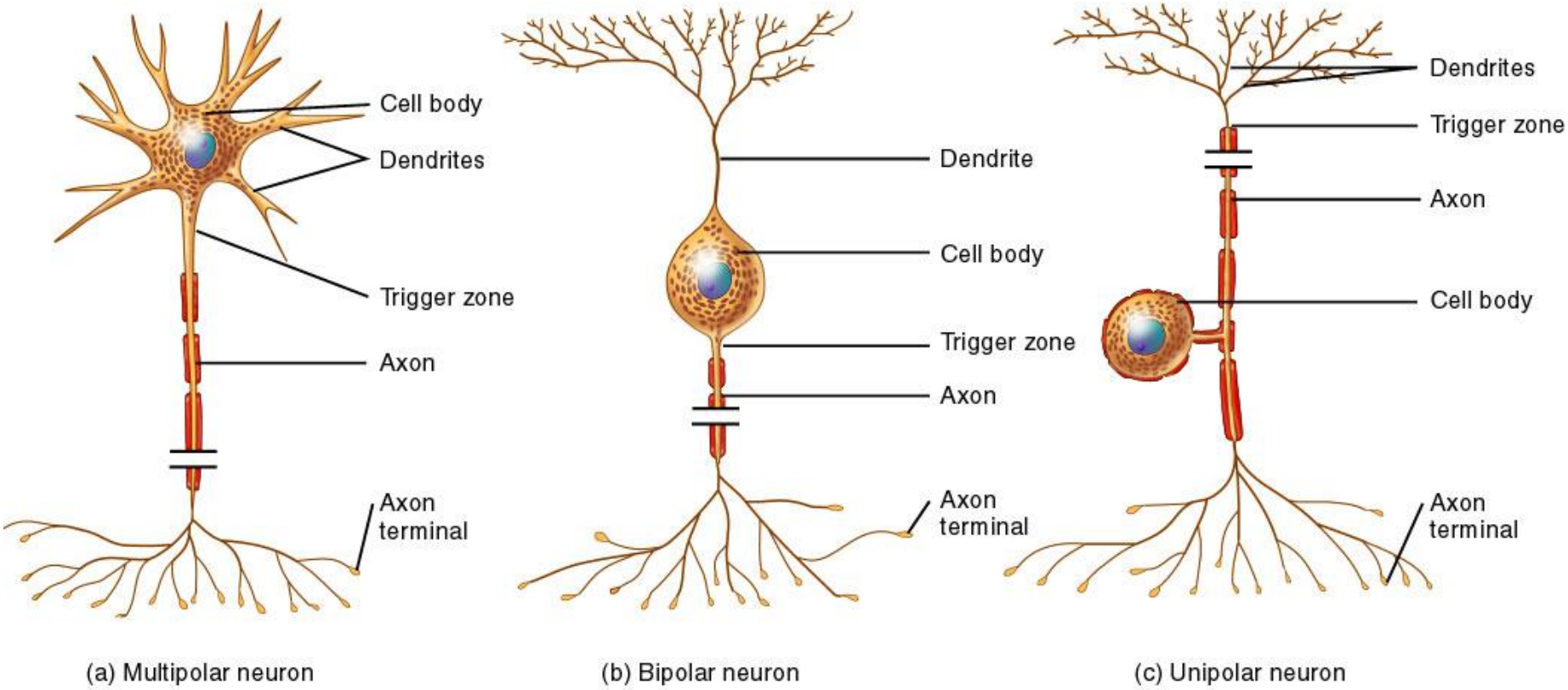
Nerve and Muscle Physiology

Plasma Membranes of Excitable tissues

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



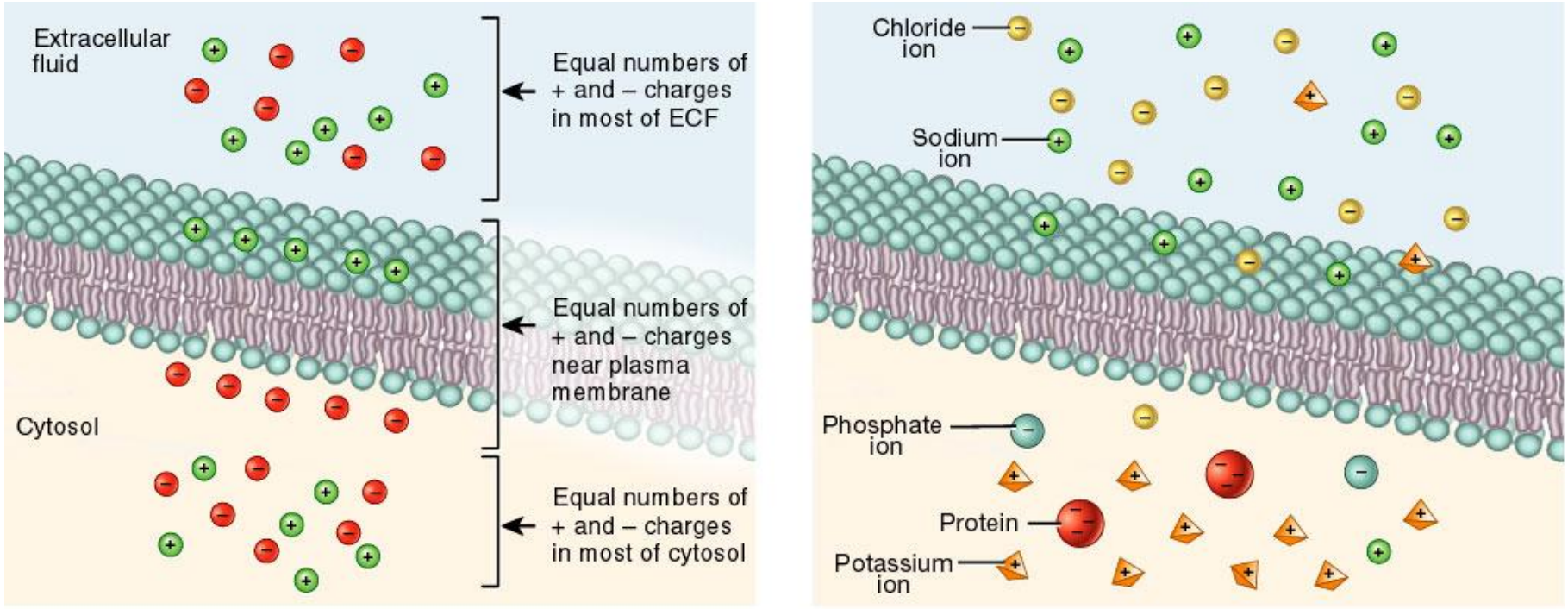
(a) Multipolar neuron

(b) Bipolar neuron

(c) Unipolar neuron

12.04

Fig. 12.09a,b



(a) Distribution of charges

(b) Distribution of ions

12.09ab

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)

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.

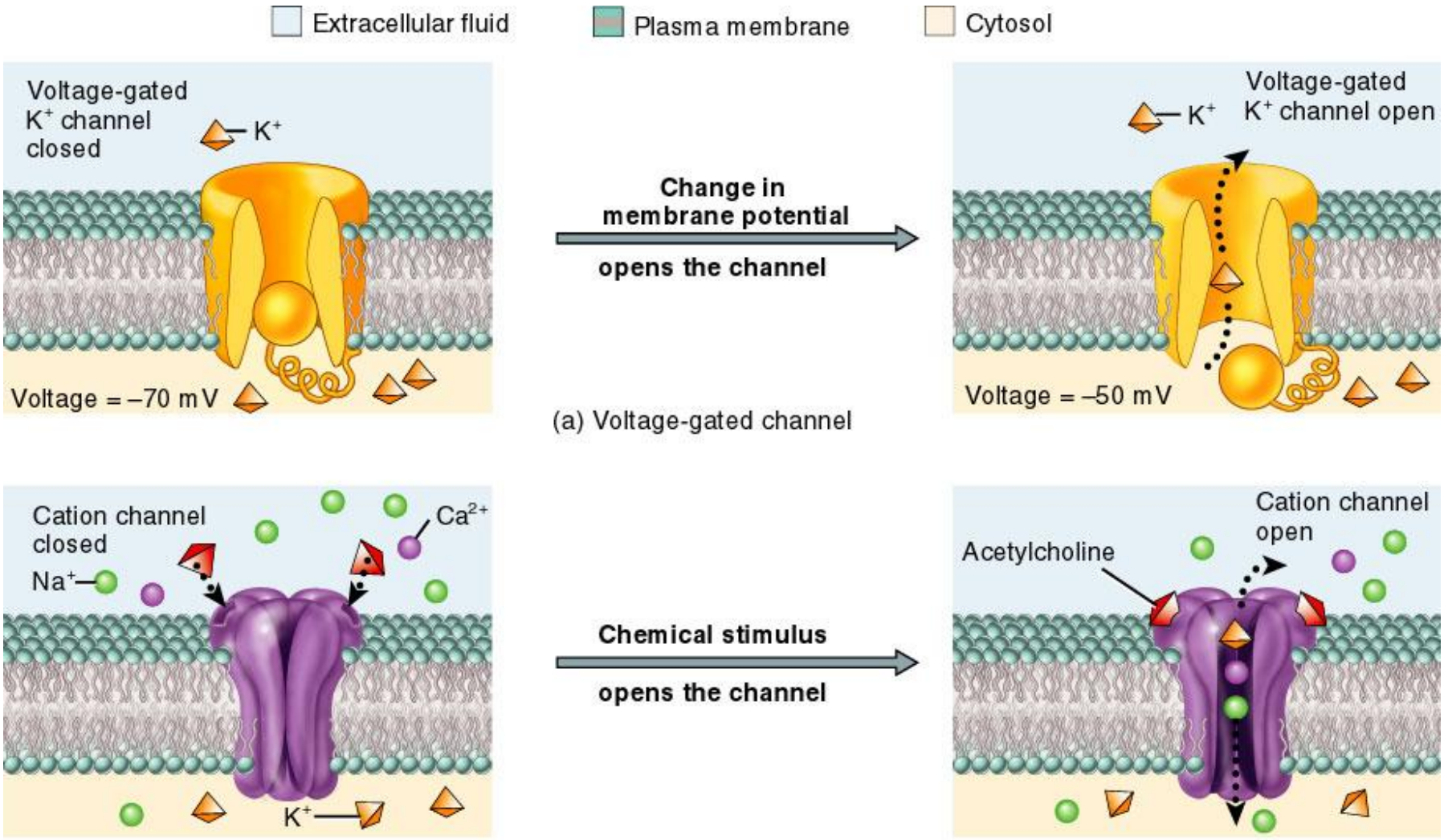
Goldman Hodgkin Katz equation

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

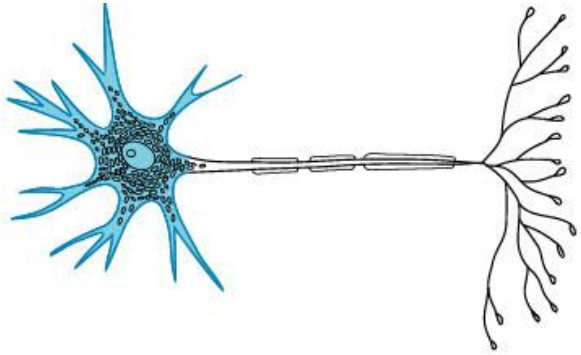
i = Conc. inside

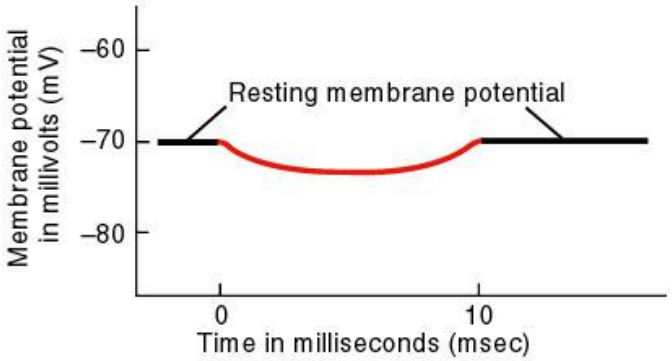
o = Conc. outside

P = permeability of the membrane to that ion.

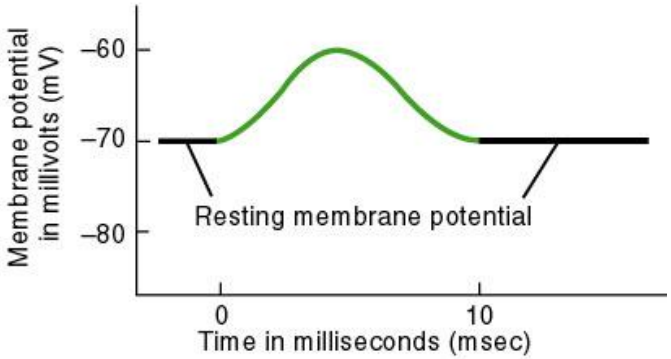

Extracellular fluid
Plasma membrane
Cytosol
Voltage-gated
K+ channel
closed
K+
Voltage = –70 mV
Change in
membrane potential
opens the channel
Voltage-gated
K+ channel open
K+
Voltage = –50 mV
(a) Voltage-gated channel
Cation channel
closed
Ca2+
Na+
K+
Chemical stimulus
opens the channel
Cation channel
open
Acetylcholine
(b) Ligand-gated channel

12.08

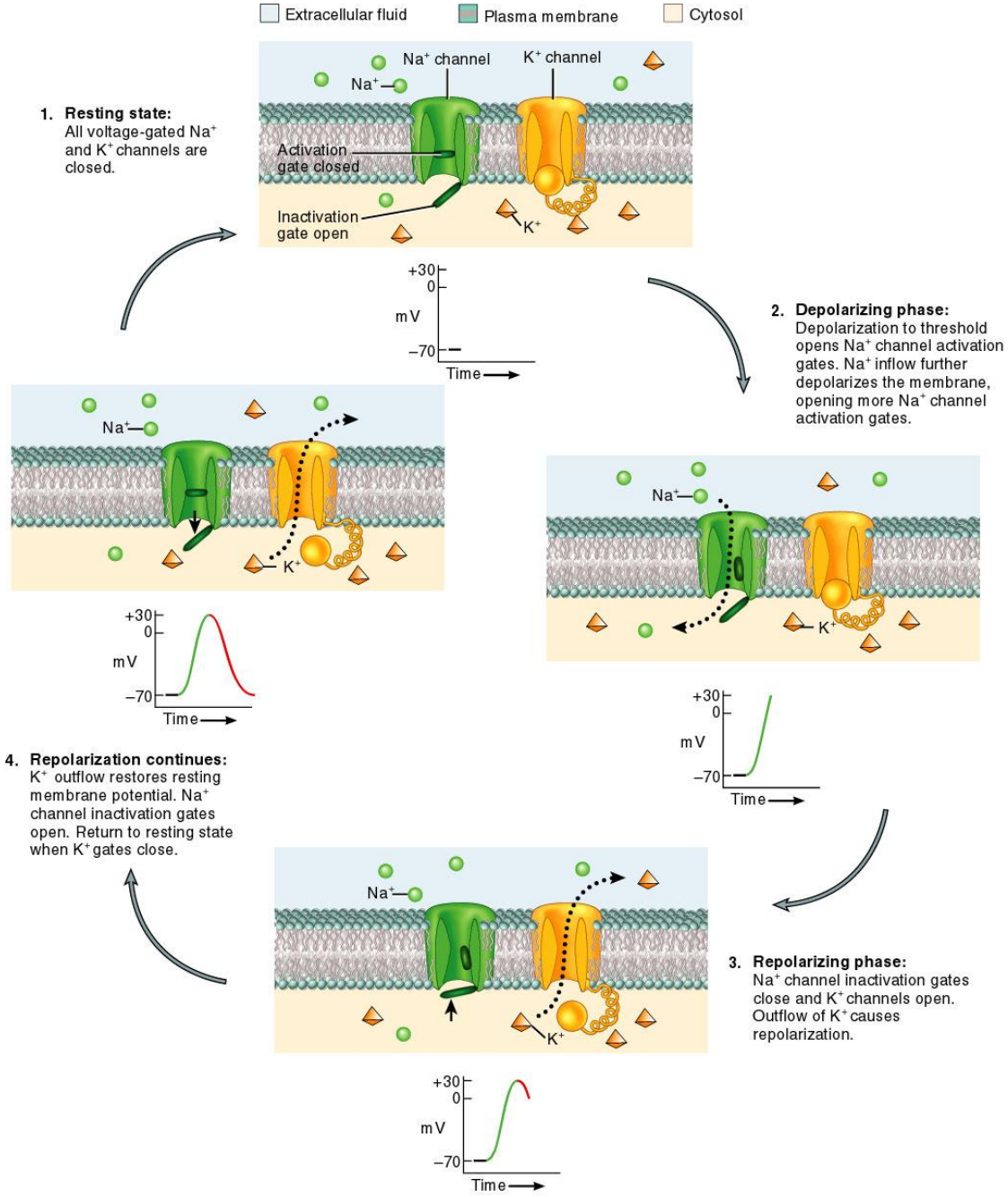




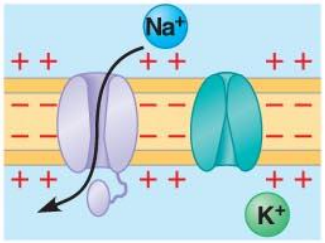
(a) Hyperpolarizing graded potential



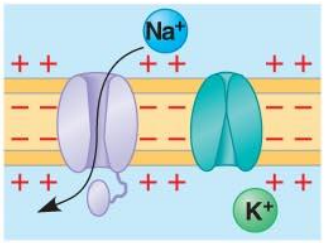
(b) Depolarizing graded potential


Extracellular fluid
Plasma membrane
Cytosol
Na+ channel
K+ channel
Na+
Activation gate closed
Inactivation gate open
K+
+30
0
mV
–70
Time
1. Resting state: All voltage-gated Na+ and K+ channels are closed.
2. Depolarizing phase: Depolarization to threshold opens Na+ channel activation gates. Na+ inflow further depolarizes the membrane, opening more Na+ channel activation gates.
3. Repolarizing phase: Na+ channel inactivation gates close and K+ channels open. Outflow of K+ causes repolarization.
4. Repolarization continues: K+ outflow restores resting membrane potential. Na+ channel inactivation gates open. Return to resting state when K+ gates close.

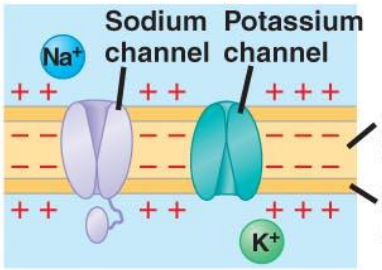
12.12



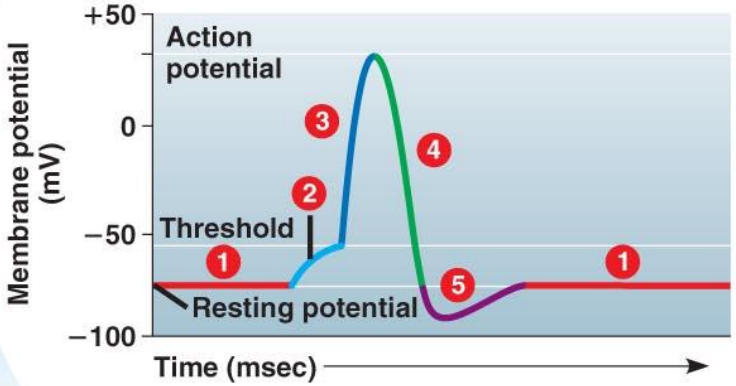
3 Additional Na^+ channels open, K^+ channels are closed; interior of cell becomes more positive.

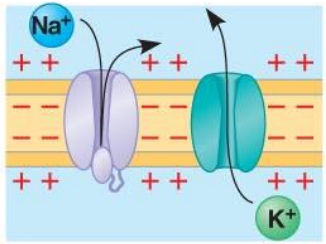


2 A stimulus opens some Na^+ channels; if threshold is reached, action potential is triggered.



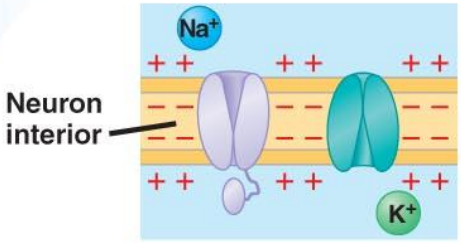
1 Resting state: voltage-gated Na^+ and K^+ channels closed; resting potential is maintained.





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.

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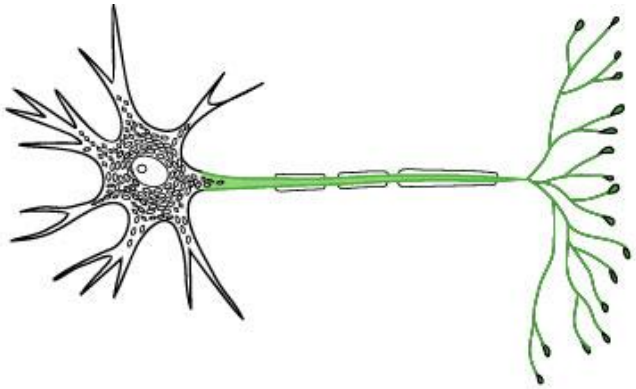
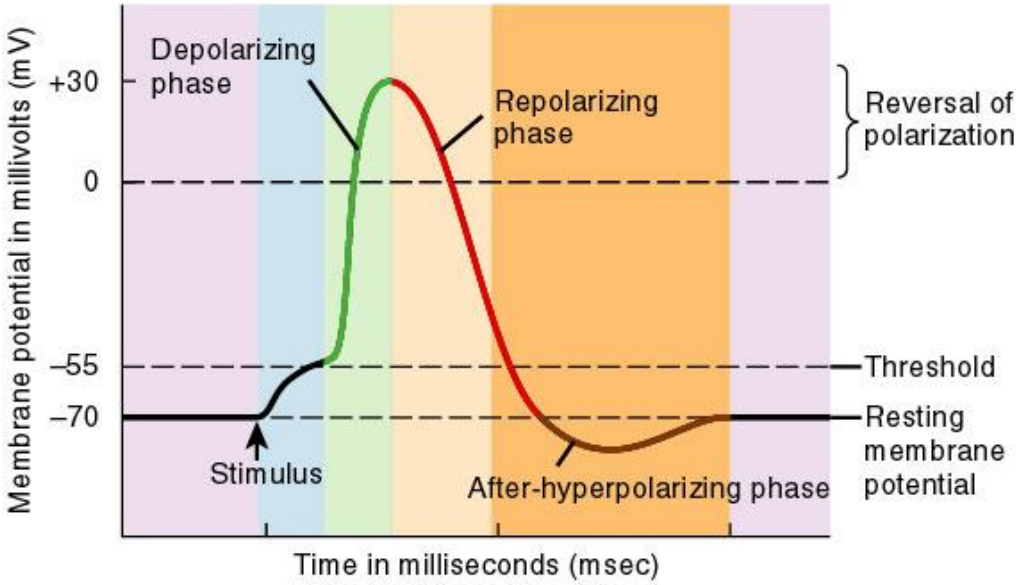




Key:

- 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

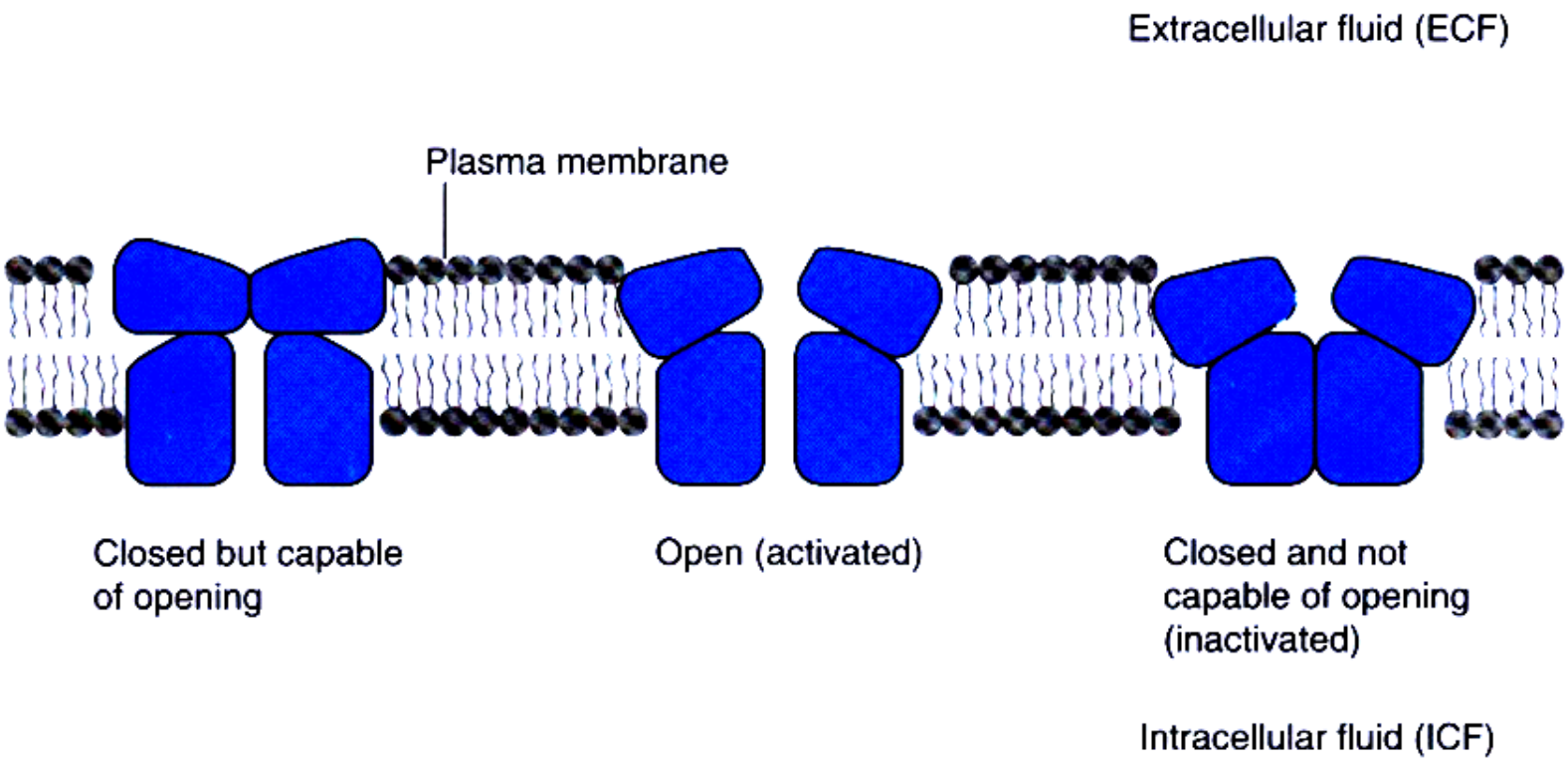
} Absolute refractory period

- Voltage-gated K^+ channels are still open; Na^+ channels are in the resting state

} Relative refractory period

12.11

Conformations of Voltage–Gated Na+ Channels



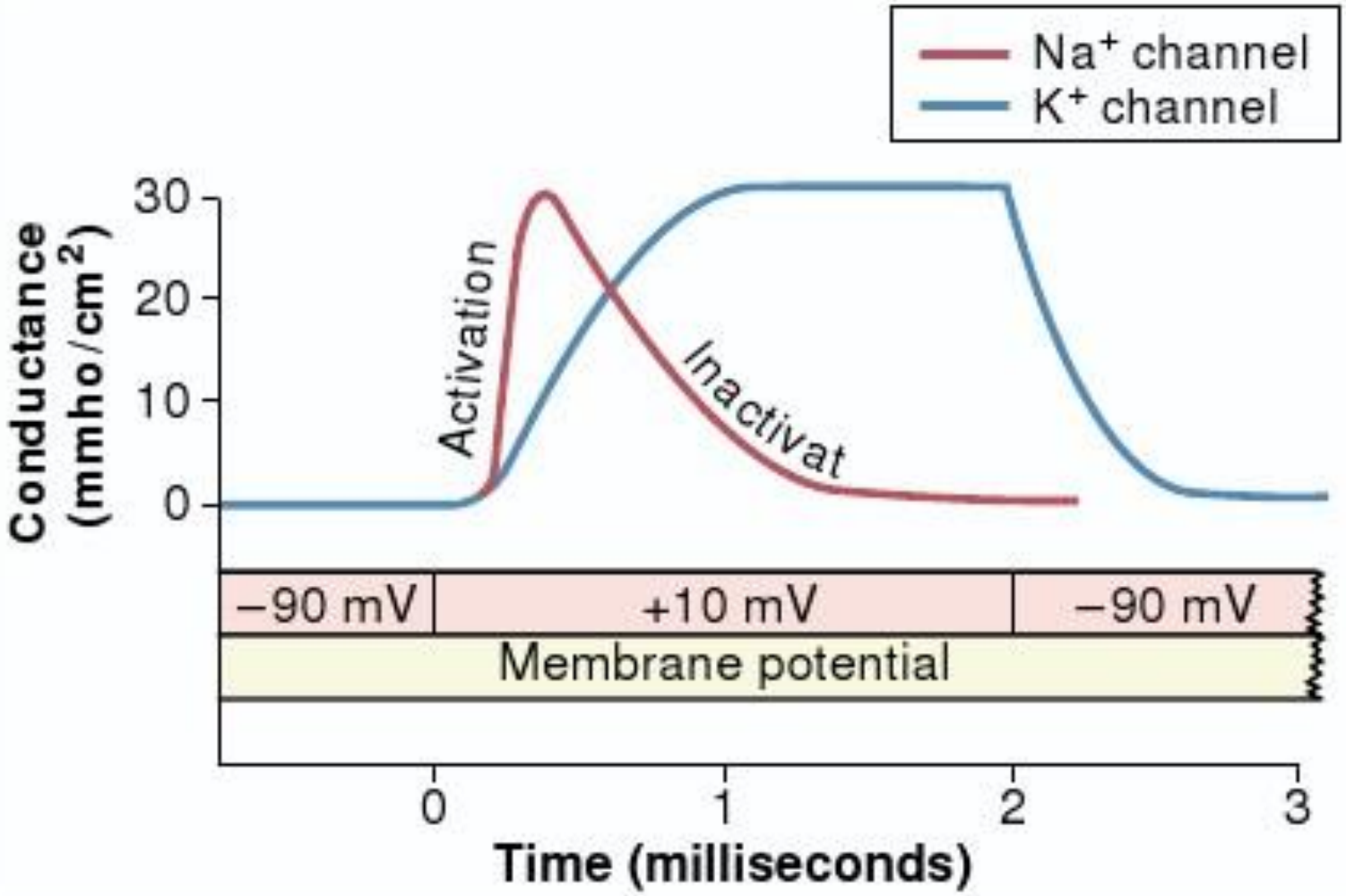
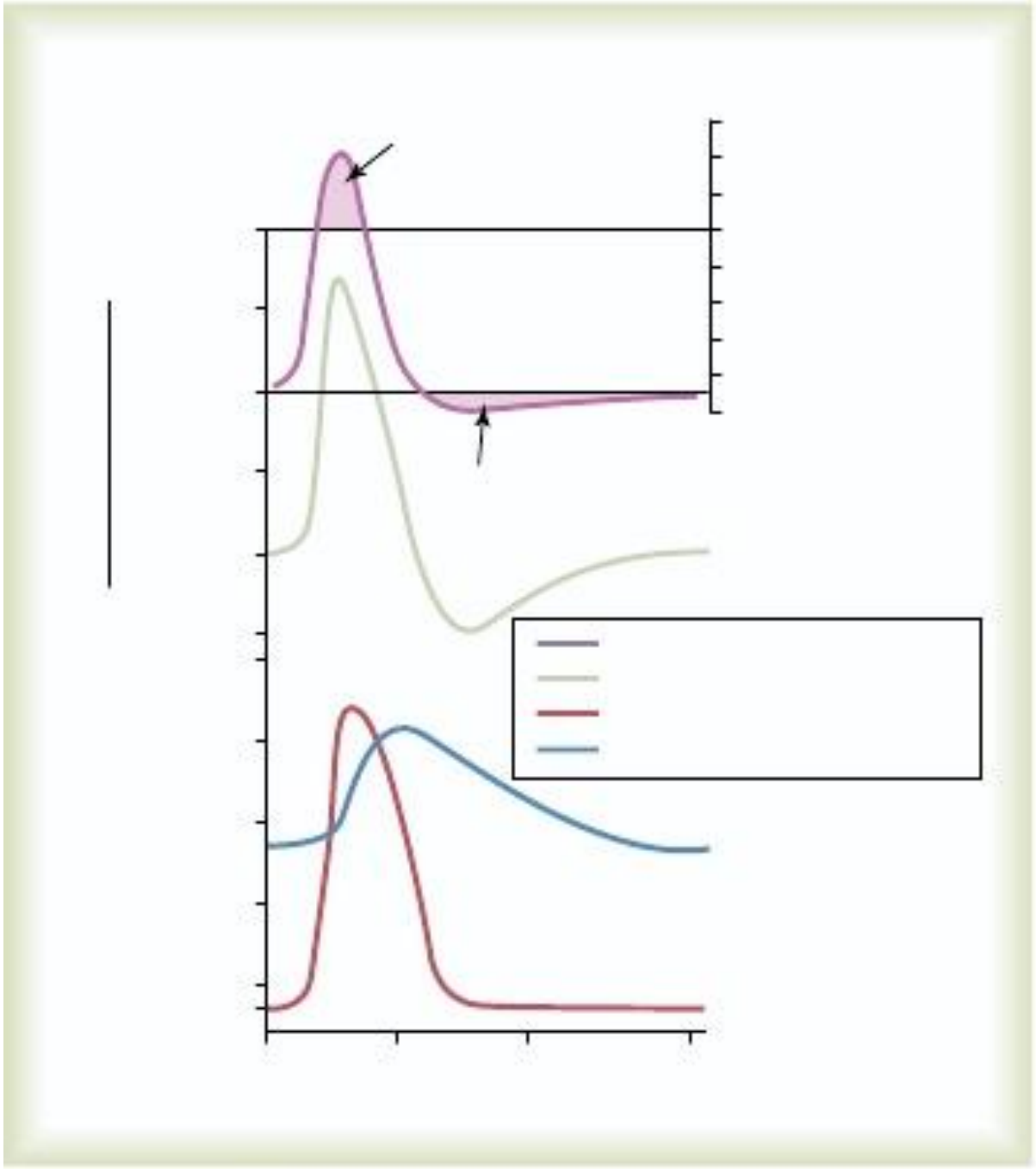
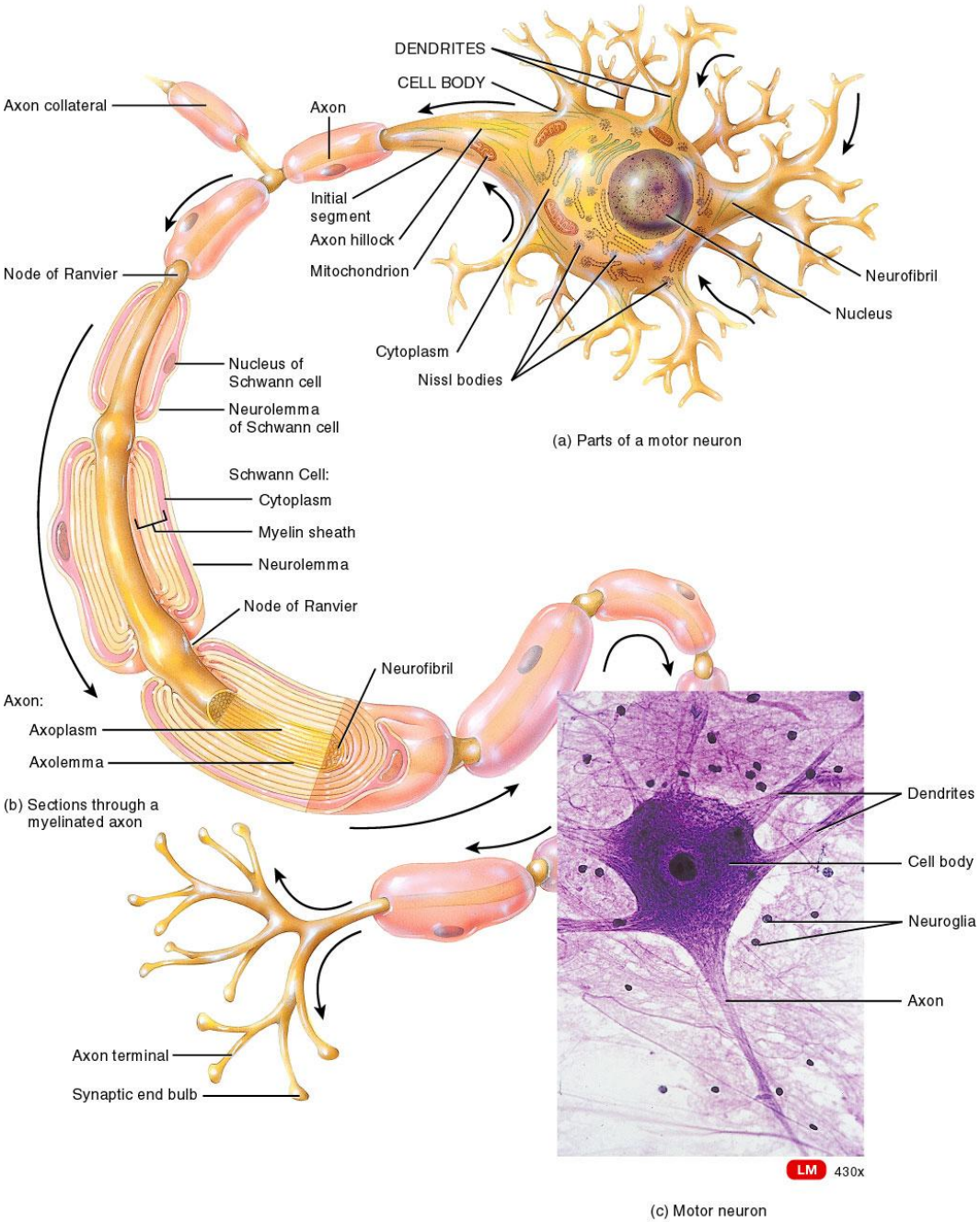
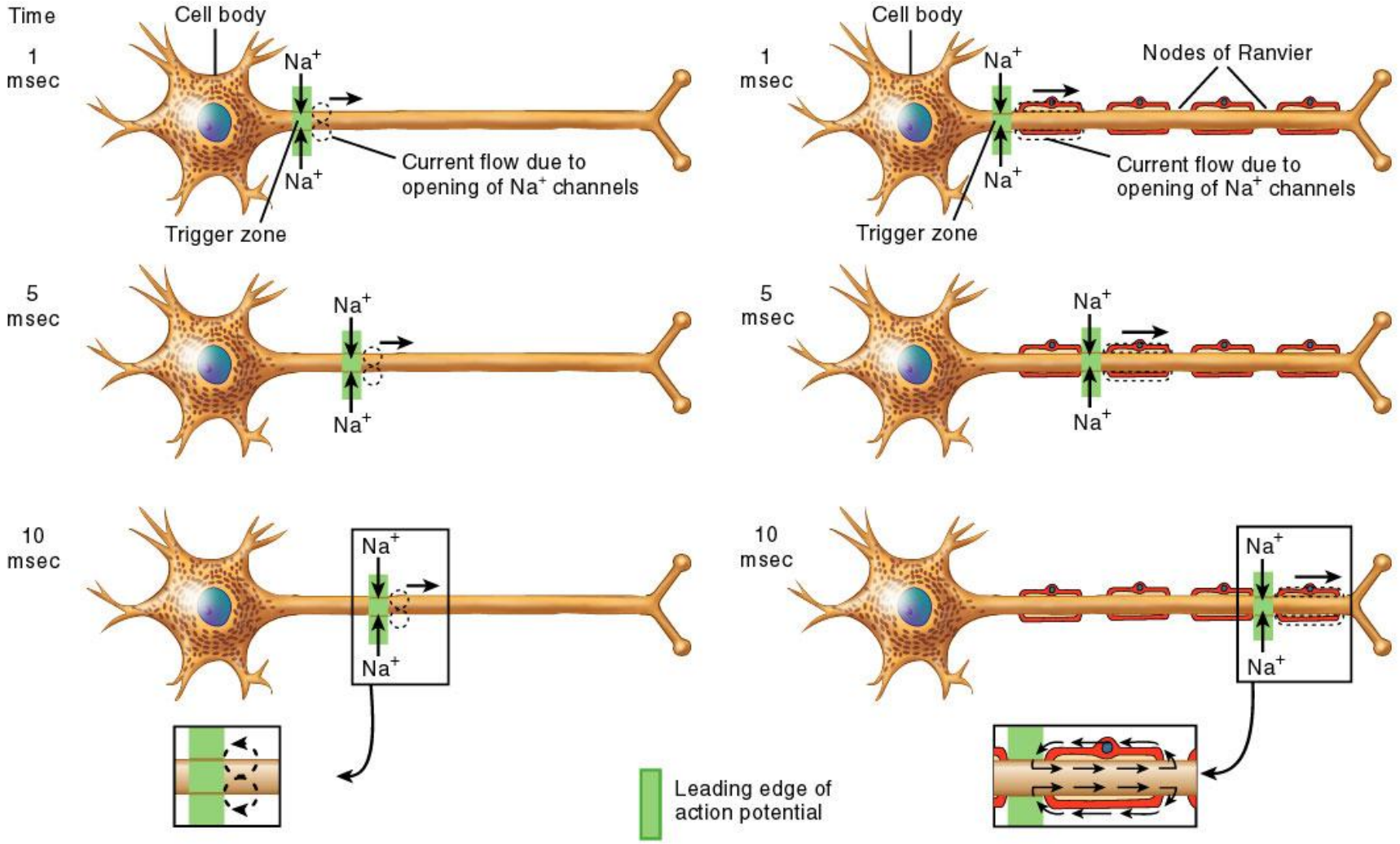
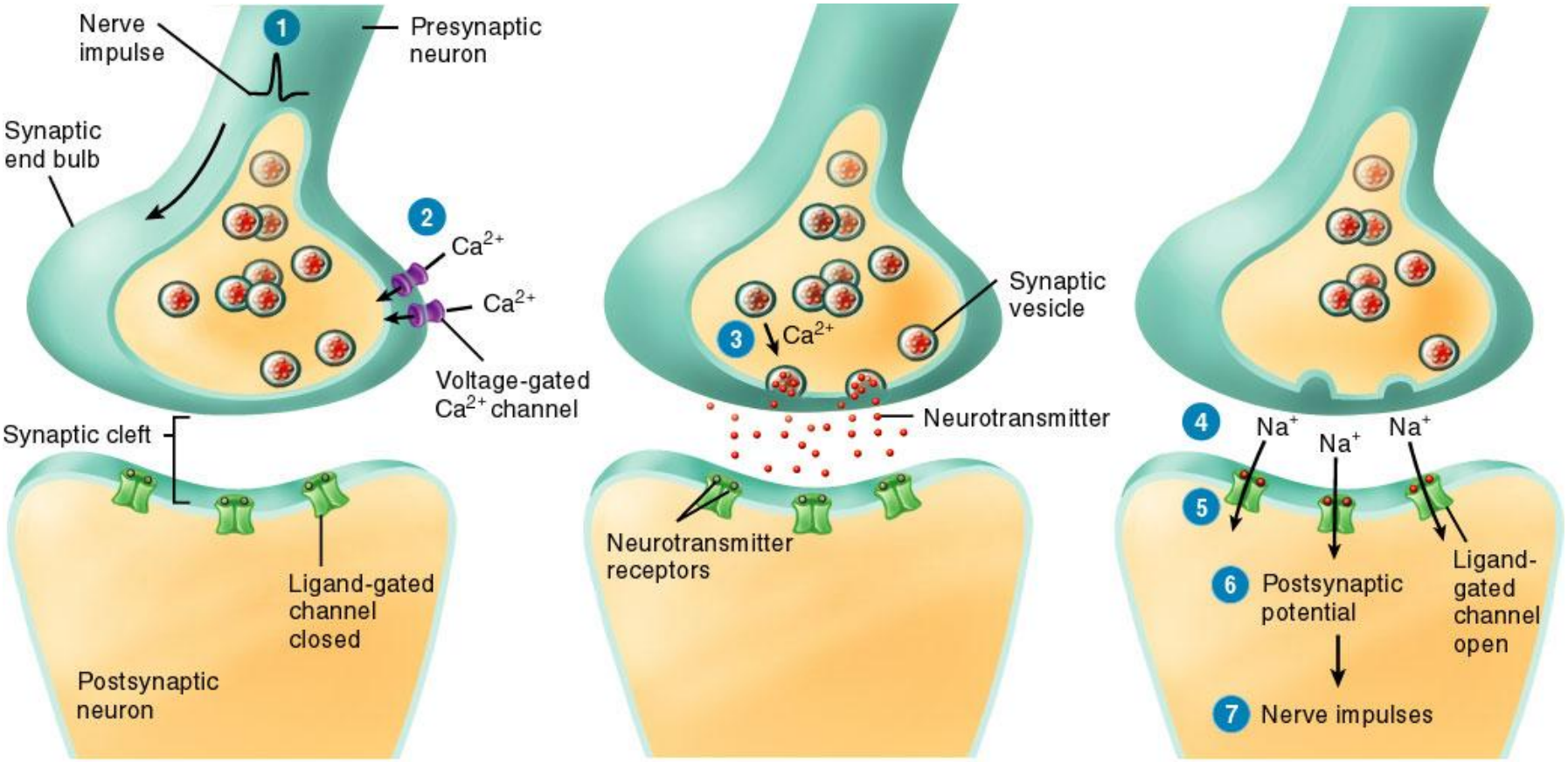

Na+ channel
K+ channel
Conductance (mmho/cm2)
30
20
10
0
Activation
Inactivat
−90 mV
+10 mV
−90 mV
Membrane potential
0
1
2
3
Time (milliseconds)

Figure 5–9



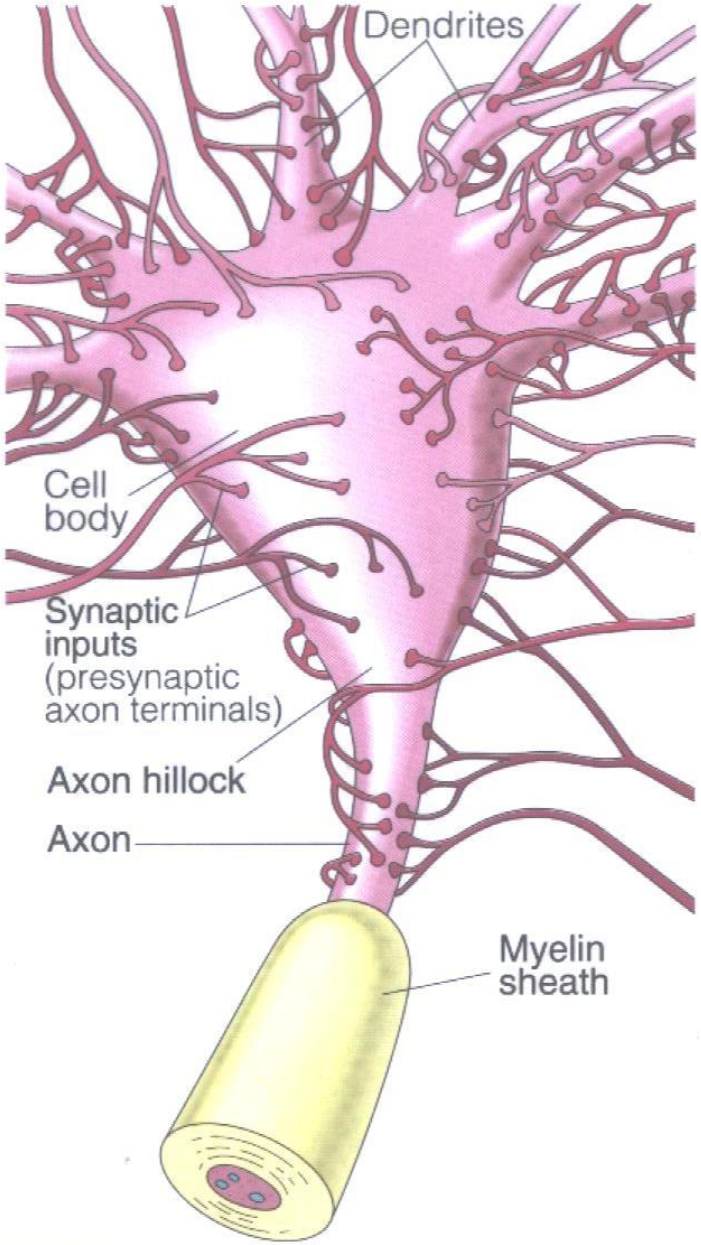

DENDRITES
CELL BODY
Axon collateral
Axon
Initial segment
Axon hillock
Mitochondrion
Node of Ranvier
Neurofibril
Nucleus
Cytoplasm
Nissl bodies
Nucleus of Schwann cell
Neurolemma of Schwann cell
(a) Parts of a motor neuron
Schwann Cell:
Cytoplasm
Myelin sheath
Neurolemma
Node of Ranvier
Neurofibril
Axon: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

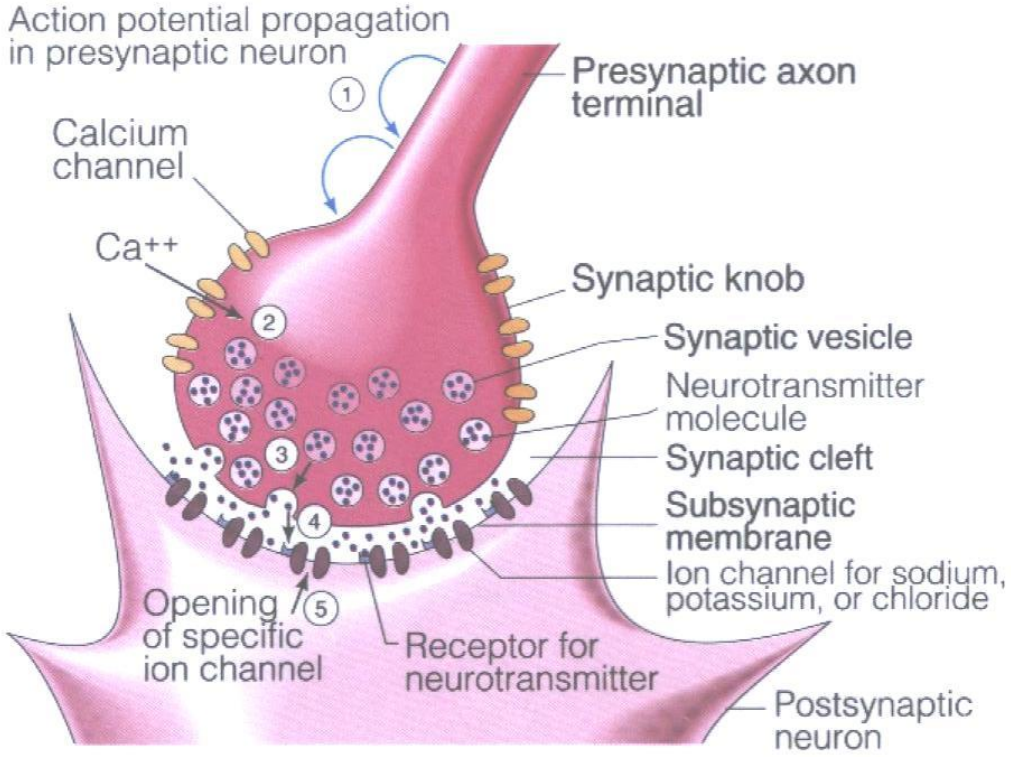

Time
1 msec
Cell body
Na+
Na+
Current flow due to opening of Na+ channels
Trigger zone
5 msec
Na+
Na+
10 msec
Na+
Na+
Leading edge of action potential
(a) Continuous conduction
1 msec
Cell body
Na+
Nodes of Ranvier
Na+
Current flow due to opening of Na+ channels
Trigger zone
5 msec
Na+
Na+
10 msec
Na+
Na+
(b) Saltatory conduction

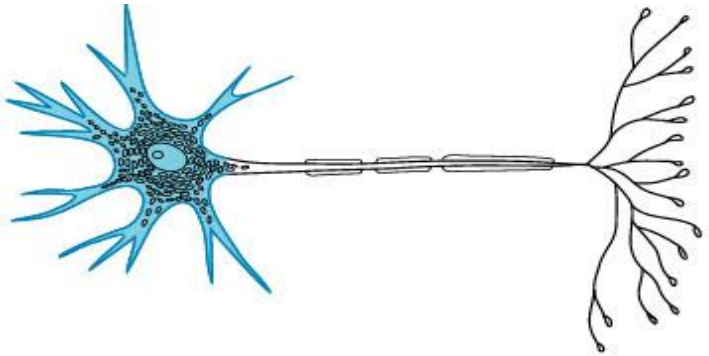

Nerve impulse
1
Presynaptic neuron
Synaptic end bulb
2
Ca^{2+}
Ca^{2+}
Voltage-gated Ca^{2+} channel
Synaptic cleft
Ligand-gated channel closed
Postsynaptic neuron
3
Ca^{2+}
Synaptic vesicle
Neurotransmitter
Neurotransmitter receptors
4
Na^{+}
Na^{+}
Na^{+}
5
6
Postsynaptic potential
Ligand-gated channel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

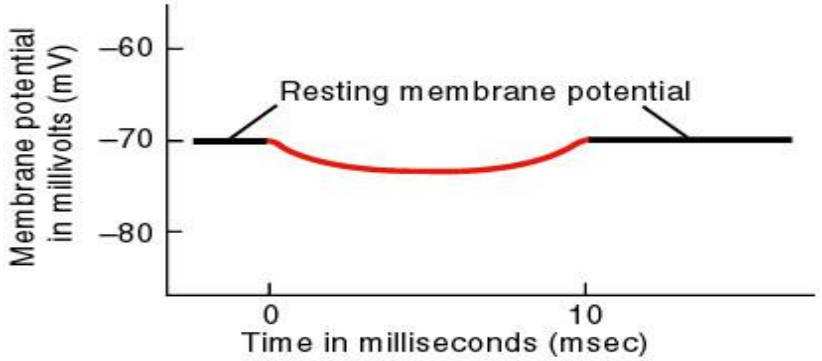
12.14

Synaptic Structure and Function

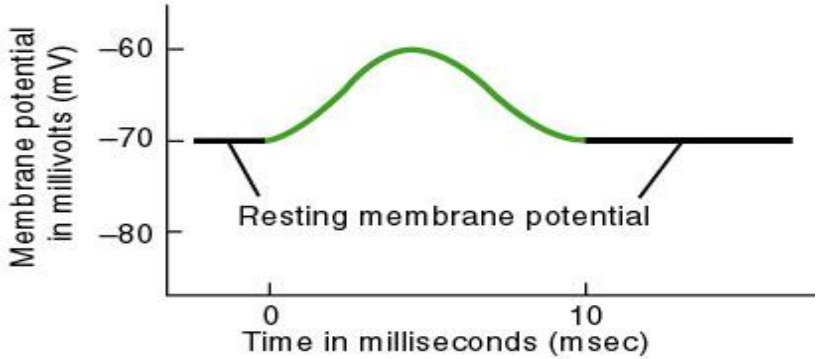




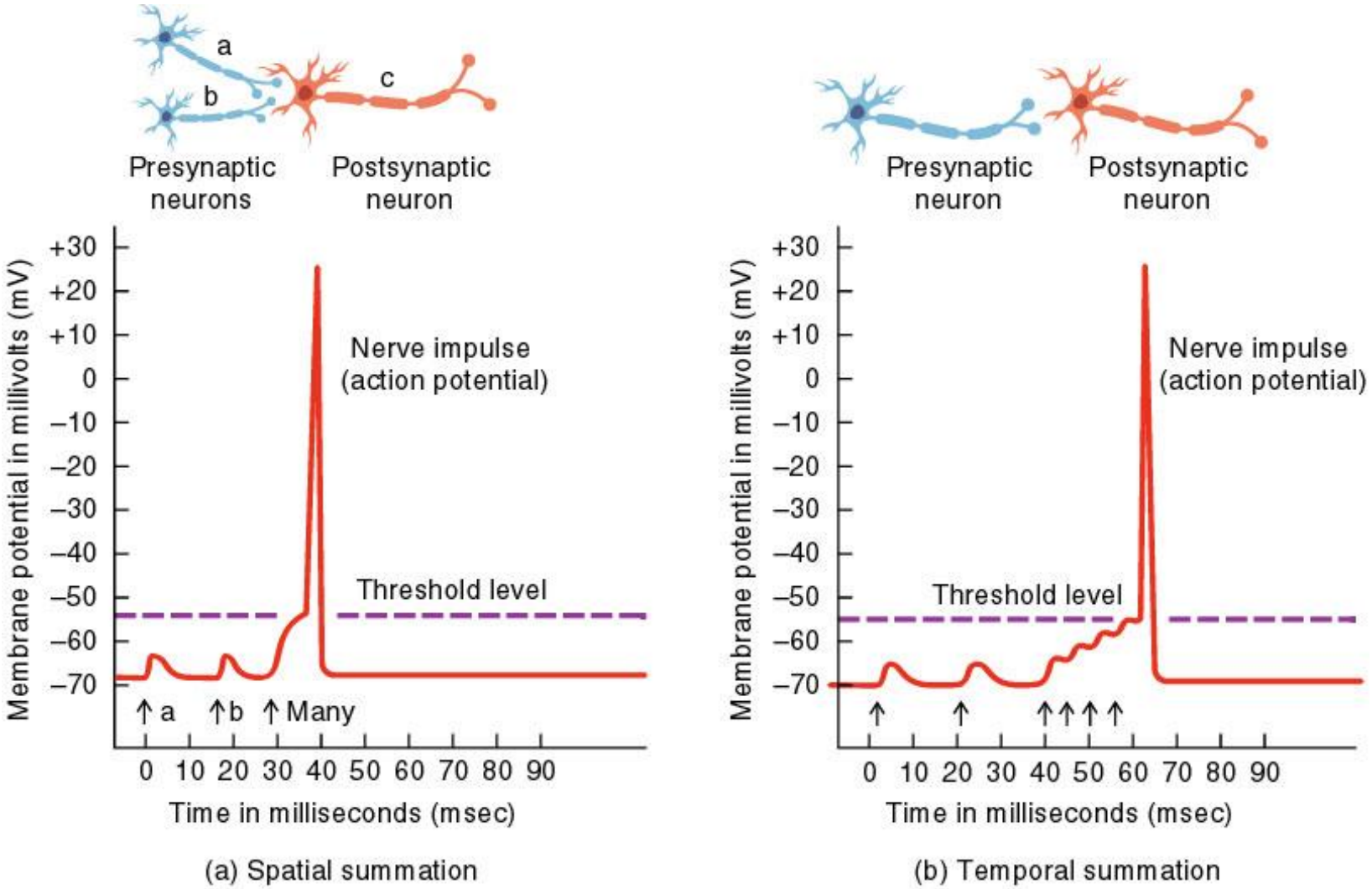




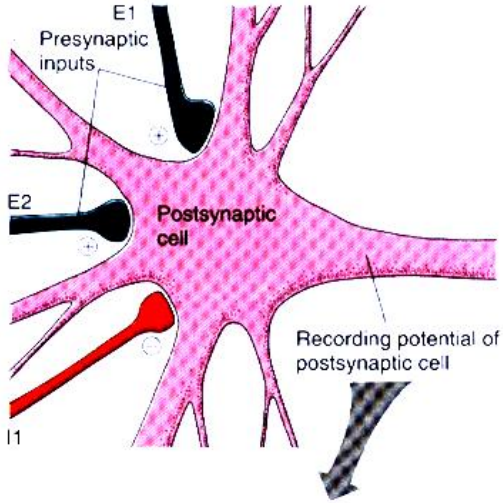
(a) Hyperpolarizing graded potential

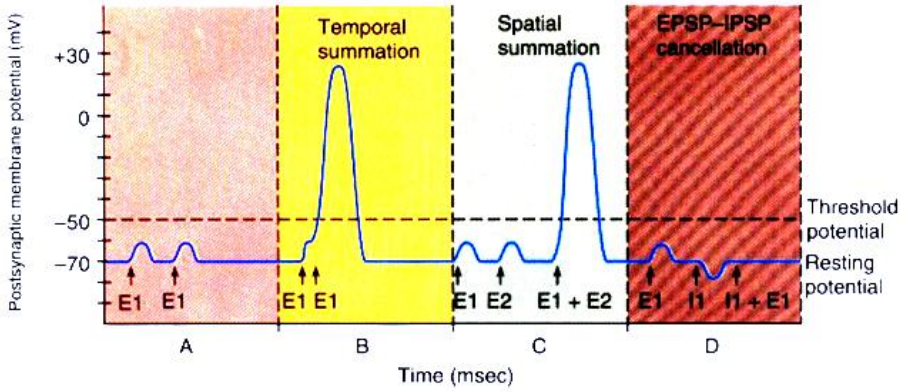


(b) Depolarizing graded potential


a
b
c
Presynaptic neurons
Postsynaptic neuron
Membrane potential in millivolts (mV)
+30
+20
+10
0
–10
–20
–30
–40
–50
–60
–70
Nerve impulse (action potential)
Threshold level
↑a
↑b
↑Many
0 10 20 30 40 50 60 70 80 90
Time in milliseconds (msec)
(a) Spatial summation
Presynaptic neuron
Postsynaptic neuron
Membrane potential in millivolts (mV)
Nerve impulse (action potential)
Threshold level
↑ ↑ ↑↑↑↑
0 10 20 30 40 50 60 70 80 90
Time in milliseconds (msec)
(b) Temporal summation

Determination of Grand Postsynaptic Potential





Acetate 28 (Figure 4-18)

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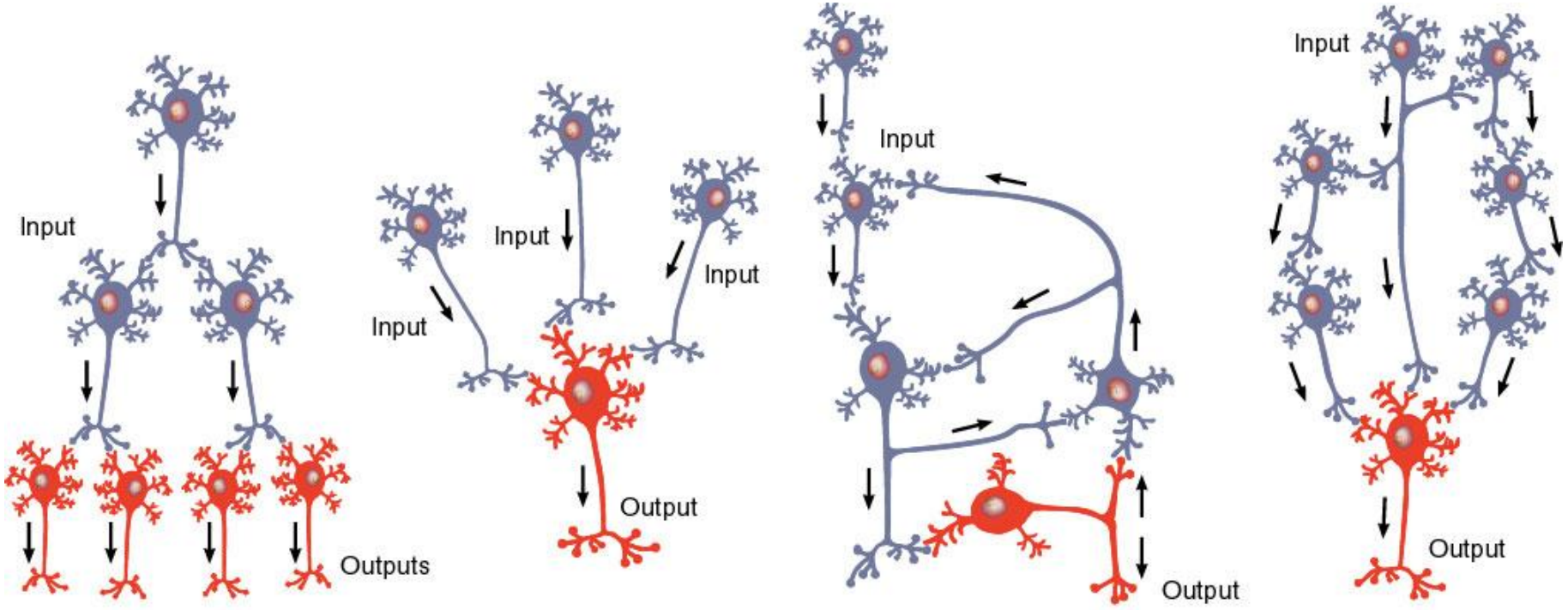

(a) Diverging circuit

(b) Converging circuit

(c) Reverberating circuit

(d) Parallel after-discharge circuit