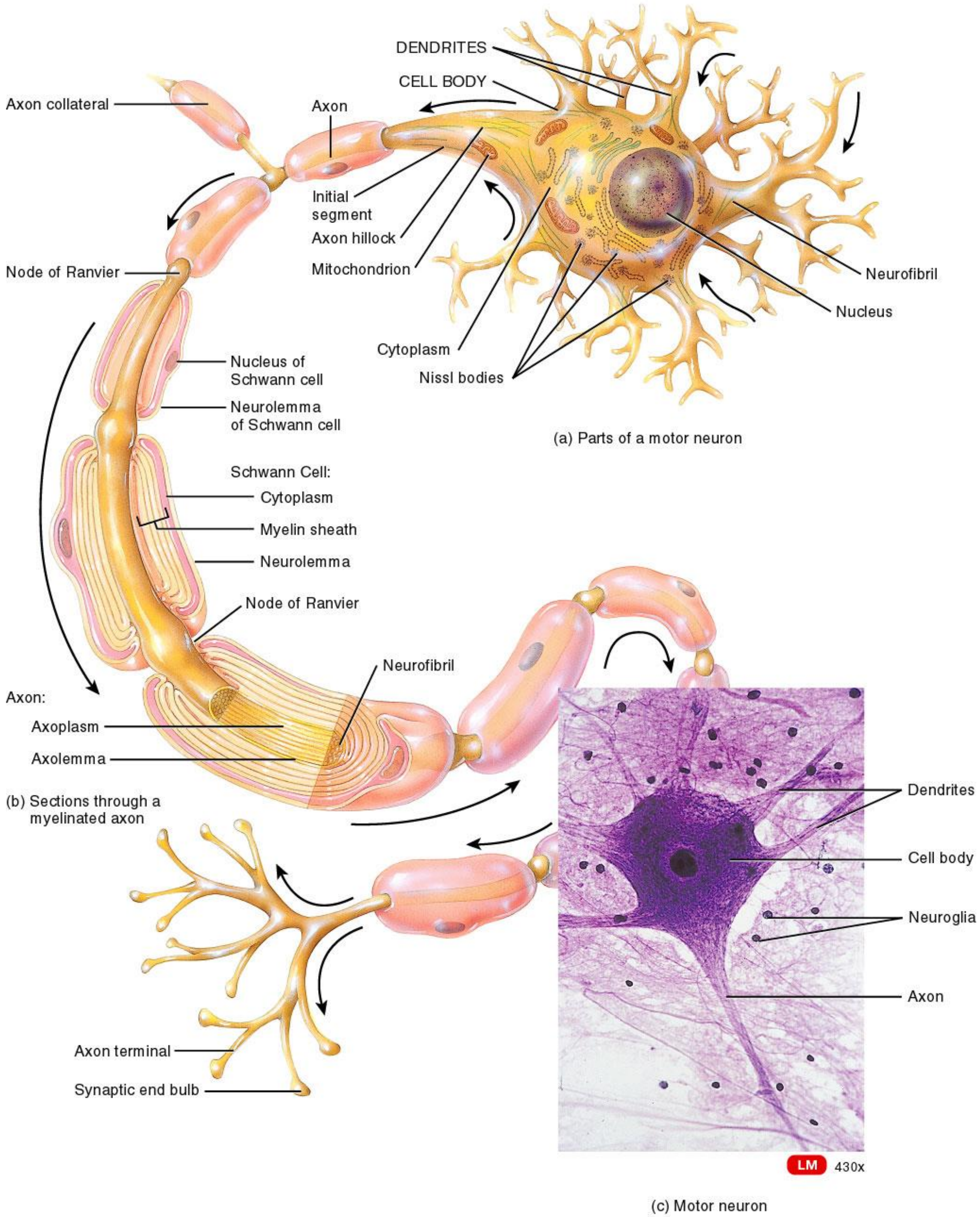


(b) Membrane permeability (P) changes

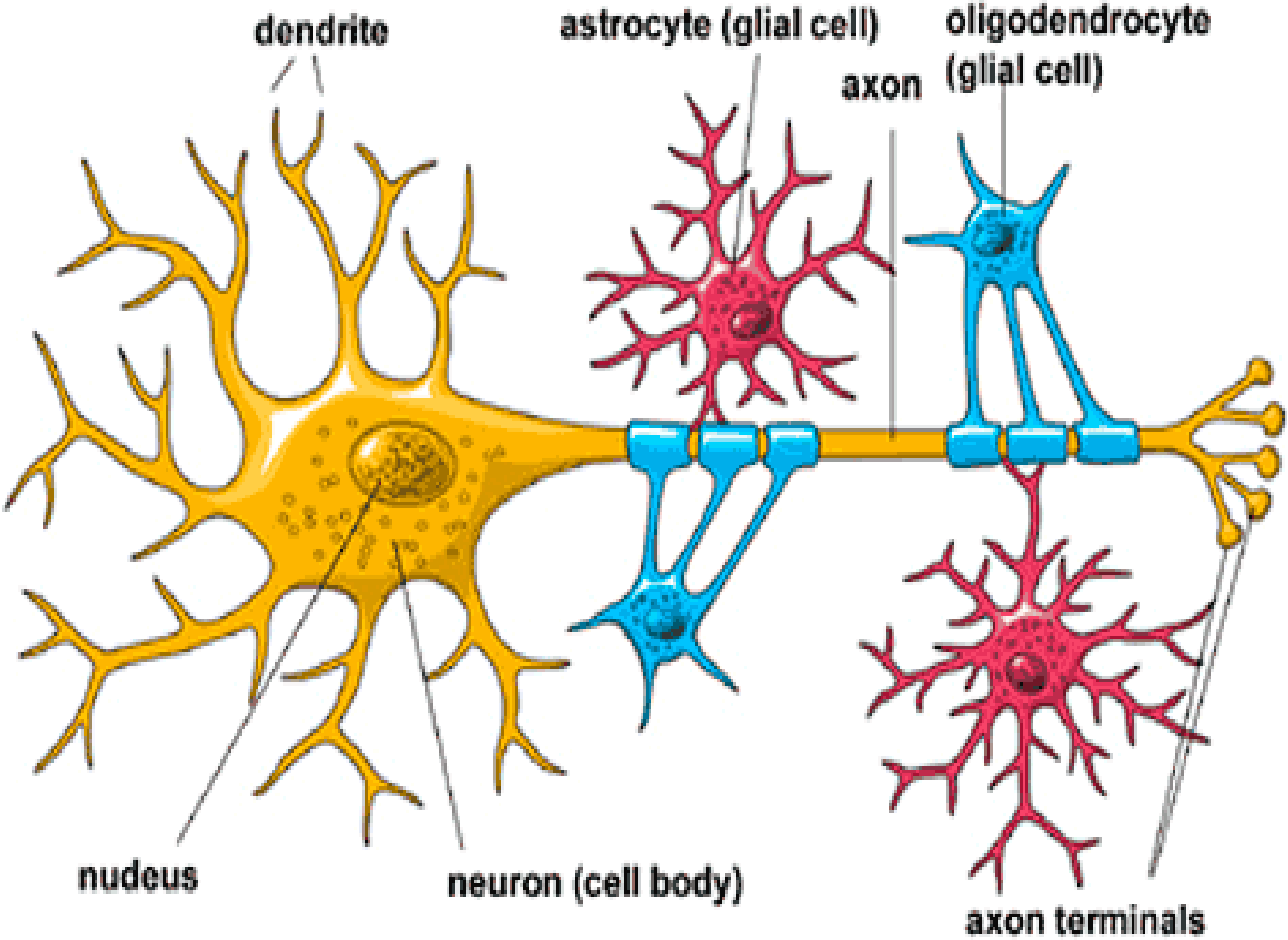
# Cardiac Muscle Action Potential



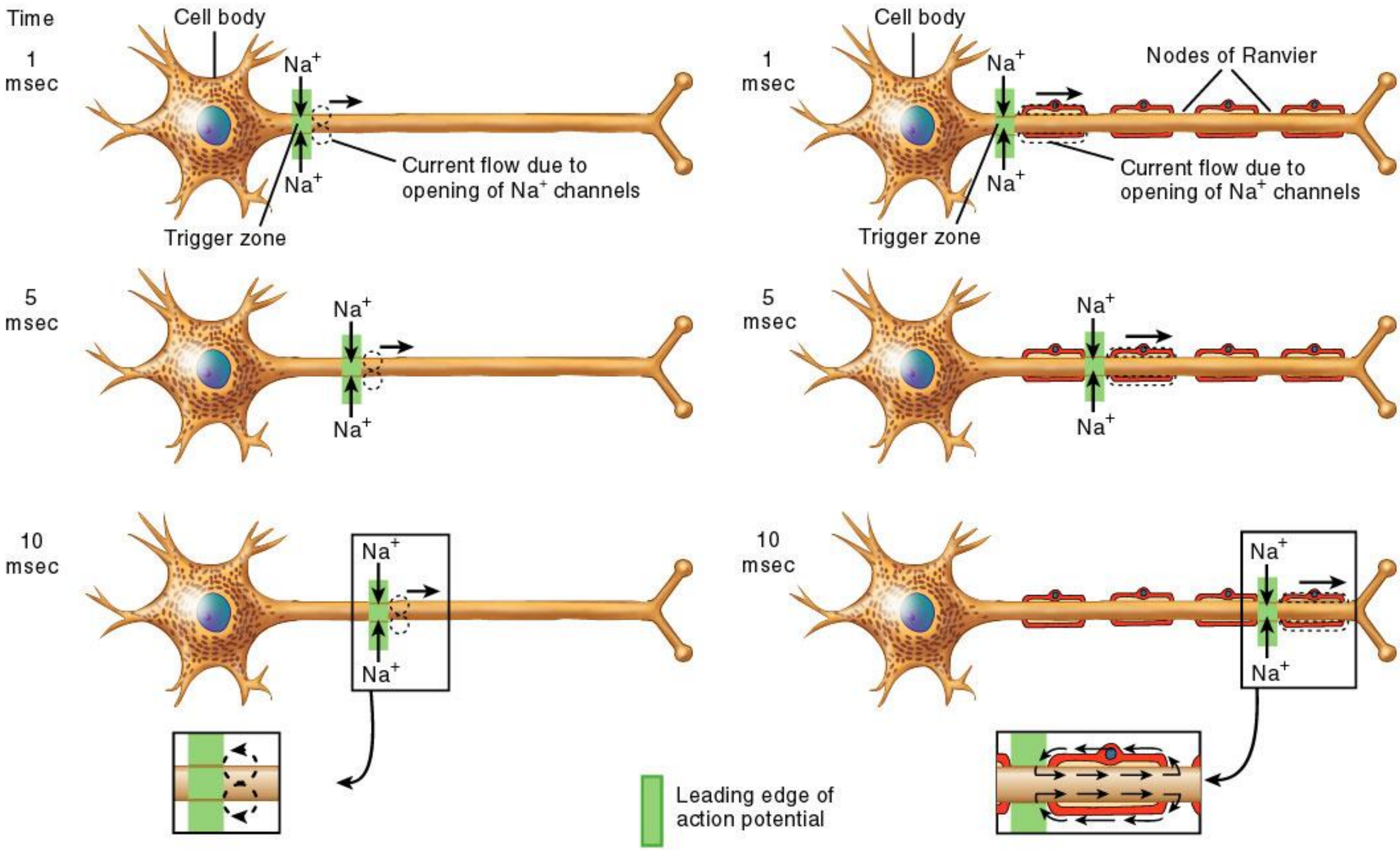
# Generation of action potential at Neural cells


DENDRITES
CELL BODY
Axon collateral
Axon
Initial segment
Axon hillock
Mitochondrion
Neurofibril
Nucleus
Cytoplasm
Nissl bodies
(a) Parts of a motor neuron
Node of Ranvier
Nucleus of Schwann cell
Neurolemma of Schwann cell
Schwann Cell:
Cytoplasm
Myelin sheath
Neurolemma
Node of Ranvier
Neurofibril
Axon:
Axoplasm
Axolemma
(b) Sections through a myelinated axon
Axon terminal
Synaptic end bulb
Dendrites
Cell body
Neuroglia
Axon
LM 430x
(c) Motor neuron

# Supportive cells



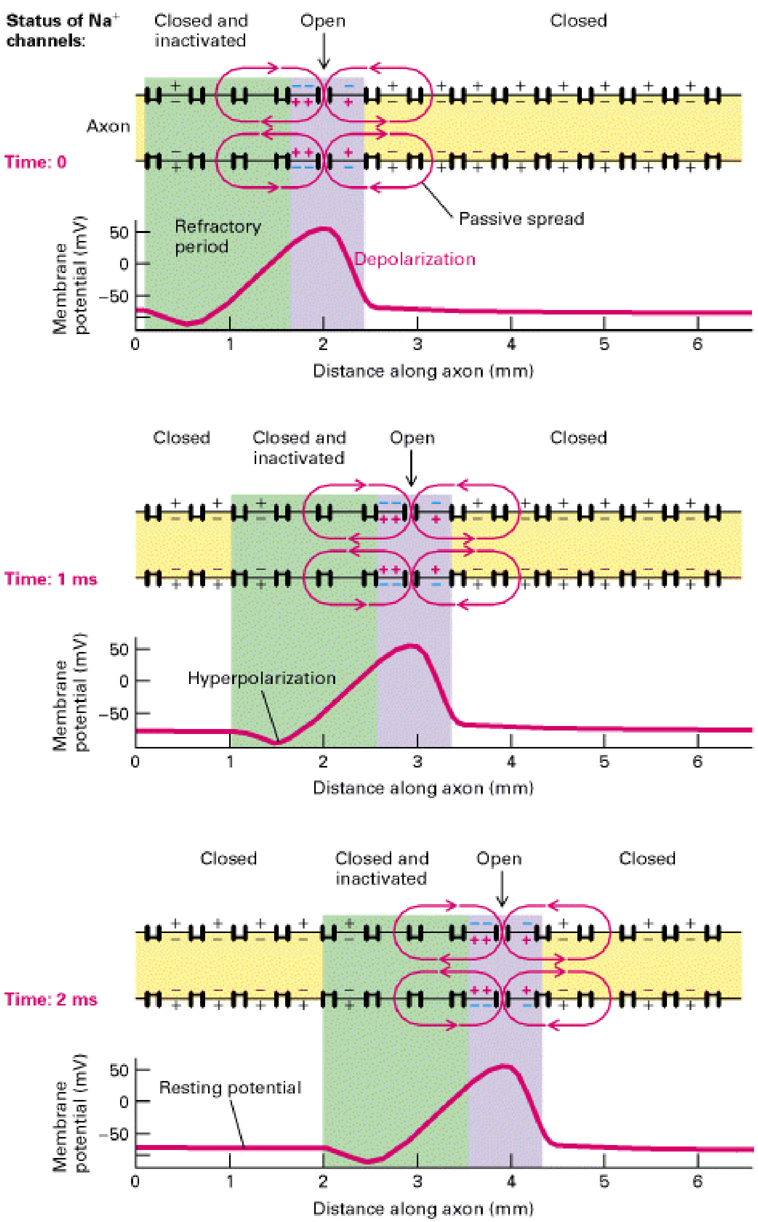
# Conduction of impulse




(a) Continuous conduction

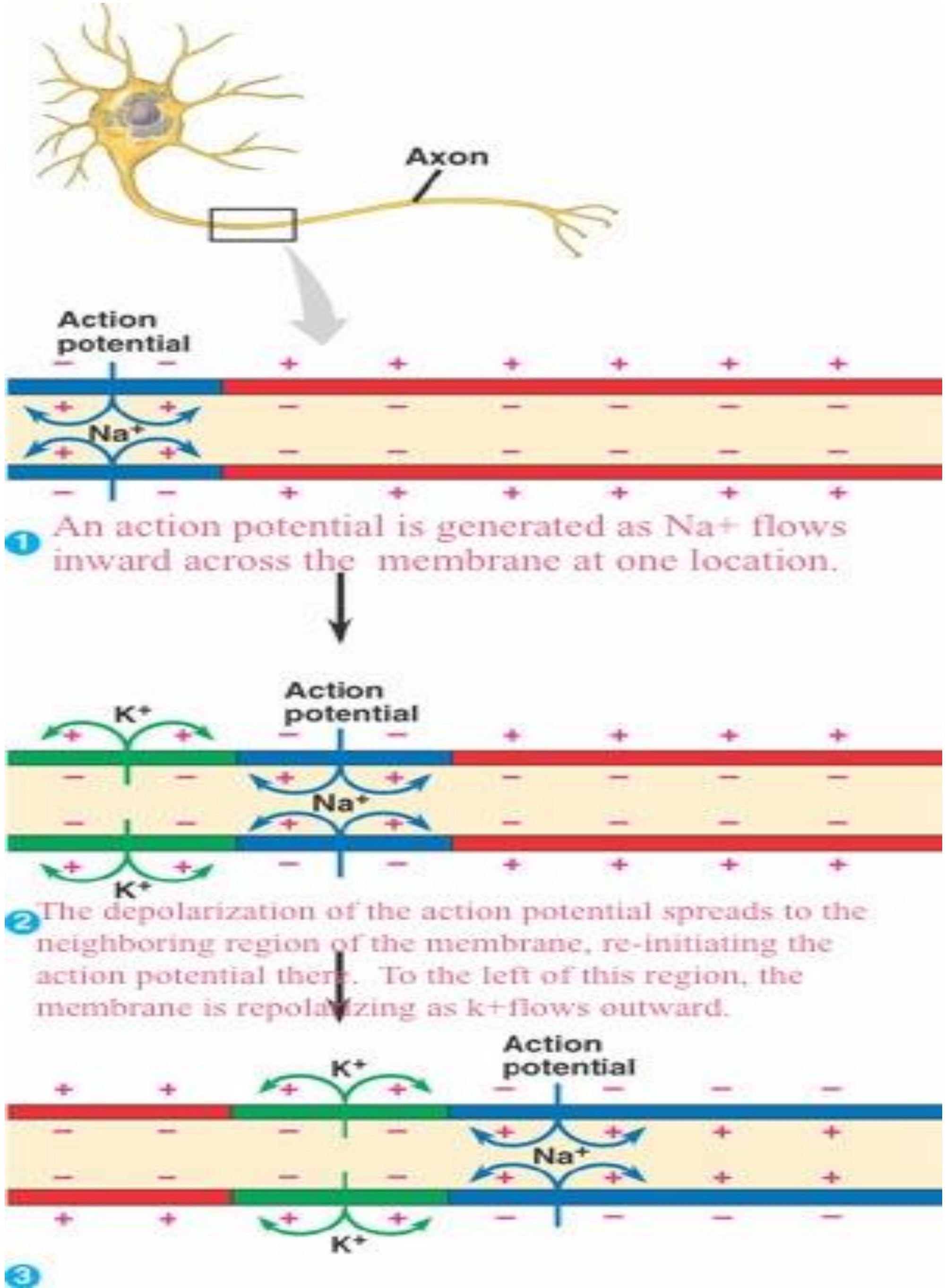
(b) Saltatory conduction

12.13



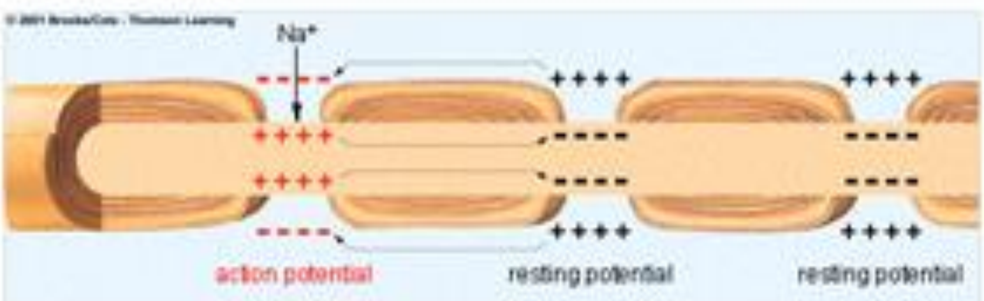

- Continuous Conduction in Unmyelinated axons

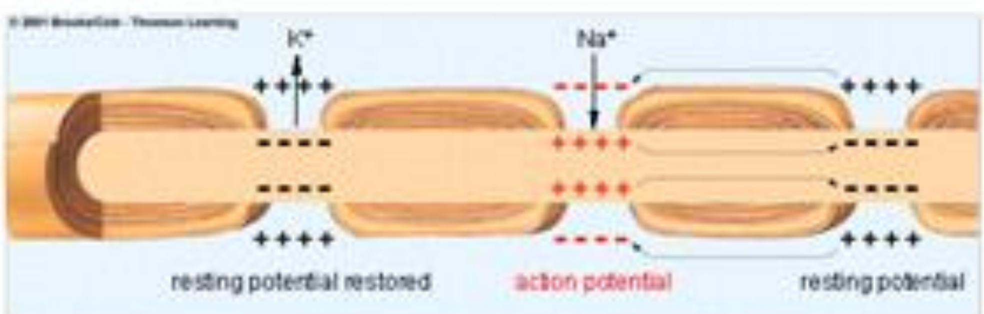
- Continuous Conduction in Unmyelinated axons



# Myelin Sheath

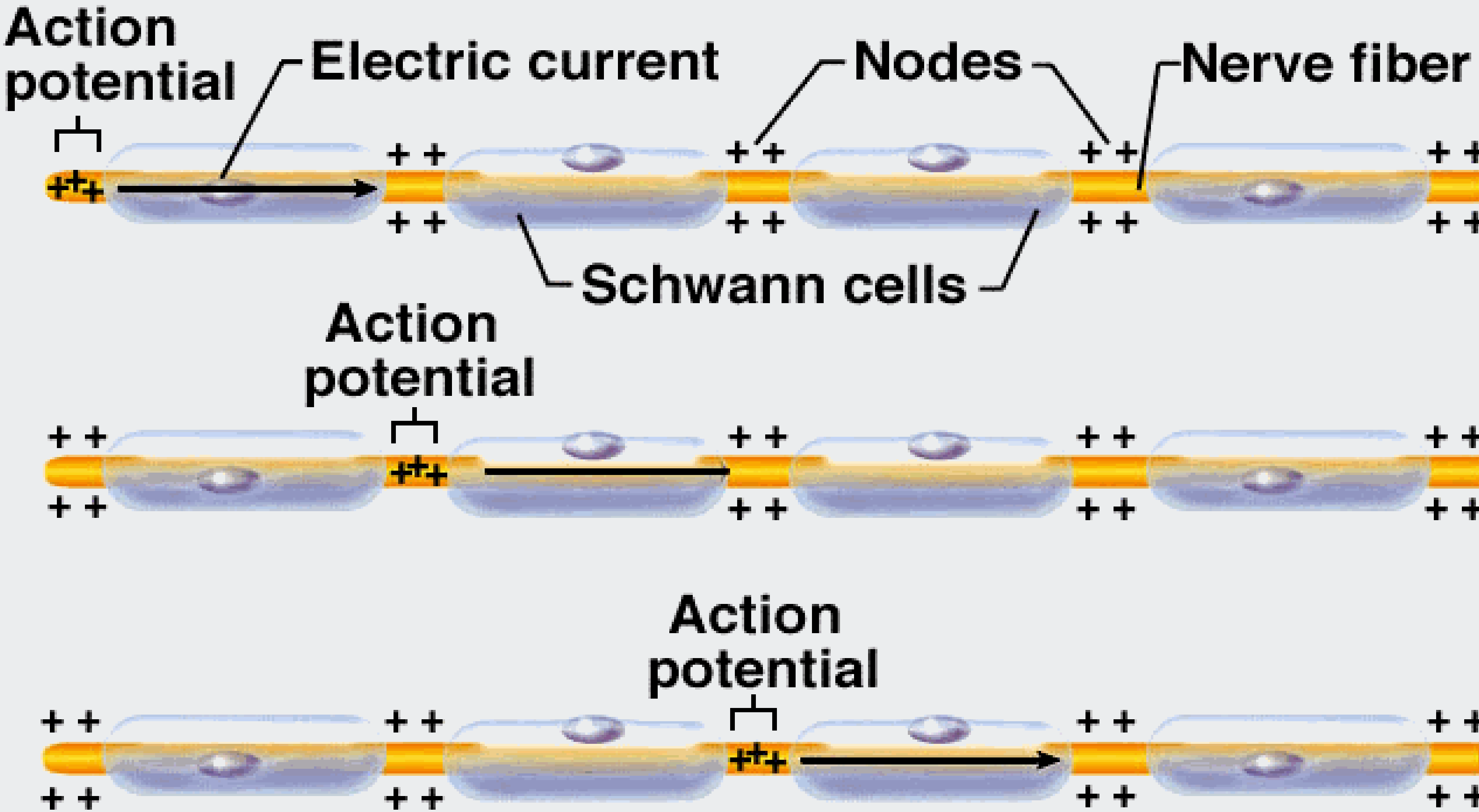


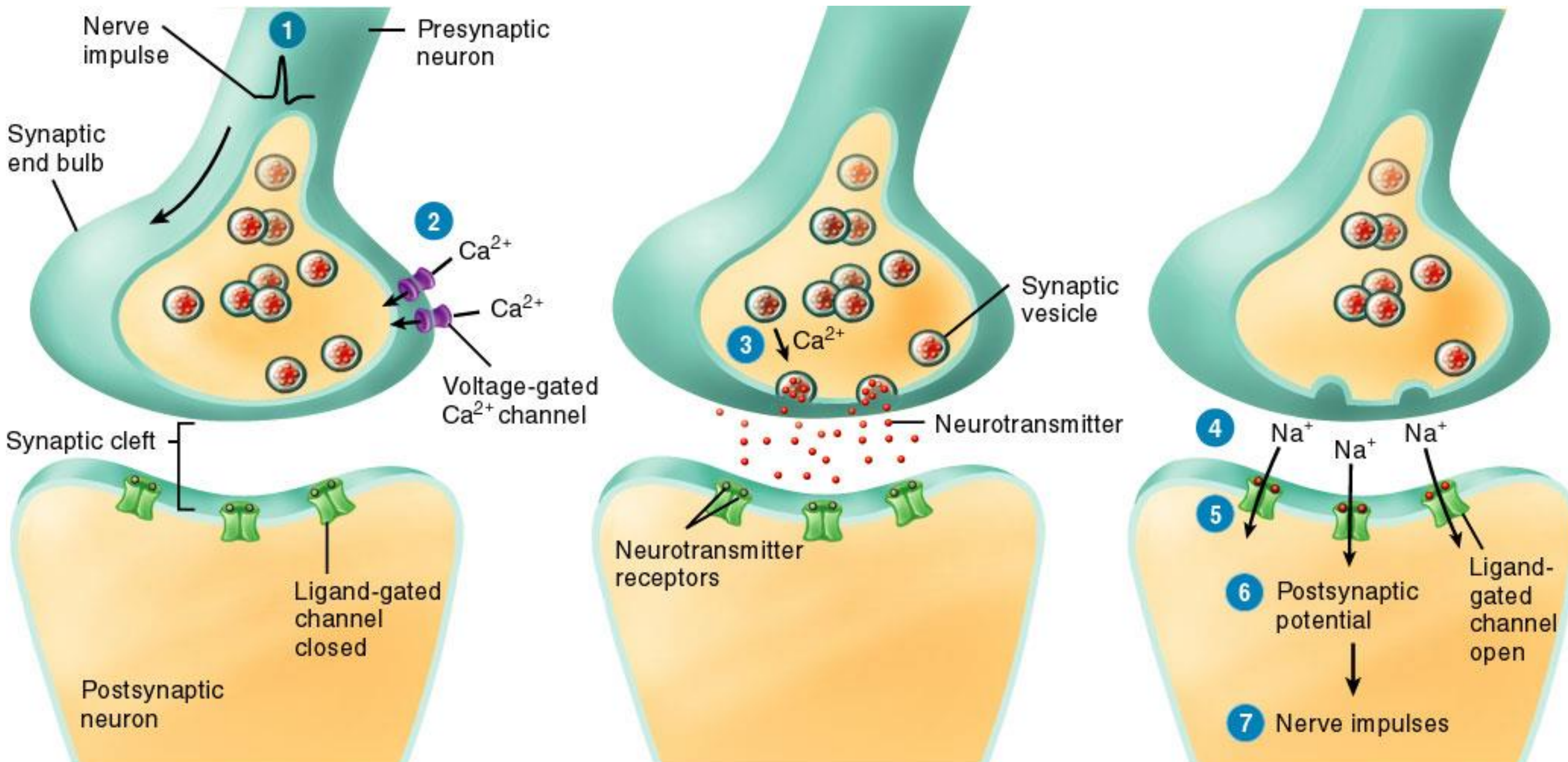




Saltatory Conduction in Myelinated axons

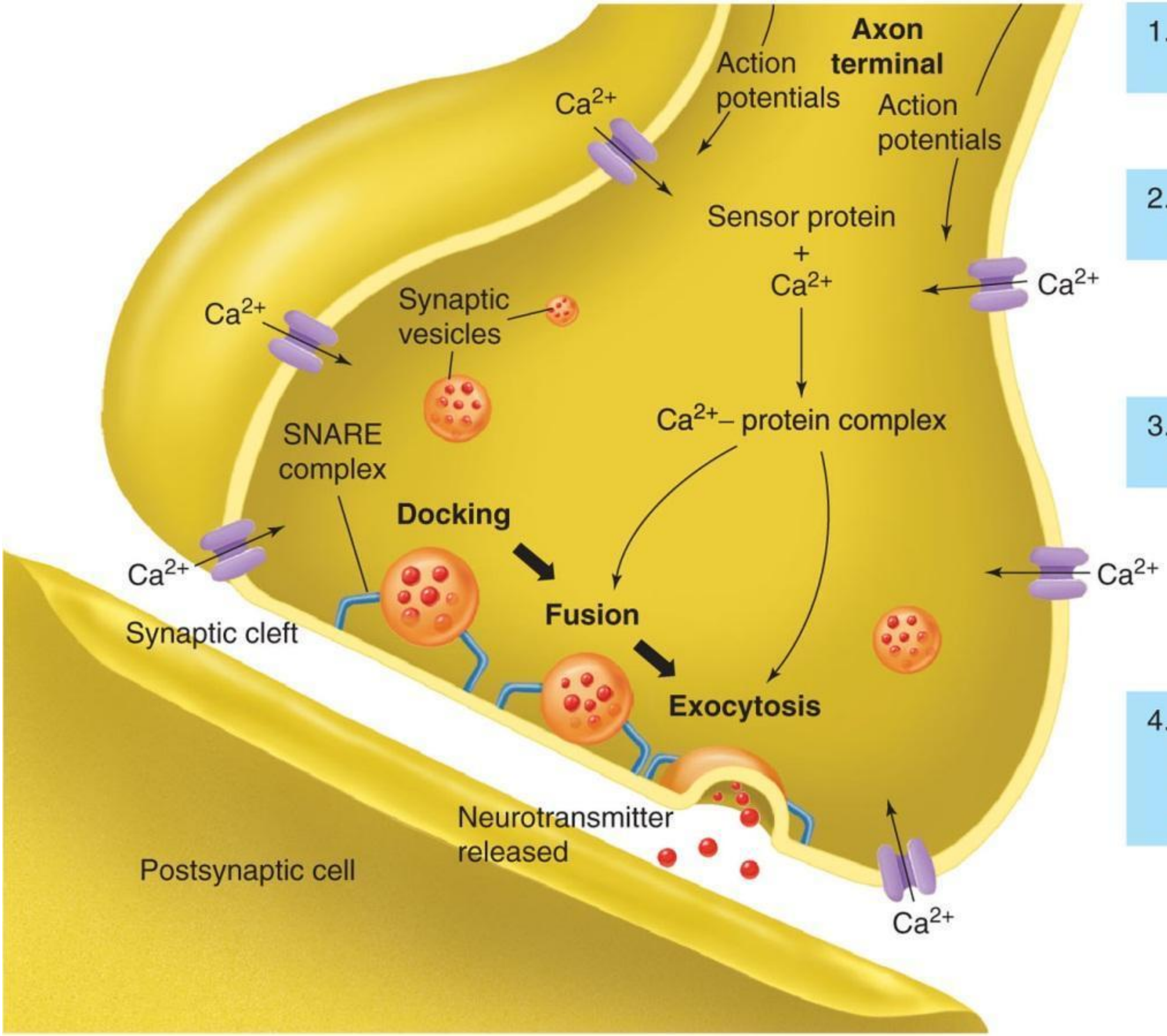
# Nerve Impulse on Myelinated Fiber



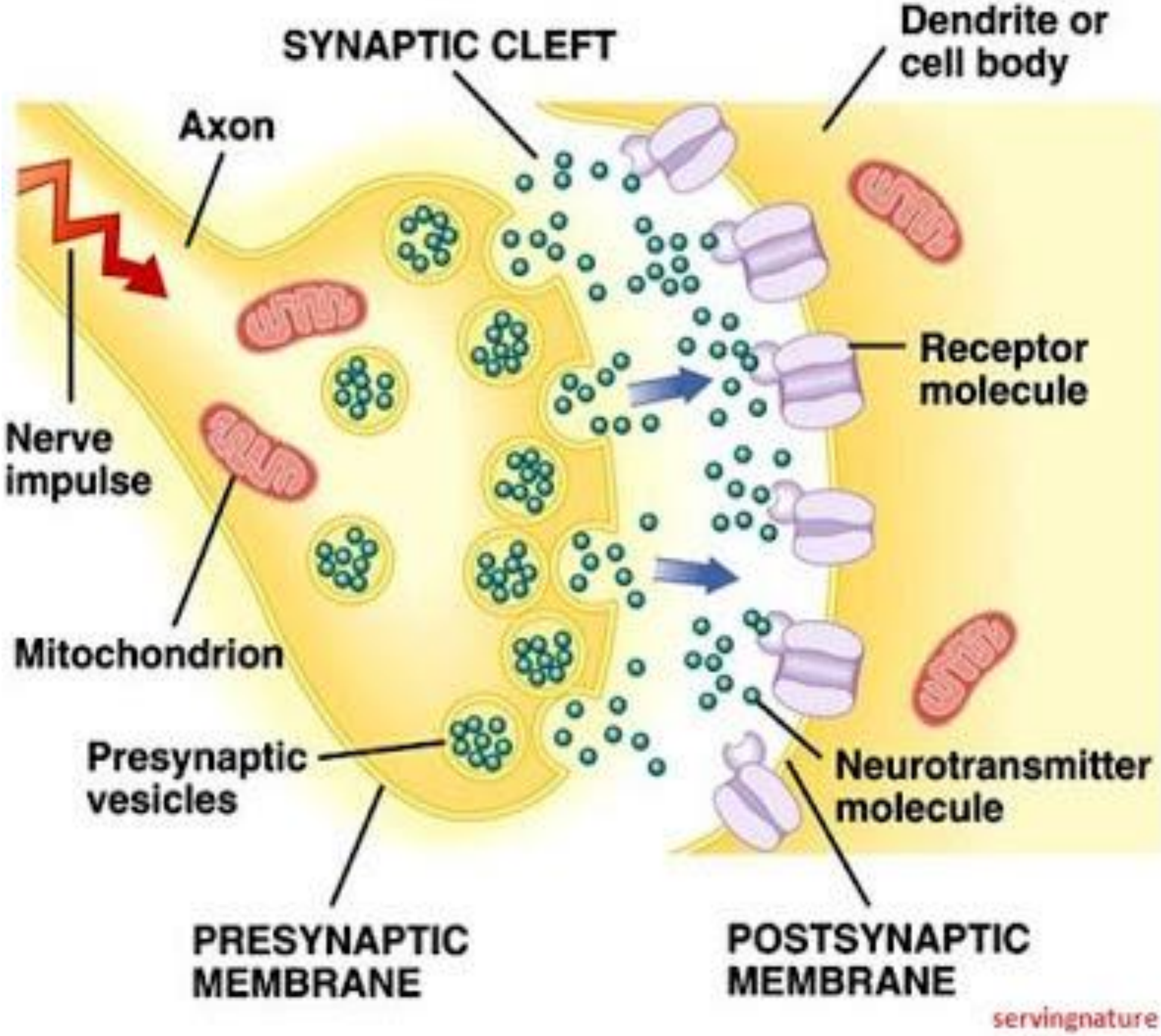


Nerve impulse
1
Presynaptic neuron
Synaptic end bulb
2
Ca2+
Ca2+
Voltage-gated Ca2+ channel
Synaptic cleft
Ligand-gated channel closed
Postsynaptic neuron
3
Ca2+
Synaptic vesicle
Neurotransmitter
Neurotransmitter receptors
4
Na+
Na+
Na+
5
6 Postsynaptic potential
7 Nerve impulses
Ligand-gated channel open

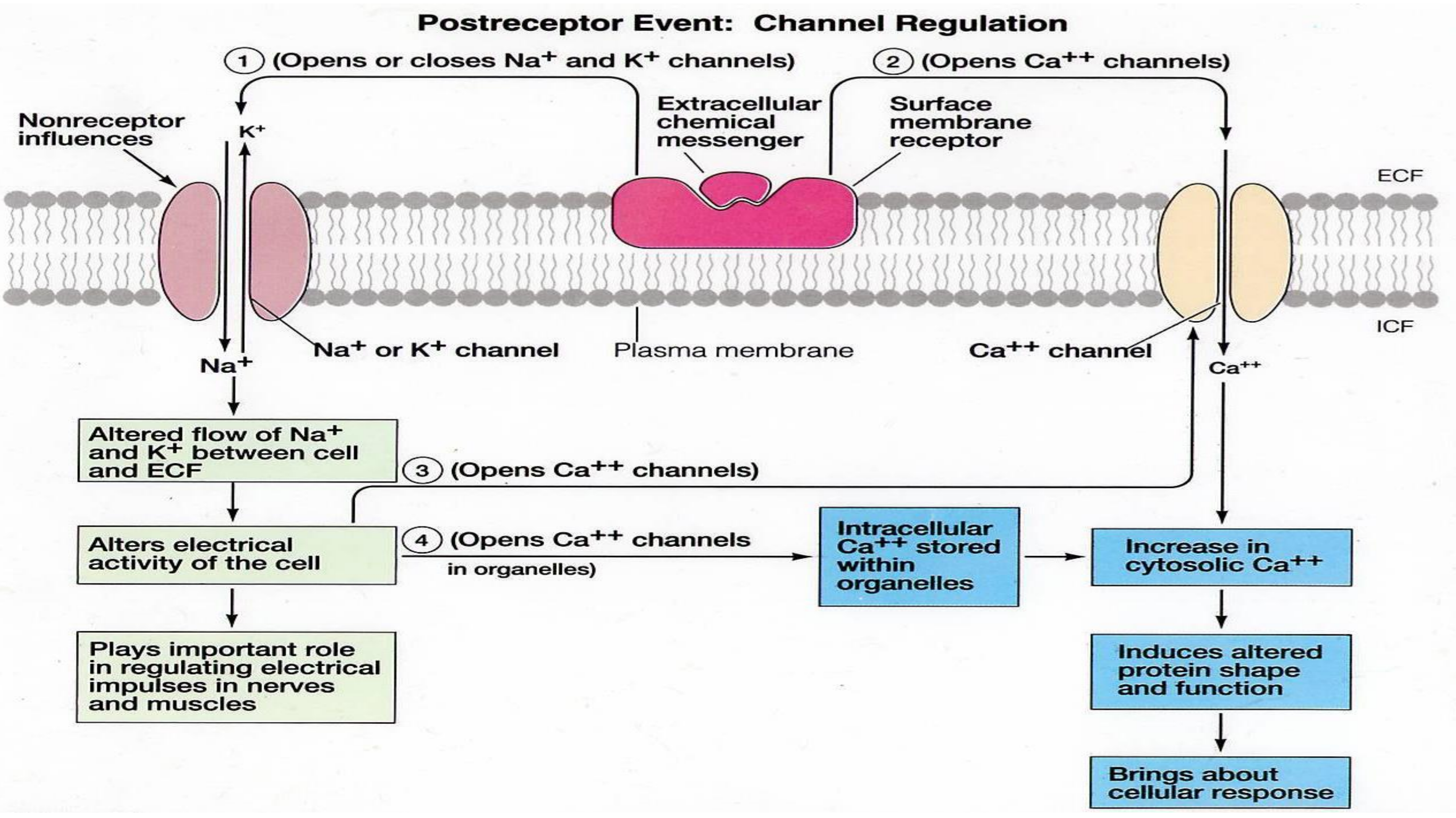

12.14

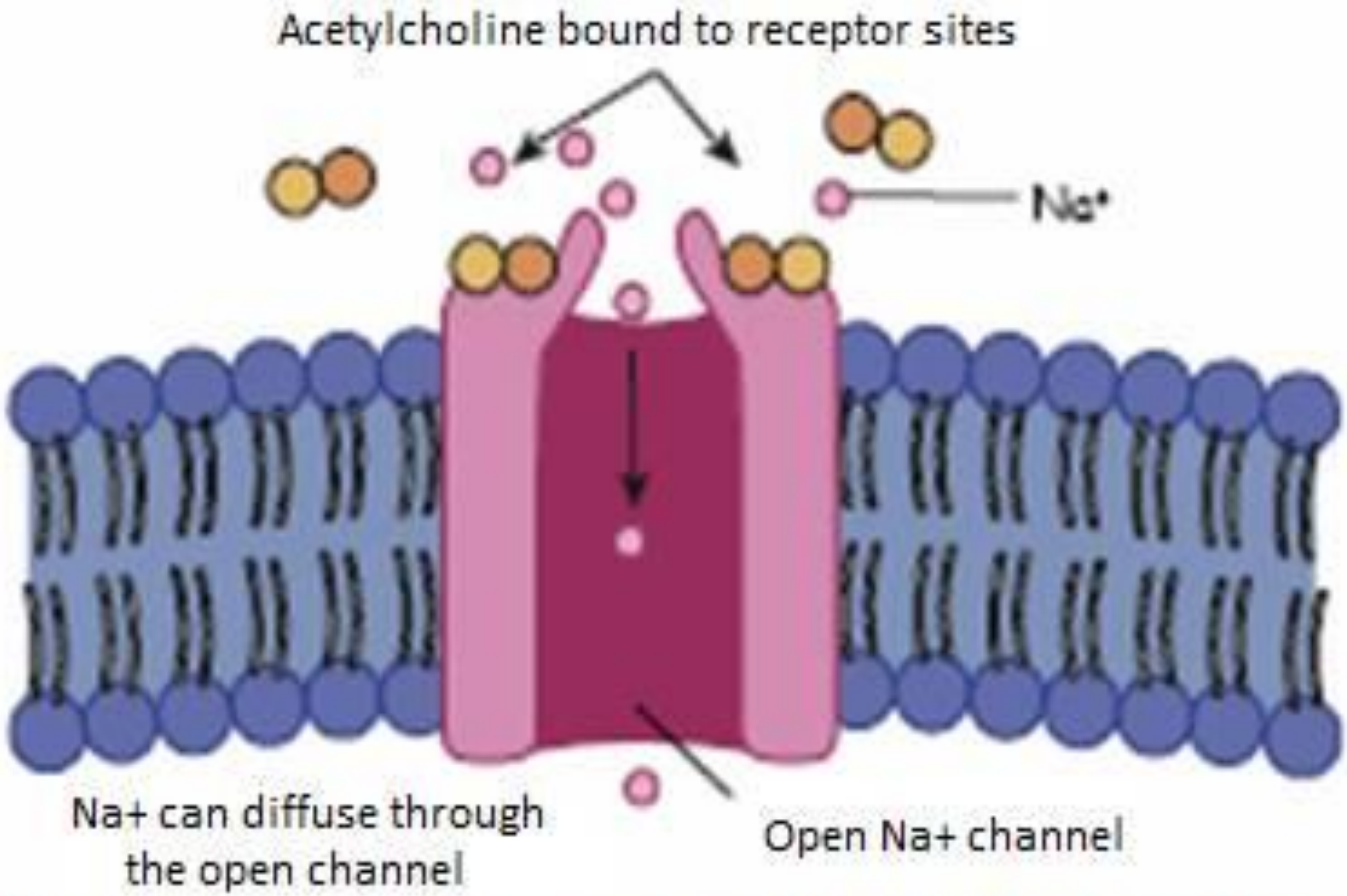



1. Action potentials reach axon terminals
2. Voltage-gated $Ca^{2+}$ channels open
3. $Ca^{2+}$ binds to sensor protein in cytoplasm
4. $Ca^{2+}$-protein complex stimulates fusion and exocytosis of neurotransmitter


SYNAPTIC CLEFT
Dendrite or cell body
Axon
Receptor molecule
Nerve impulse
Mitochondrion
Presynaptic vesicles
Neurotransmitter molecule
PRESYNAPTIC MEMBRANE
POSTSYNAPTIC MEMBRANE
servingnature

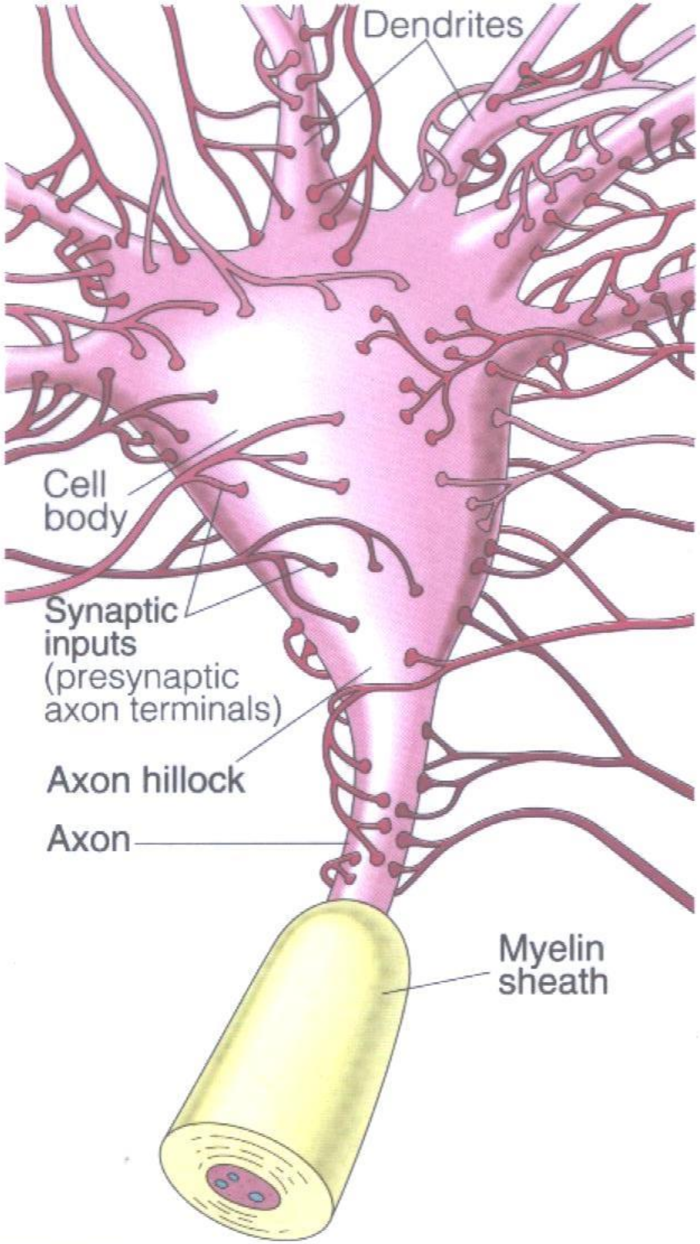
# Chemical gated Channels

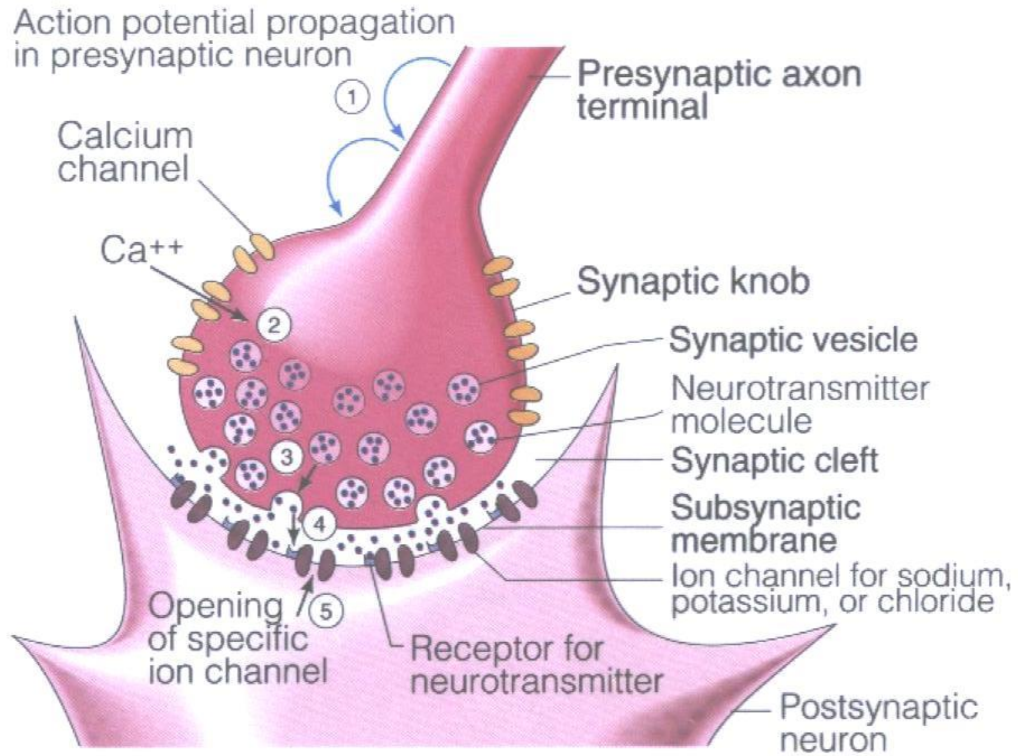


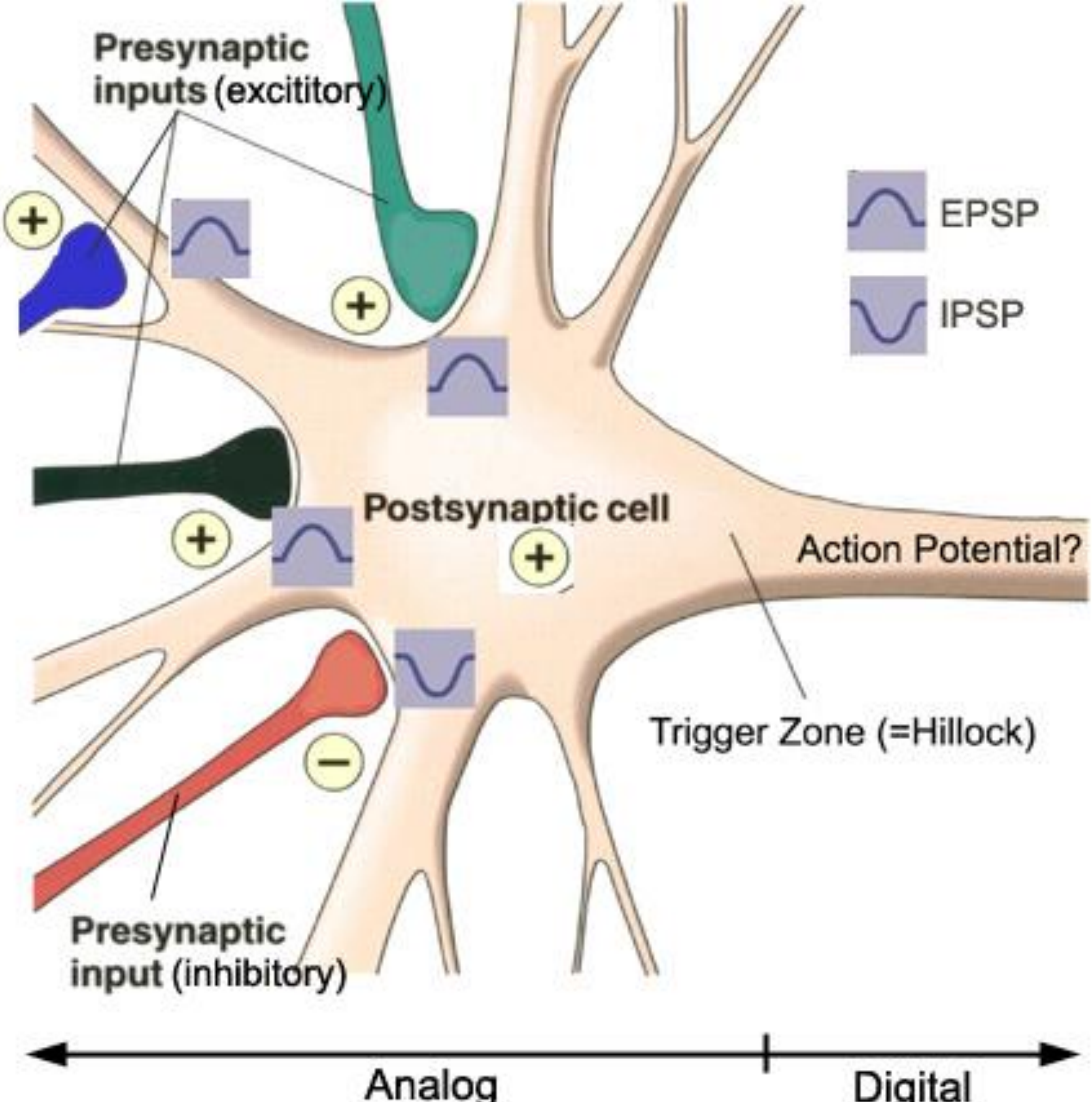


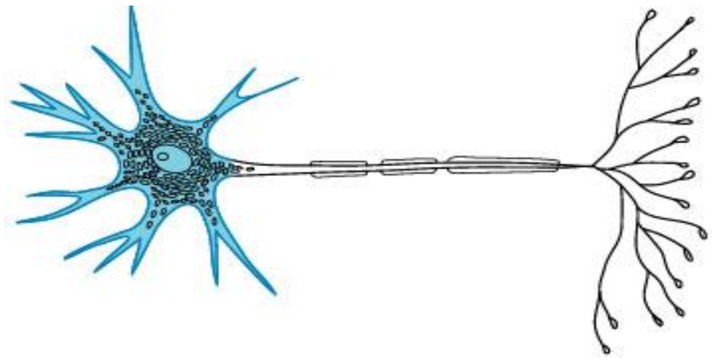

When 2 acetylcholine molecules bind to their receptor sites on the Na+ channel, the channel opens to allow Na+ to diffuse through the channel into the cell

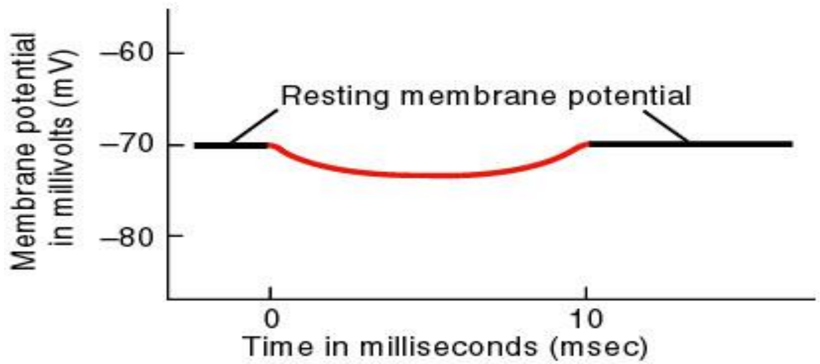
## Synaptic Structure and Function



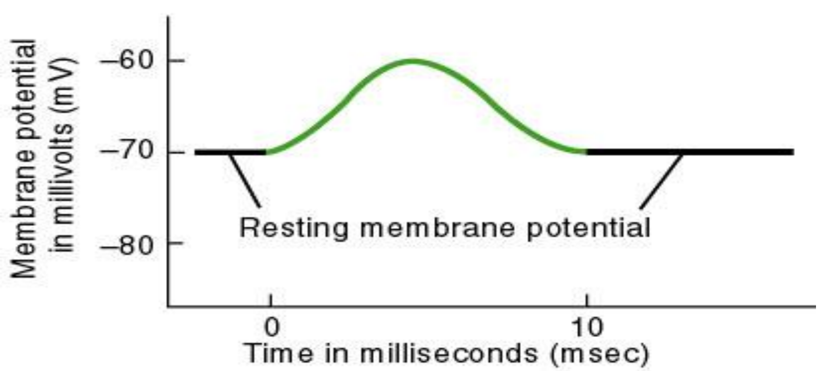




Presynaptic inputs (excititory)
EPSP
IPSP
Postsynaptic cell
Action Potential?
Trigger Zone (=Hillock)
Presynaptic input (inhibitory)
Analog
Digital





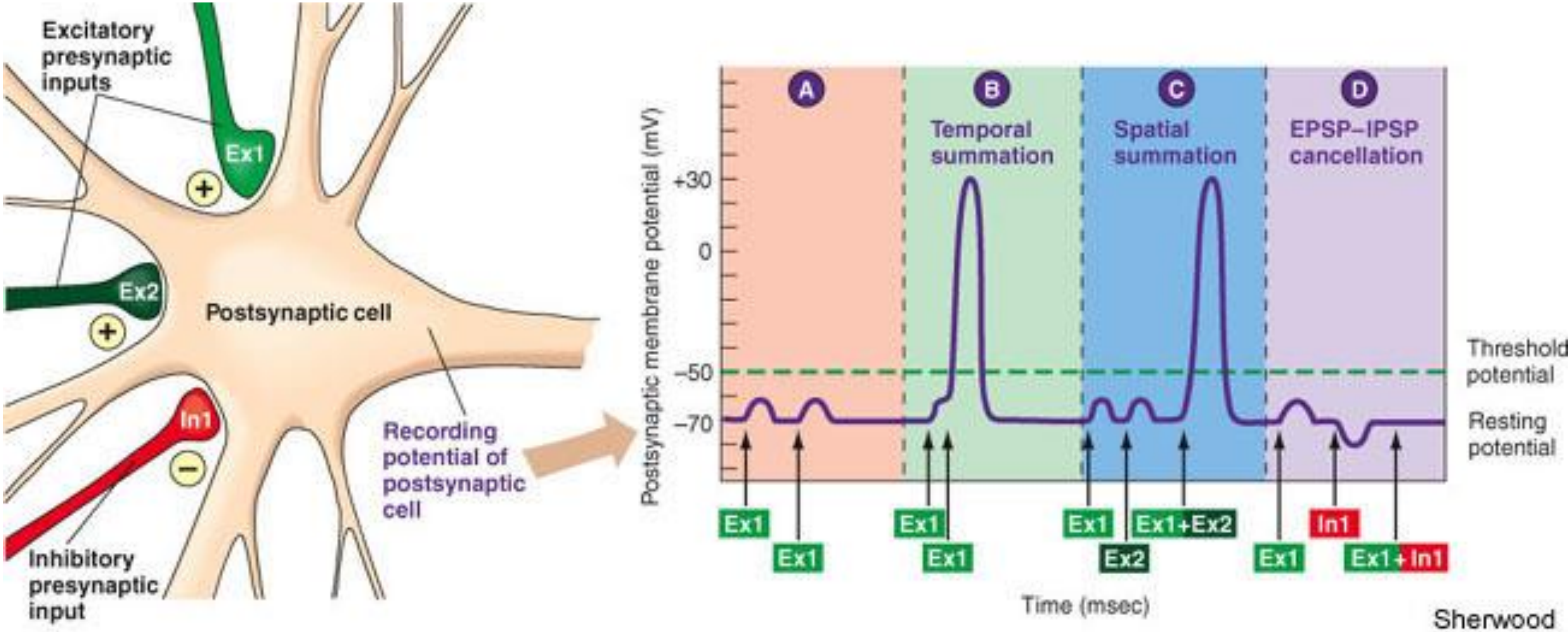

(a) Hyperpolarizing graded potential



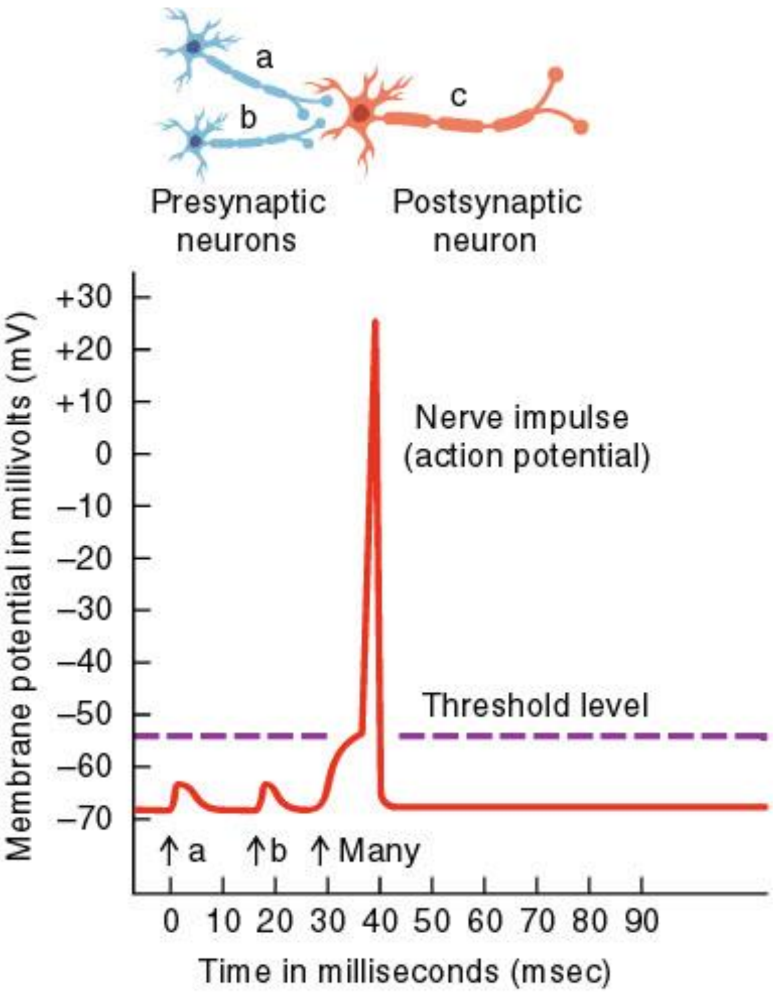

(b) Depolarizing graded potential

12.10

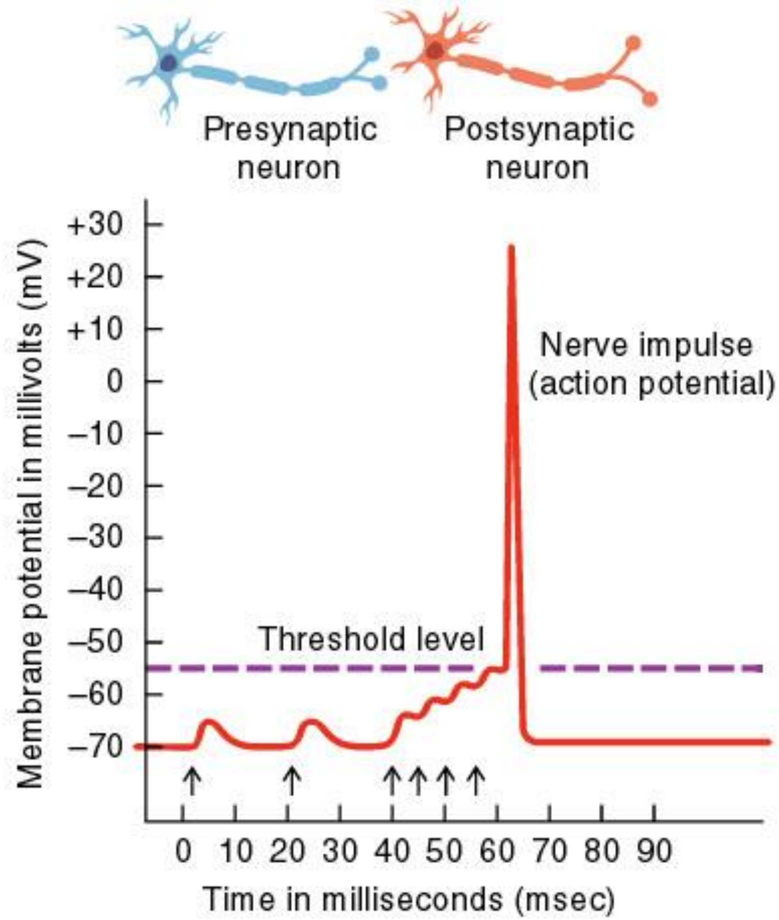
# Summation of postsynaptic potentials




Sherwood

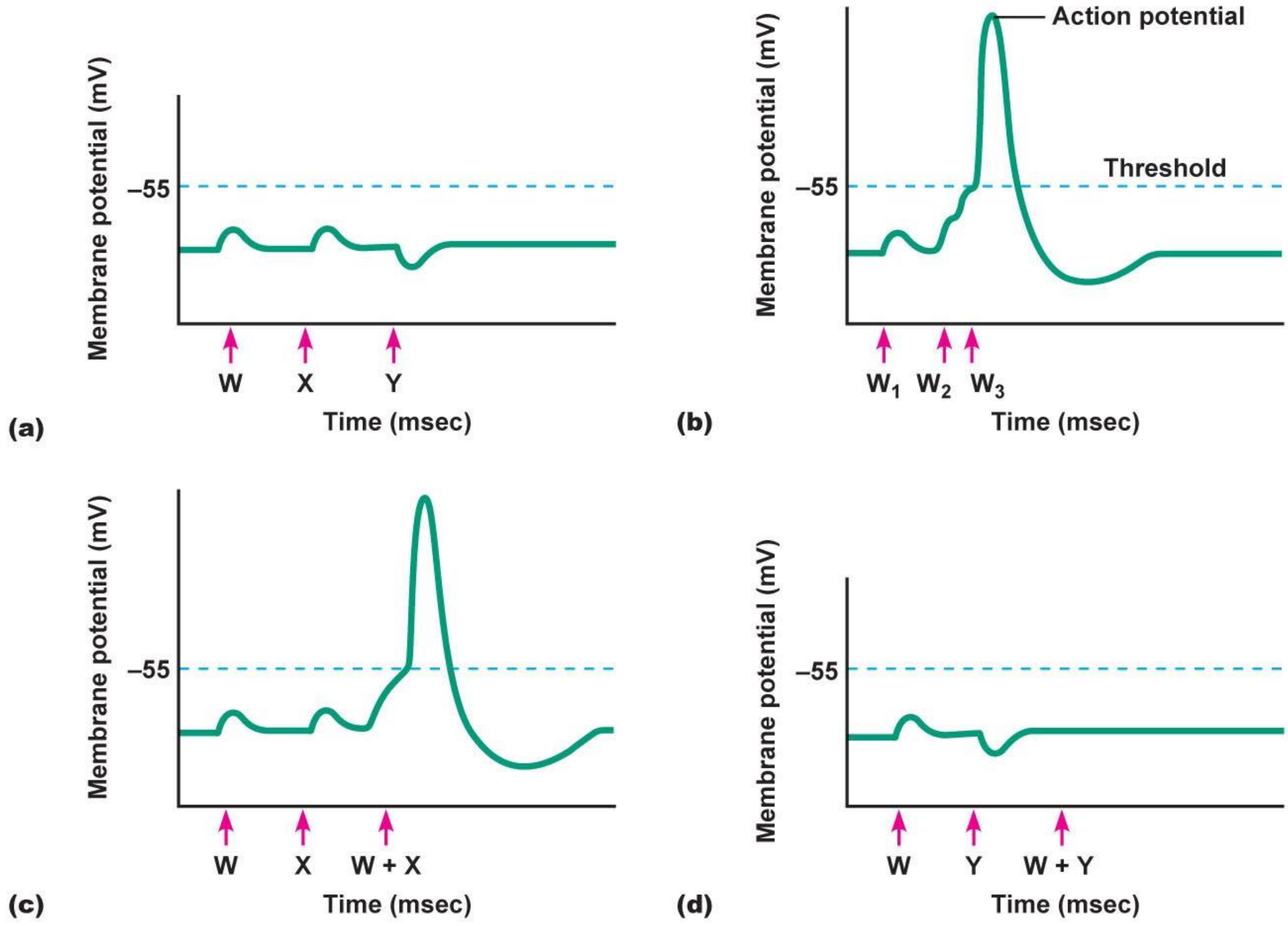



(a) Spatial summation

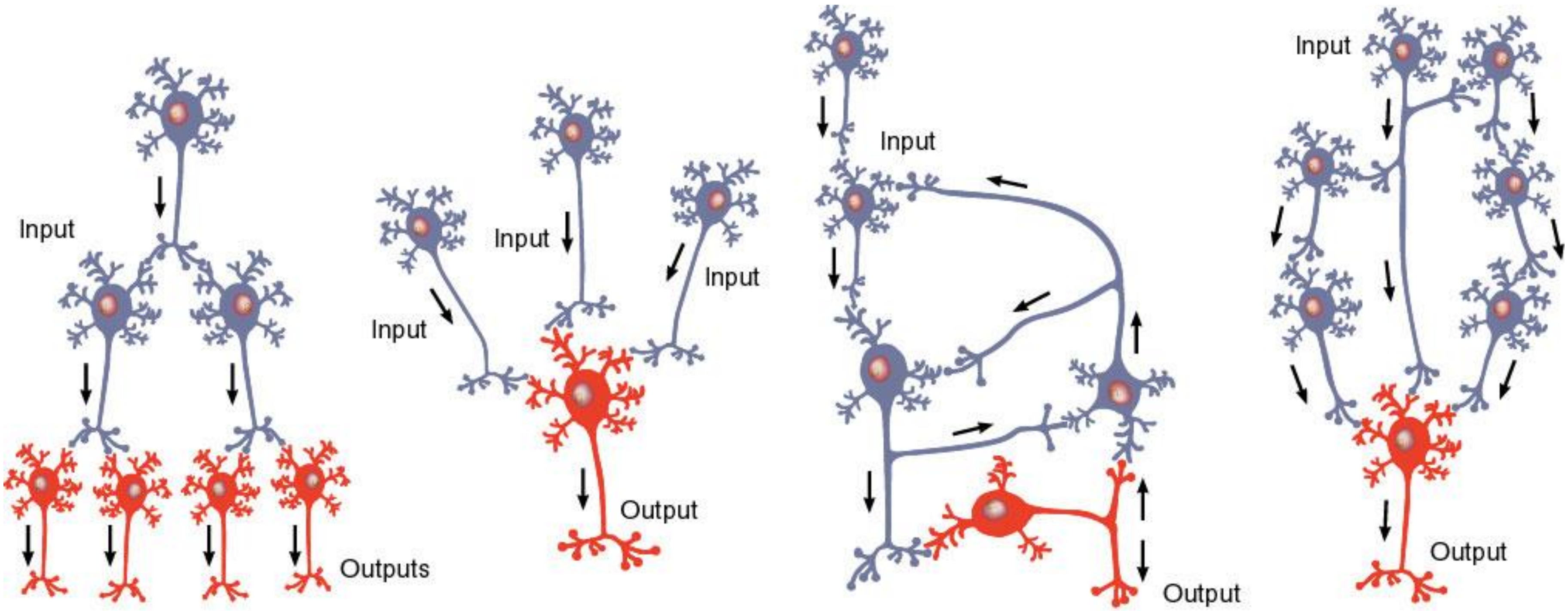



(b) Temporal summation

12.15


Action potential
Threshold
–55
Membrane potential (mV)
Time (msec)
W
X
Y
$W_1$
$W_2$
$W_3$
W + X
W + Y
(a)
(b)
(c)
(d)

# Synaptic organization




(a) Diverging circuit (b) Converging circuit (c) Reverberating circuit (d) Parallel after-discharge circuit

12.16