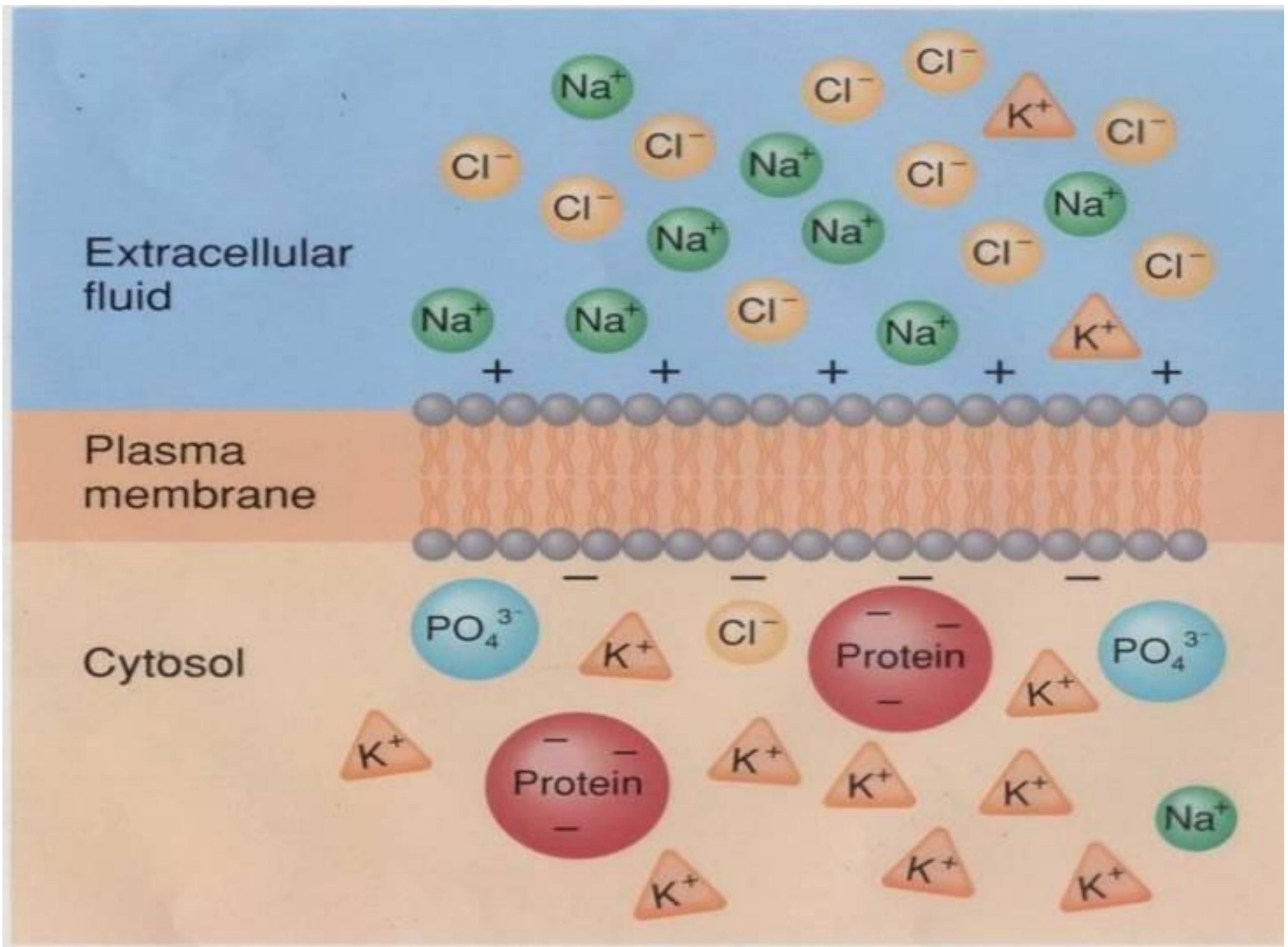
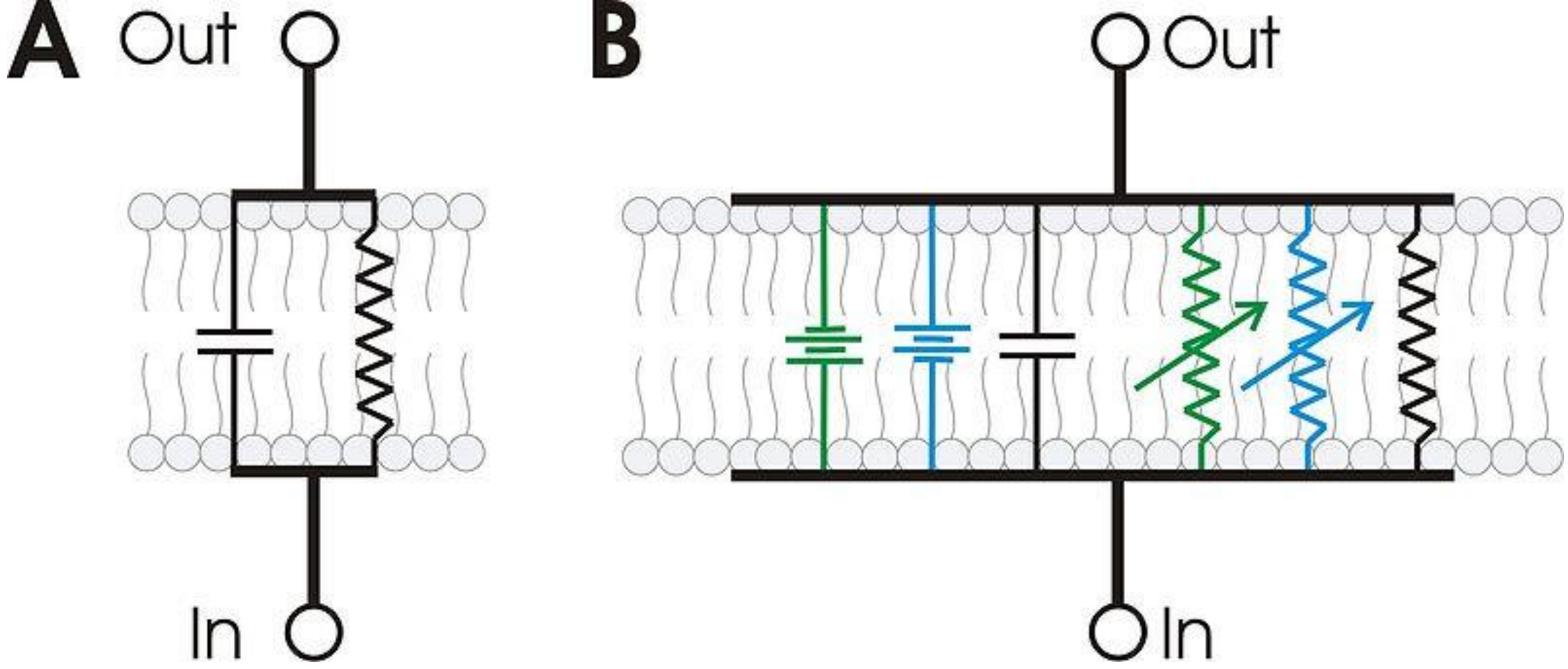
Plasma membrane of Excitable Cells

Plasma Membrane of Excitable tissues

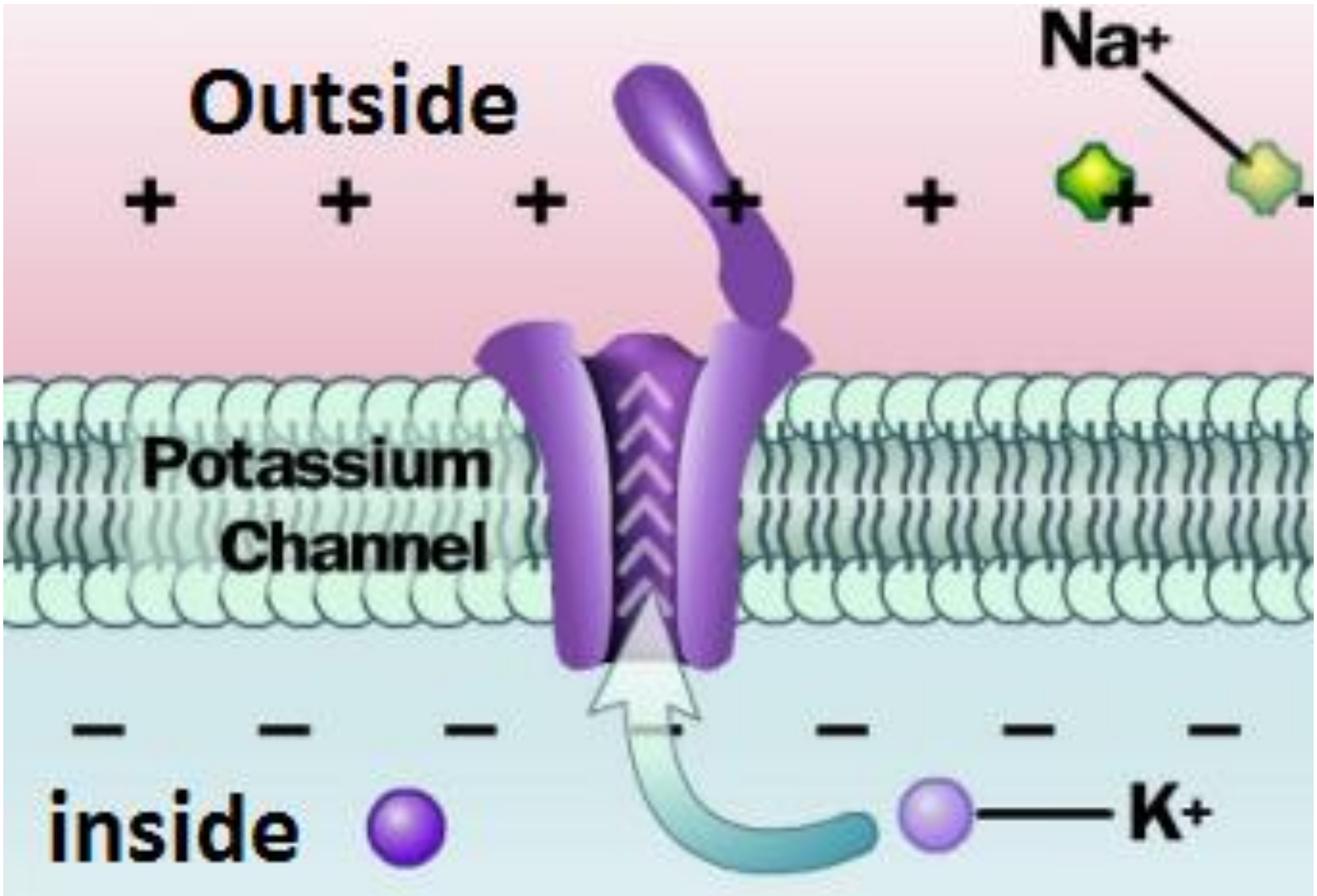
Ref: Guyton, 13th ed: pp: 61-71. 12th ed: pp: 57-69. 11th ed: **p57-71**,

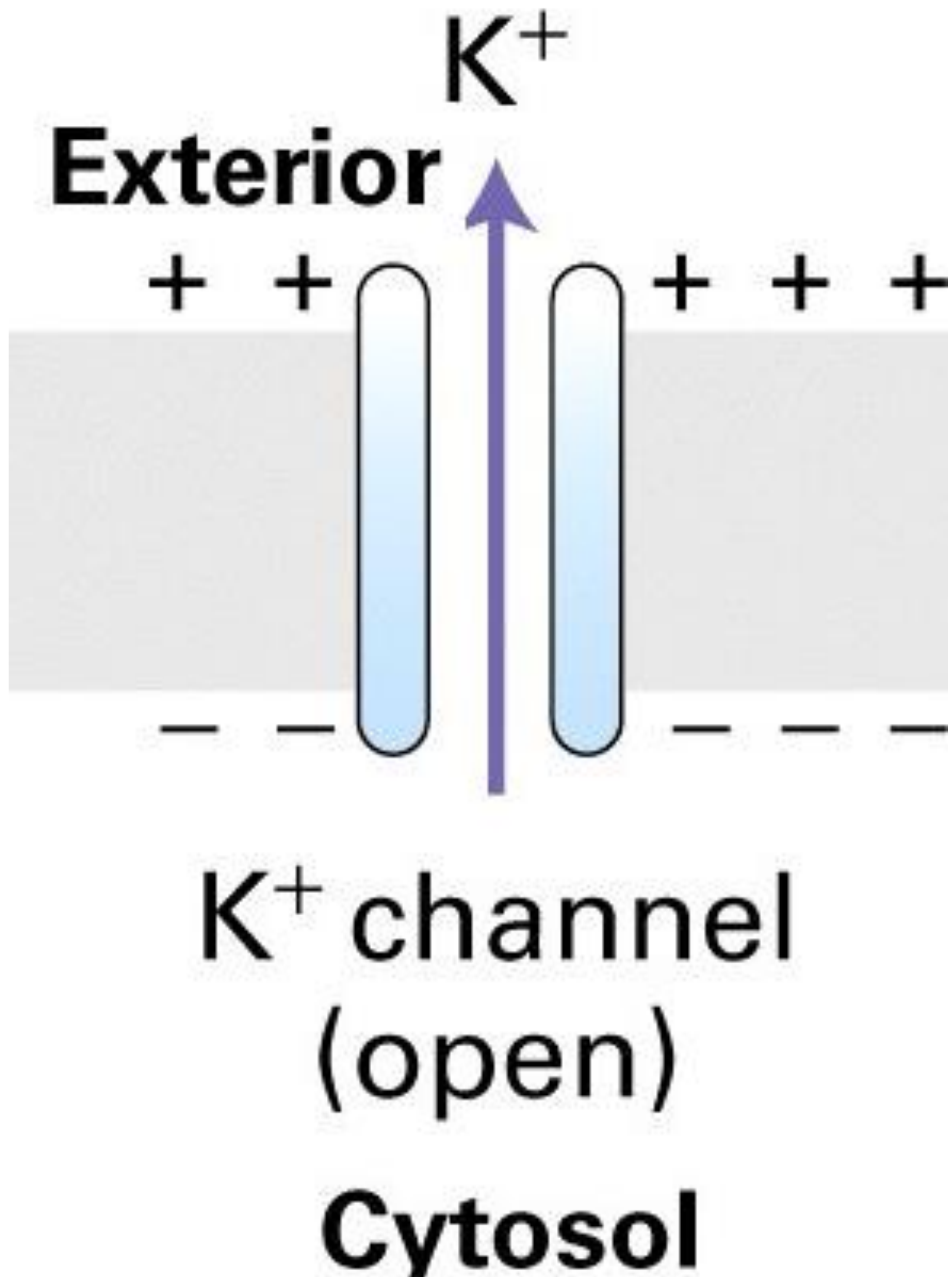

Extracellular fluid
Plasma membrane
Cytosol
Na+
Cl−
K+
PO4 3−
Protein
+
−

Electrical properties of plasma membranes

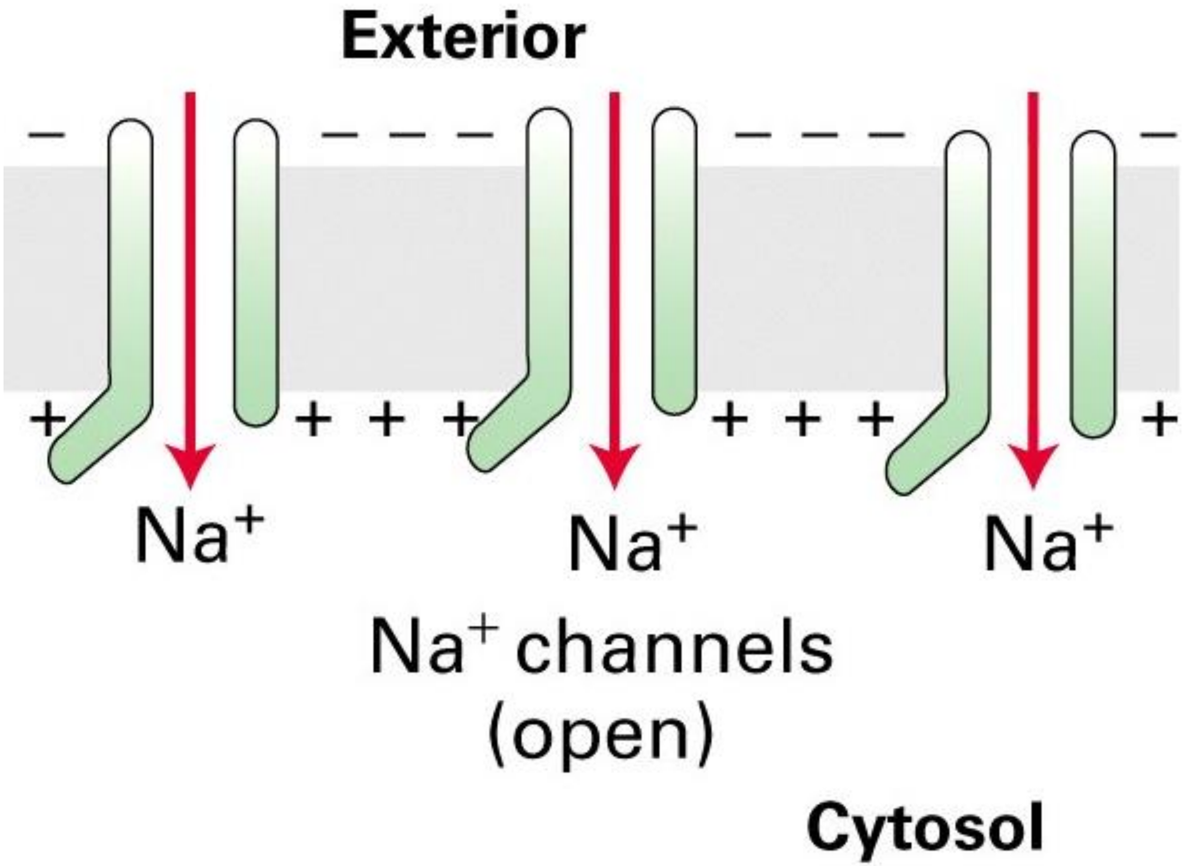


- **Part A:** A basic en:RC circuit, superimposed on an image of a membrane bilayer to show the relationship between the two. **Part B:** A more elaborate en:RC circuit, superimposed on an image of a membrane bilayer. This RC circuit represents the electrical characteristics of a minimal patch of membrane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


Outside
Na+
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) = 9.6485309×10^4 (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+}

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

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

E = Equilibrium potential for a univalent ion

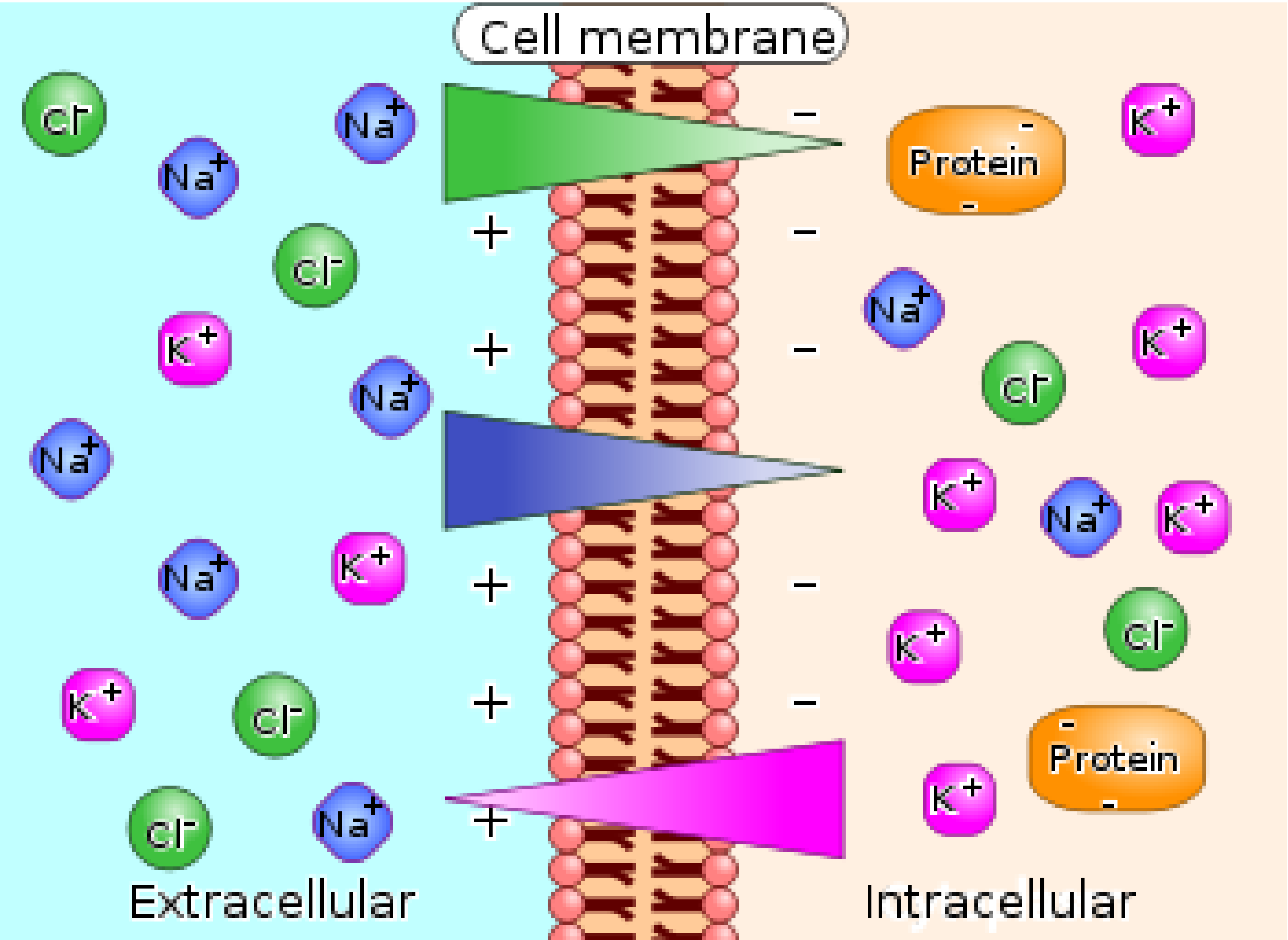
Ci = conc. inside the cell.

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



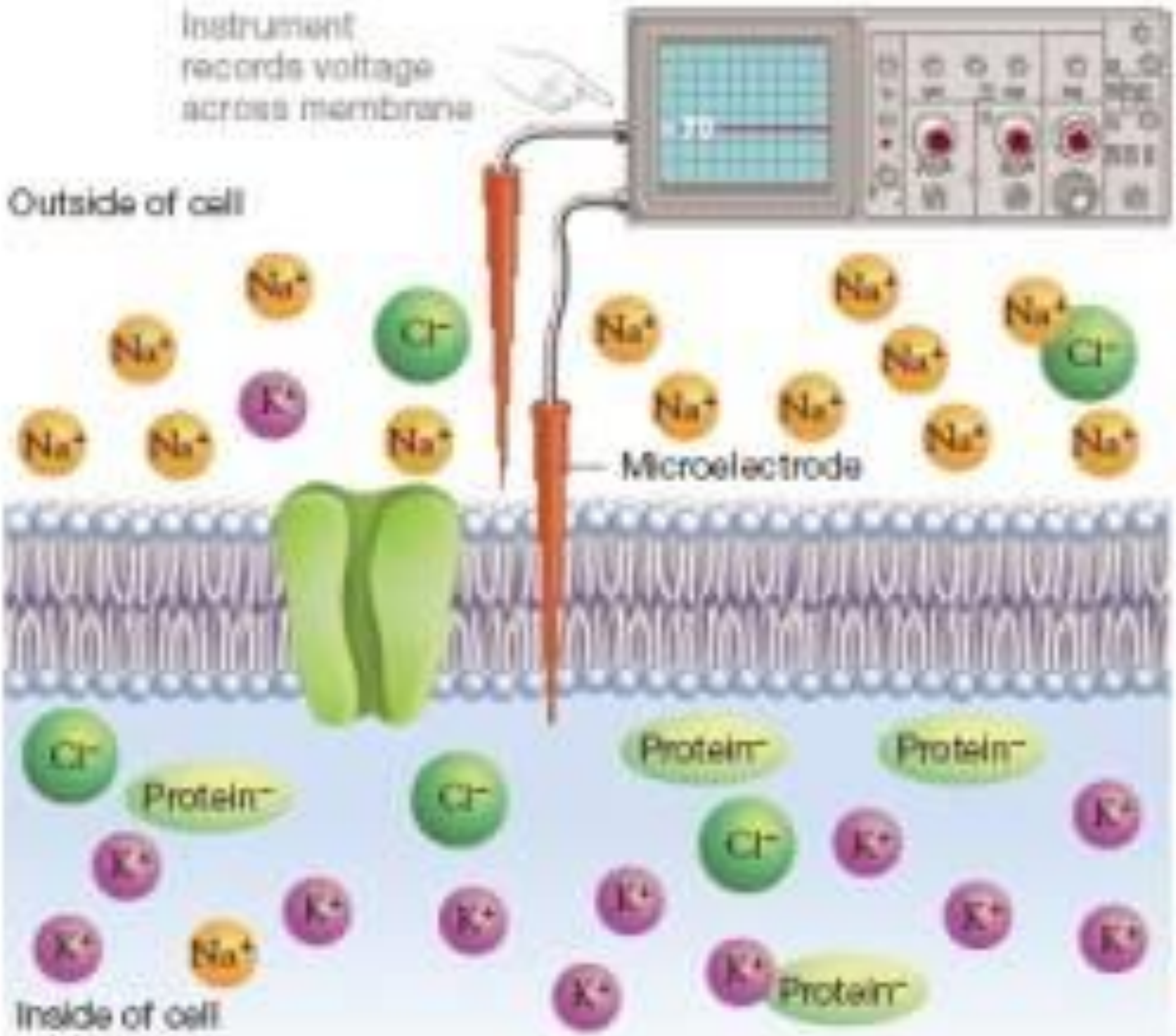
Goldman Hodgkin Katz equation

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

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

Resting membrane potential

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

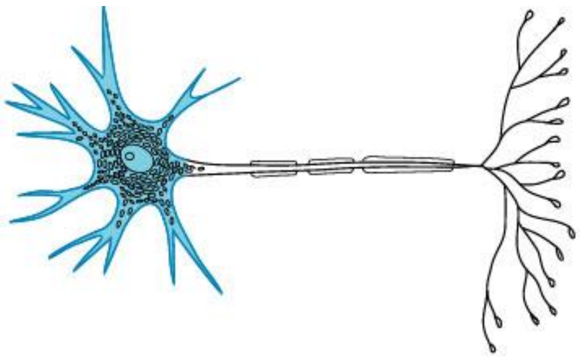
Conductance of plasma membrane (Ohm's Law)

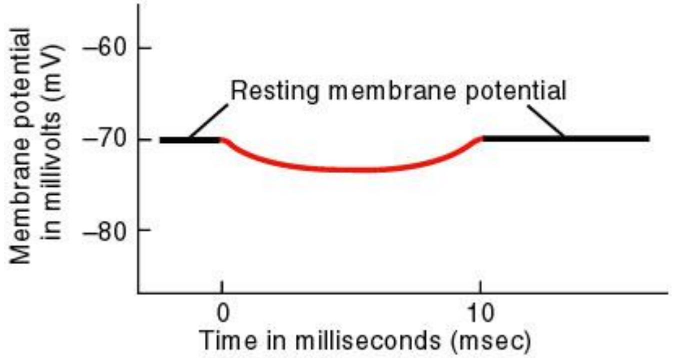
- $I = \Delta V/R$
- G (conductance)= 1/R
- $I = G. \Delta V$

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

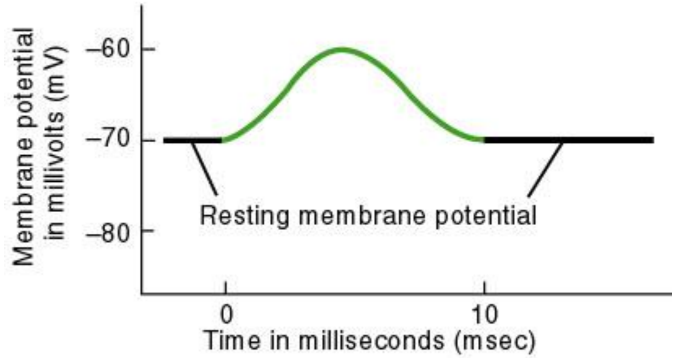
$$V_m = \frac{g_K}{g_{tot}} E_K + \frac{g_{Na}}{g_{tot}} E_{Na} + \frac{g_{Cl}}{g_{tot}} E_{Cl}$$

- Changes in Resting membrane potential



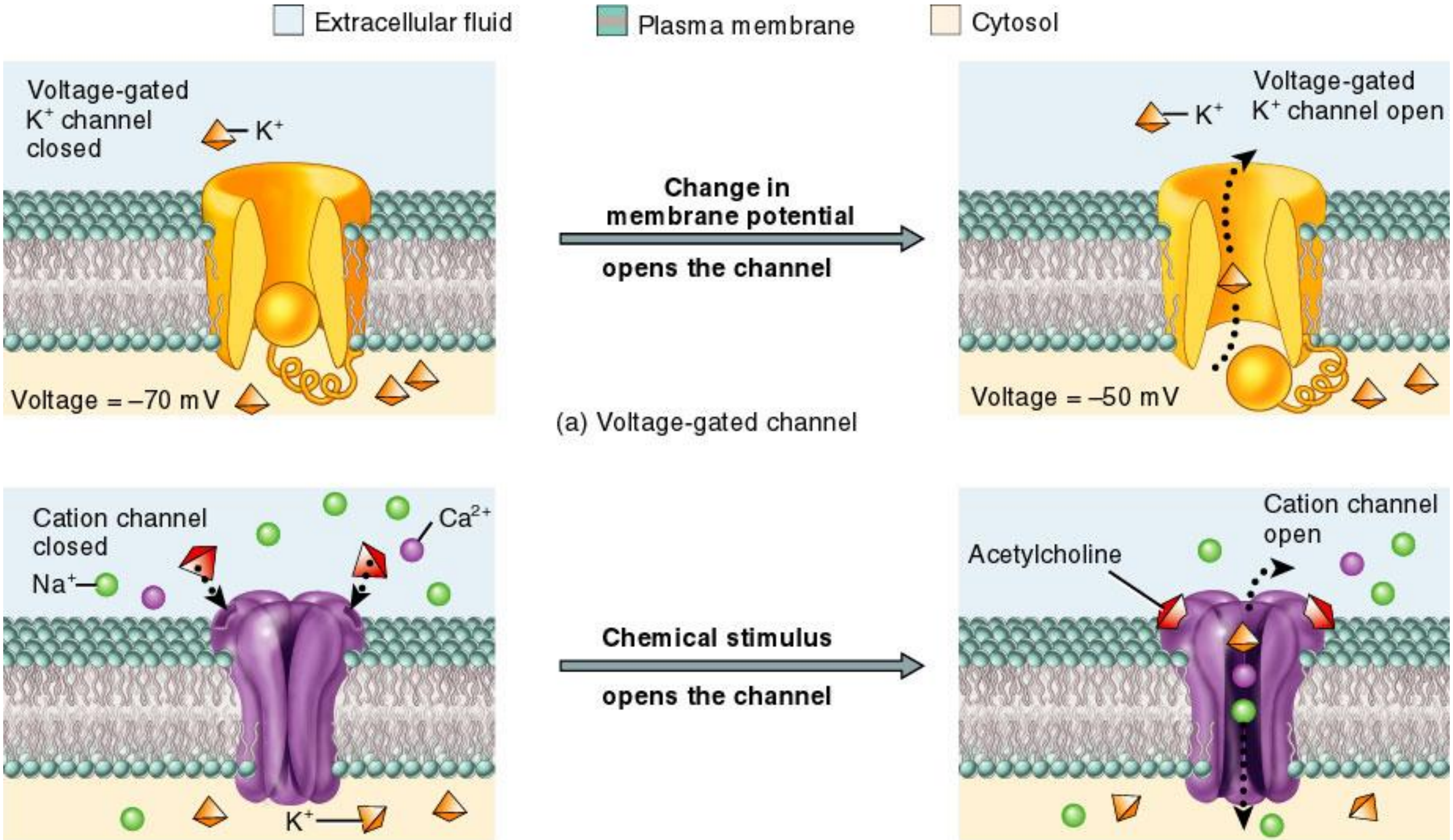


(a) Hyperpolarizing graded potential



(b) Depolarizing graded potential

12.10

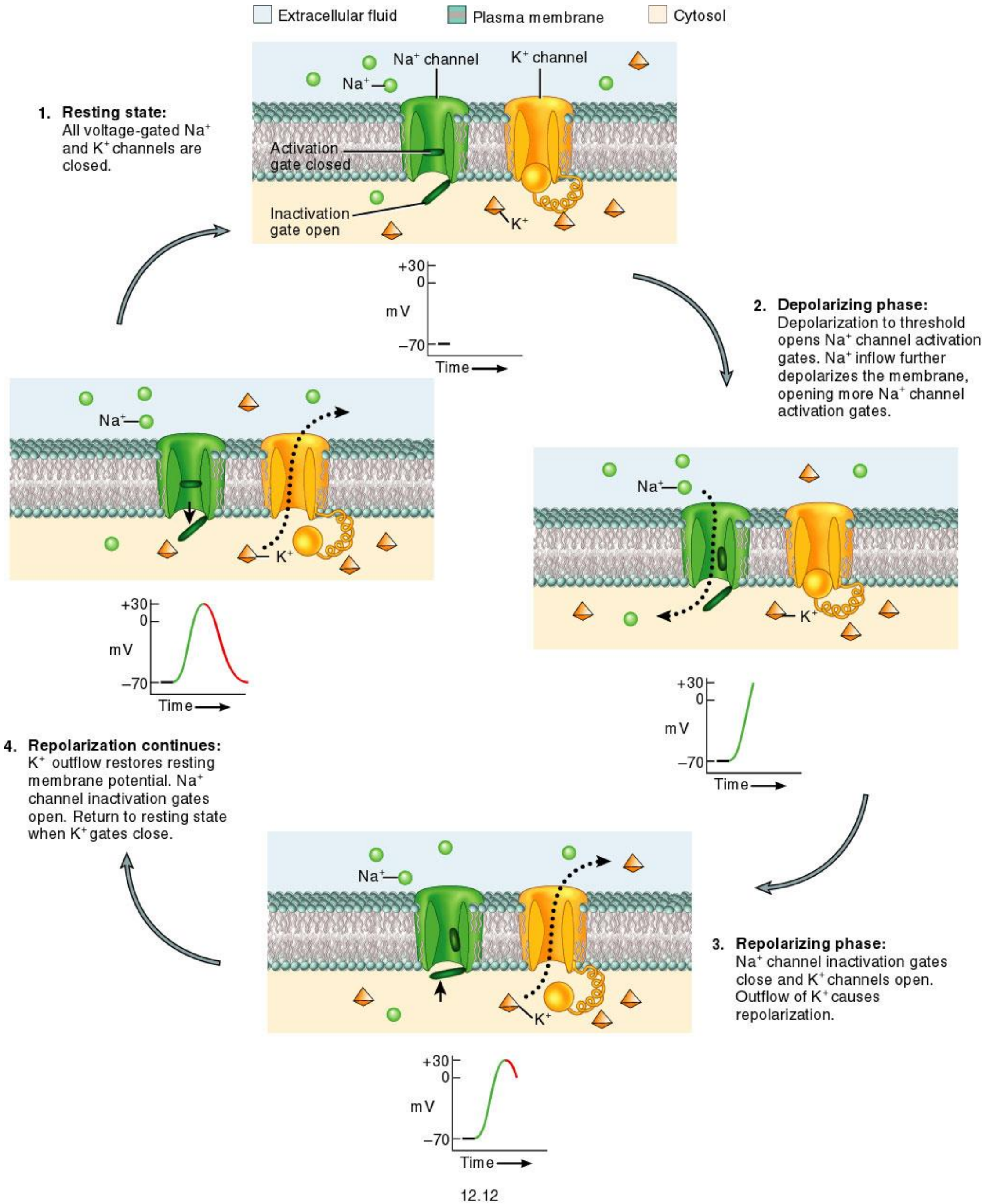


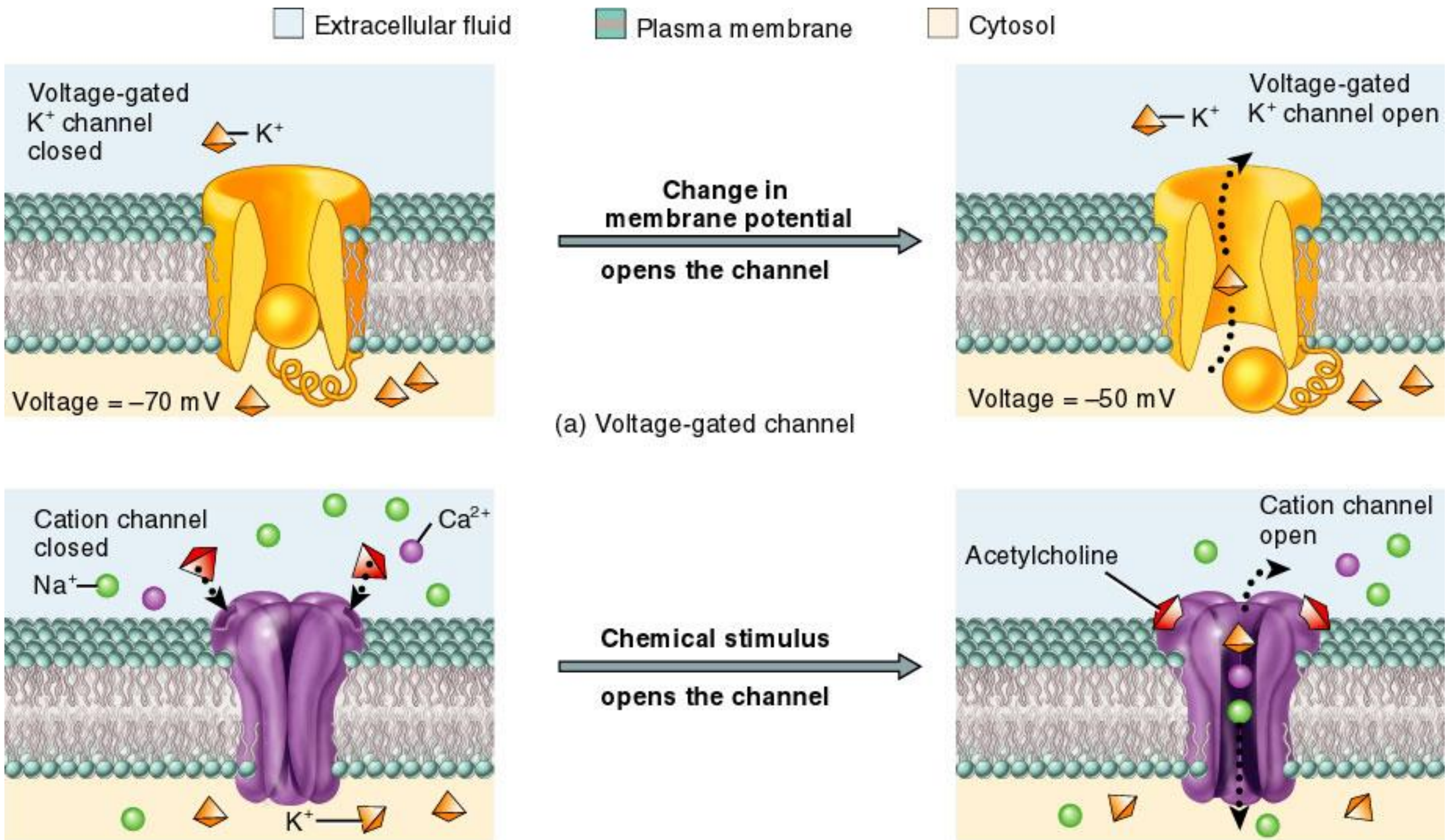
(a) Voltage-gated channel

(b) Ligand-gated channel

12.08

- Changes in Channels activity results in action potential



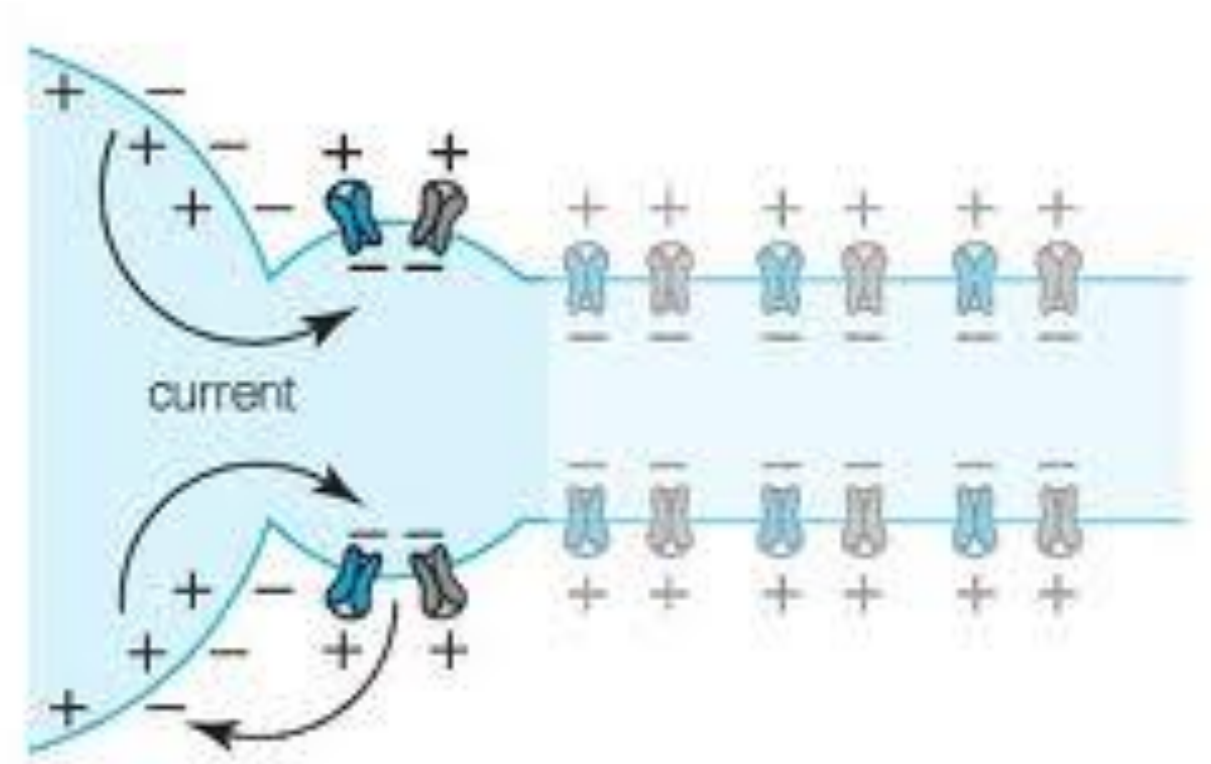


(a) Voltage-gated channel

(b) Ligand-gated channel

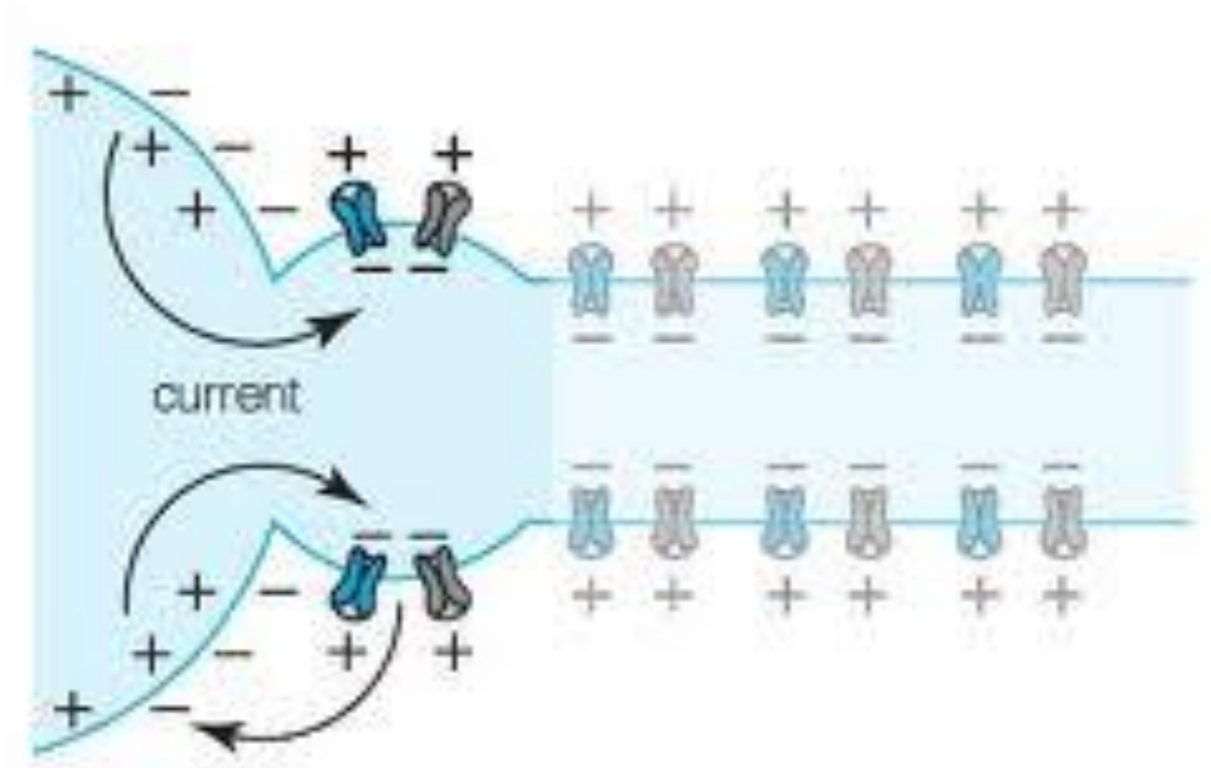
12.08

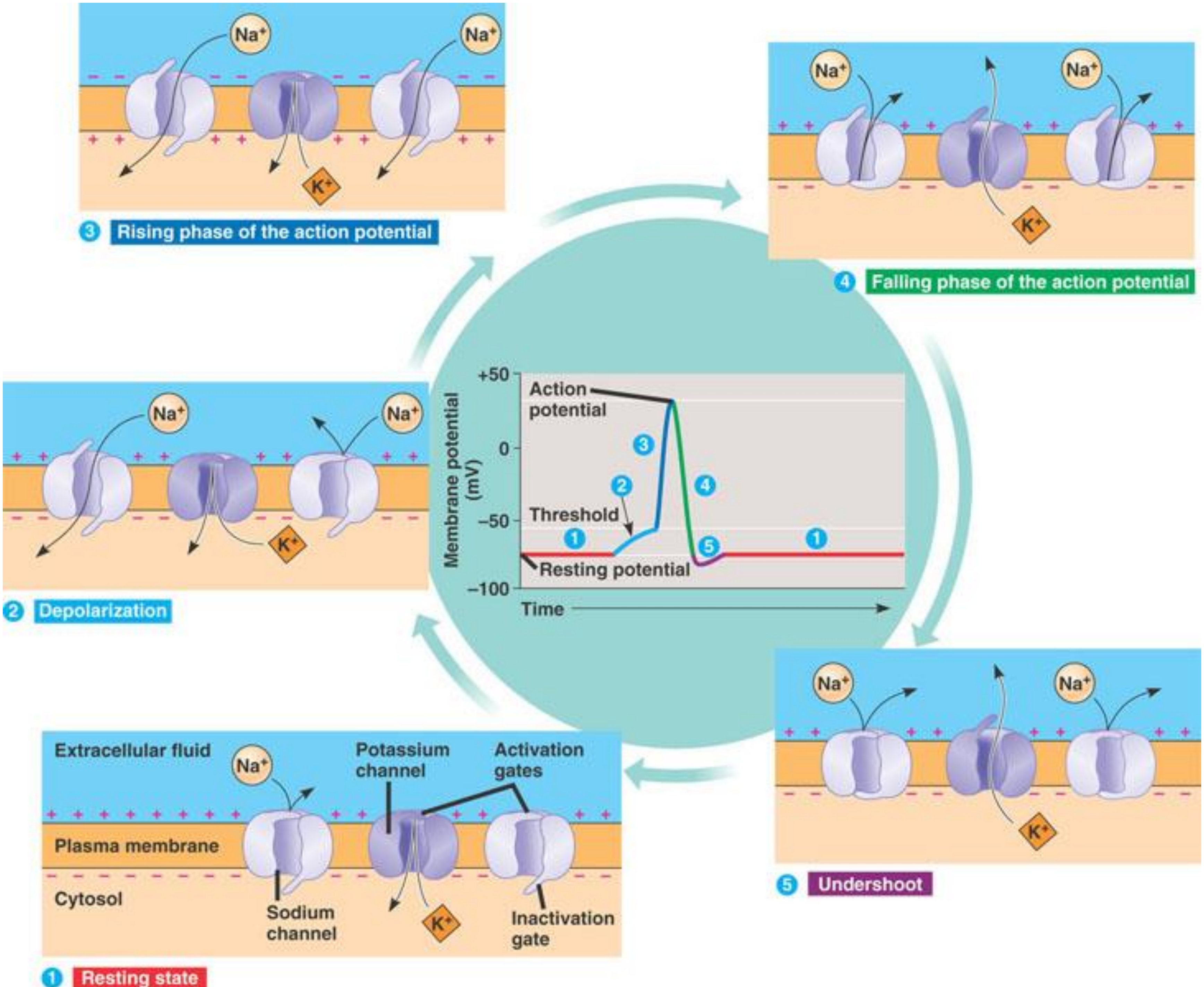
Ionic currents cause depolarization



Resistance to Ionic currents and activation of channels

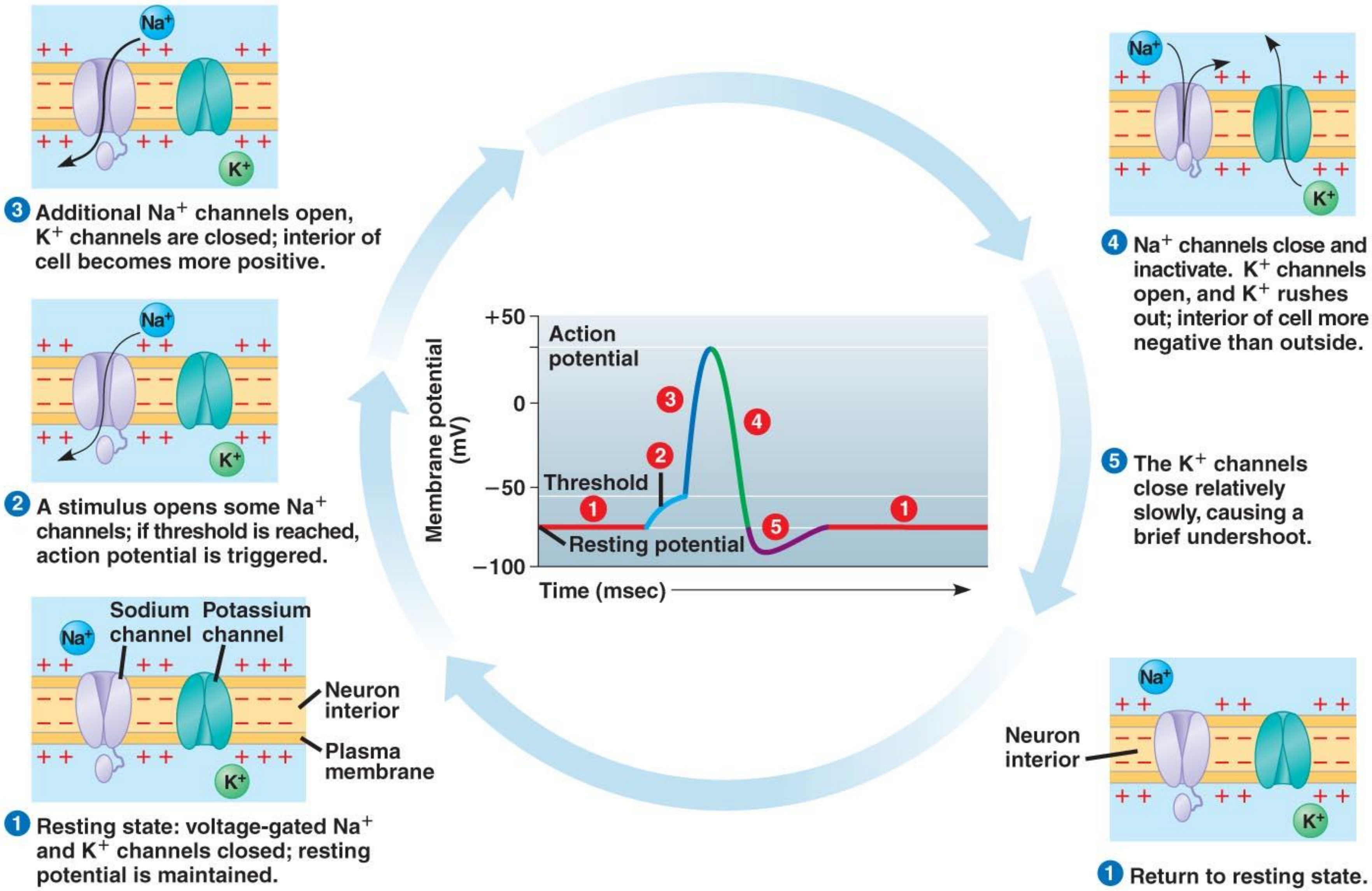
Action potentials

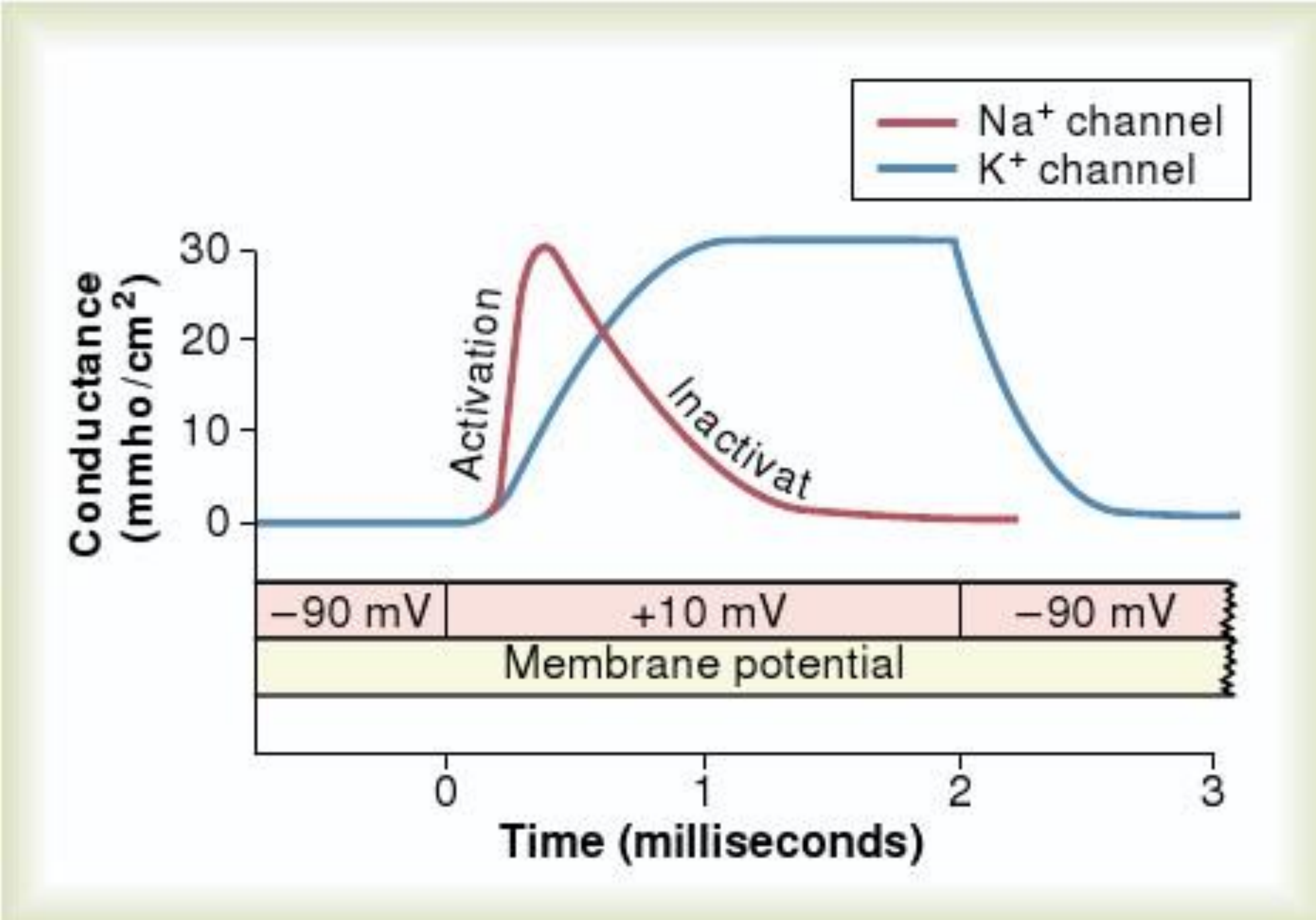




Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
Membrane potential (mV)
+50
0
−50
−100
Action potential
Threshold
Resting potential
Time
1
2
3
4
5
2 Depolarization
5 Undershoot
Extracellular fluid
Potassium channel
Activation gates
Plasma membrane
Cytosol
Sodium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

Generation of action potentials

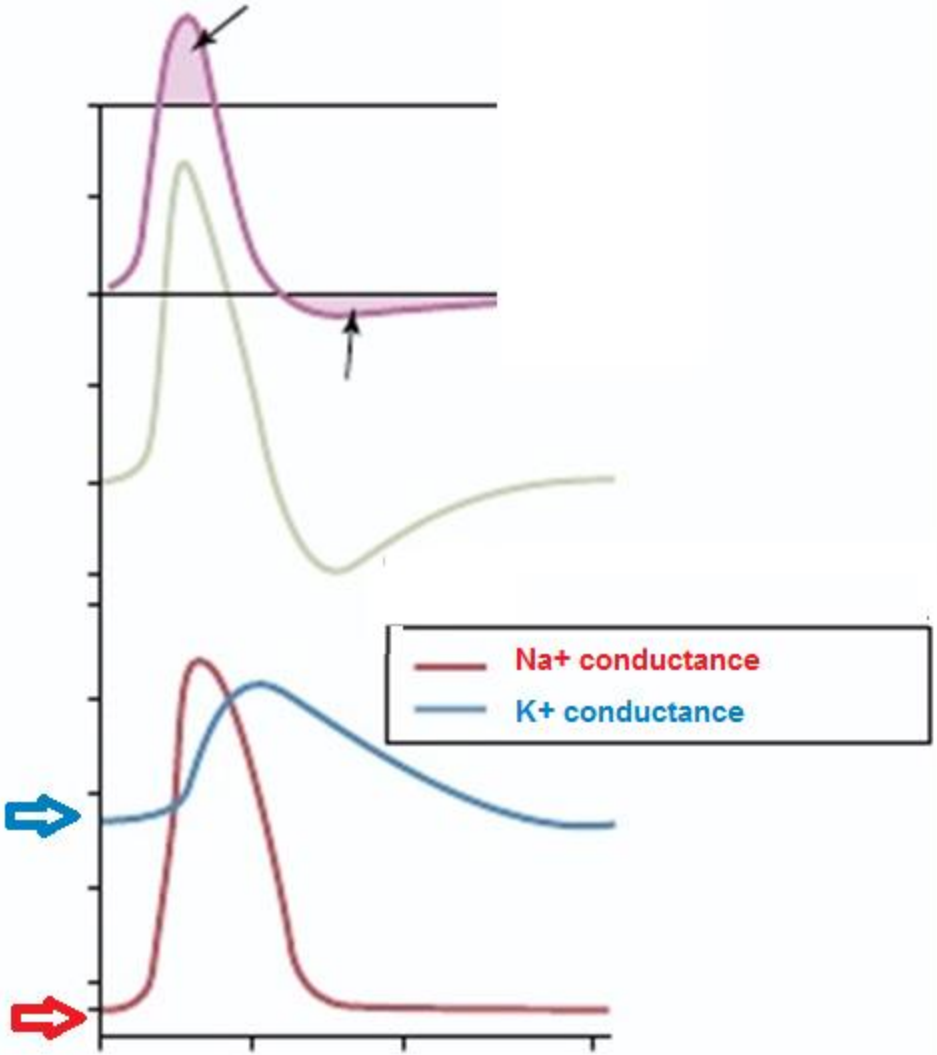




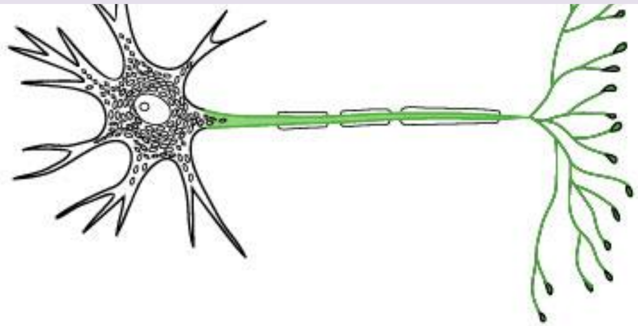
Na+ channel
K+ channel
Conductance (mmho/cm2)
30
20
10
0
Activation
Inactivat
−90 mV
+10 mV
−90 mV
Membrane potential
0
1
2
3
Time (milliseconds)

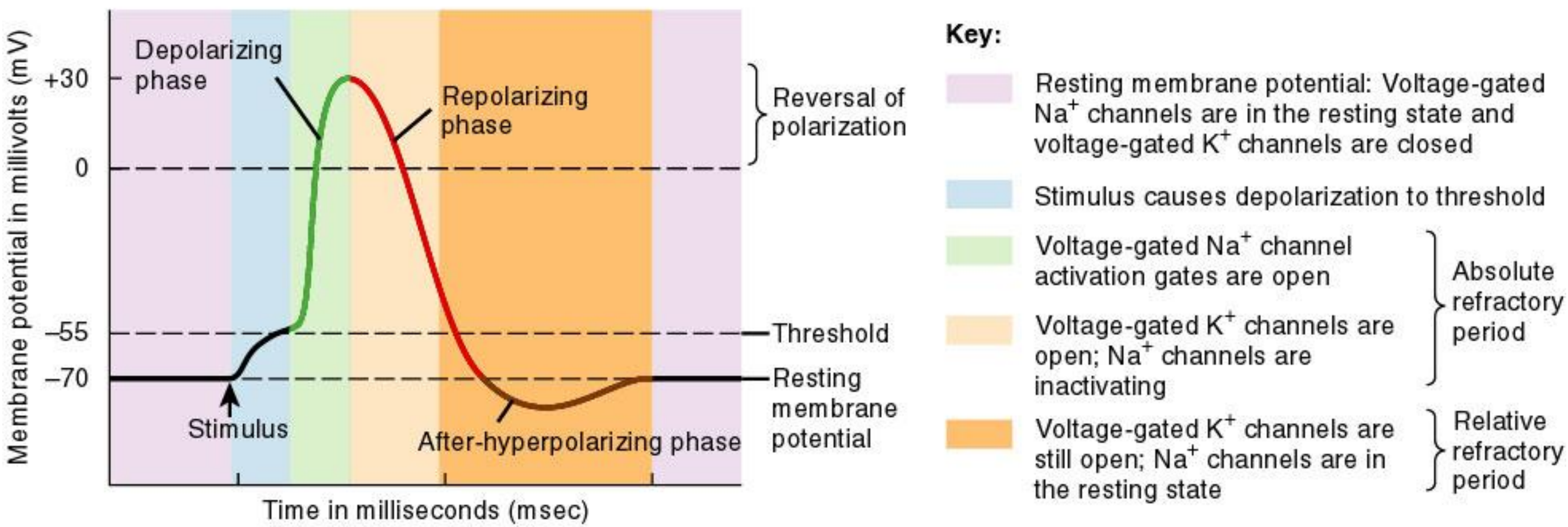
Figure 5–9

- Na+ and K+ conductance at resting potentials



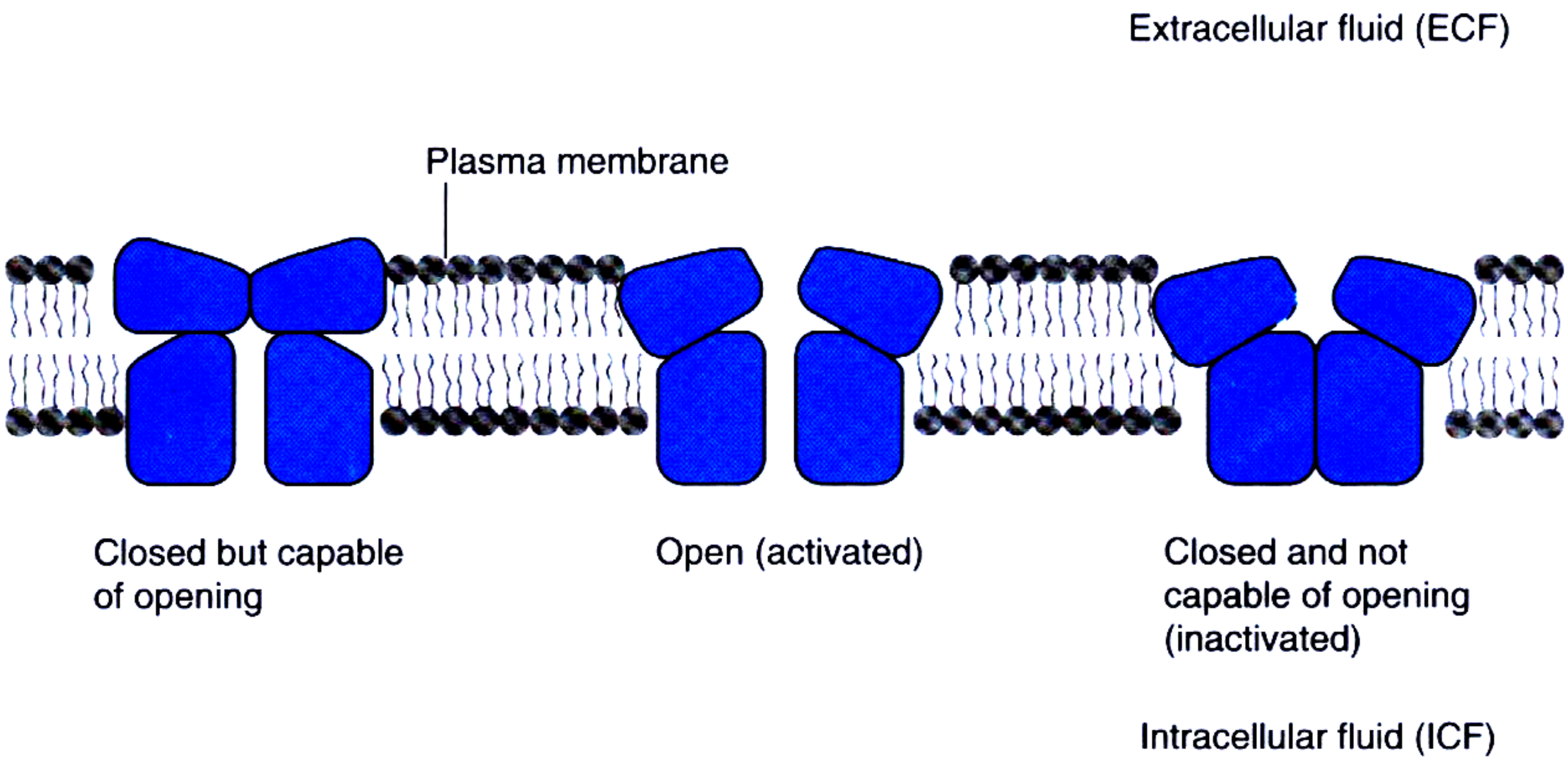
Refractory periods



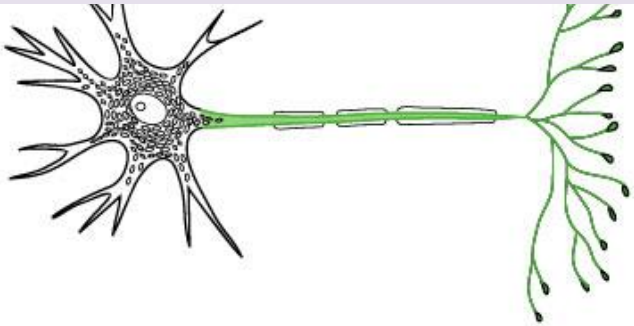


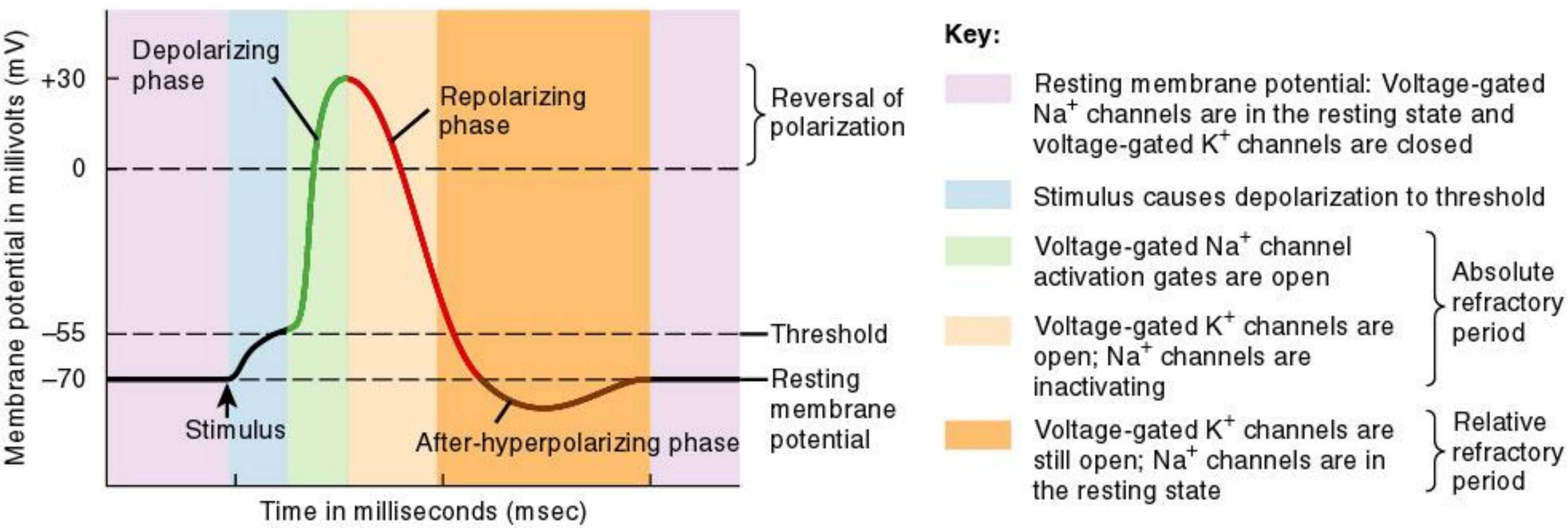
12.11

Refractory periods and Na+ Channels



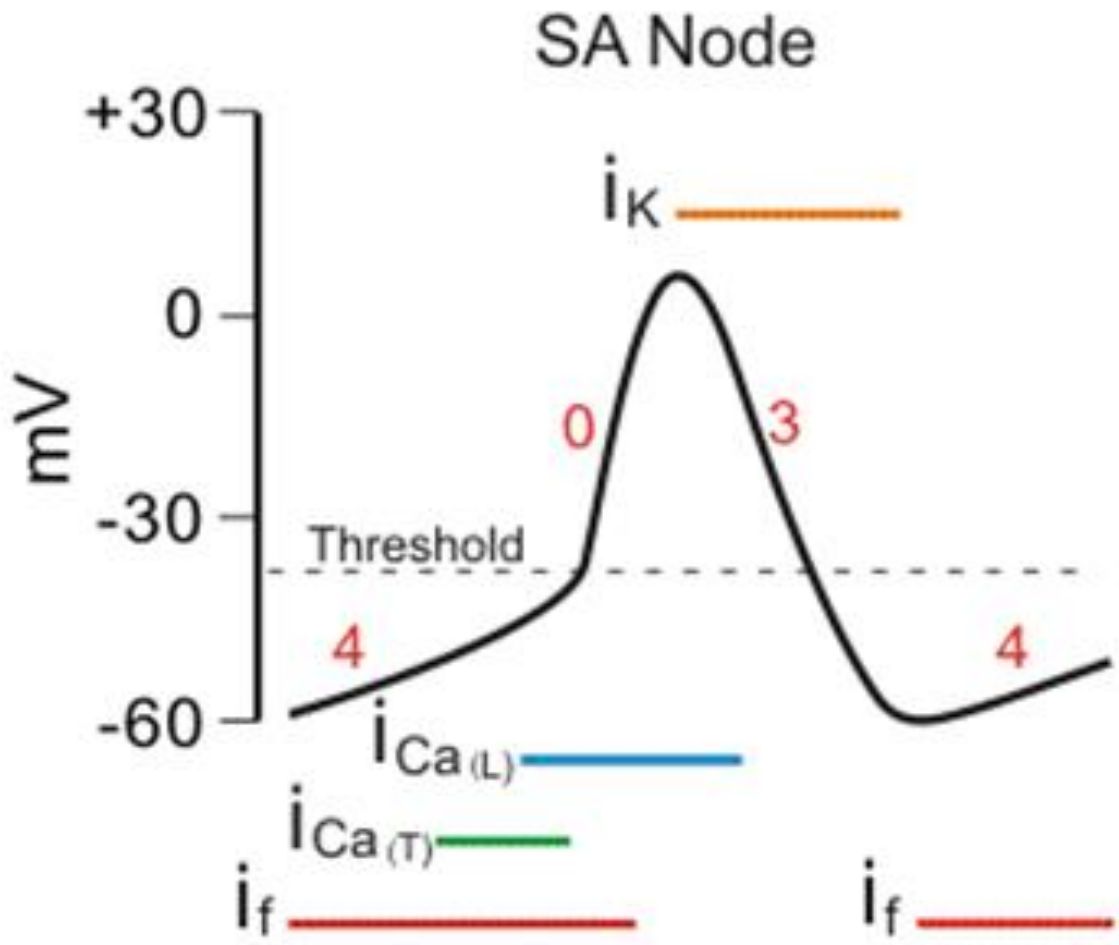
Refractory periods





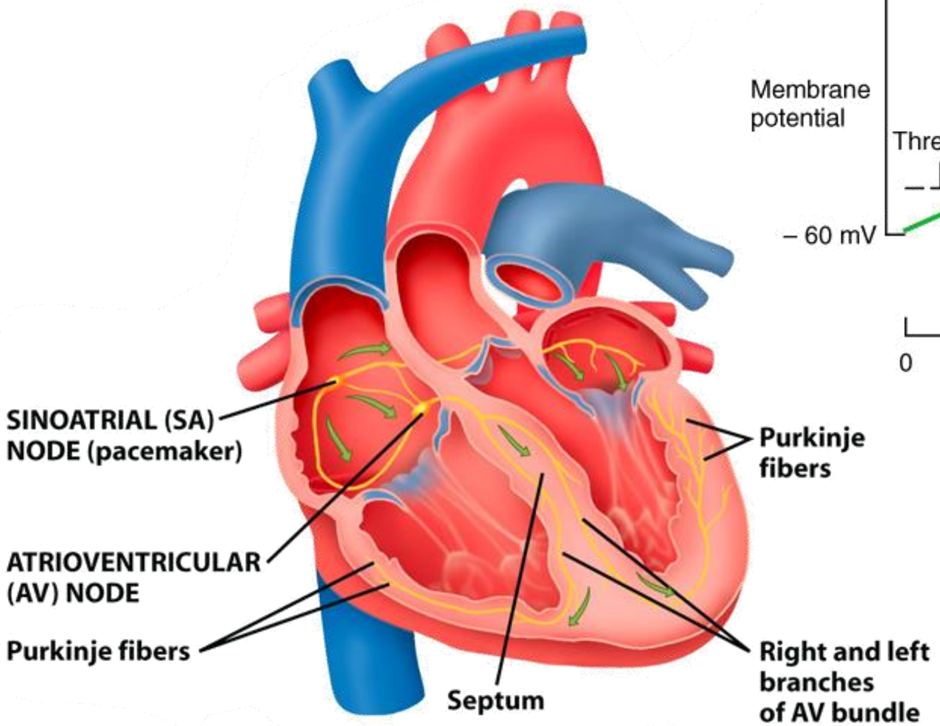
12.11

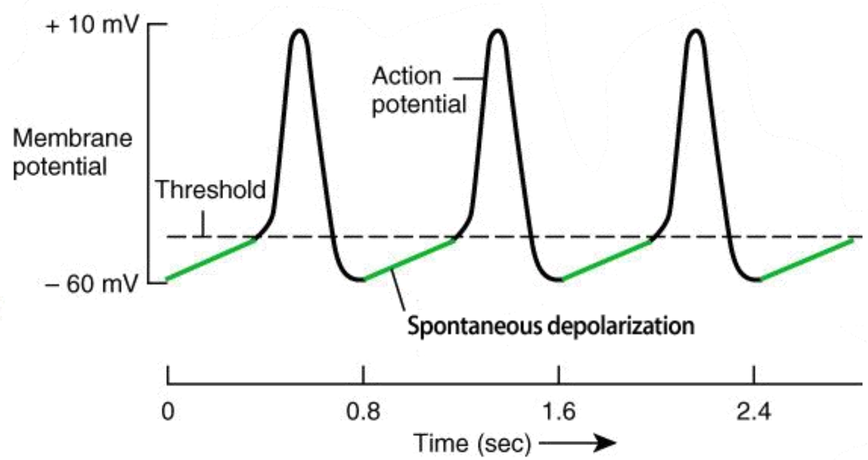
Involvement of other Ions in Action potential



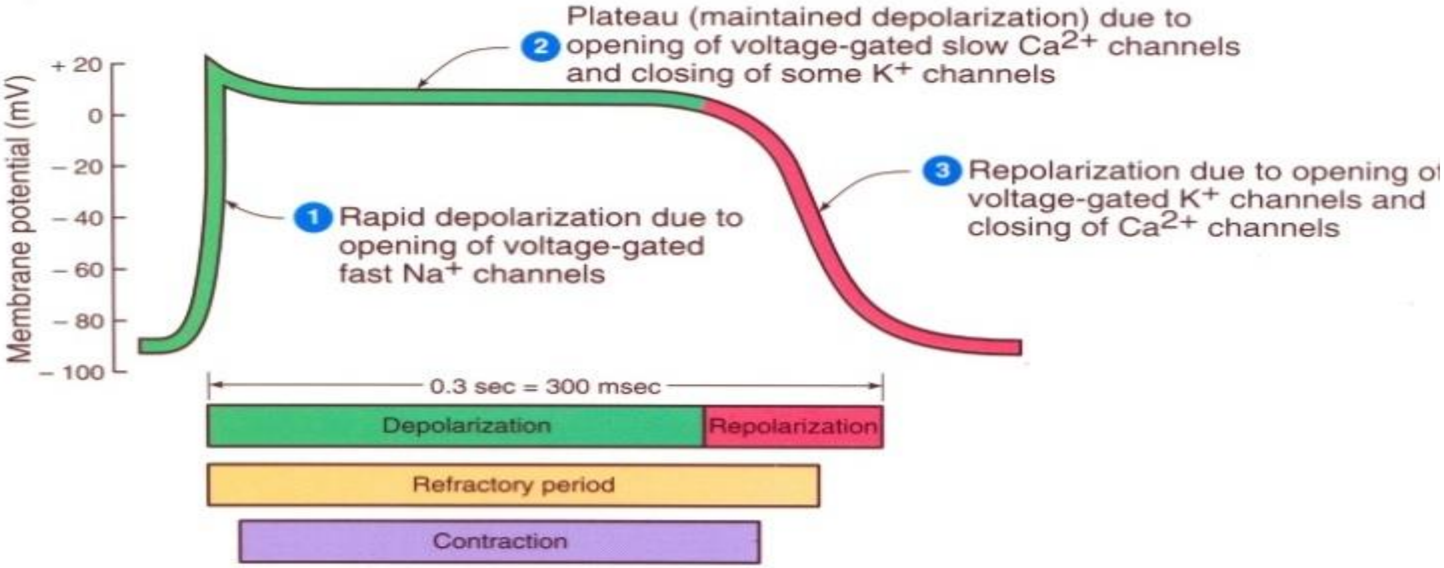
SA Node
+30
0
-30
-60
mV
i_K
0
3
Threshold
4
4
$i_{Ca(L)}$
$i_{Ca(T)}$
i_f
i_f

Cardiac Conduction

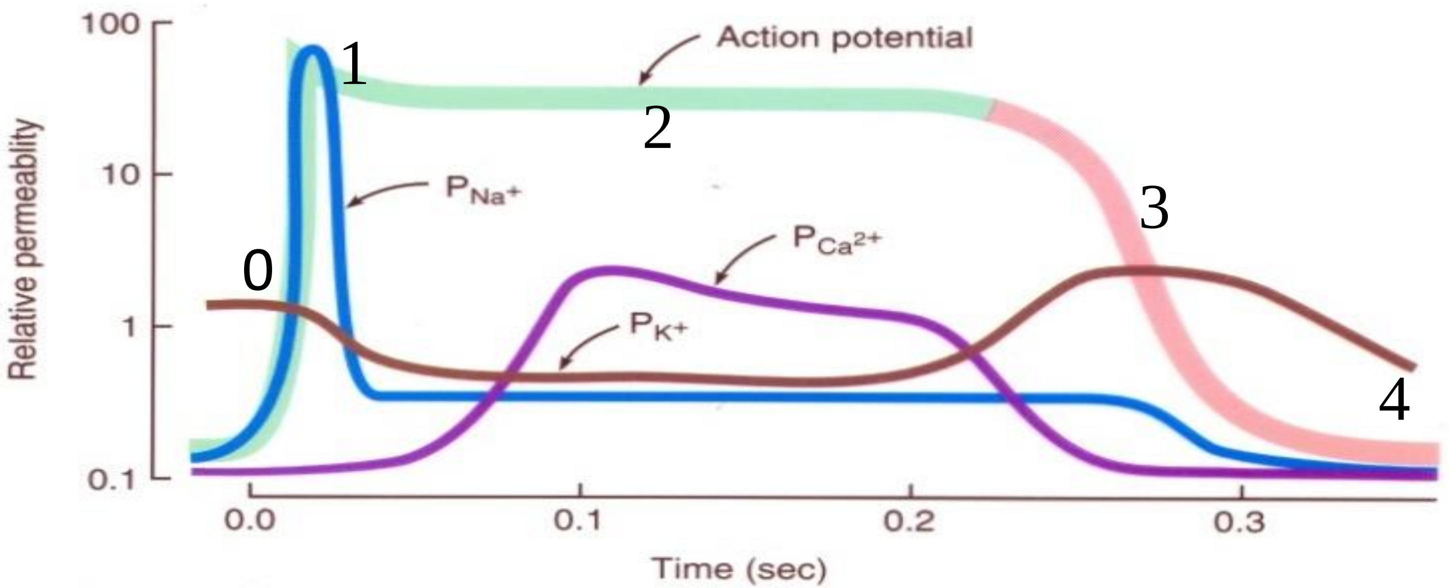




Generation of Action potential every 0.8 seconds, or 75 action potentials per minute at the SA node (Pacemaker of the heart)

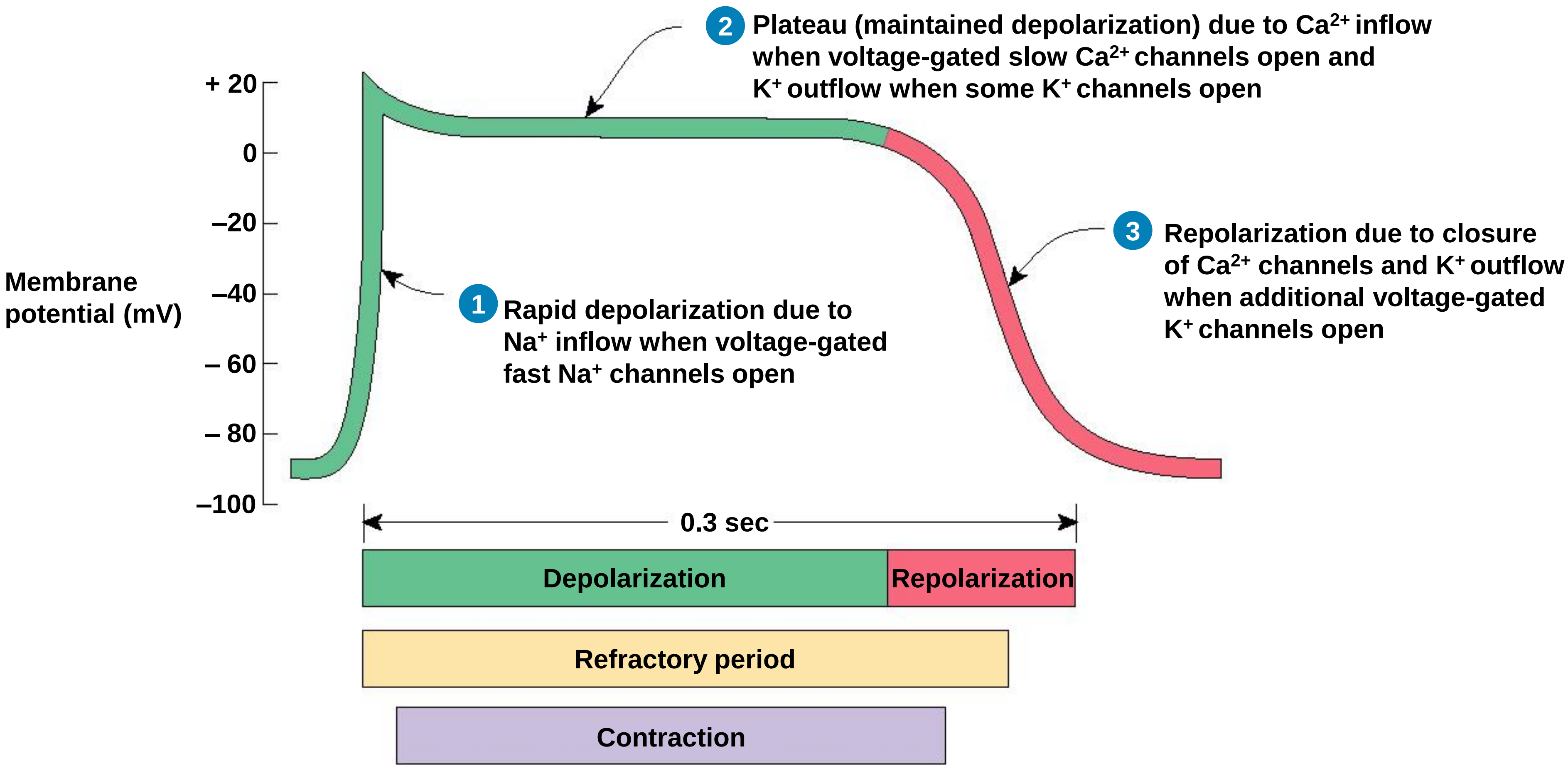


(a) Action potential, refractory period, and contraction

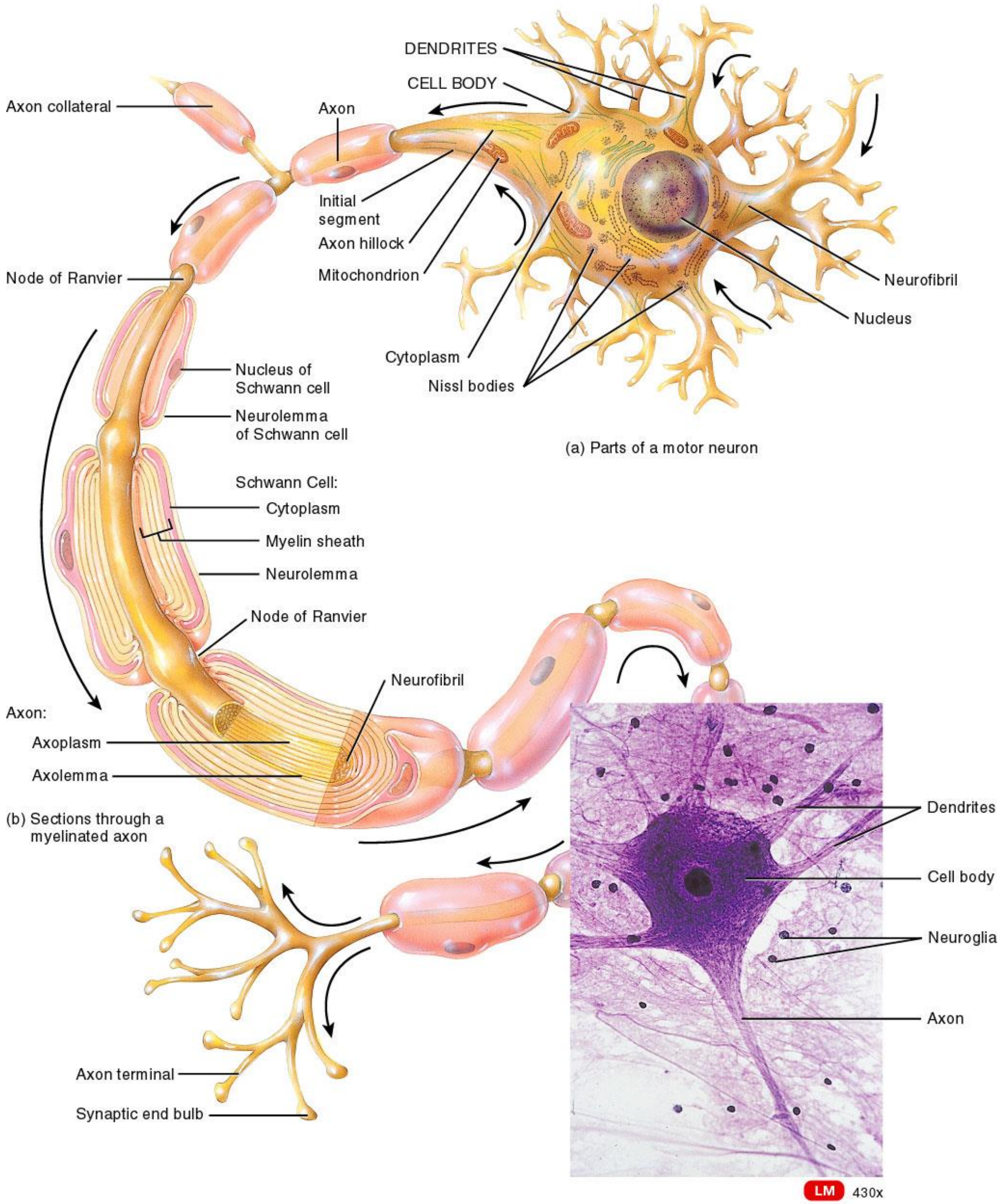


(b) Membrane permeability (P) changes

Cardiac Muscle Action Potential



Generation of action potential at Neural cells

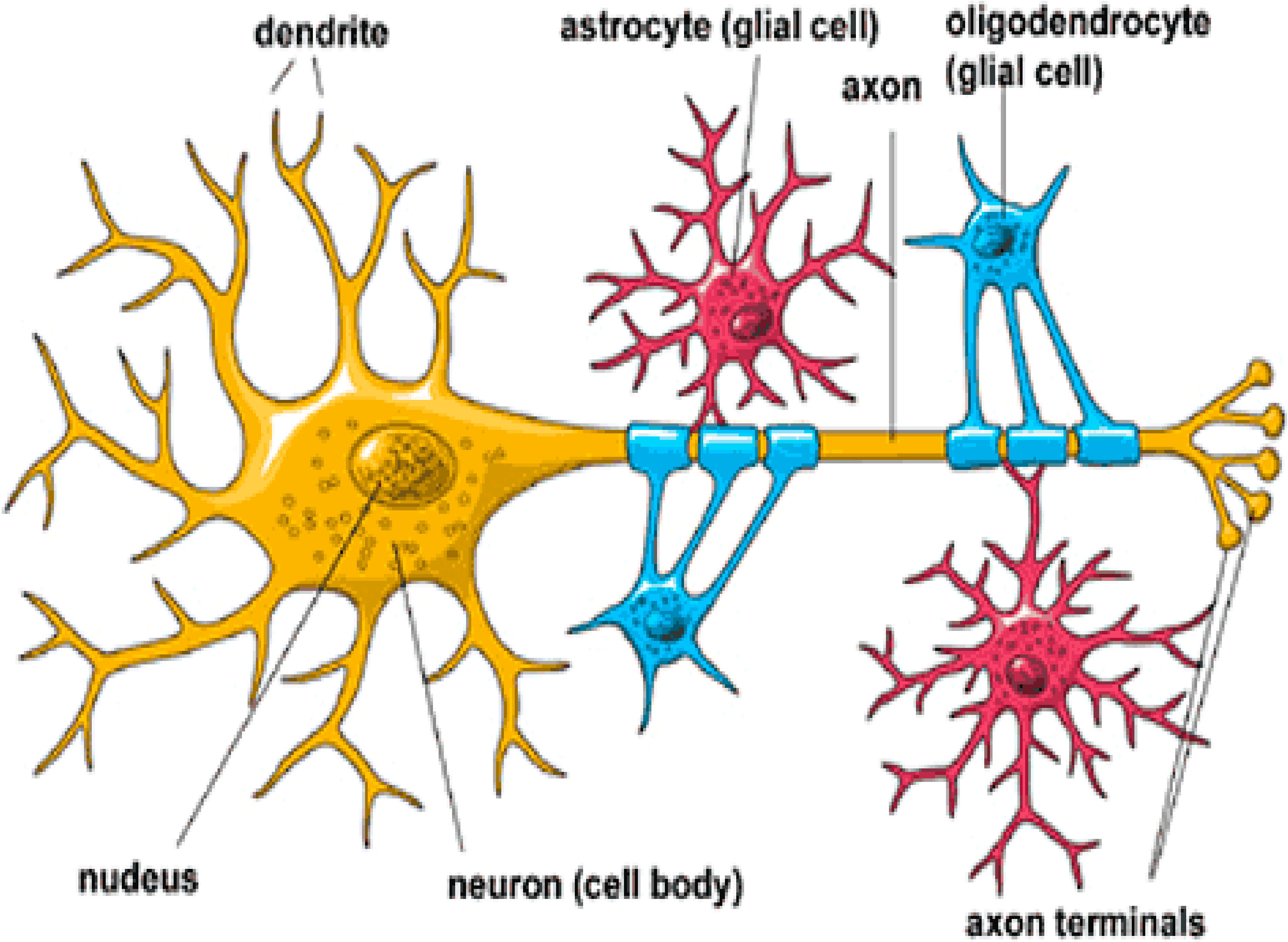


(a) Parts of a motor neuron

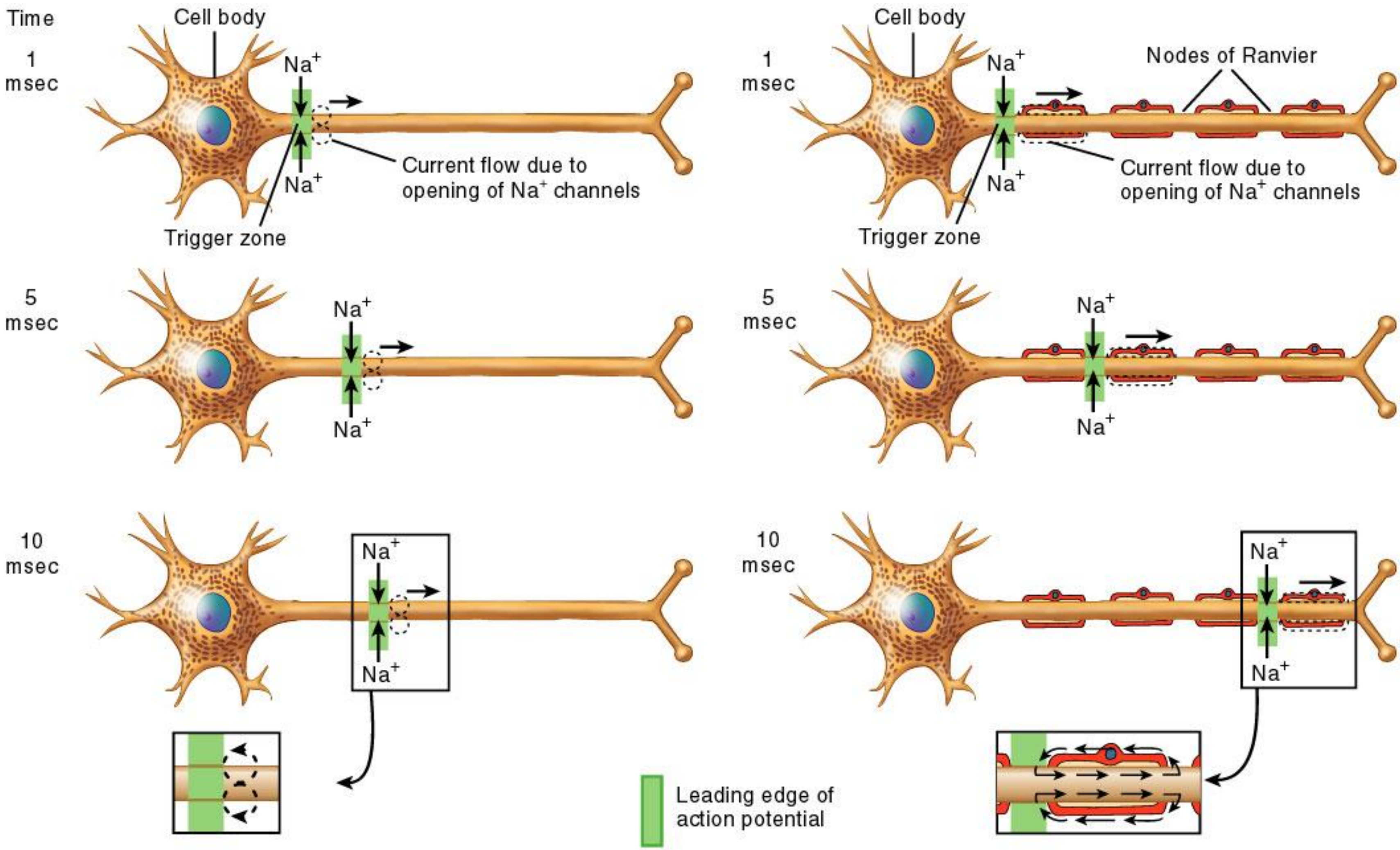
(b) Sections through a myelinated axon

(c) Motor neuron

Supportive cells

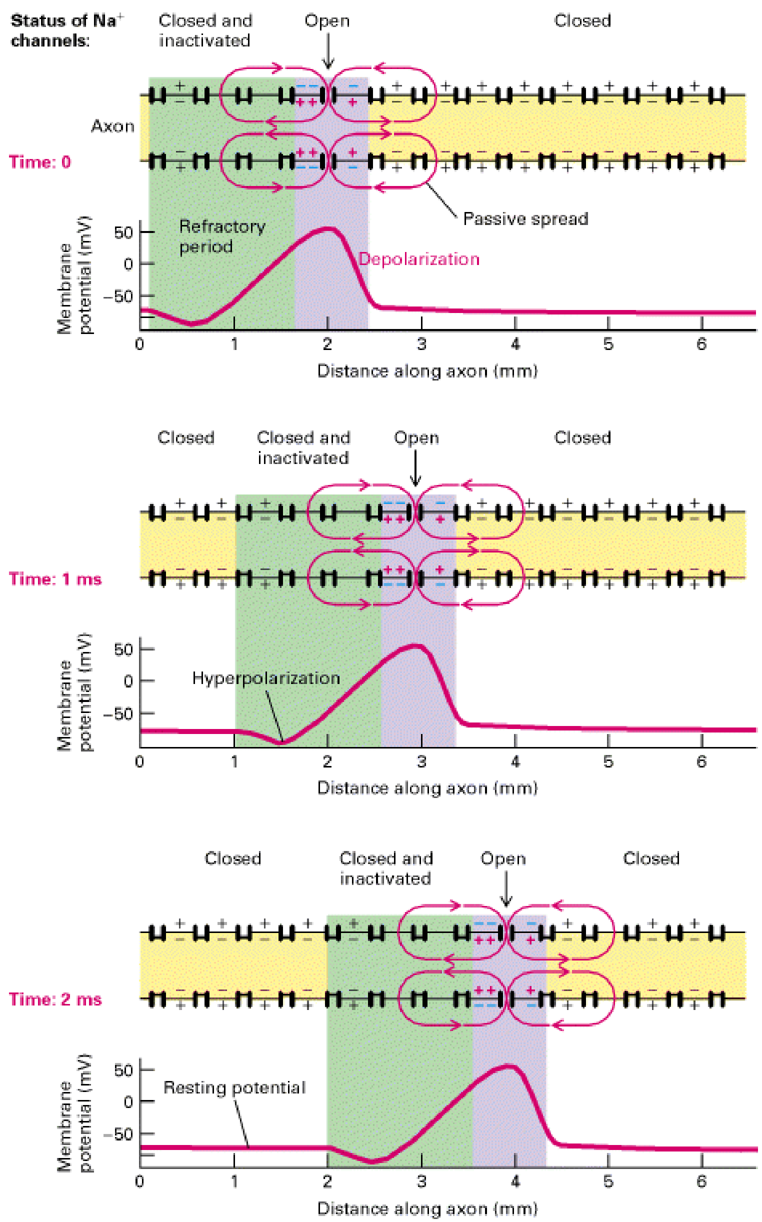


Conduction of impulse



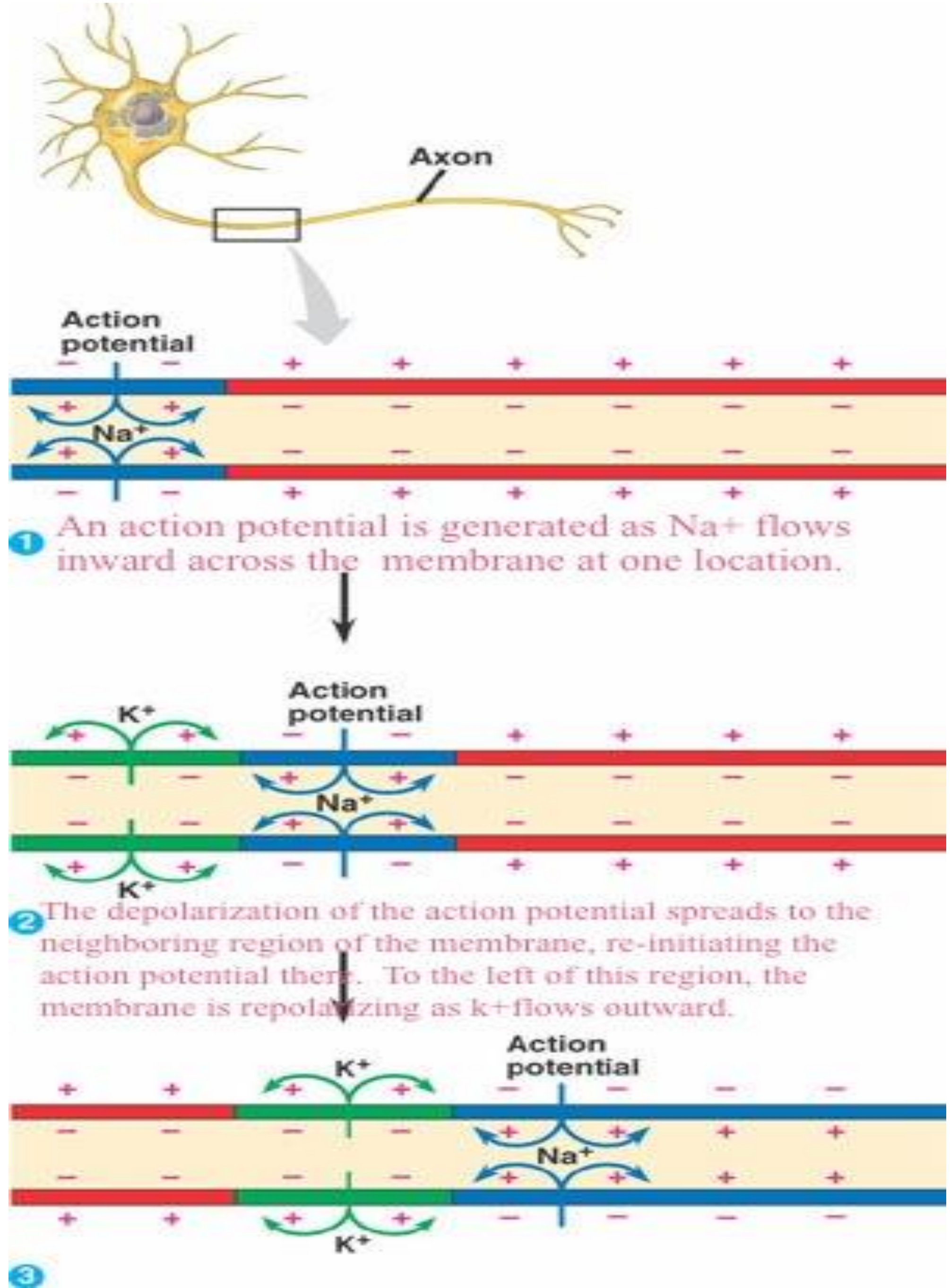
(a) Continuous conduction

(b) Saltatory conduction

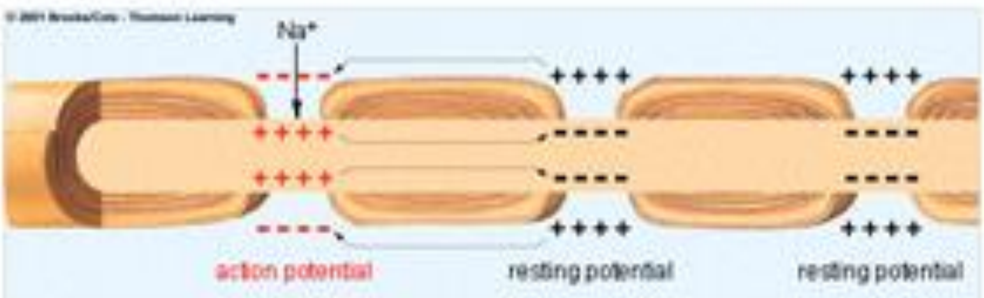


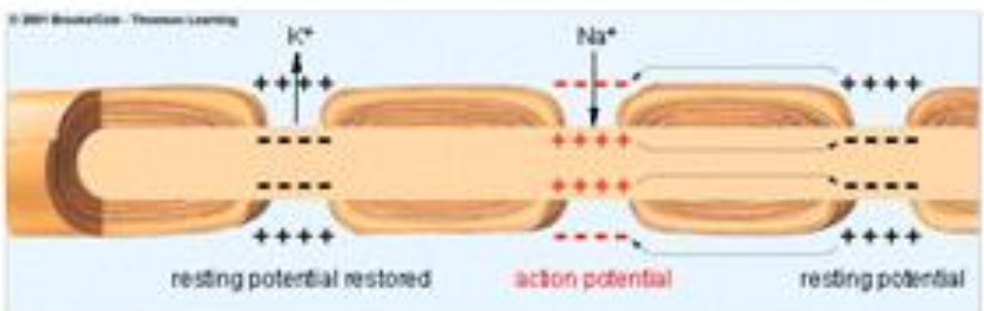
- Continuous Conduction in Unmyelinated axons

- Continuous Conduction in Unmyelinated axons



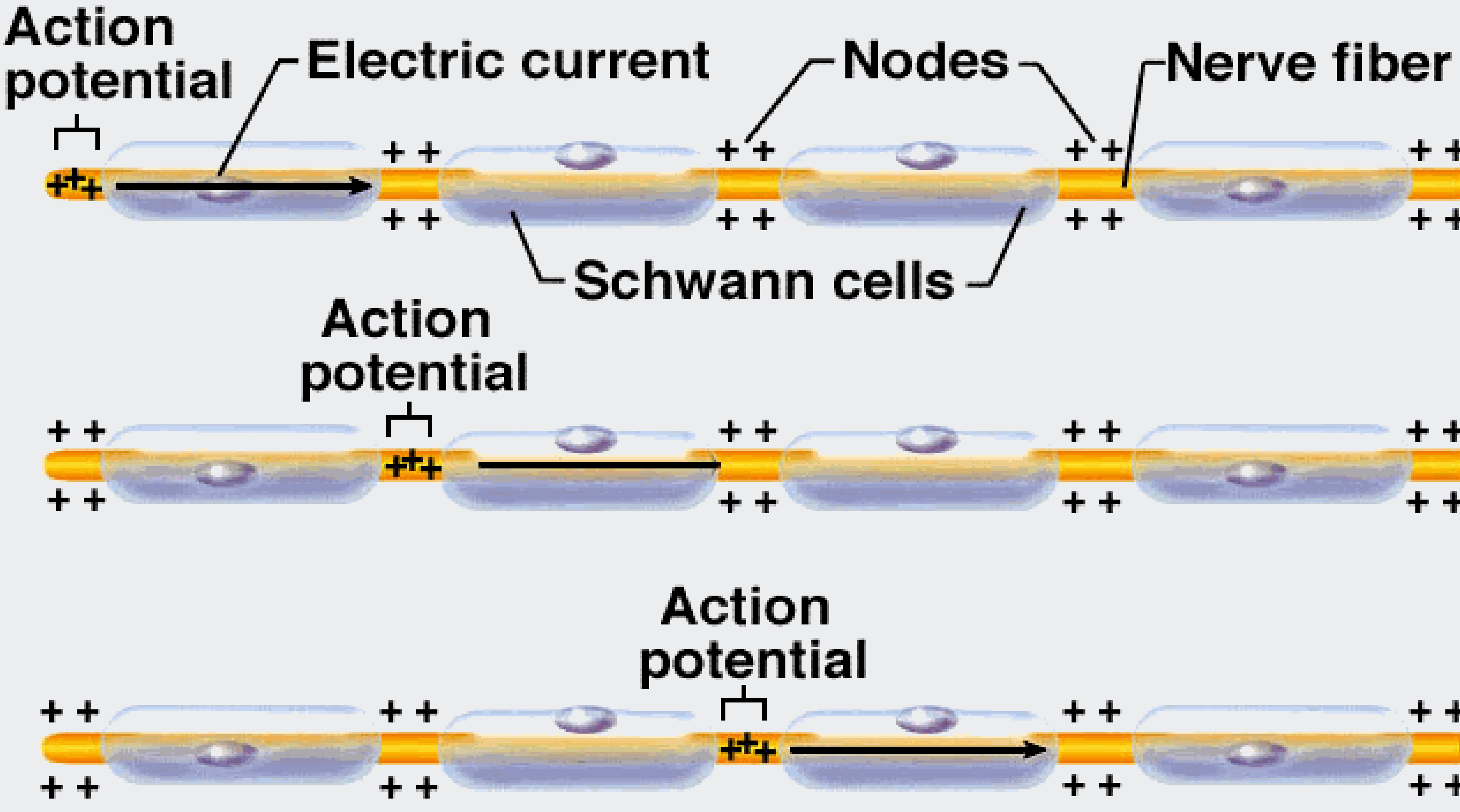
Myelin Sheath

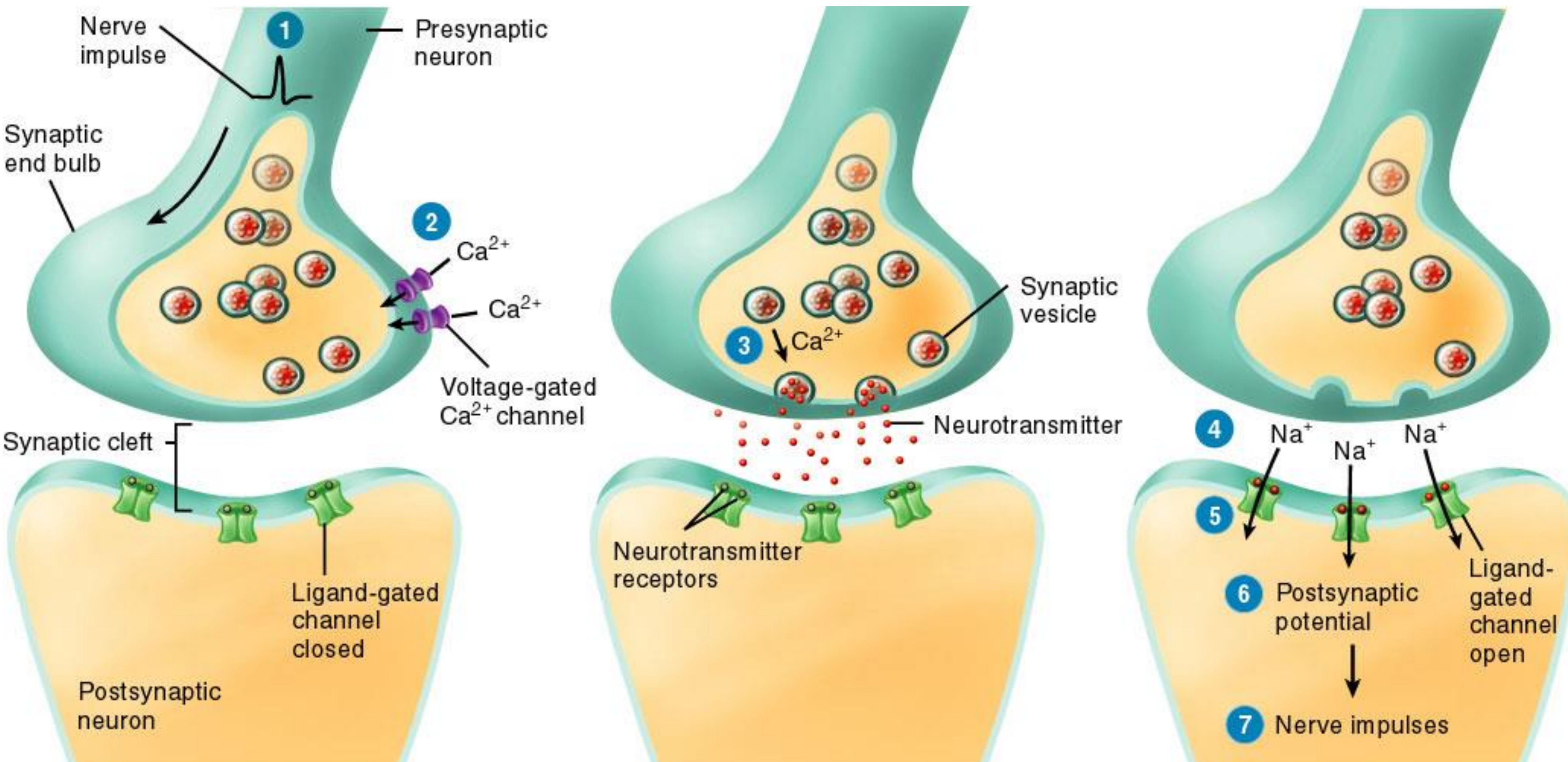




Saltatory Conduction in Myelinated axons

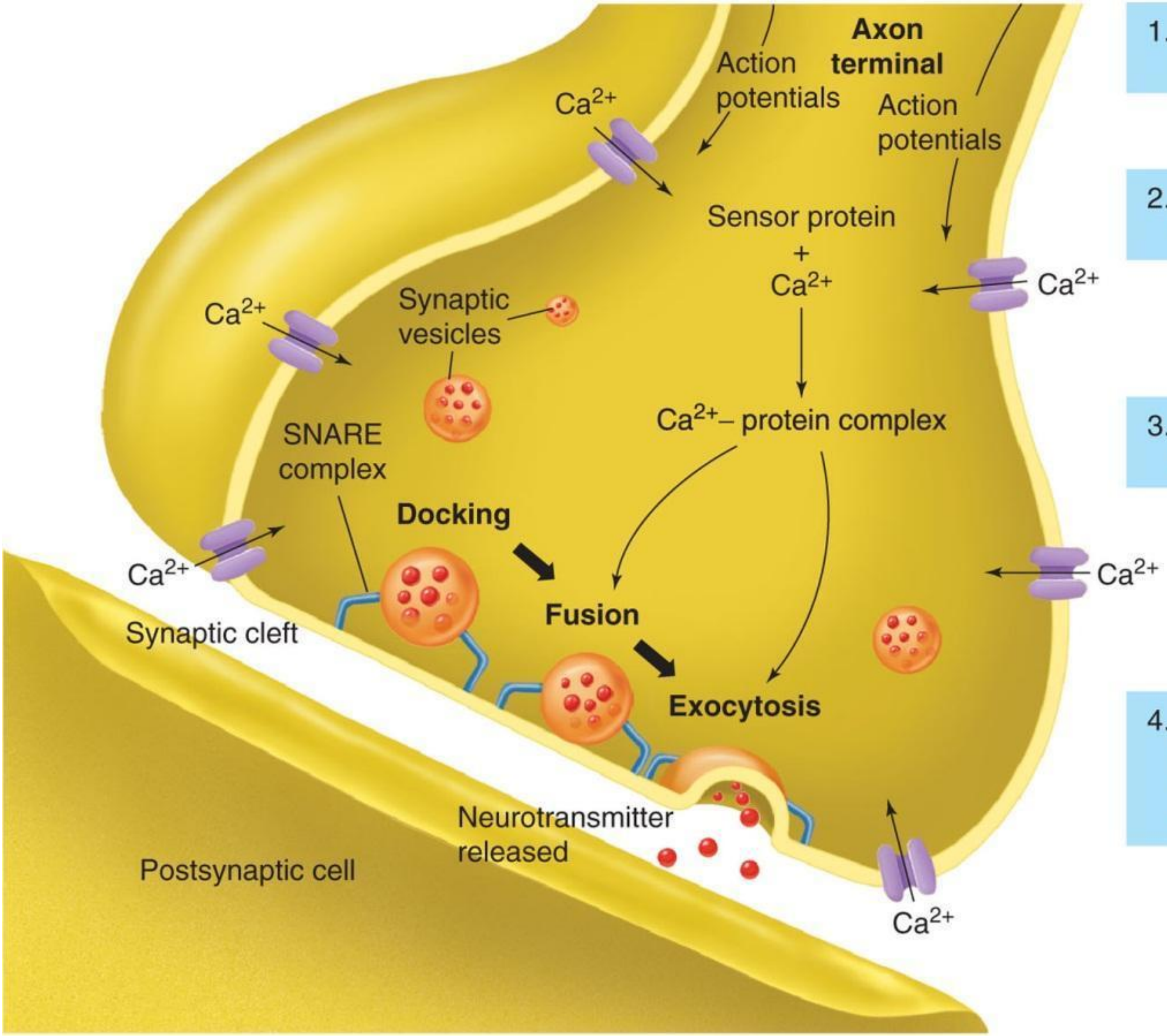
Nerve Impulse on Myelinated Fiber



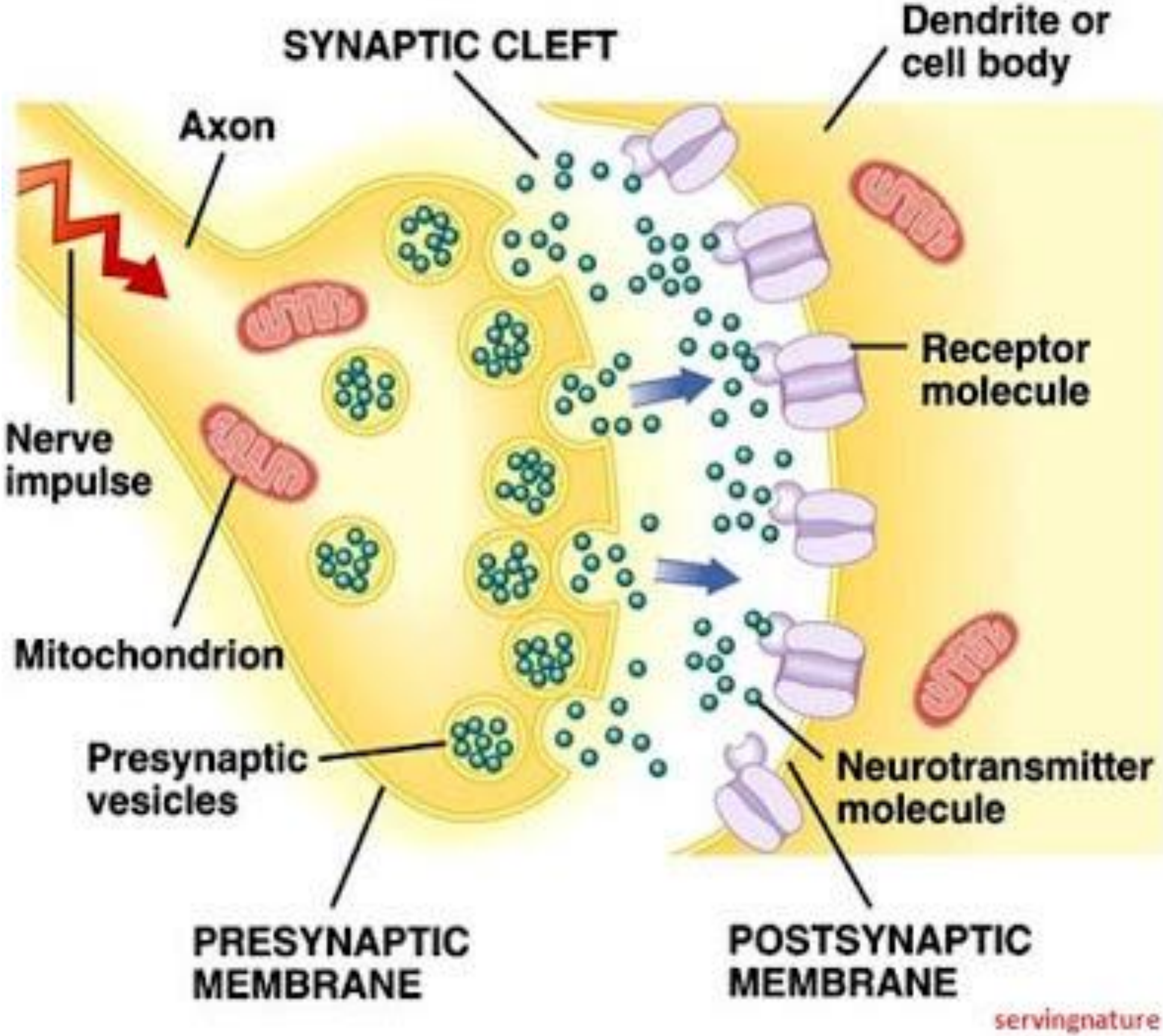


Nerve impulse
1
Presynaptic neuron
Synaptic end bulb
2
Ca2+
Ca2+
Voltage-gated Ca2+ channel
Synaptic cleft
Ligand-gated channel closed
Postsynaptic neuron
3
Ca2+
Synaptic vesicle
Neurotransmitter
Neurotransmitter receptors
4
Na+
Na+
Na+
5
6 Postsynaptic potential
7 Nerve impulses
Ligand-gated channel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

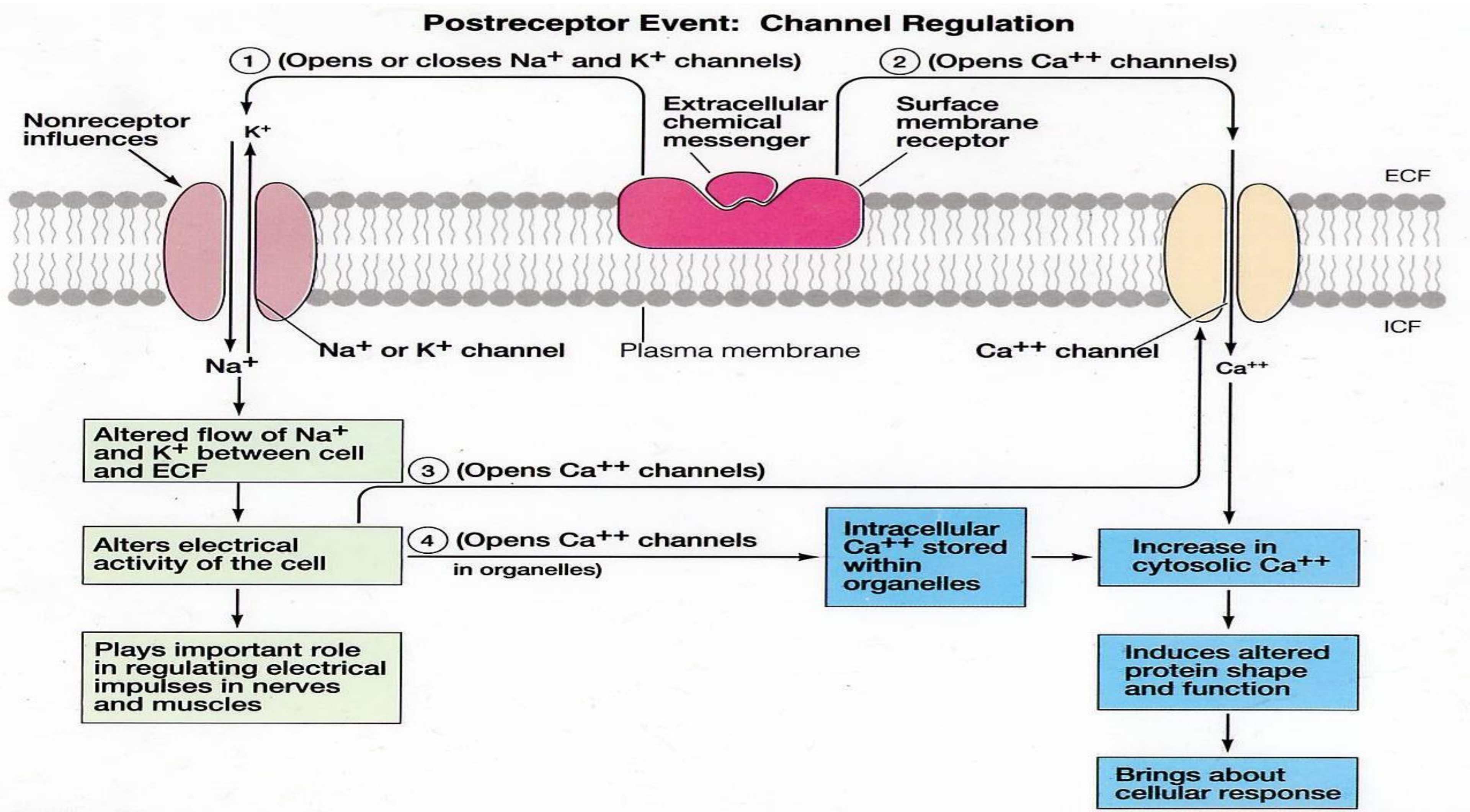
12.14

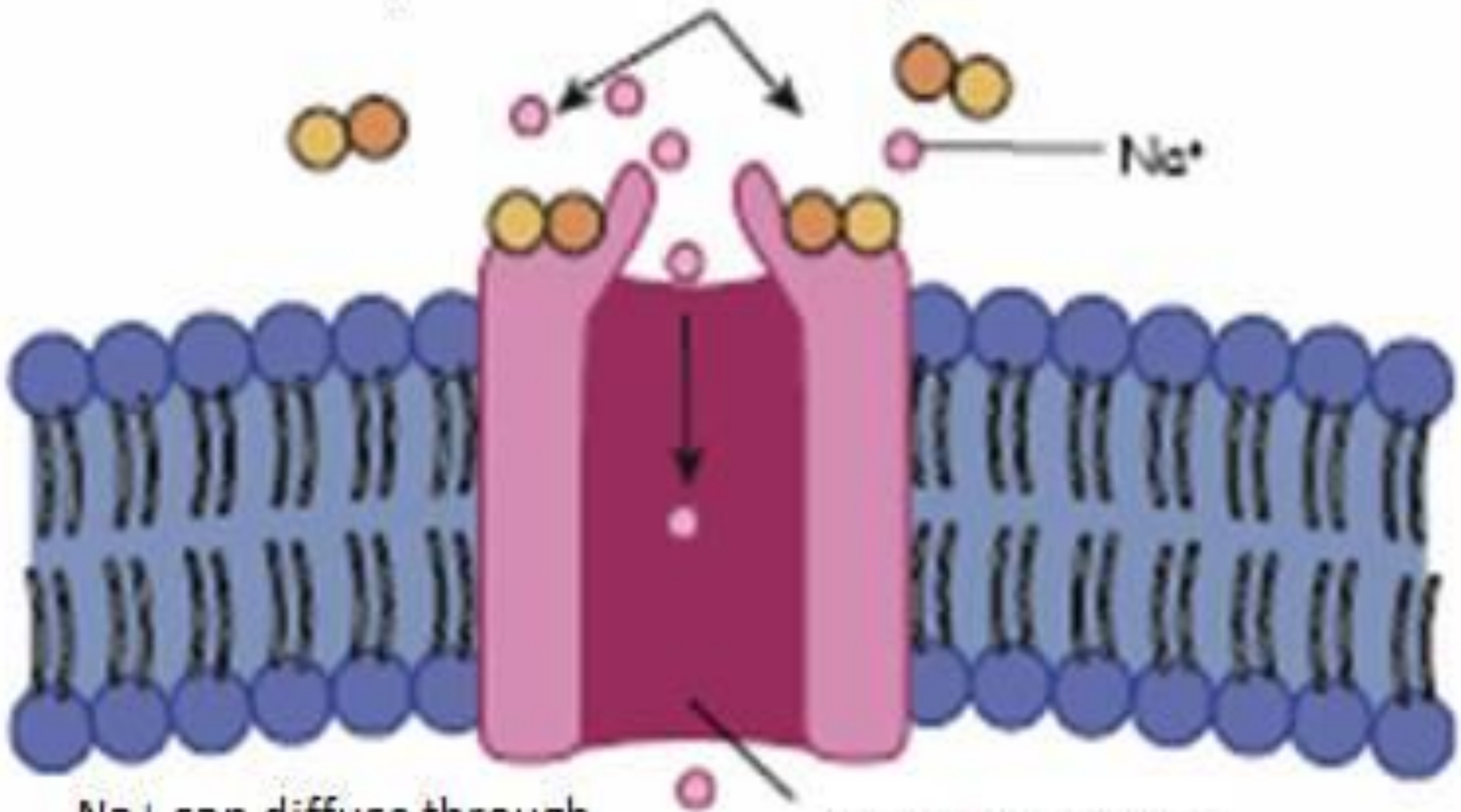


1. Action potentials reach axon terminals
2. Voltage-gated Ca^{2+} channels open
3. Ca^{2+} binds to sensor protein in cytoplasm
4. Ca^{2+}-protein complex stimulates fusion and exocytosis of neurotransmitter


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

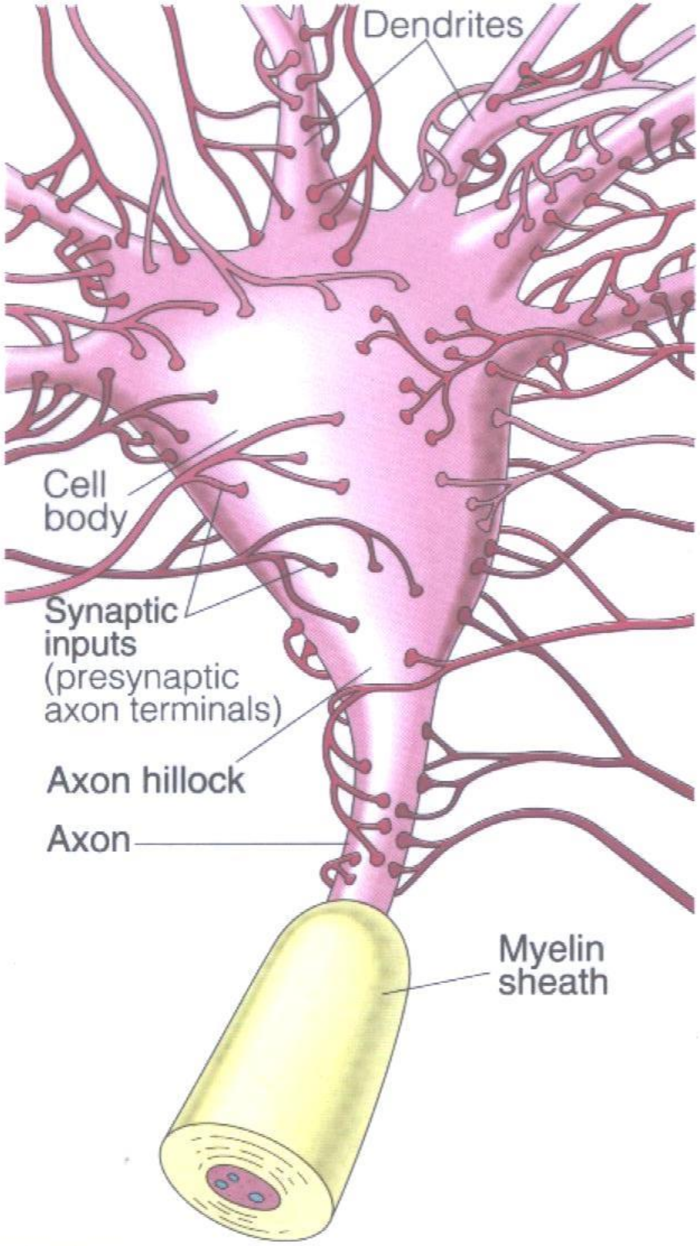
Chemical gated Channels

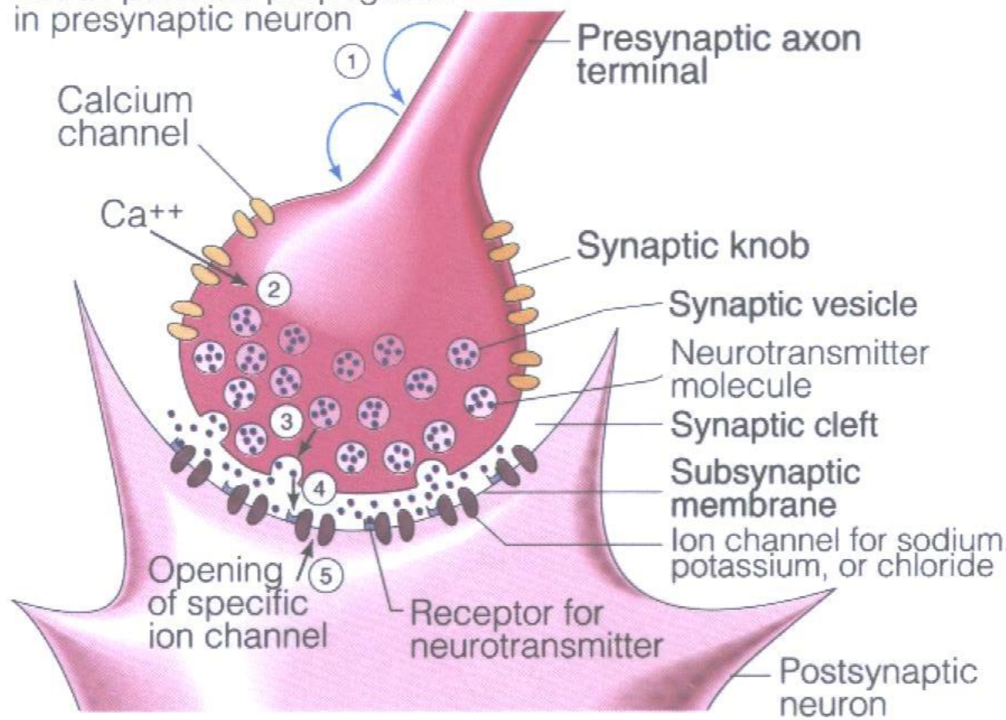


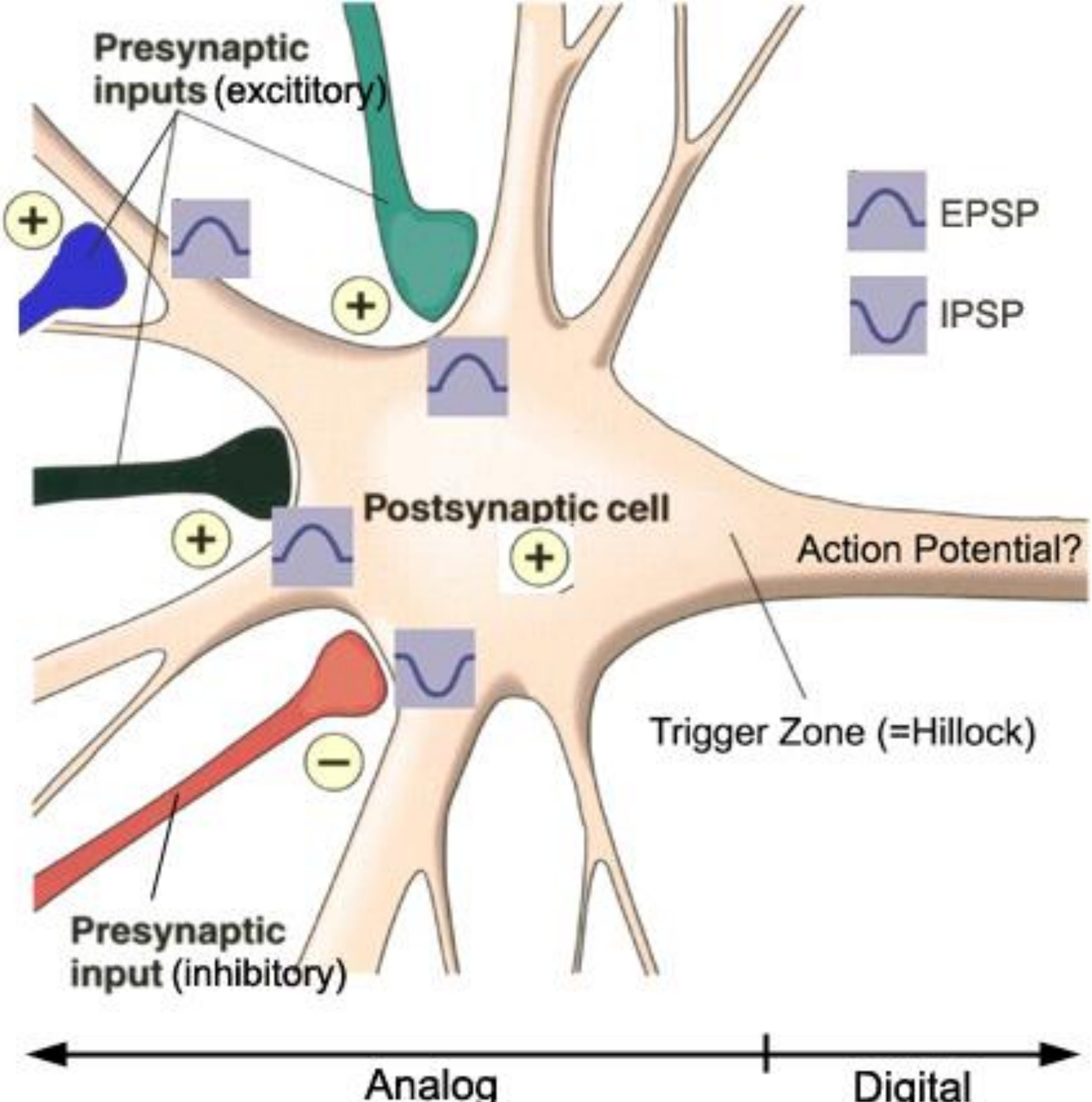


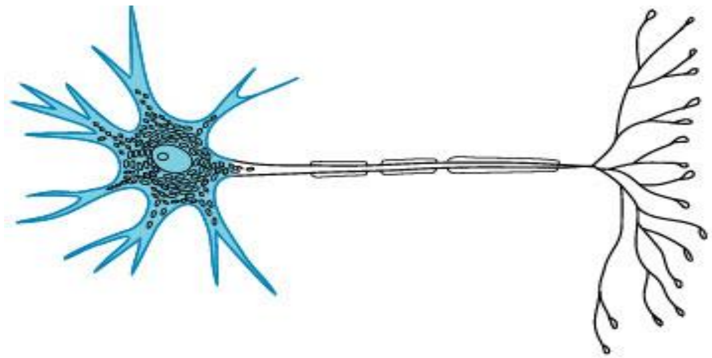
When 2 acetylcholine molecules bind to their receptor sites on the Na+ channel, the channel opens to allow Na+ to diffuse through the channel into the cell

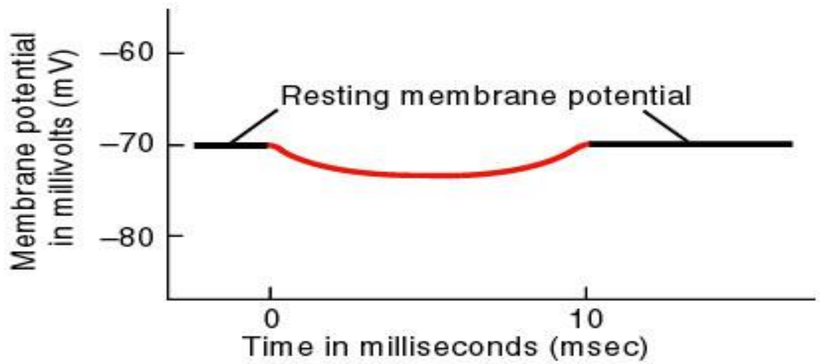
Synaptic Structure and Function



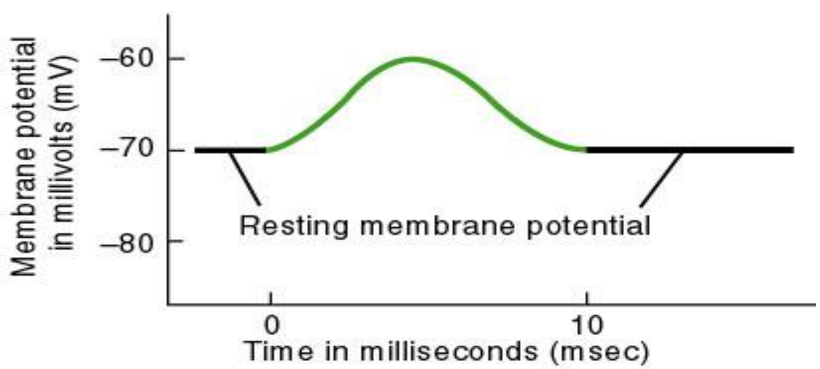



Presynaptic
inputs (excititory)
EPSP
IPSP
Postsynaptic cell
Action Potential?
Trigger Zone (=Hillock)
Presynaptic
input (inhibitory)
Analog
Digital





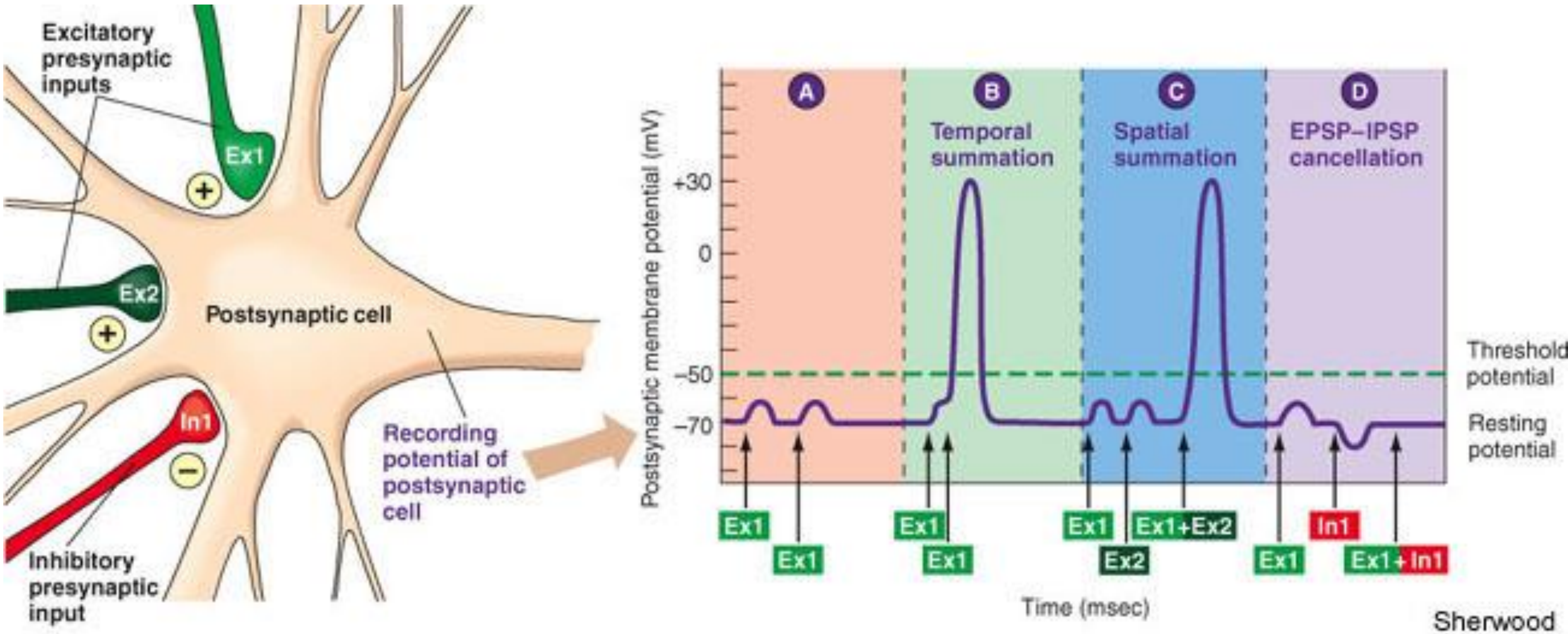
(a) Hyperpolarizing graded potential

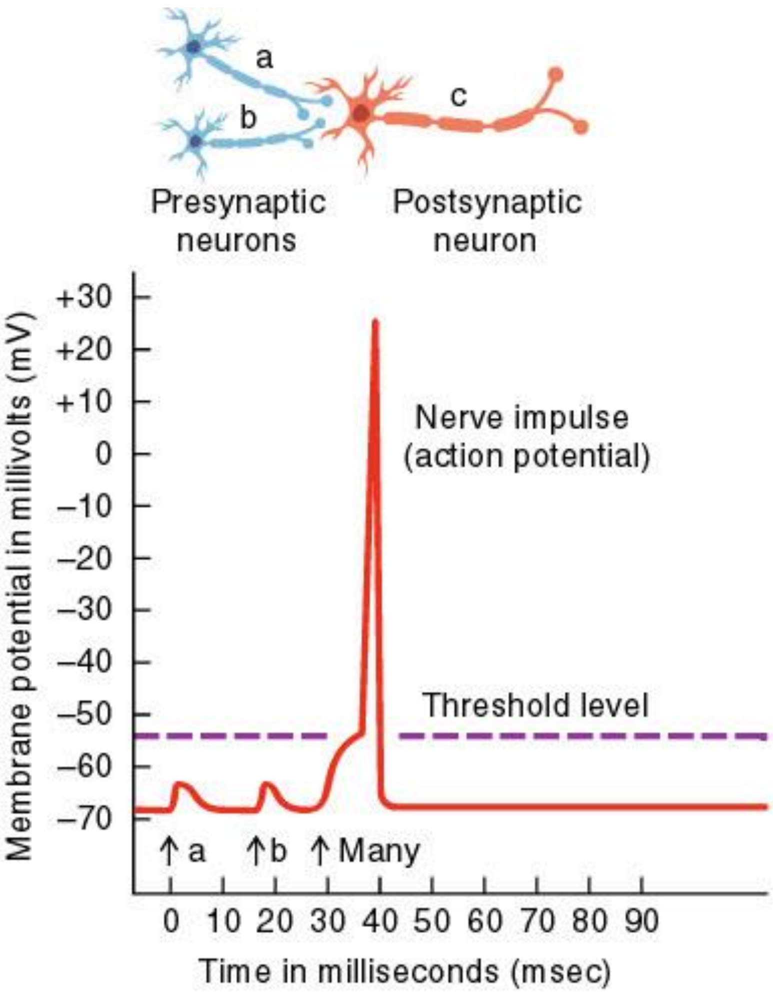


(b) Depolarizing graded potential

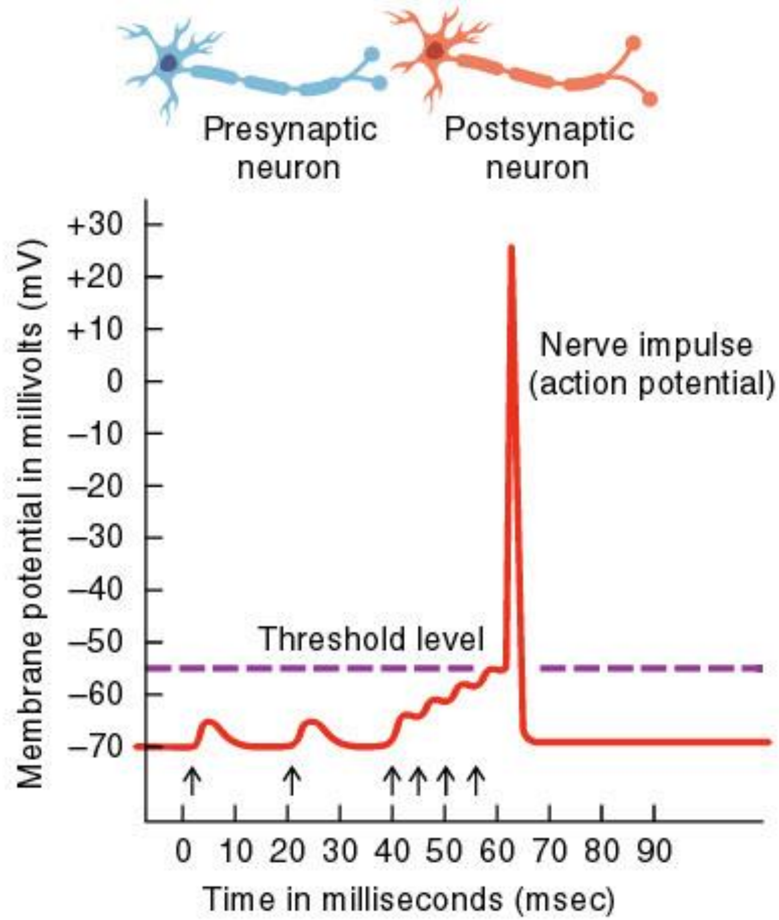
12.10

Summation of postsynaptic potentials



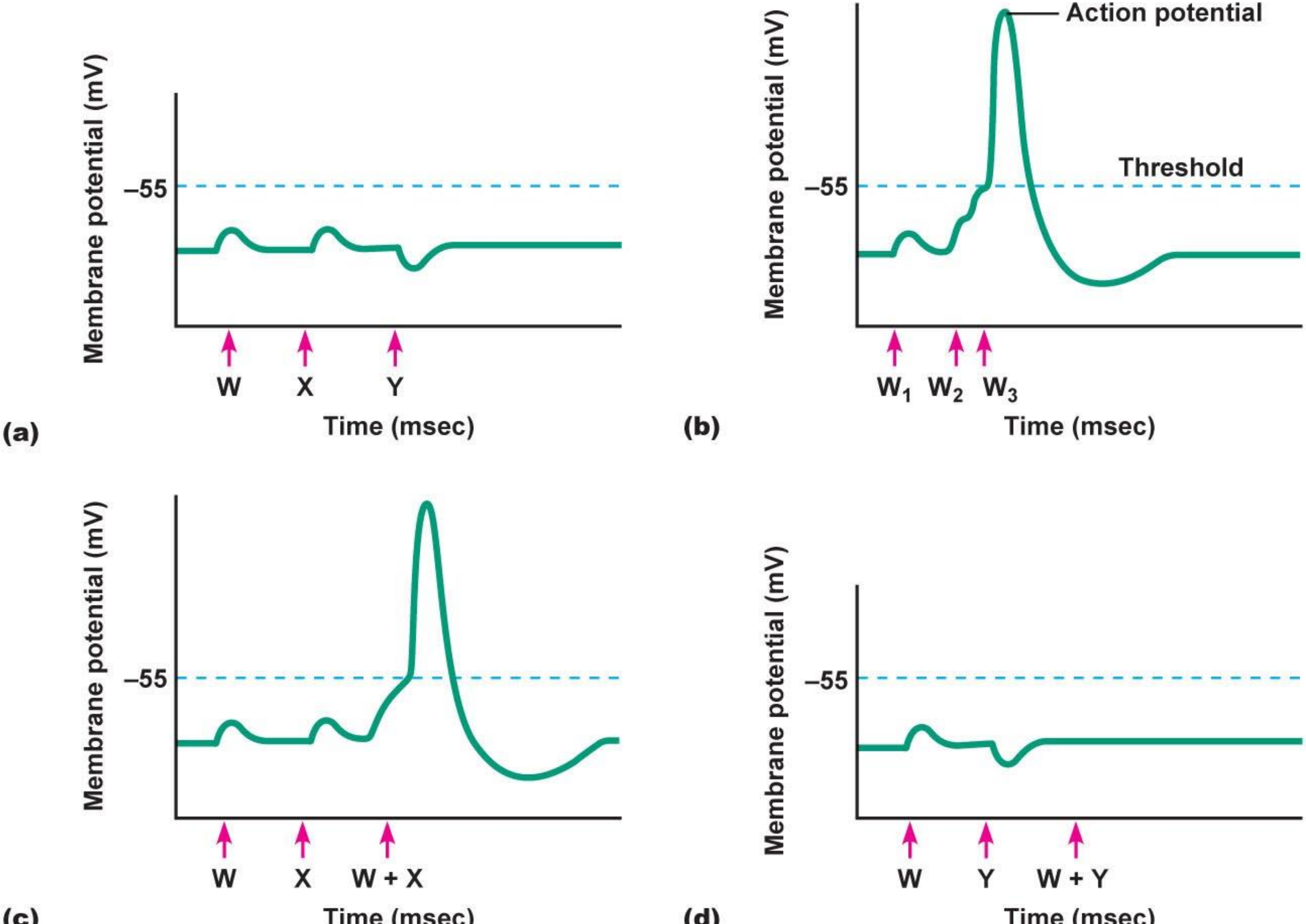


(a) Spatial summation

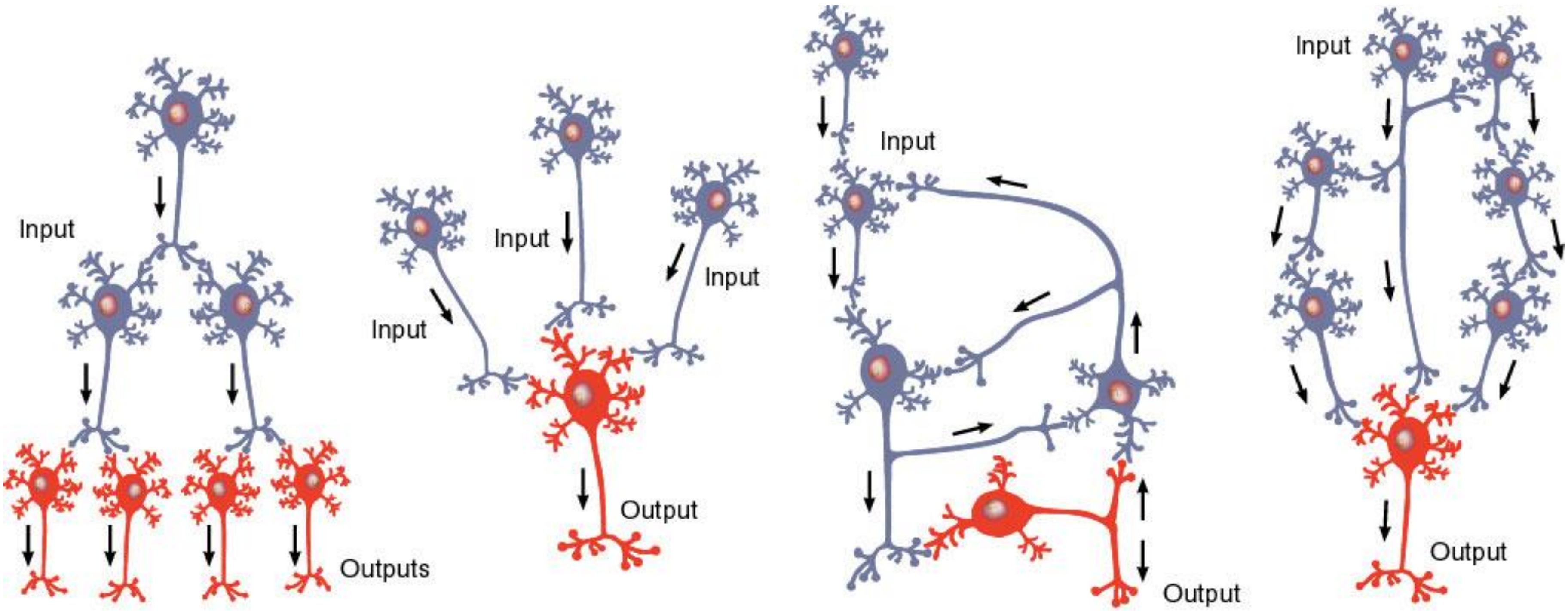


(b) Temporal summation

12.15


Membrane potential (mV)
–55
W
X
Y
Time (msec)
(a)
Action potential
Threshold
Membrane potential (mV)
–55
W1
W2
W3
Time (msec)
(b)
Membrane potential (mV)
–55
W
X
W + X
Time (msec)
(c)
Membrane potential (mV)
–55
W
Y
W + Y
Time (msec)
(d)

Synaptic organization



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

12.16