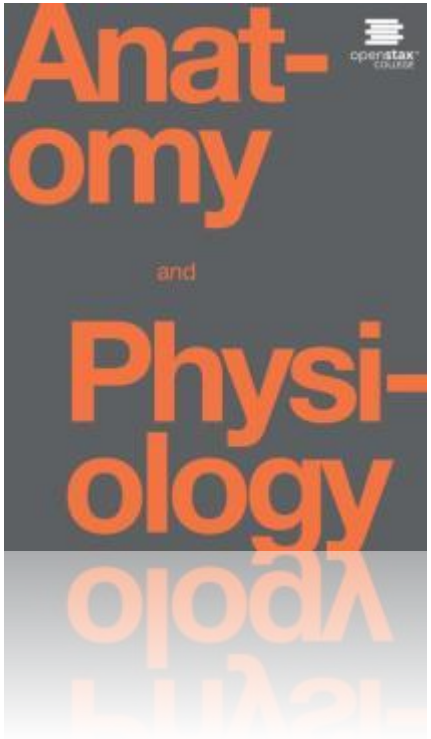
ANATOMY & PHYSIOLOGY

Chapter 12 THE NERVOUS SYSTEM AND NERVOUS TISSUE

PowerPoint Image Slideshow



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MAJOR CHAPTER OBJECTIVES

- Name the major divisions of the nervous system, both anatomical and functional
- Describe the functional and structural differences between gray matter and white matter structures
- Name the parts of the multipolar neuron in order of polarity
- List the types of glial cells and assign each to the proper division of the nervous system, along with their function(s)
- Distinguish the major functions of the nervous system: sensation, integration, and response
- Describe the components of the membrane that establish the resting membrane potential
- Describe the changes that occur to the membrane that result in the action potential
- Explain the differences between types of graded potentials
- Categorize the major neurotransmitters by chemical type and effect

Add:

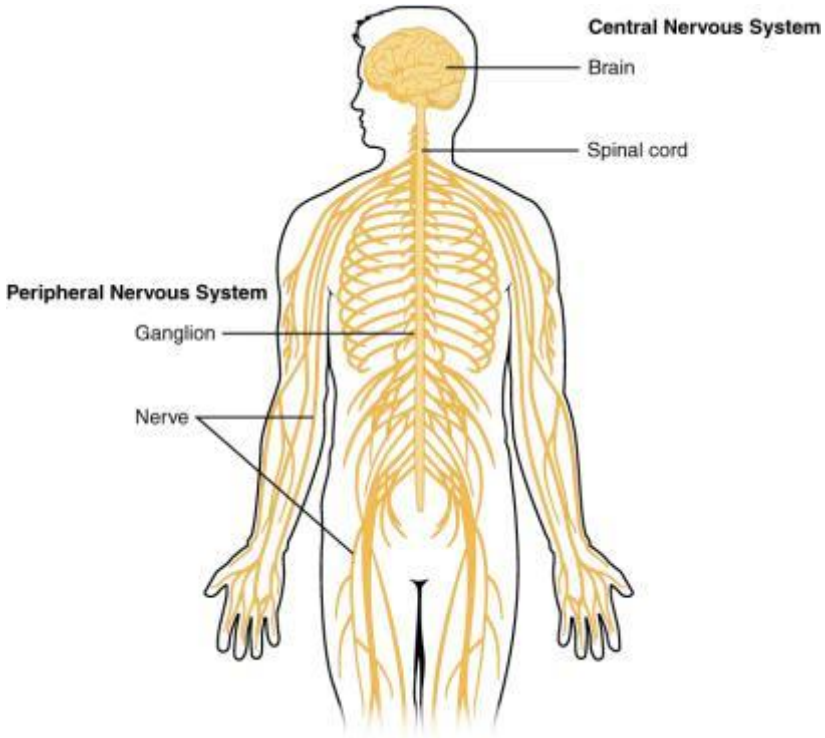
- Be able to discuss normal development and selected aging issues
- Be able to discuss selected, associated disorders

12.1 BASIC STRUCTURE AND FUNCTION OF THE NERVOUS SYSTEM
MAJOR SECTION OBJECTIVES

- Identify the anatomical and functional divisions of the nervous system
  - Central (CNS)
  - Peripheral (PNS)

  or
  - Somatic (SNS)
  - Autonomic (ANS)
- Relate the functional and structural differences between gray matter and white matter structures of the nervous system to the structure of neurons
- List the basic functions of the nervous system
  - Sensation (Input / Afferent signaling)
  - Integration (Analysis)
  - Response (Output / Efferent signaling)

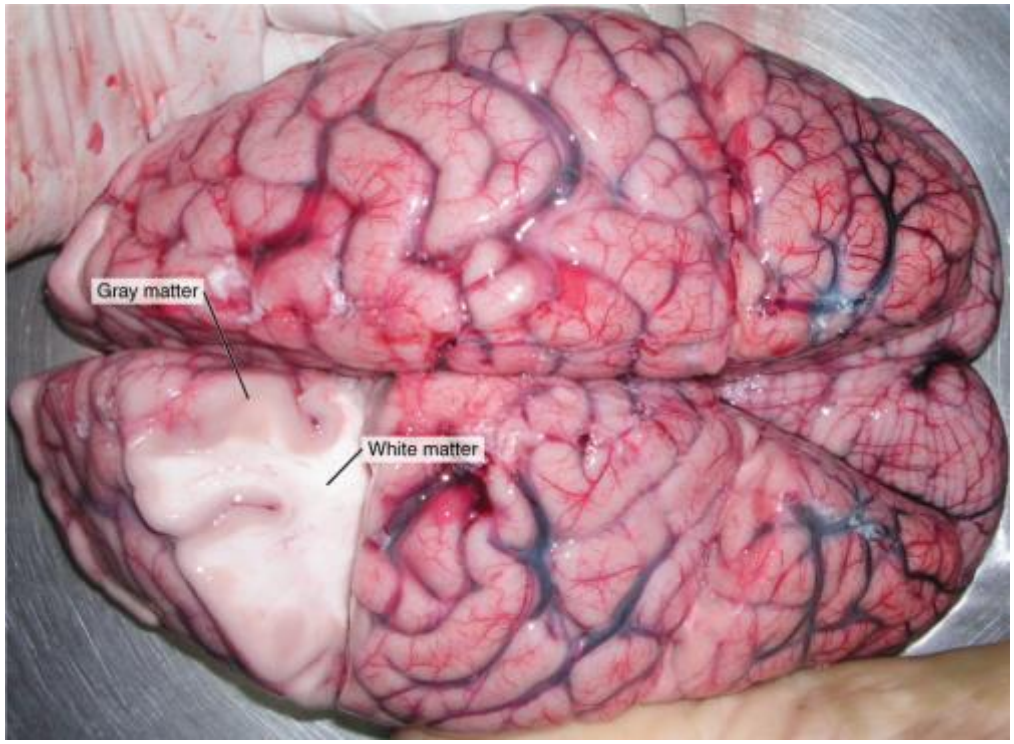
FIGURE 12.2



Central and Peripheral Nervous System

The structures of the PNS are referred to as ganglia and nerves, which can be seen as distinct structures. The equivalent structures in the CNS are not obvious from this overall perspective and are best examined in prepared tissue under the microscope.

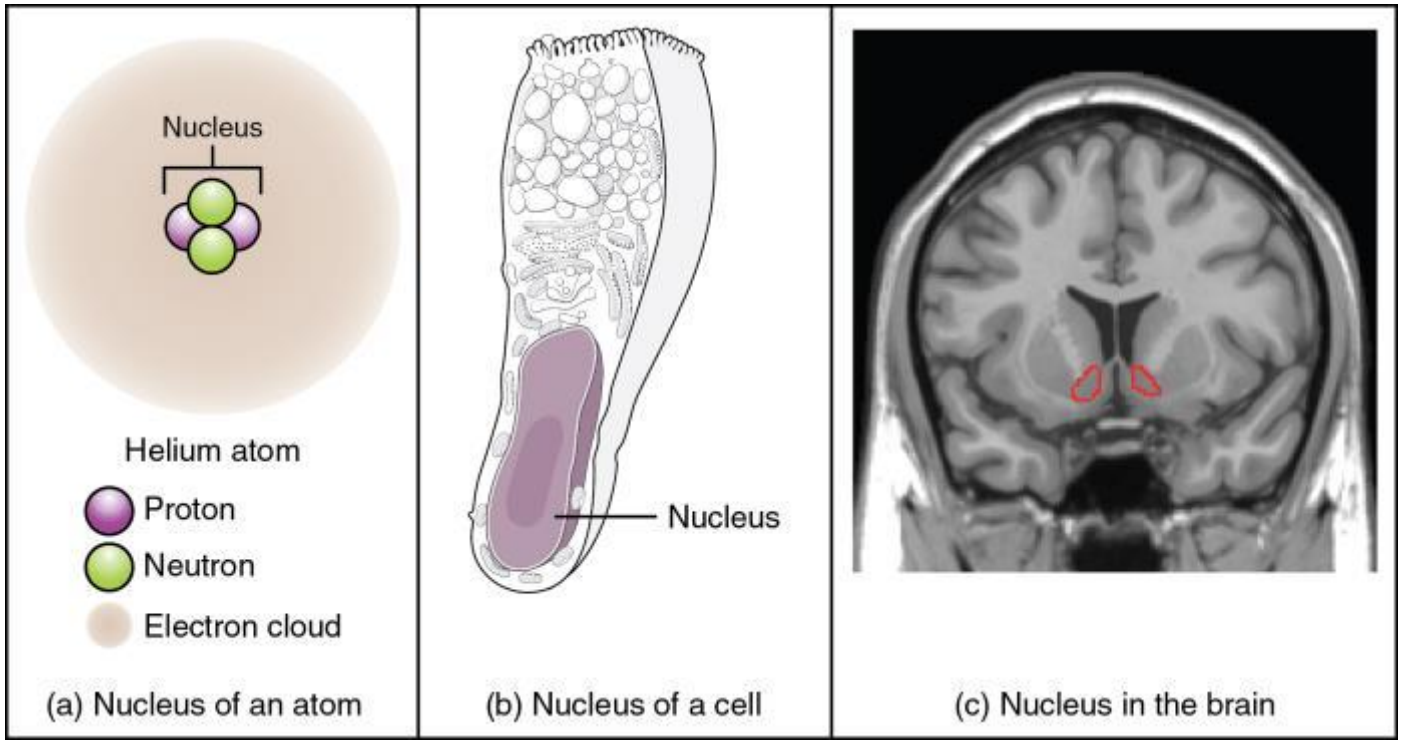
FIGURE 12.3



Gray Matter and White Matter

A brain removed during an autopsy, with a partial section removed, shows white matter surrounded by gray matter. Gray matter makes up the outer cortex of the brain. (credit: modification of work by “Suseno”/Wikimedia Commons)

FIGURE 12.4



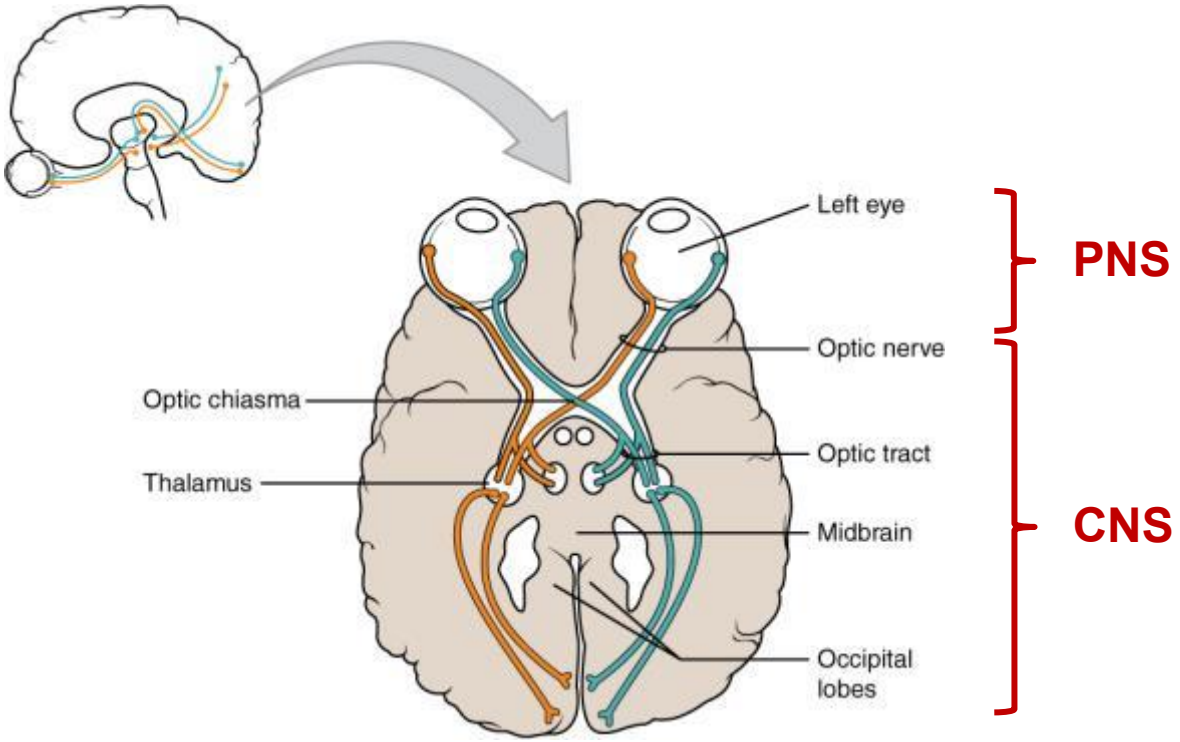
What Is a Nucleus?

(a) The nucleus of an atom contains its protons and neutrons.

(b) The nucleus of a cell is the organelle that contains DNA.

(c) A nucleus in the CNS is a localized center of function with the cell bodies of several neurons, shown here circled in red. (credit c: “Was a bee”/Wikimedia Commons)

FIGURE 12.5



Optic Nerve Versus Optic Tract

This drawing of the connections of the eye to the brain shows the optic nerve extending from the eye to the chiasm, where the structure continues as the optic tract. The same axons extend from the eye to the brain through these two bundles of fibers, but the chiasm represents the border between peripheral and central.

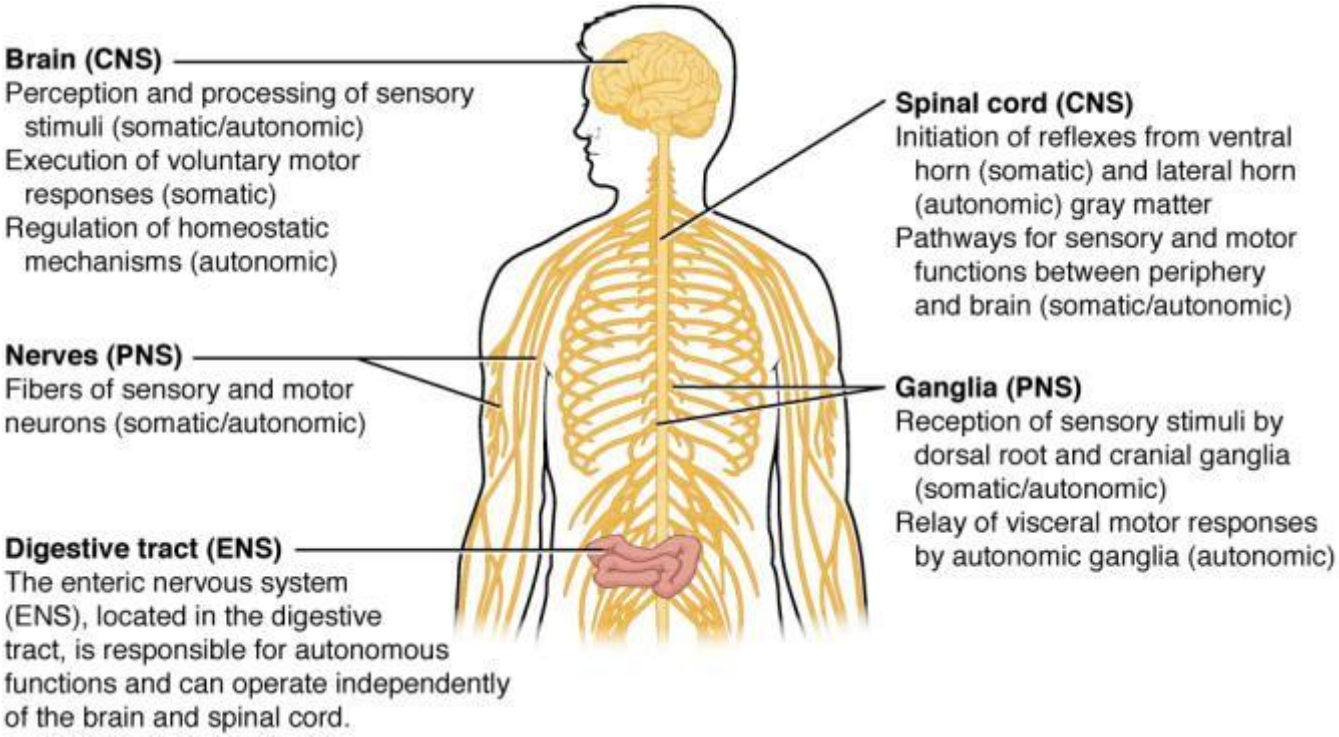
N.B.:
In Figure 12.5, the two colors differentiate the left/right origin of the visual stimuli – not whether the structures are peripheral (nerves) or central (tracts)!

TABLE 12.1

Structures of the CNS and PNS

Structures	CNS	PNS
Group of Neuron Cell Bodies (i.e., gray matter)	Nucleus	Ganglion
Bundle of Axons (i.e., white matter)	Tract	Nerve

FIGURE 12.6



Somatic, Autonomic, and Enteric Structures of the Nervous System

Somatic structures include the spinal nerves, both motor and sensory fibers, as well as the sensory ganglia (posterior root ganglia and cranial nerve ganglia). Autonomic structures are found in the nerves also, but include the sympathetic and parasympathetic ganglia. The enteric nervous system includes the nervous tissue within the organs of the digestive tract.

RELATIONSHIPS BETWEEN THE SUBDIVISIONS OF THE NERVOUS SYSTEM

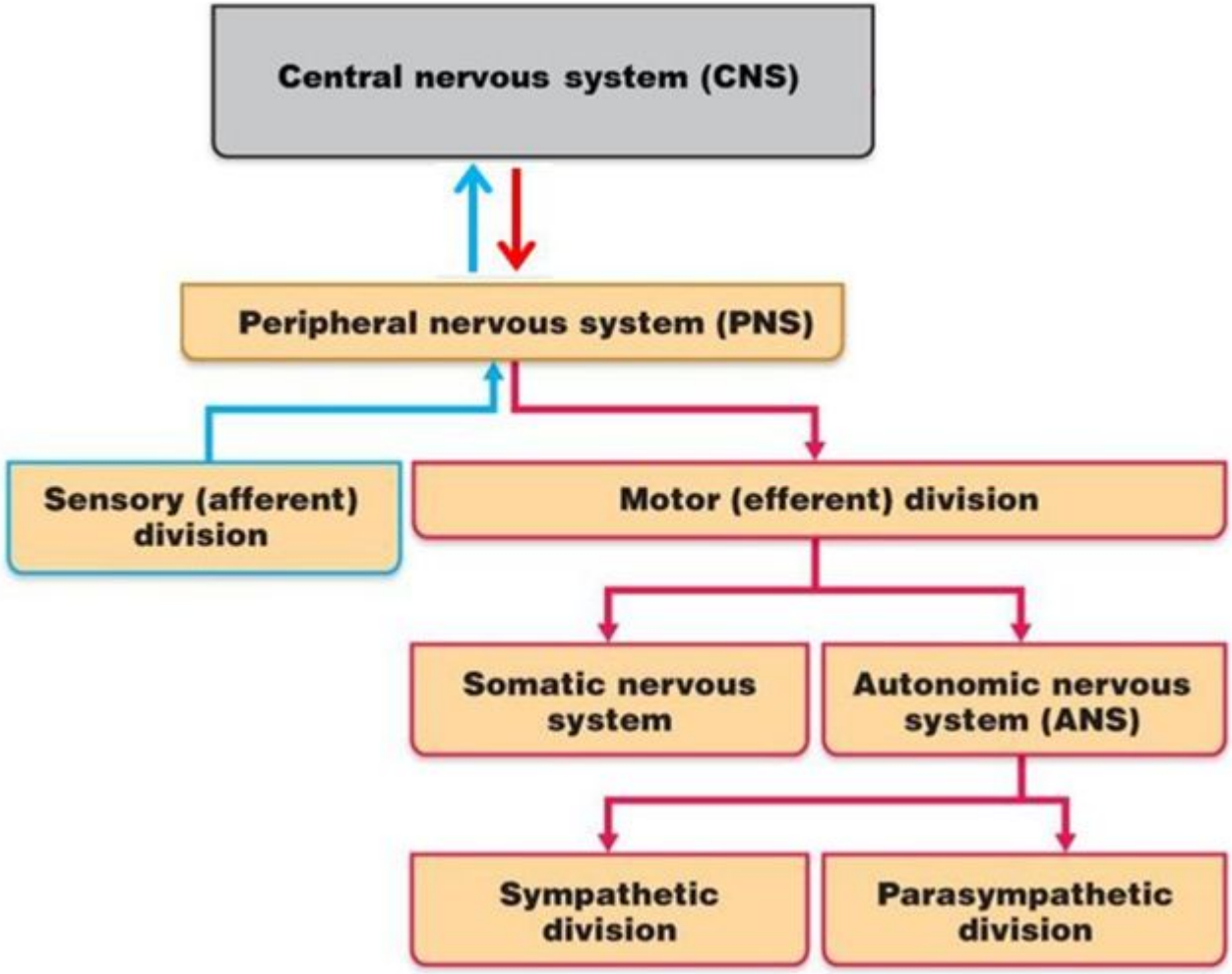


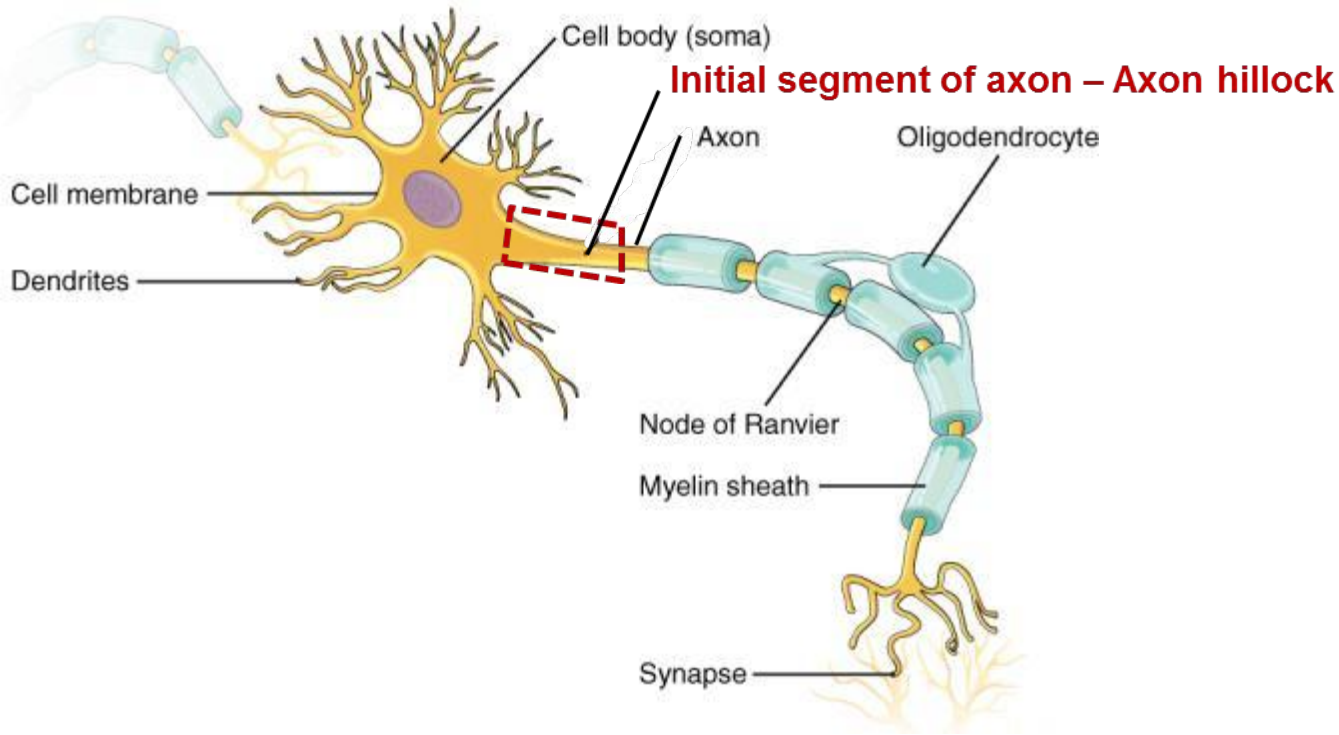
Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

12.2 NERVOUS TISSUE
MAJOR SECTION OBJECTIVES

- Describe the basic structure of a neuron
- Identify the different types of neurons on the basis of polarity
- List the glial cells of the CNS and describe their function
- List the glial cells of the PNS and describe their function

FIGURE 12.8

Add

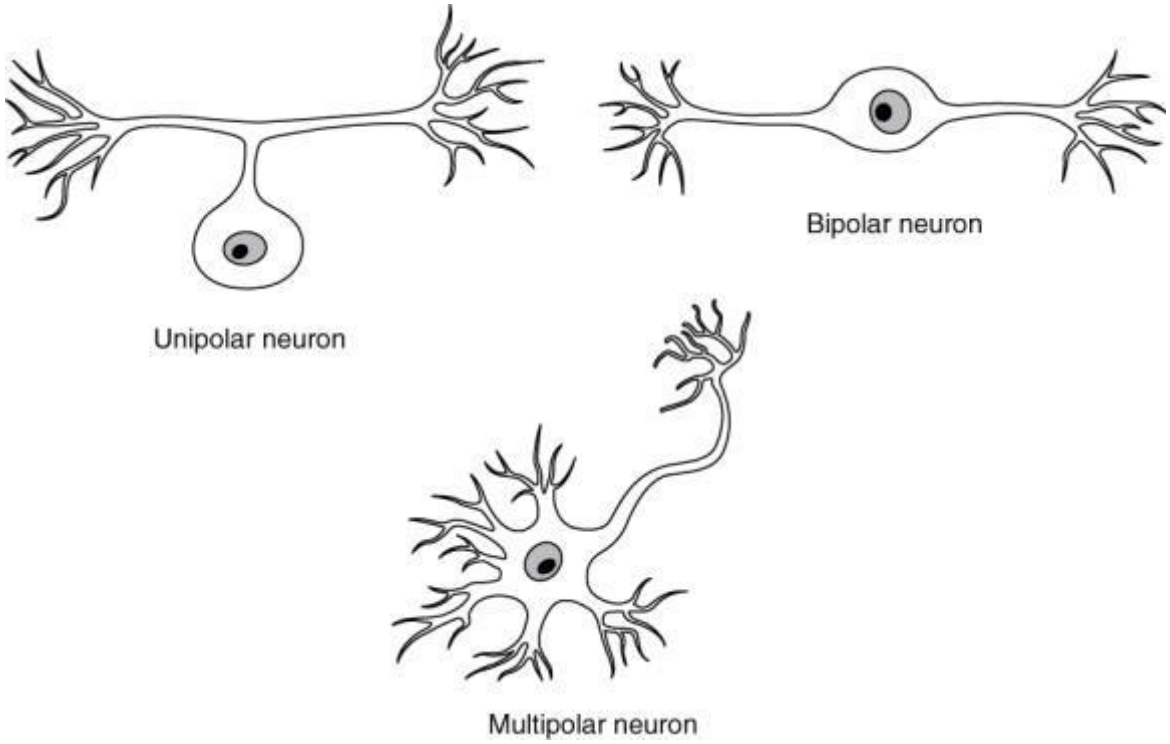


Parts of a Neuron

The major parts of the neuron are labeled on a multipolar neuron from the CNS.

N.B.: the axon's initial segment is more often called "**axon hillock**" in the literature.
N.B. The synaptic end bulbs are also called "**terminal boutons**".

FIGURE 12.9

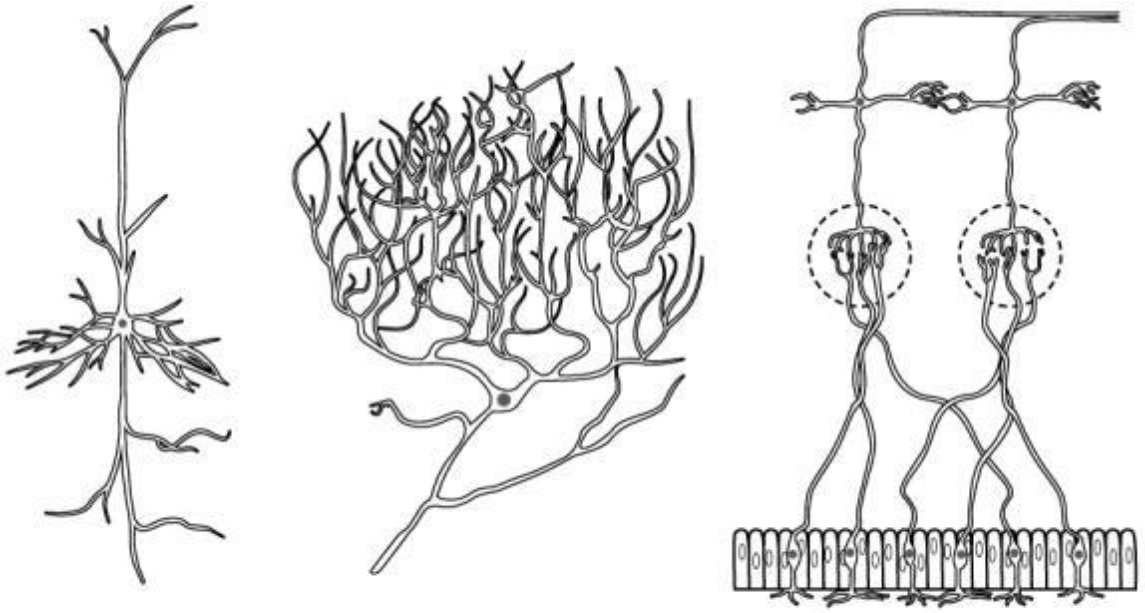


Neuron Classification by Shape

Unipolar cells have one process that includes both the axon and dendrite. Bipolar cells have two processes, the axon and a dendrite. Multipolar cells have more than two processes, the axon and two or more dendrites.

N.B.: The type of unipolar neuron above is often referred to as "**pseudo-unipolar**."

FIGURE 12.10



(a) Pyramidal cell of the cerebral cortex

(b) Purkinje cell of the cerebellar cortex

(c) Olfactory cells in the olfactory epithelium and olfactory bulbs

Other Neuron Classifications

Three examples of neurons that are classified on the basis of other criteria. (a) The pyramidal cell is a multipolar cell with a cell body that is shaped something like a pyramid. (b) The Purkinje cell in the cerebellum was named after the scientist who originally described it. (c) Olfactory neurons are named for the functional group to which they belong.

MODIFIED TABLE 12.2

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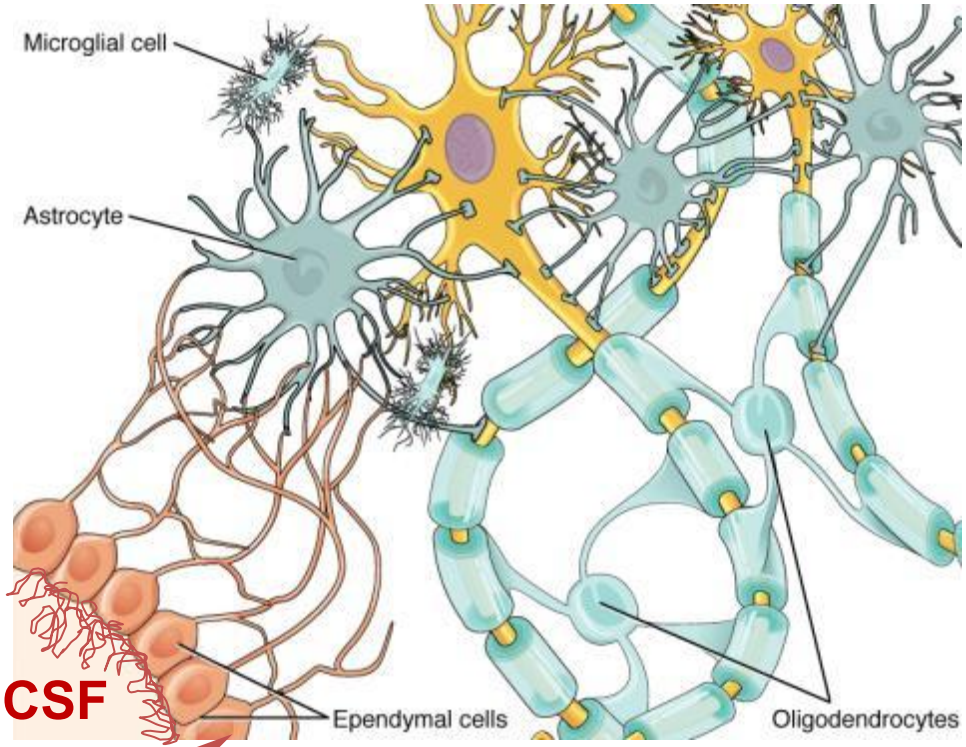
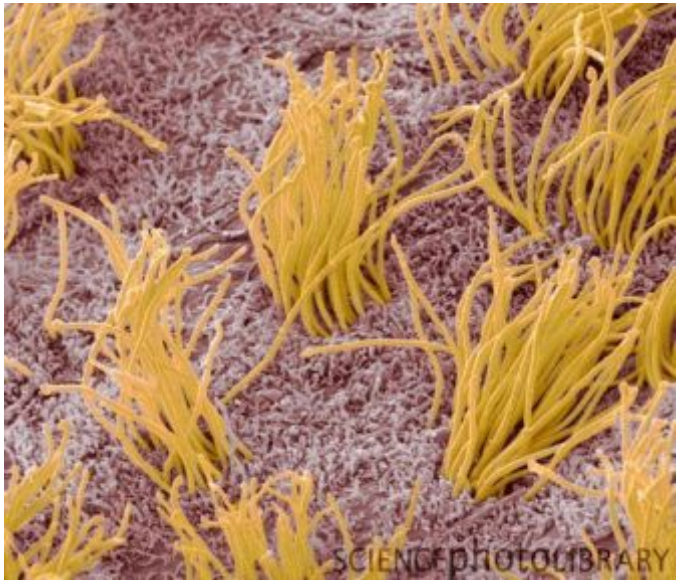
Basic Function and Glial Cell Types by Location

Basic function	CNS glia	PNS glia
Support	Astrocyte*	Satellite cell
Insulation, myelination	Oligodendrocyte	Schwann cell
Immune surveillance, phagocytosis	Microglia	-
Lining neural cavities, creating CSF	Ependymal cell	-

* Also have an important role in establishing the blood-brain barrier (BBB)

FIGURE 12.11





Add **CSF**

Glial Cells of the CNS

The CNS has astrocytes, oligodendrocytes, microglia, and ependymal cells that support the neurons of the CNS in several ways.

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Image source:
Science Photo Library, accessed 07/2017.

THE FOUR MAJOR GLIAL CELL TYPES OF THE CNS

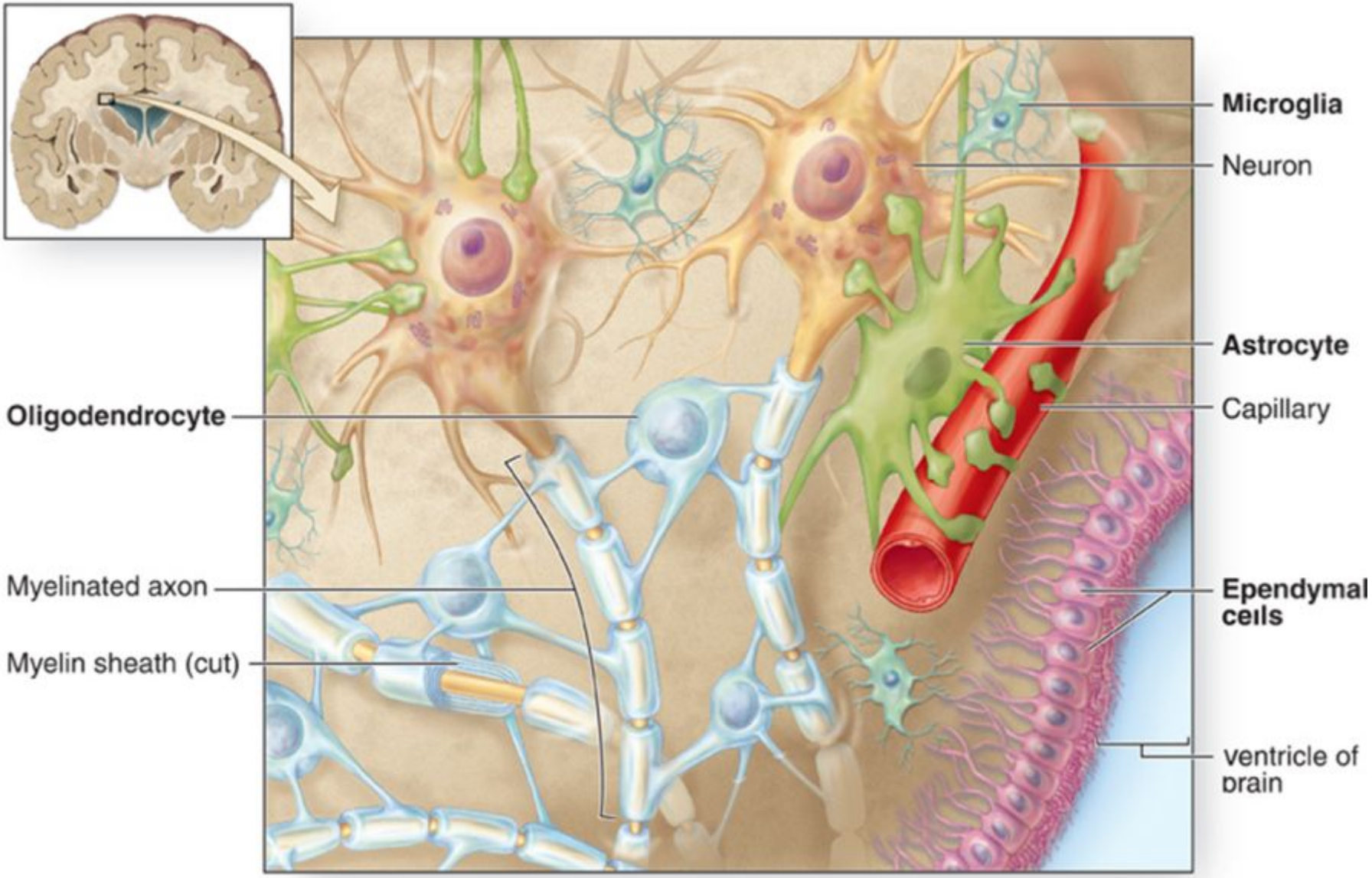
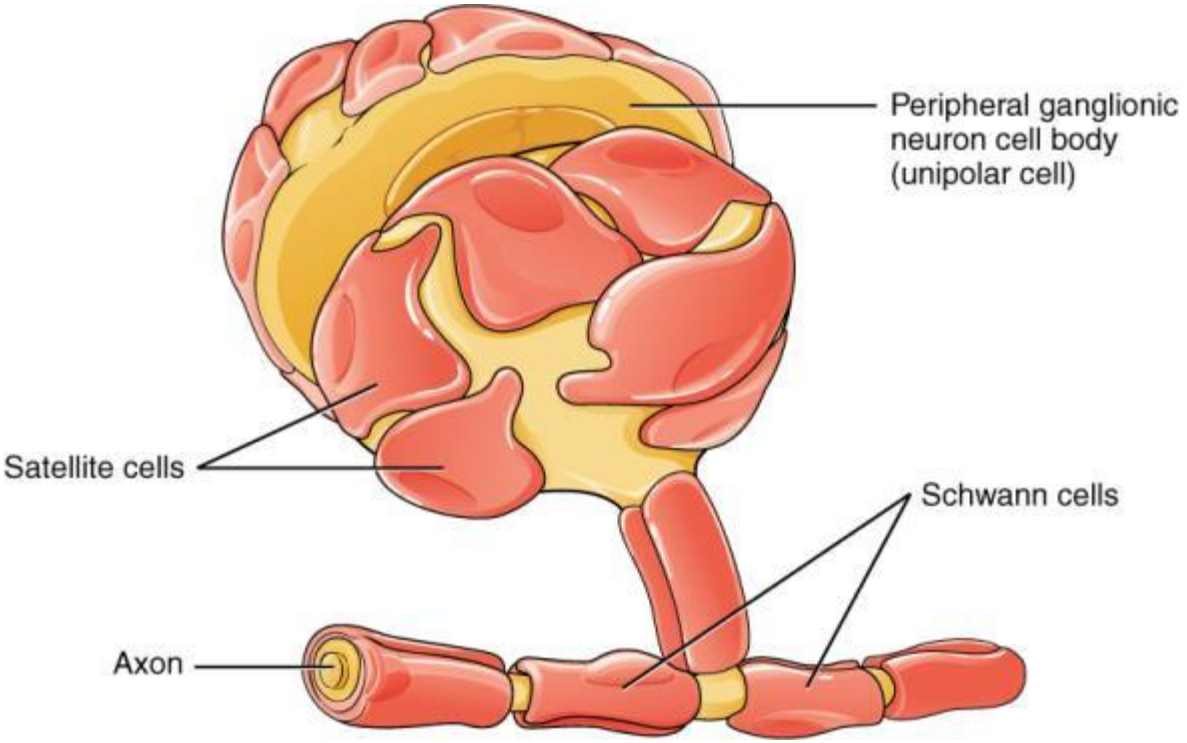


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

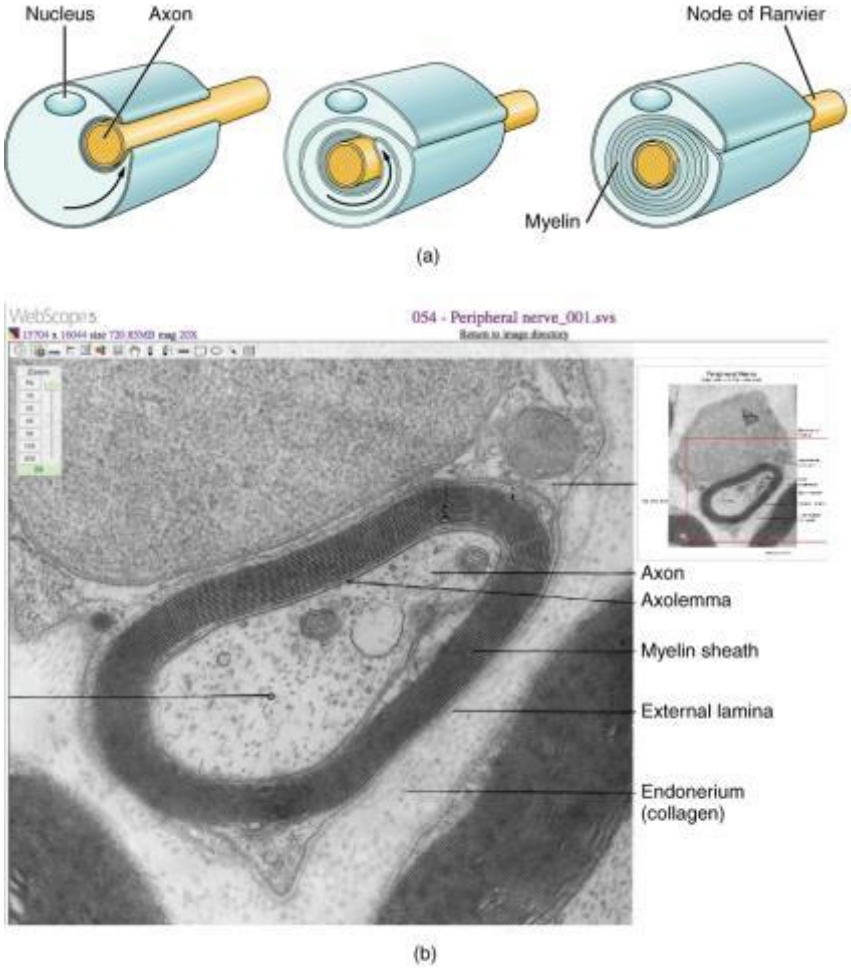
FIGURE 12.12



Glial Cells of the PNS

The PNS has satellite cells and Schwann cells.

FIGURE 12.13



The Process of Myelination

Myelinating glia wrap several layers of cell membrane around the cell membrane of an axon segment. A single Schwann cell insulates a segment of a peripheral nerve, whereas in the CNS, an oligodendrocyte may provide insulation for a few separate axon segments. EM × 1,460,000. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

12.3 NERVOUS TISSUE
MAJOR SECTION OBJECTIVES

- Distinguish the major functions of the nervous system:
  - sensation
  - integration
  - response
- List the sequence of events in a simple sensory receptor–motor response pathway

FIGURE 12.14

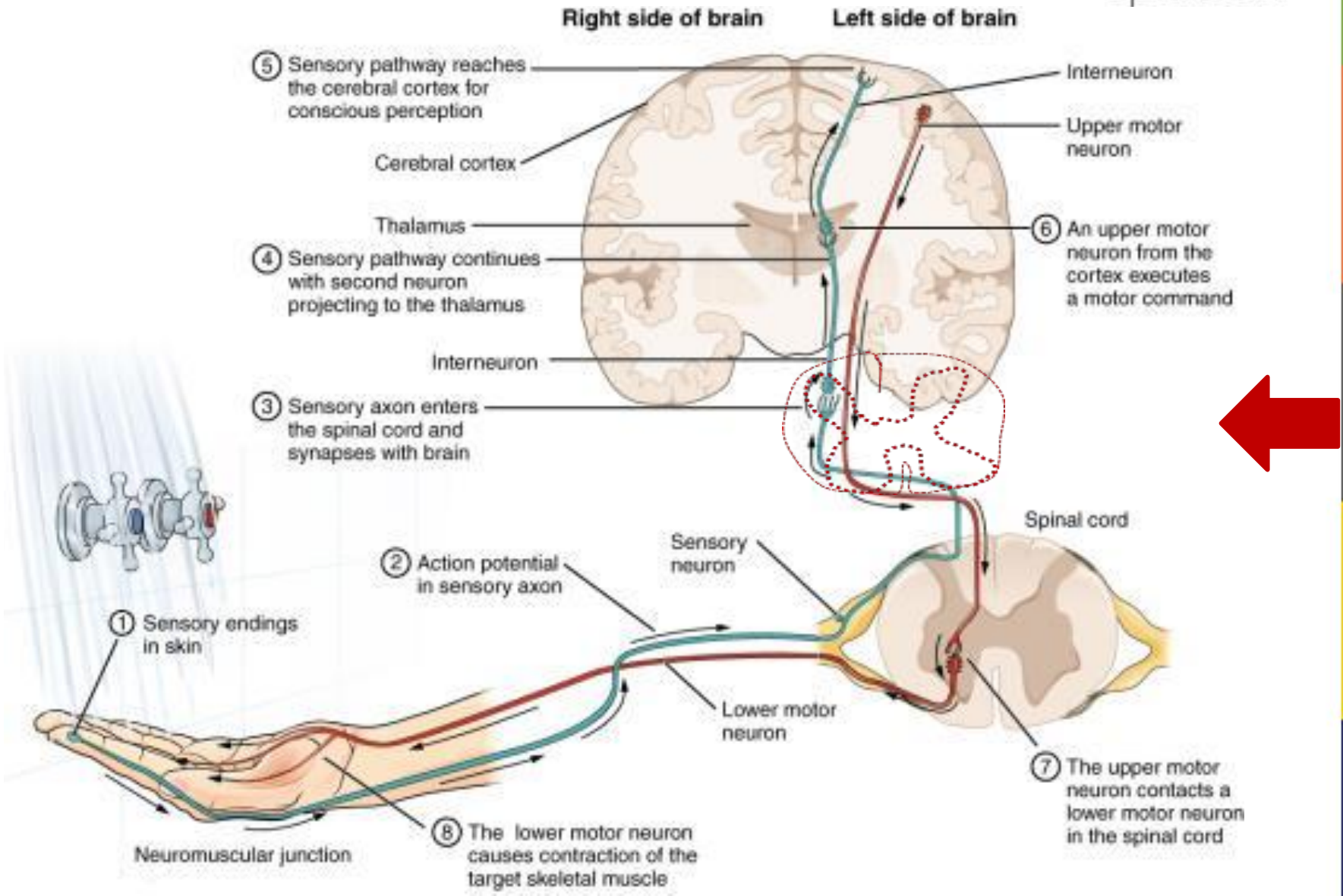
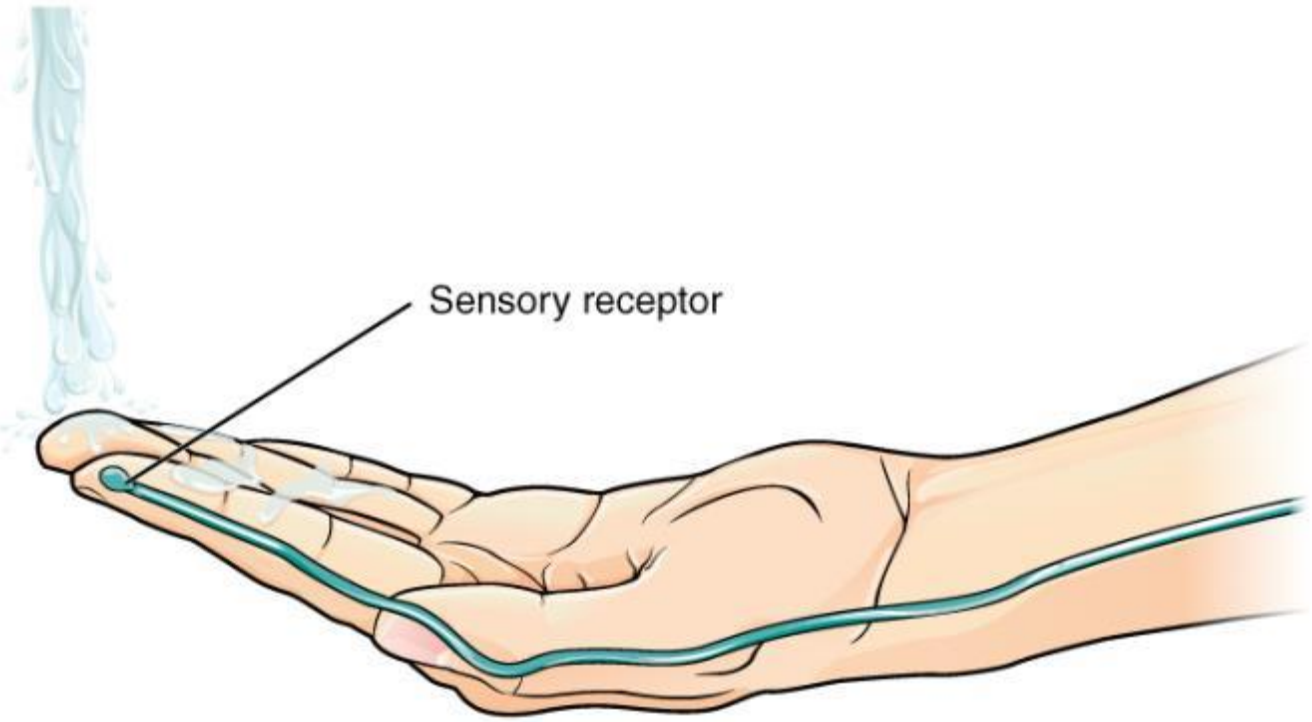

Right side of brain
Left side of brain
5 Sensory pathway reaches the cerebral cortex for conscious perception
Cerebral cortex
Interneuron
Upper motor neuron
Thalamus
6 An upper motor neuron from the cortex executes a motor command
4 Sensory pathway continues with second neuron projecting to the thalamus
Interneuron
3 Sensory axon enters the spinal cord and synapses with brain
Spinal cord
Sensory neuron
2 Action potential in sensory axon
1 Sensory endings in skin
Lower motor neuron
7 The upper motor neuron contacts a lower motor neuron in the spinal cord
Neuromuscular junction
8 The lower motor neuron causes contraction of the target skeletal muscle

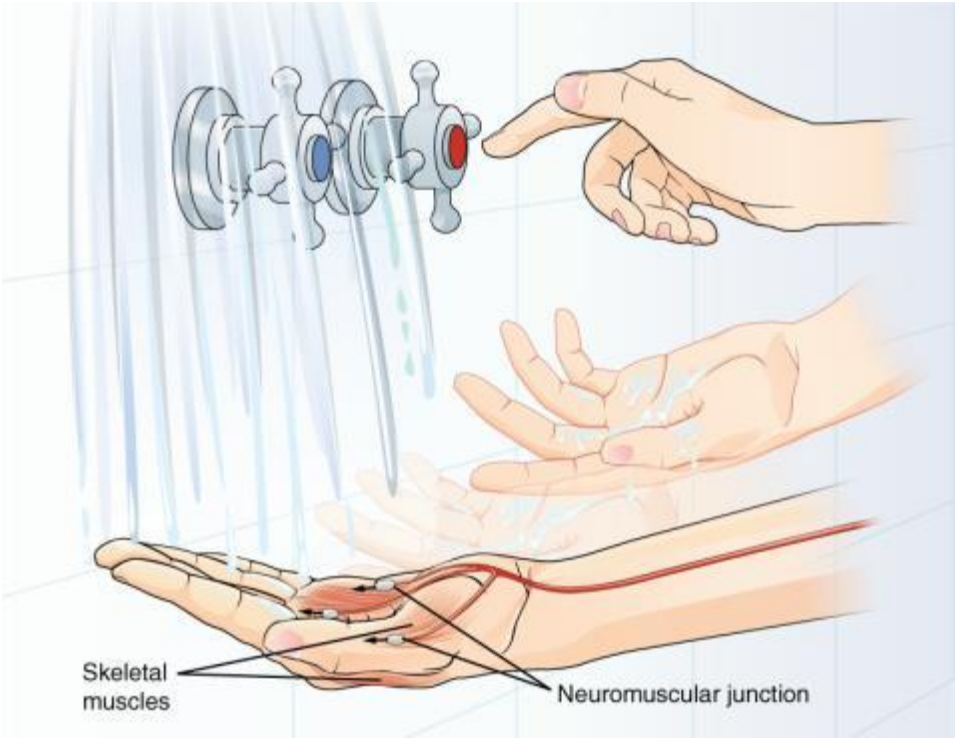
FIGURE 12.15



The Sensory Input

Receptors in the skin sense the temperature of the water.

FIGURE 12.16



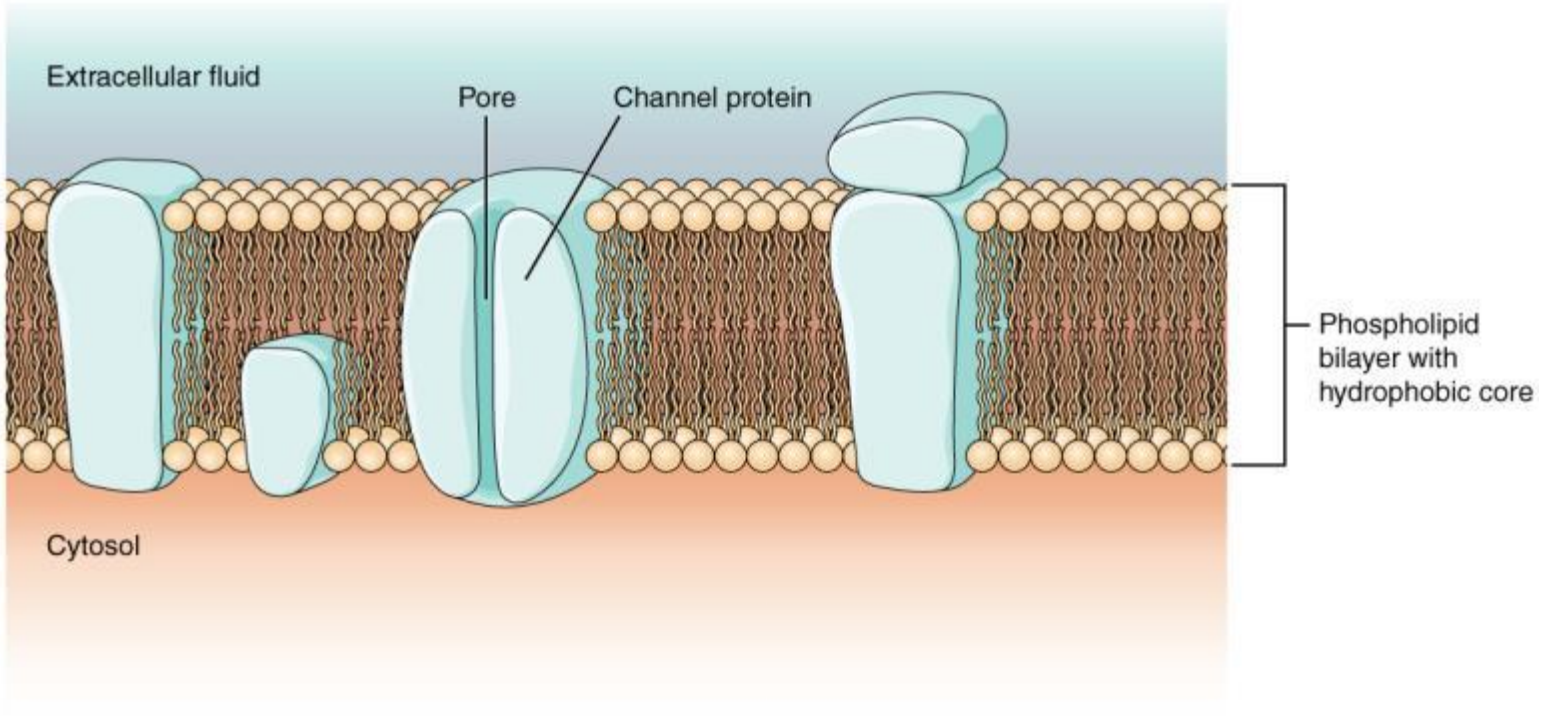
The Motor Response

On the basis of the sensory input and the integration in the CNS, a motor response is formulated and executed.

12.4 THE ACTION POTENTIAL
MAJOR SECTION OBJECTIVES

- Describe the components of the membrane that establish the resting membrane potential
- Describe the changes that occur to the membrane that result in the action potential

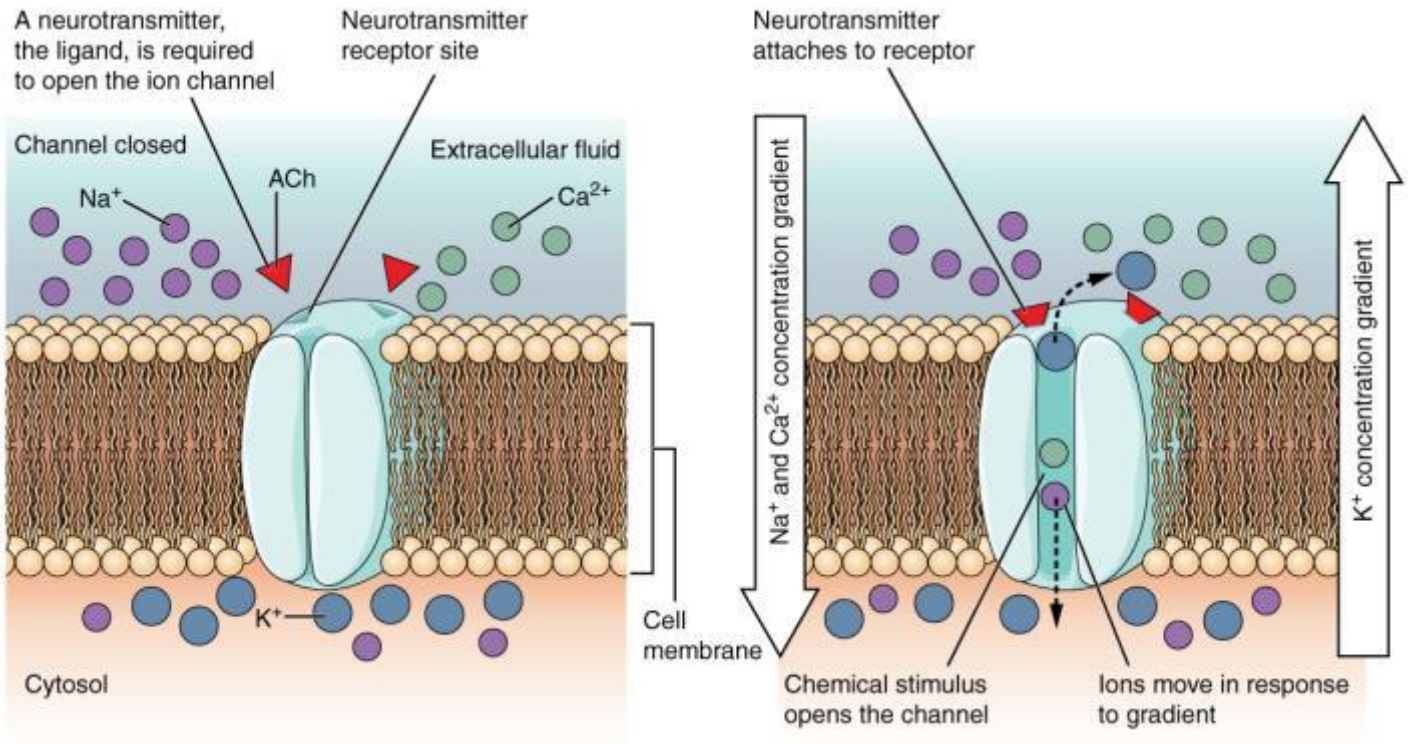
FIGURE 12.17



Cell Membrane and Transmembrane Proteins

The cell membrane is composed of a phospholipid bilayer and has many transmembrane proteins, including different types of channel proteins that serve as ion channels.

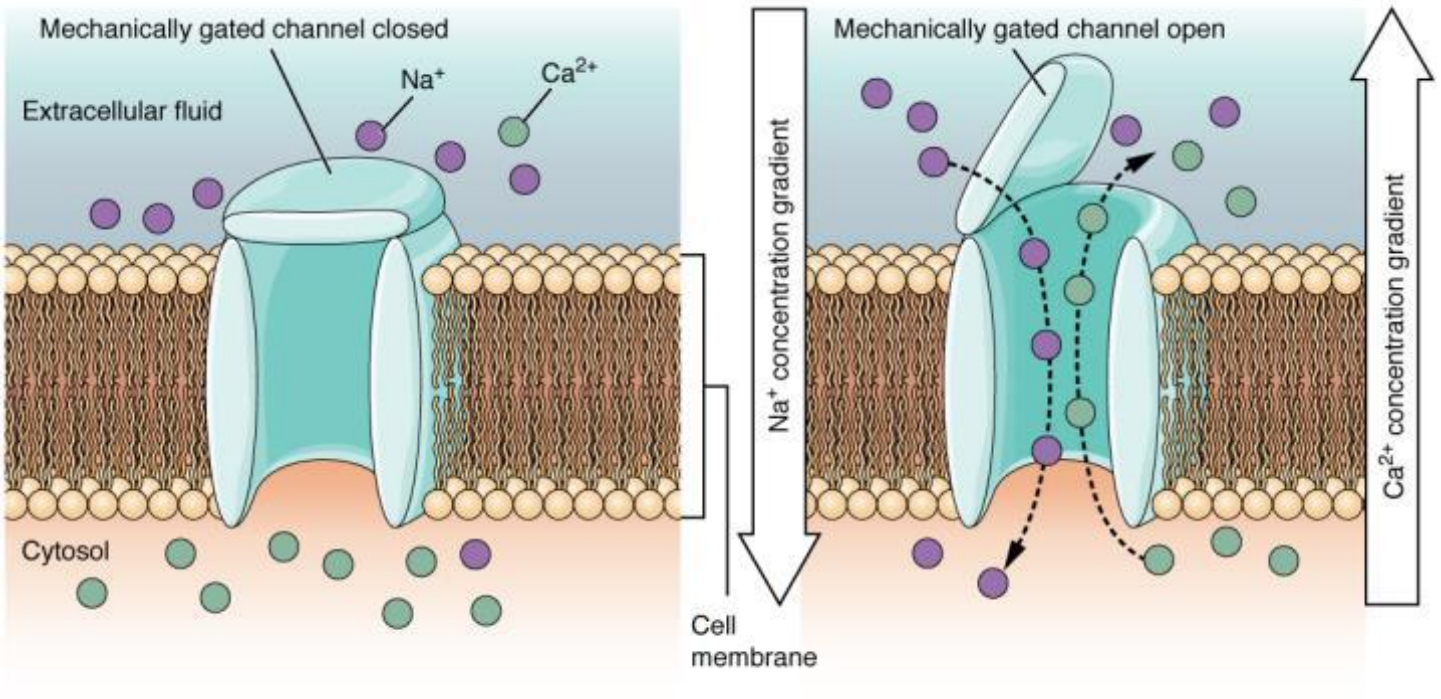
FIGURE 12.18



Ligand-Gated Channels

When the ligand, in this case the neurotransmitter acetylcholine, binds to a specific location on the extracellular surface of the channel protein, the pore opens to allow select ions through. The ions, in this case, are cations of sodium, calcium, and potassium.

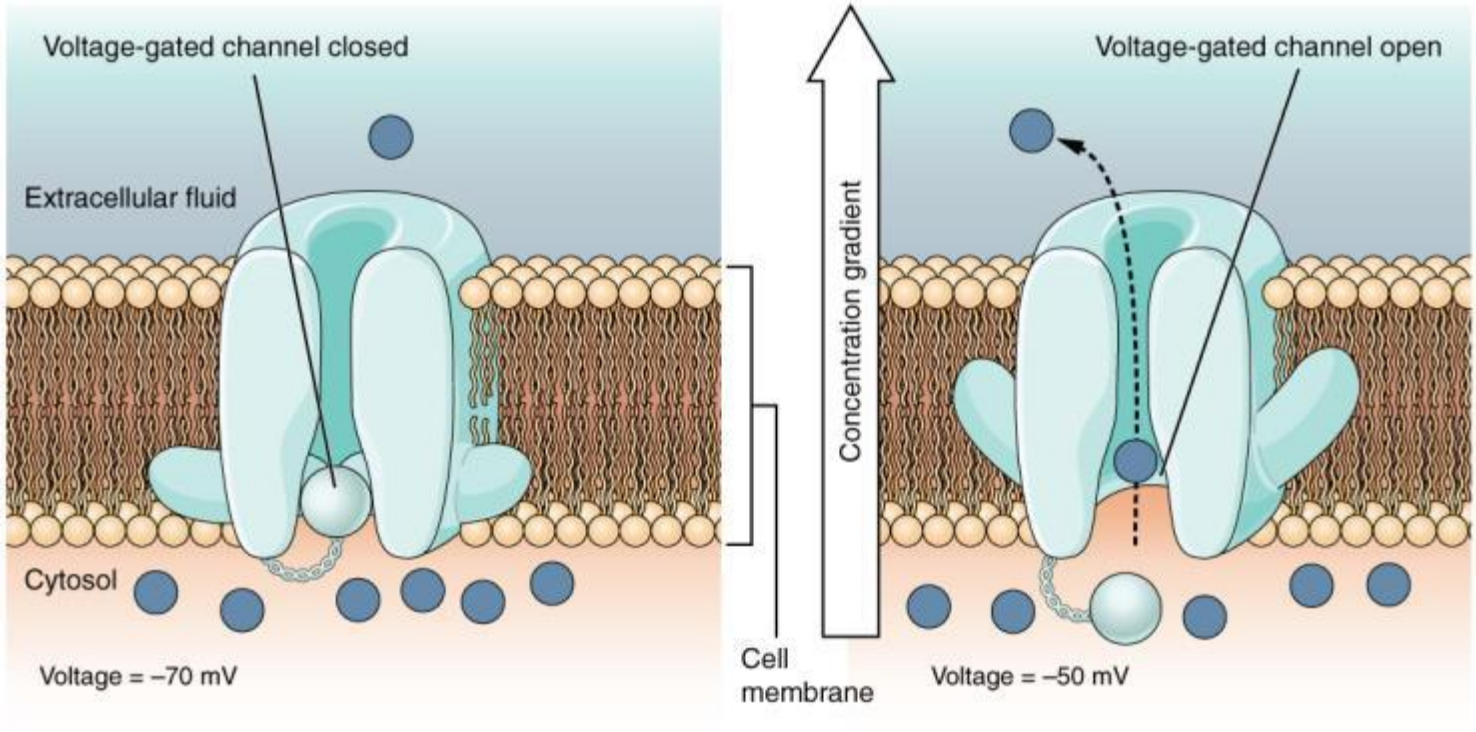
FIGURE 12.19



Mechanically Gated Channels

When a mechanical change occurs in the surrounding tissue, such as pressure or touch, the channel is physically opened. Thermoreceptors work on a similar principle. When the local tissue temperature changes, the protein reacts by physically opening the channel.

FIGURE 12.20

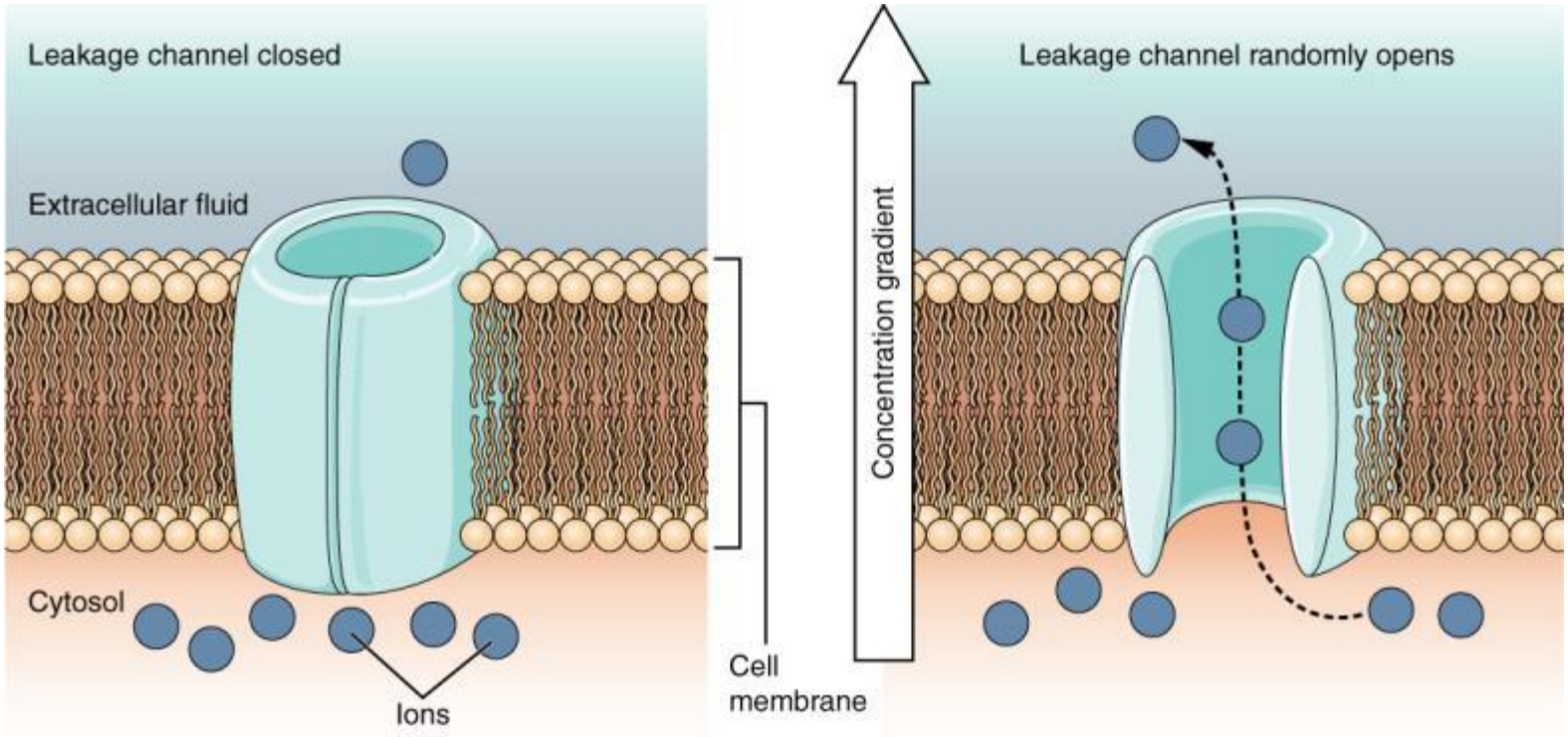


Voltage-Gated Channels

Voltage-gated channels open when the transmembrane voltage changes around them. Amino acids in the structure of the protein are sensitive to charge and cause the pore to open to the selected ion.

N.B.: The voltage-gated sodium channels of the axolemma have two gates: an activation gate and a deactivation gate.

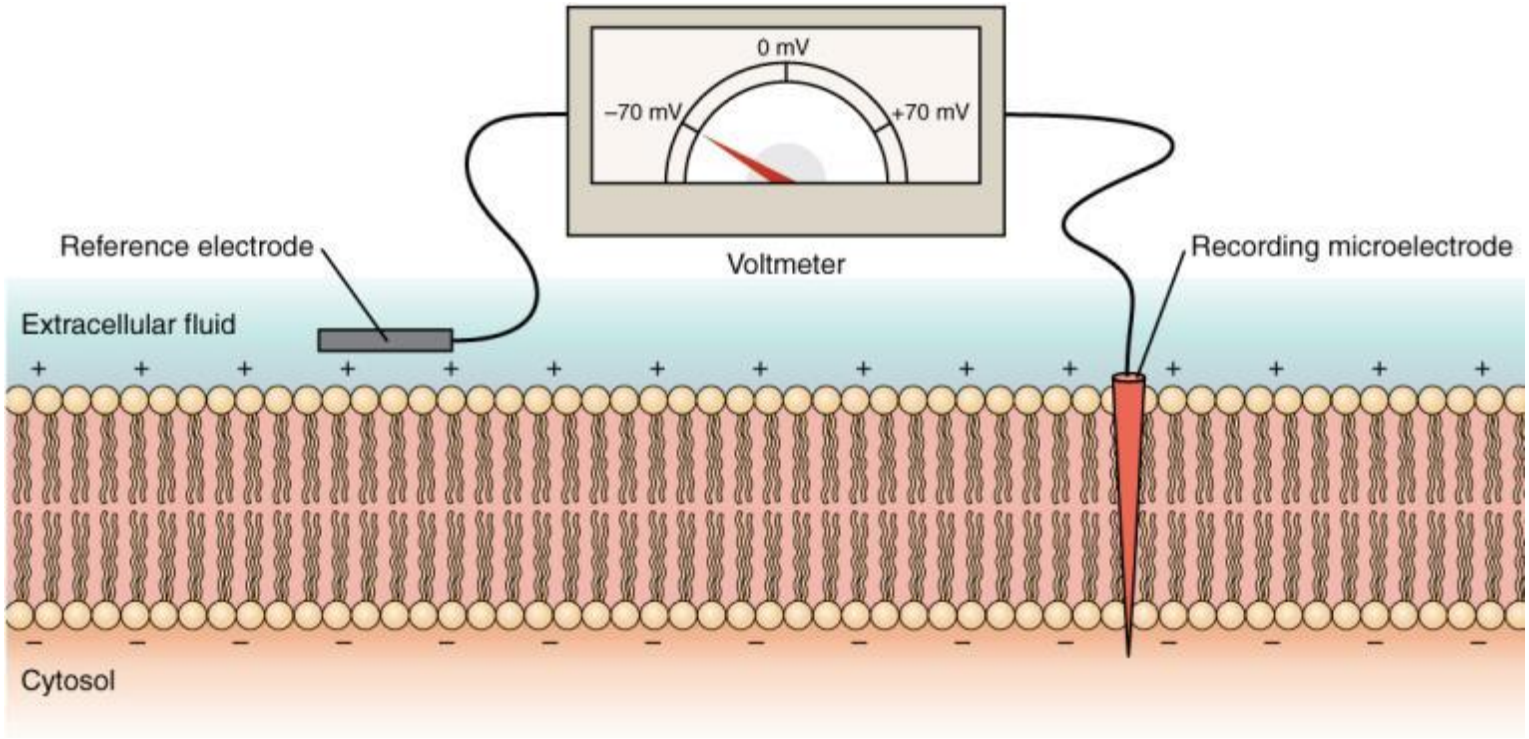
FIGURE 12.21



Leakage Channels

In certain situations, ions need to move across the membrane randomly. The particular electrical properties of certain cells are modified by the presence of this type of channel.

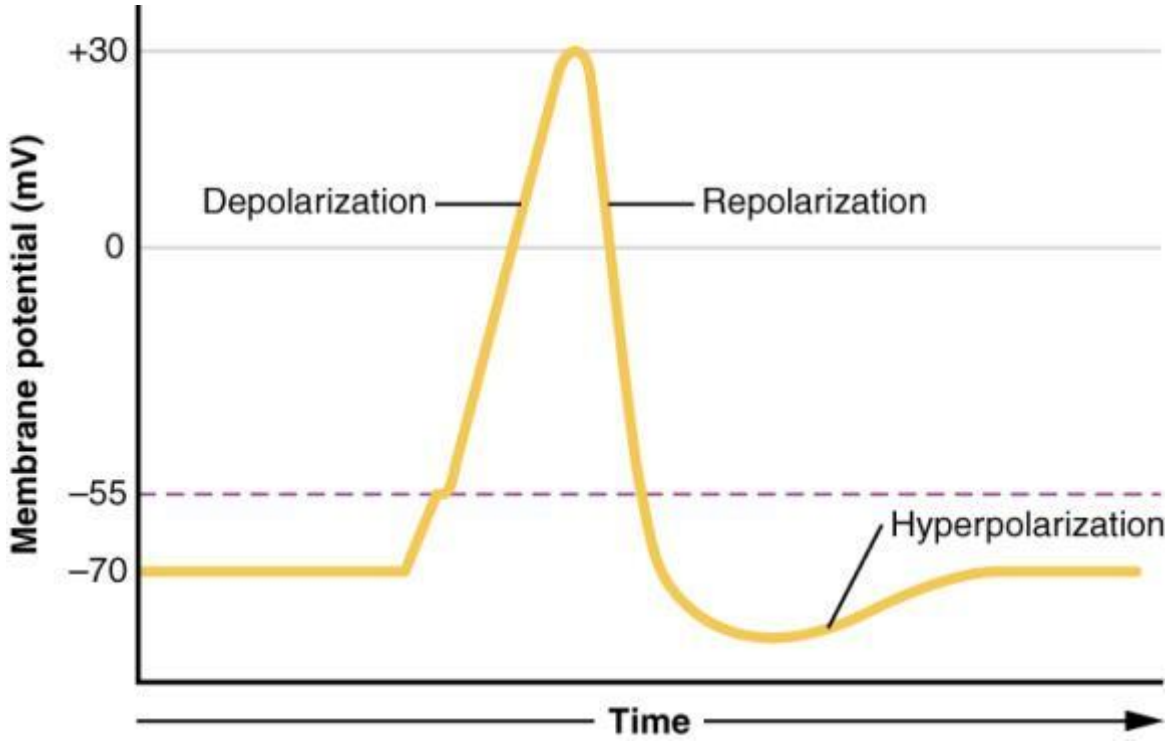
FIGURE 12.22



Measuring Charge across a Membrane with a Voltmeter

A recording electrode is inserted into the cell and a reference electrode is outside the cell. By comparing the charge measured by these two electrodes, the transmembrane voltage is determined. It is conventional to express that value for the cytosol relative to the outside.

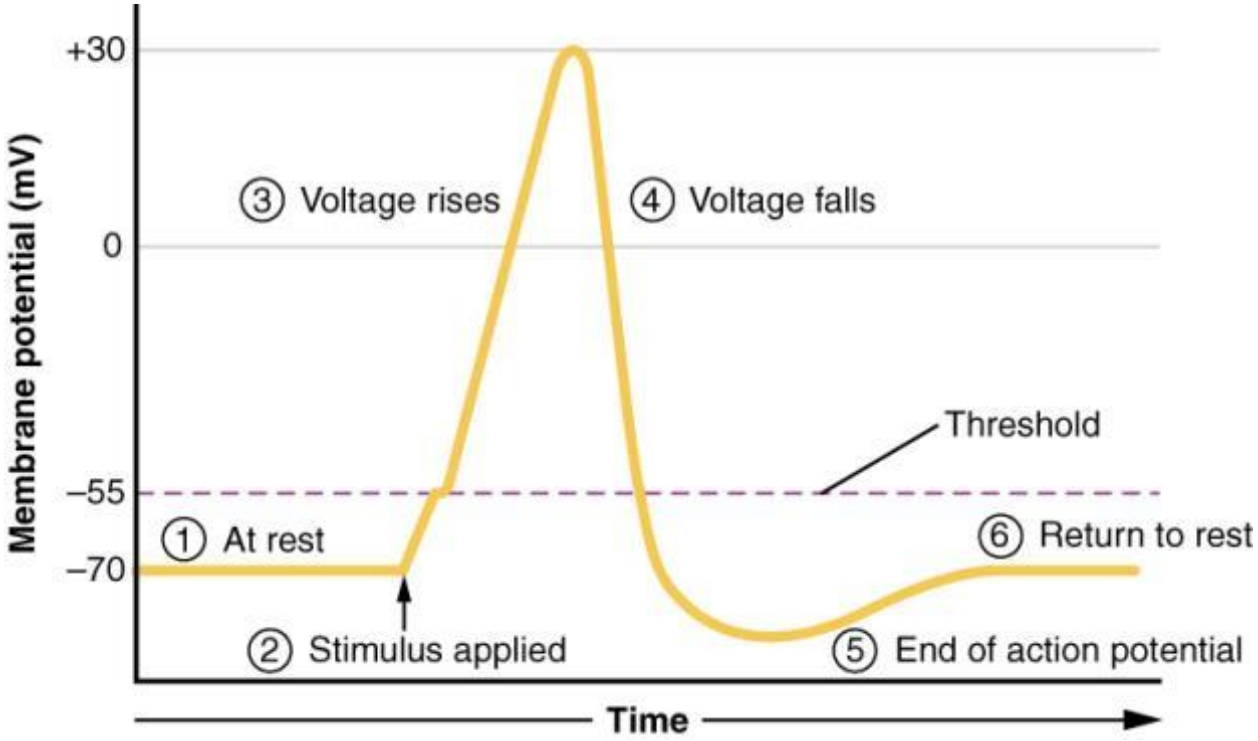
FIGURE 12.23



Graph of Action Potential

Plotting voltage measured across the cell membrane against time, the action potential begins with depolarization, followed by repolarization, which goes past the resting potential into hyperpolarization, and finally the membrane returns to rest.

FIGURE 12.24

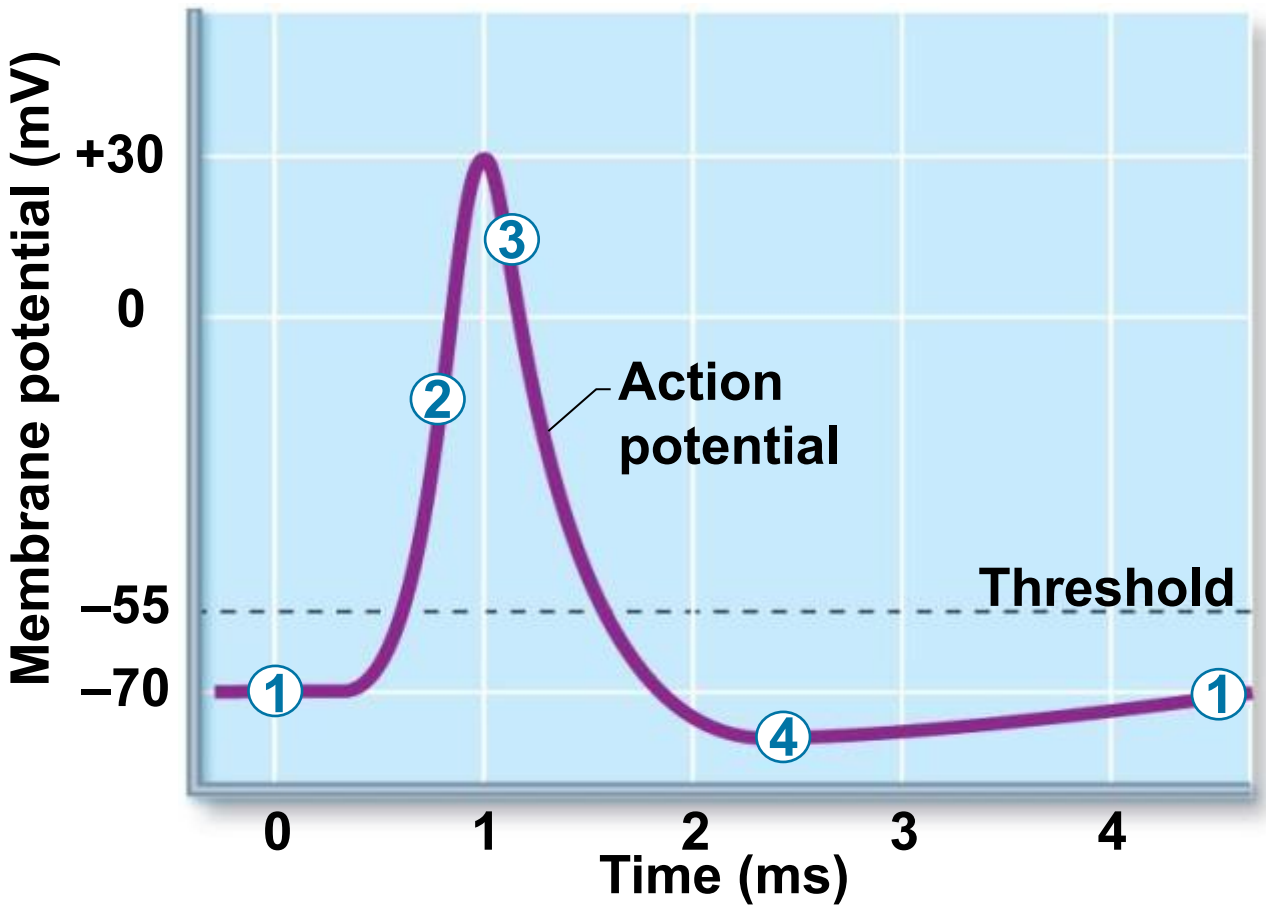


Stages of an Action Potential

Plotting voltage measured across the cell membrane against time, the events of the action potential can be related to specific changes in the membrane voltage. (1) At rest, the membrane voltage is -70 mV. (2) The membrane begins to depolarize when an external stimulus is applied. (3) The membrane voltage begins a rapid rise toward+30 mV. (4) The membrane voltage starts to return to a negative value. (5) Repolarization continues past the resting membrane voltage, resulting in hyperpolarization. (6) The membrane voltage returns to the resting value shortly after hyperpolarization.

GENERATION OF AN ACTION POTENTIAL

"**Initial segment**" of the axon ≈ "**axon hillock**".



① **Resting state.** No ions move through voltage-gated channels.

② **Depolarization** is caused by Na^+ flowing into the cell.

③ **Repolarization** is caused by K^+ flowing out of the cell.

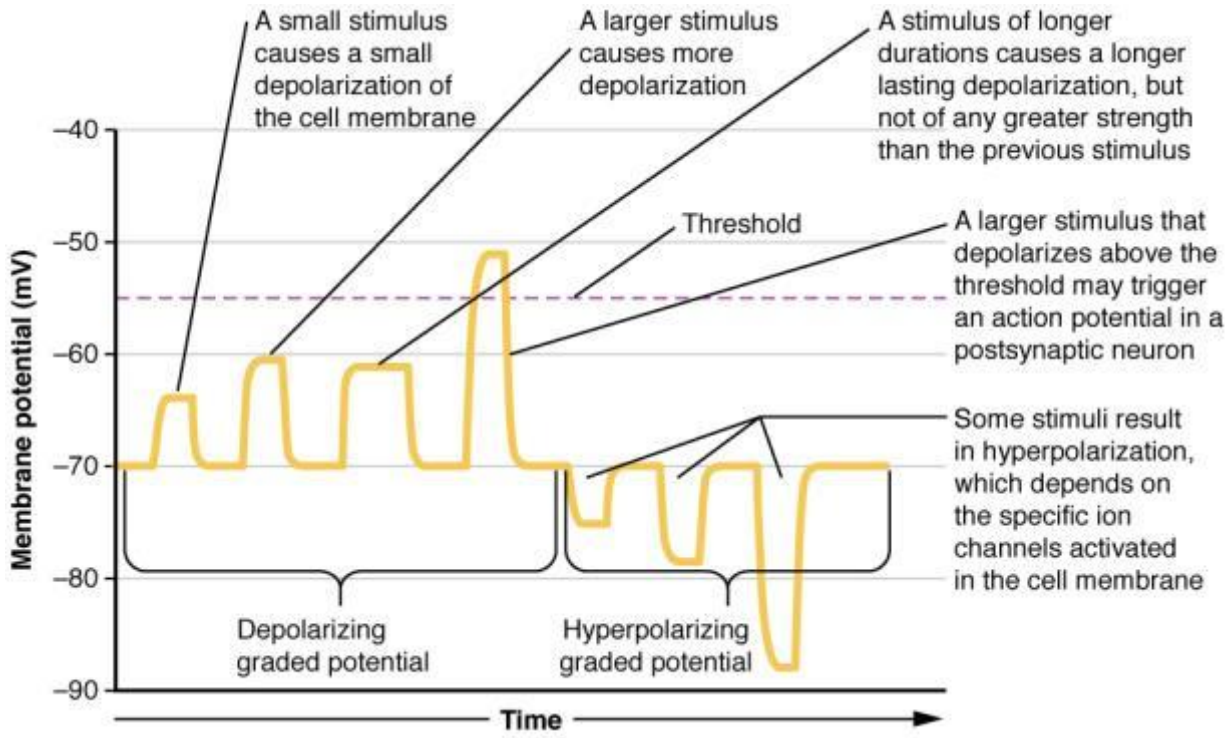
④ **Hyperpolarization** is caused by K^+ continuing to leave the cell.

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

12.5 THE GRADED POTENTIALS
MAJOR SECTION OBJECTIVES

- Explain the differences between the types of graded potentials
- Categorize the major neurotransmitters by chemical type and effect

FIGURE 12.25

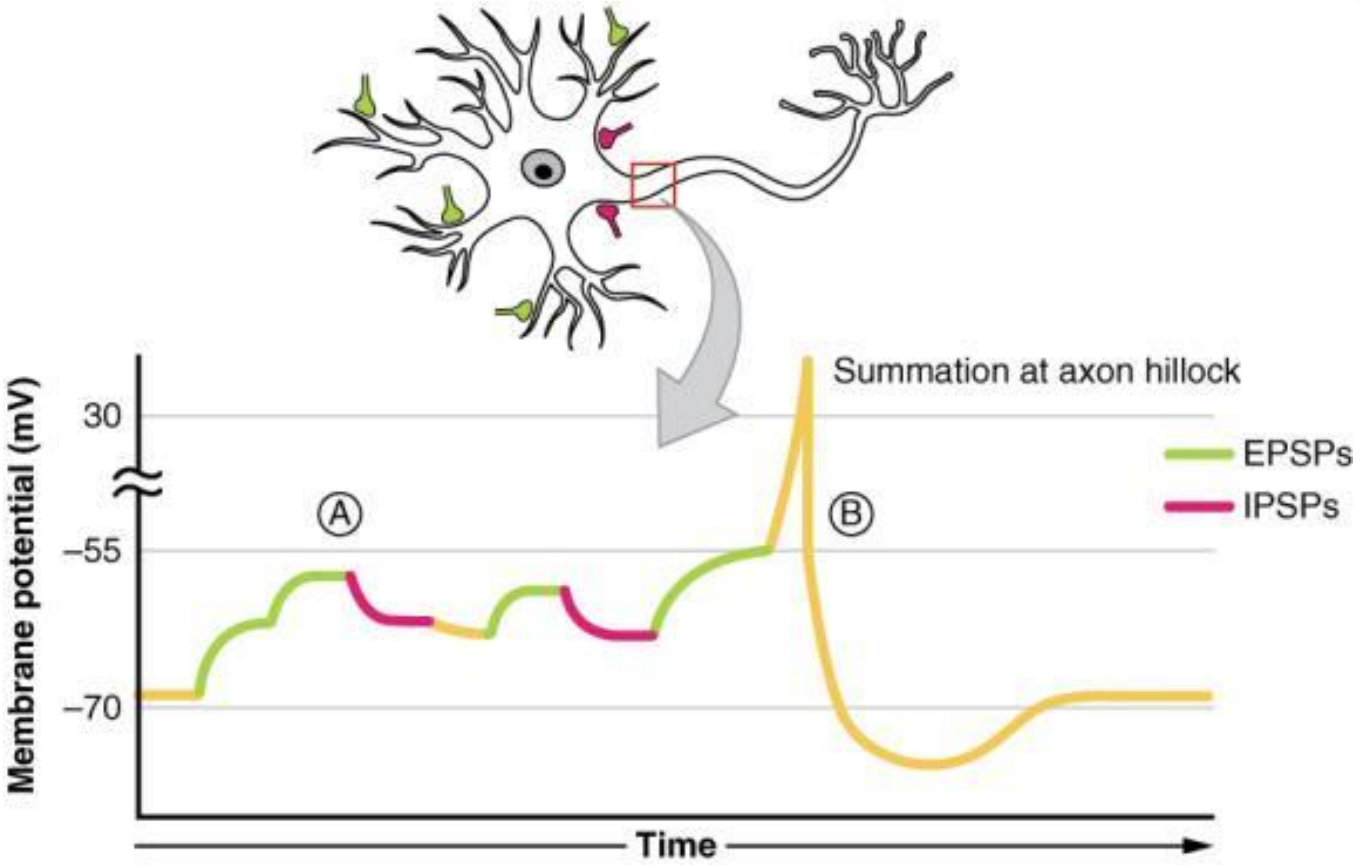


Graded Potentials

Graded potentials are temporary changes in the membrane voltage, the characteristics of which depend on the size of the stimulus. Some types of stimuli cause depolarization of the membrane, whereas others cause hyperpolarization. It depends on the specific ion channels that are activated in the cell membrane.

N.B.: Graded potentials form along dendrites, but also on the neuron's soma (although not at the axon hillock).

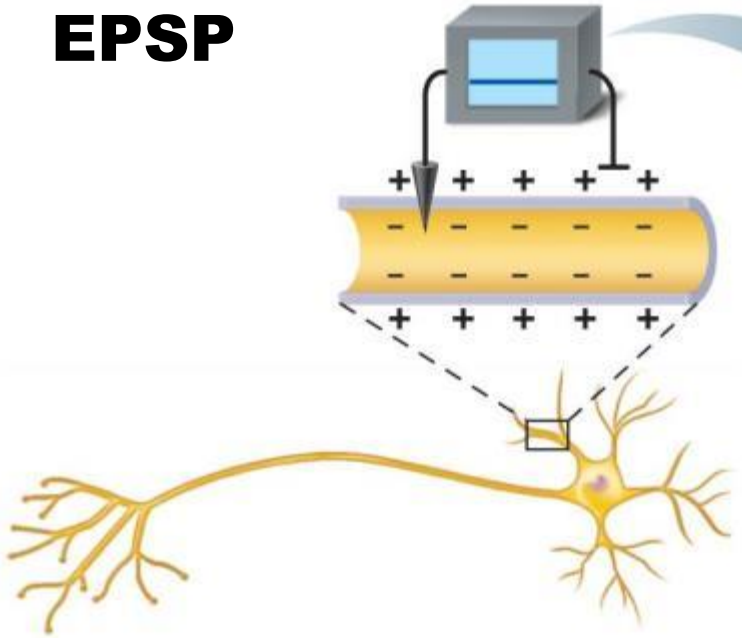
FIGURE 12.26

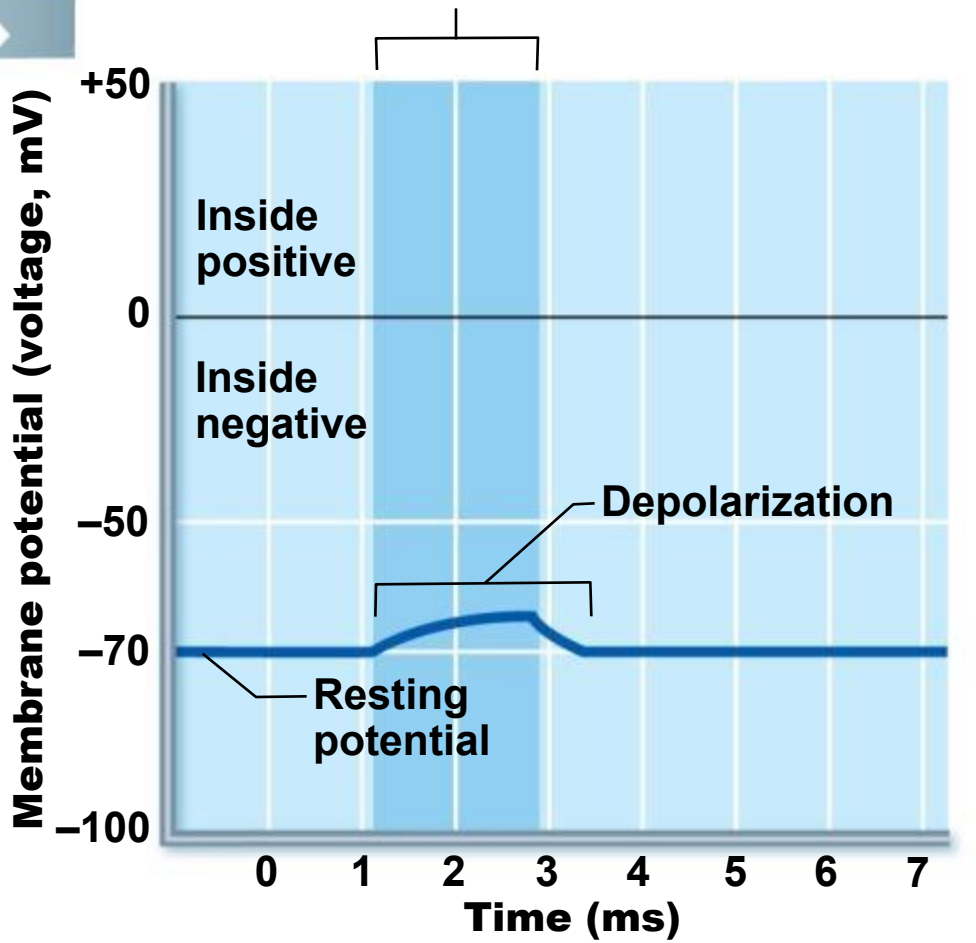


Postsynaptic Potential Summation

The result of summation of postsynaptic potentials is the overall change in the membrane potential. At point A, several different excitatory postsynaptic potentials add up to a large depolarization. At point B, a mix of excitatory and inhibitory postsynaptic potentials result in a different end result for the membrane potential.

EPSP

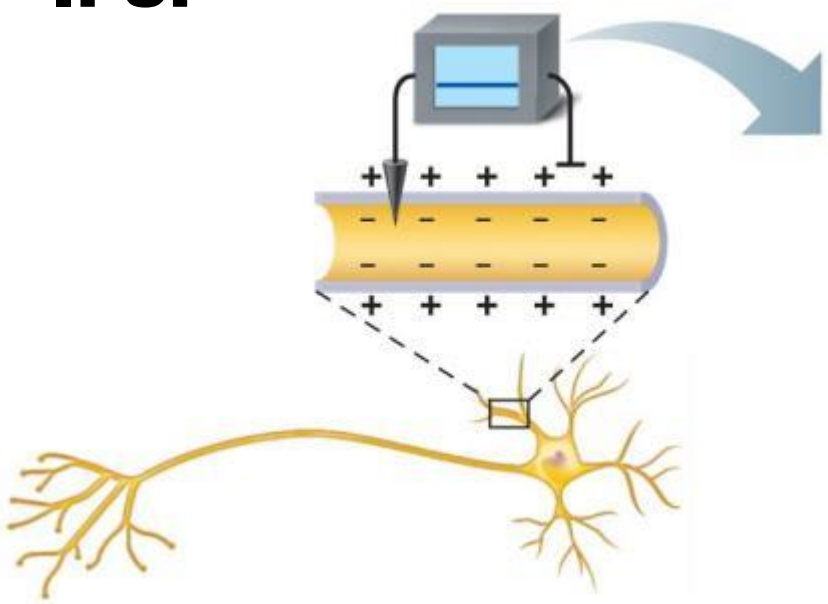


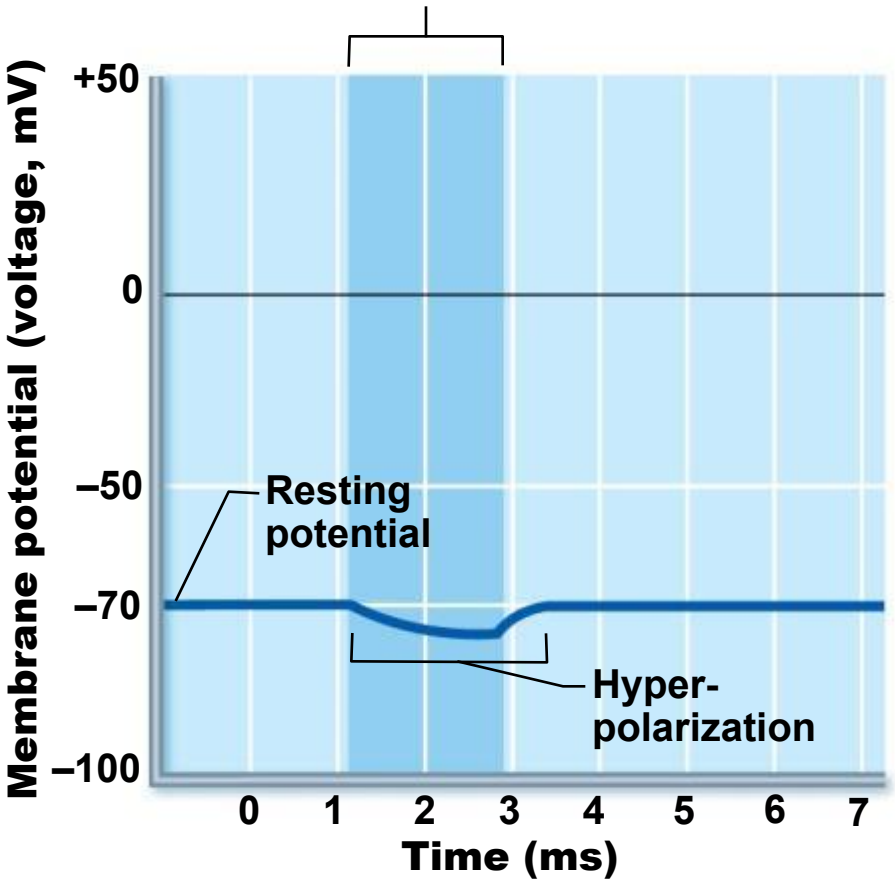


(a) Depolarization: The membrane potential moves toward 0 mV, the inside becoming less negative (more positive).

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

IPSP

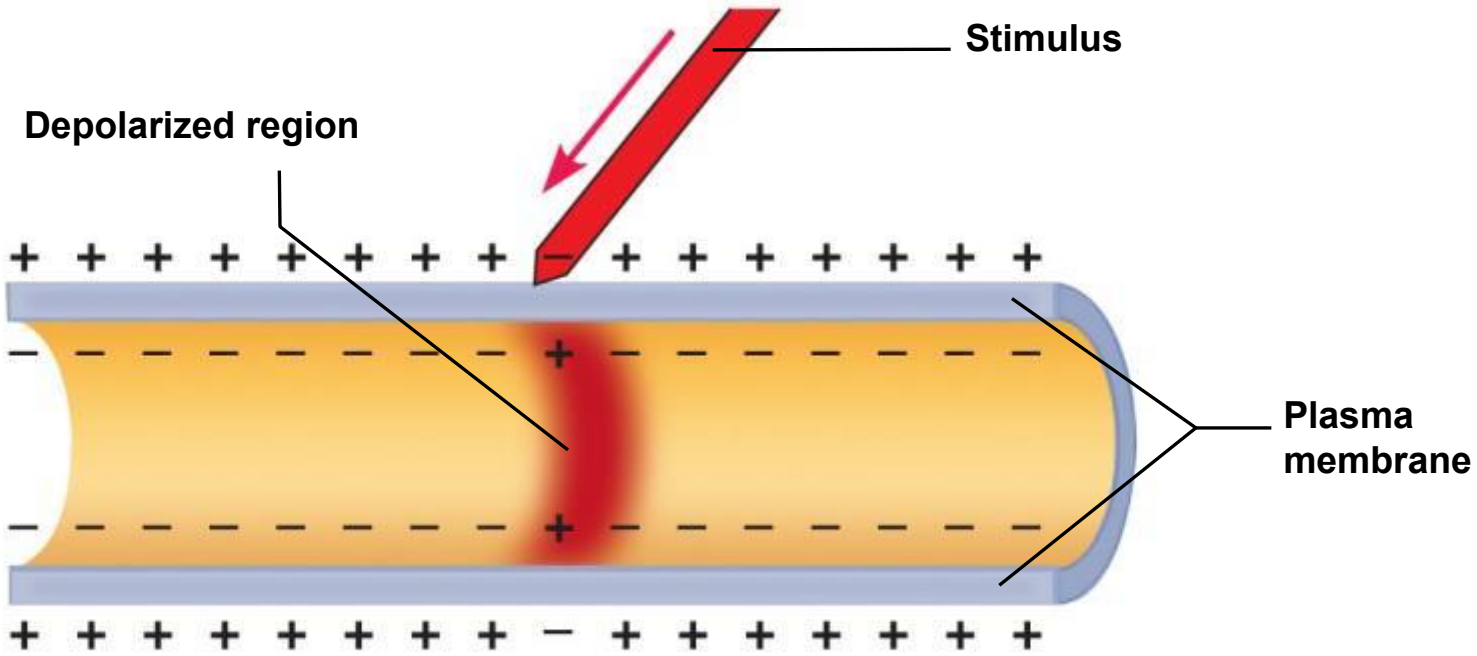




(b) Hyperpolarization: The membrane potential increases, the inside becoming more negative.

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

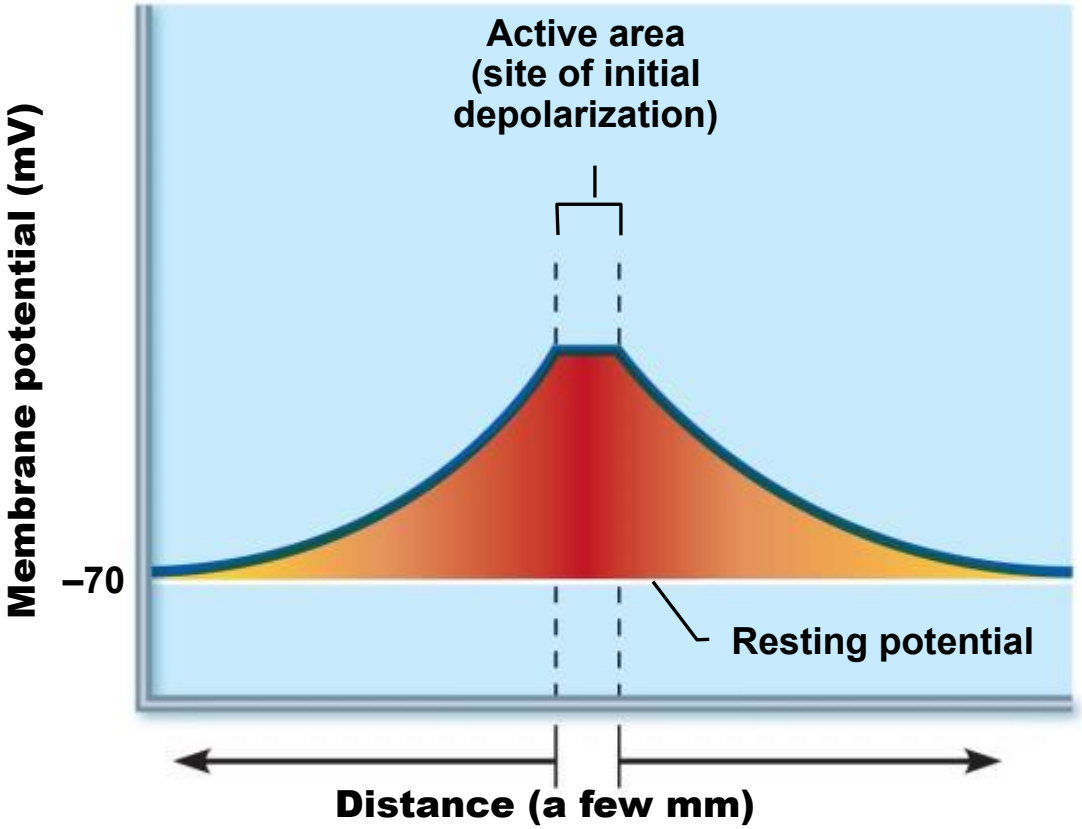
GRADED POTENTIALS (1/2): GENERATION



Depolarization: A small patch of the membrane (red area) depolarizes.

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

GRADED POTENTIALS (2/2): DECAY



Decay with distance: Because current is lost through the "leaky" plasma membrane, the voltage declines with distance from the stimulus (the voltage is *decremental*).

Graded potentials are short-distance signals.

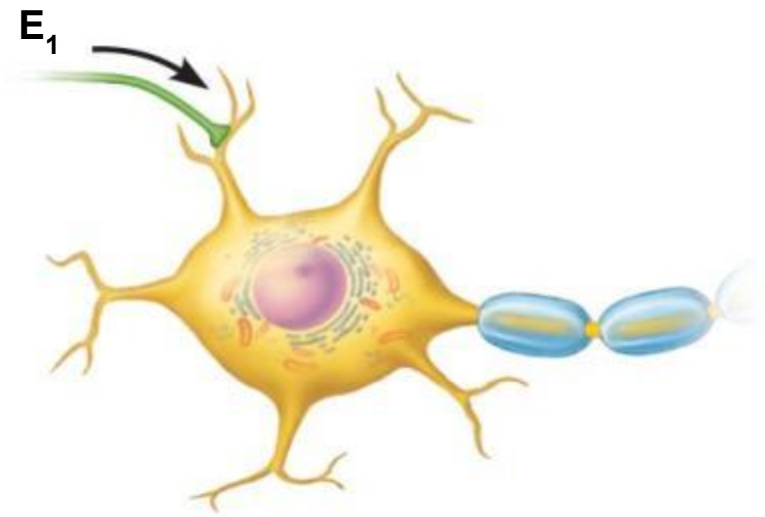
Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

SYNAPTIC INTEGRATION: SUMMATION

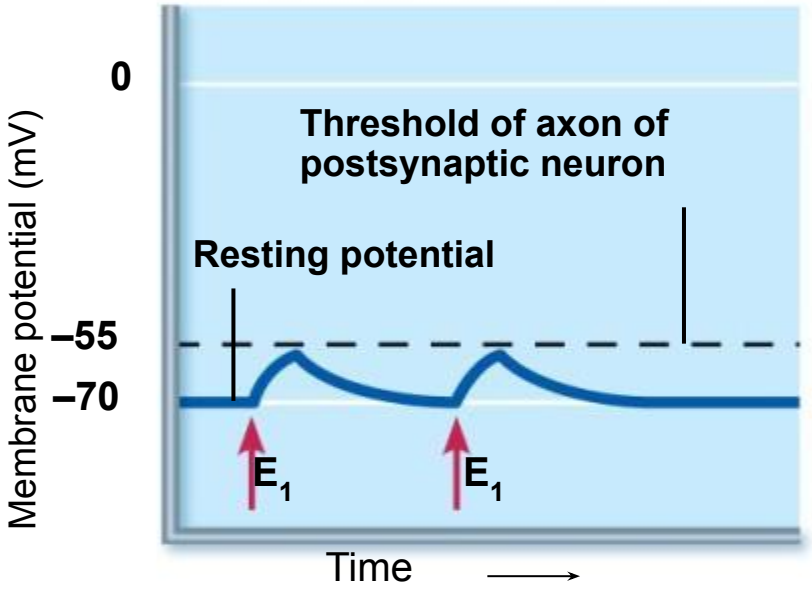
- Most neurons receive both excitatory and inhibitory inputs from thousands of other neurons
- A single EPSP cannot induce an AP
- EPSPs and IPSPs can summate to influence postsynaptic neuron:
    - **Temporal summation**
    - **Spatial summation**

- AP occurs only if ($\sum$ EPSPs **+** $\sum$ IPSPs) **≥** AP threshold

EXAMPLE 1: NO SUMMATION (EPSPS)



No summation:
2 stimuli separated in time cause EPSPs that do not add together.



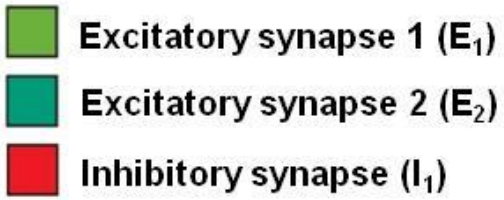
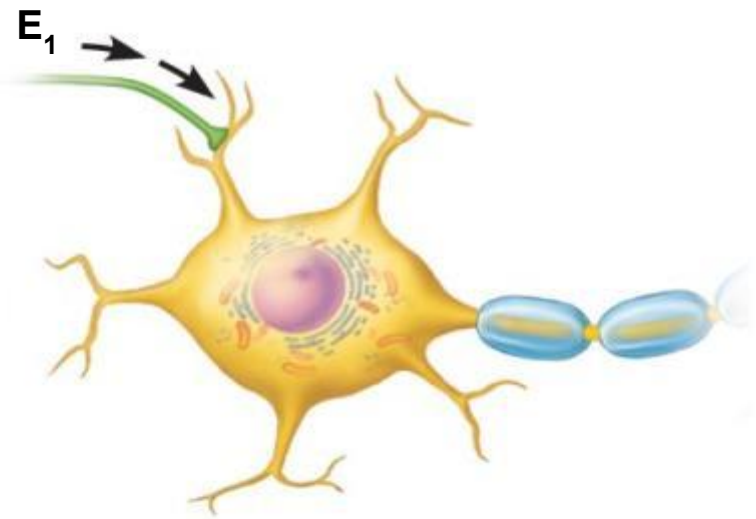


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

TEMPORAL SUMMATION (EPSPS)



Temporal summation:
2 excitatory stimuli close in time cause EPSPs that add together.

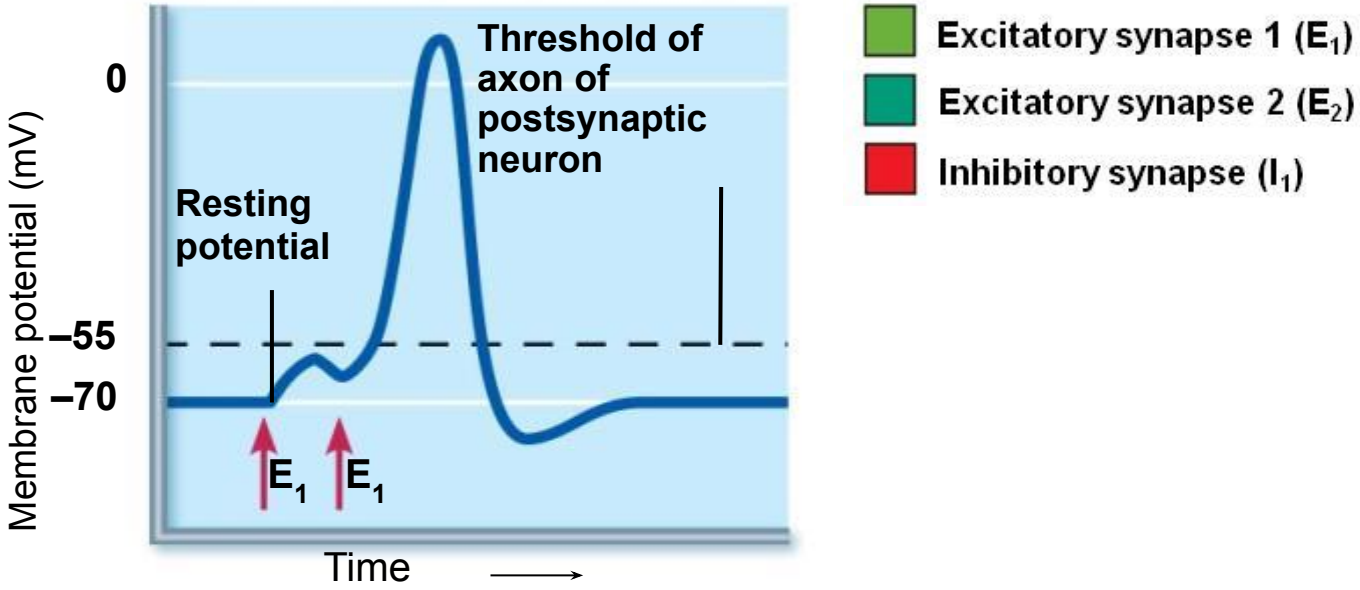
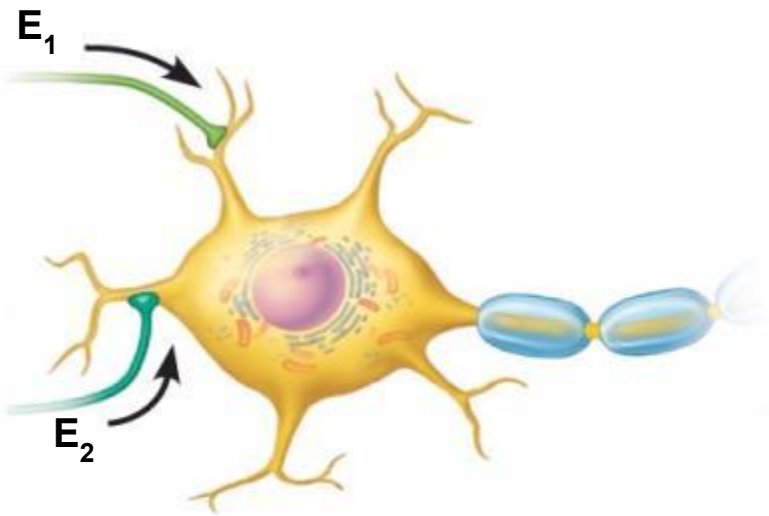


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

SPATIAL SUMMATION (EPSPS)



Spatial summation:
2 simultaneous stimuli at different locations cause EPSPs that add together.

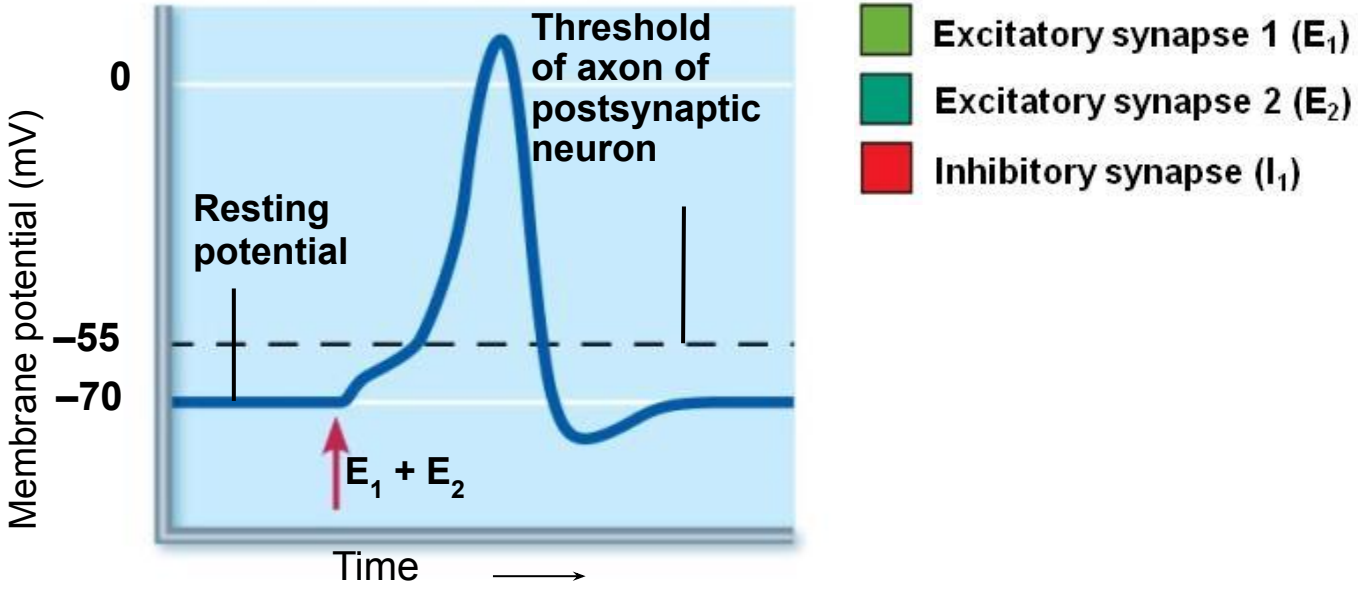
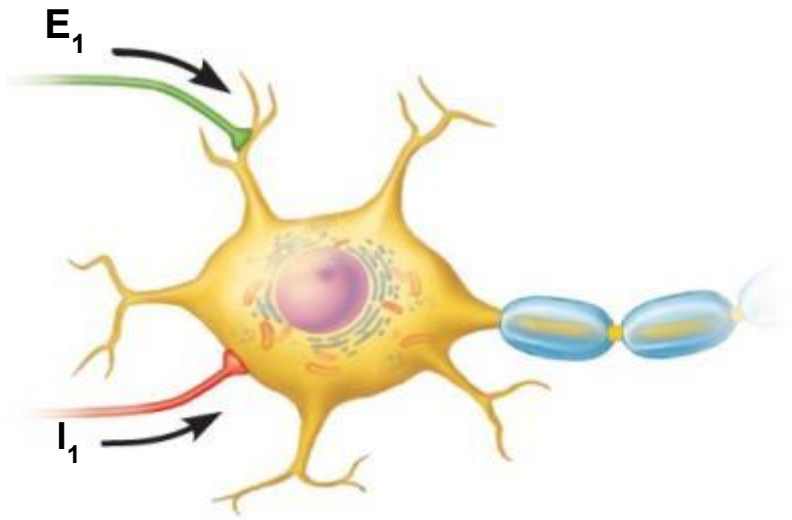


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

SUMMATION BUT NO AP (EPSPS AND IPSPS)



Spatial summation of EPSPs and IPSPs:
Changes in membrane potential can cancel each other out.

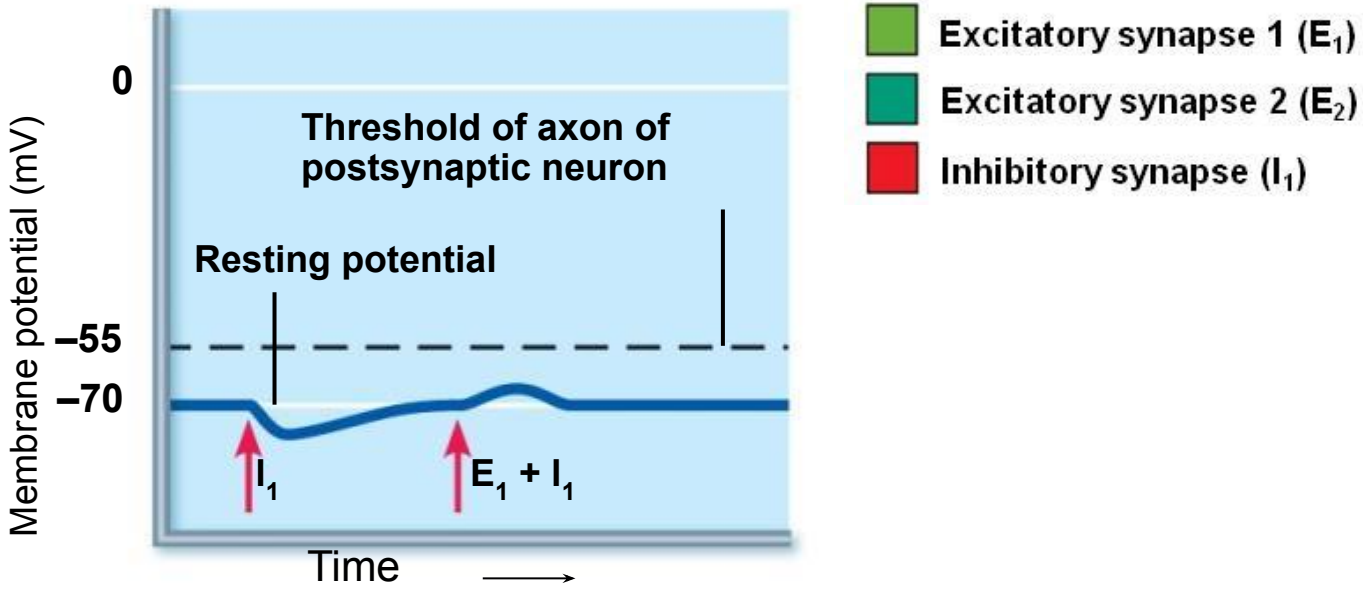


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

INTEGRATION: SYNAPTIC POTENTIATION

Synaptic potentiation: the repeated use of a given synapse increases ability of presynaptic cell to excite postsynaptic neuron

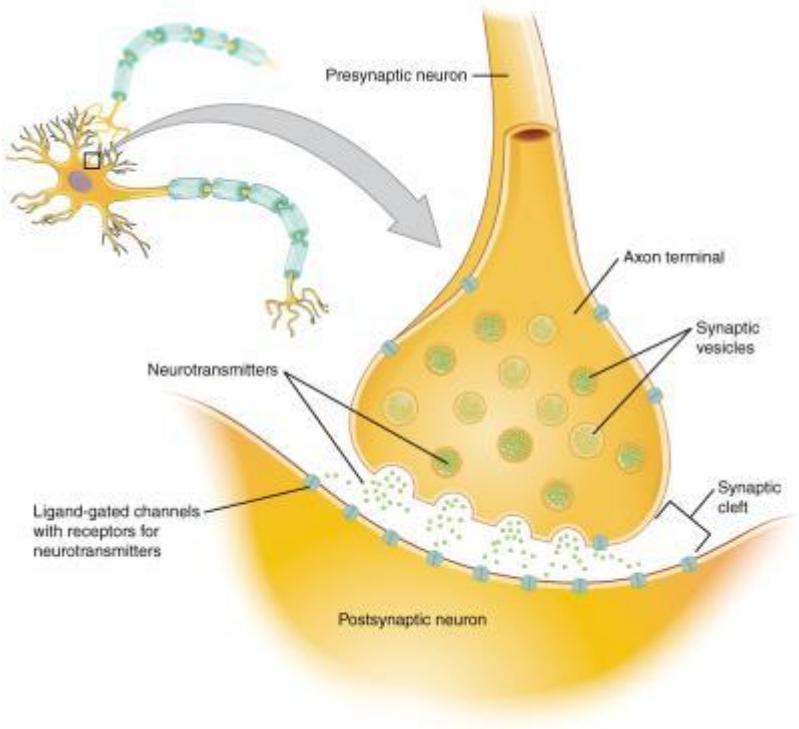
- **Ca^{2+} concentration increases in presynaptic terminal and postsynaptic neuron**
- Ca^{2+} activates kinase enzymes that promote more effective responses to subsequent stimuli

SYNAPSES

- Electrical
  - Physical connection of pre- and post-synaptic elements
  - Electric signals go through
  - Most abundant in embryo
  - Two-way signal transduction

- Chemical
  - A gap separates the pre- post-synaptic elements (synaptic cleft)
  - Signal switches from electric to chemical to electric again
  - Increasingly abundant in fetus and the majority of synapses after birth
  - One-way signal transduction only

FIGURE 12.27



The Chemical Synapse

The synapse is a connection between a neuron and its target cell (which is not necessarily a neuron). The presynaptic element is the synaptic end bulb of the axon where Ca^{2+} enters the bulb to cause vesicle fusion and neurotransmitter release. The neurotransmitter diffuses across the synaptic cleft to bind to its receptor. The neurotransmitter is cleared from the synapse either by enzymatic degradation, neuronal reuptake, or glial reuptake.

INFORMATION TRANSFER ACROSS CHEMICAL SYNAPSES

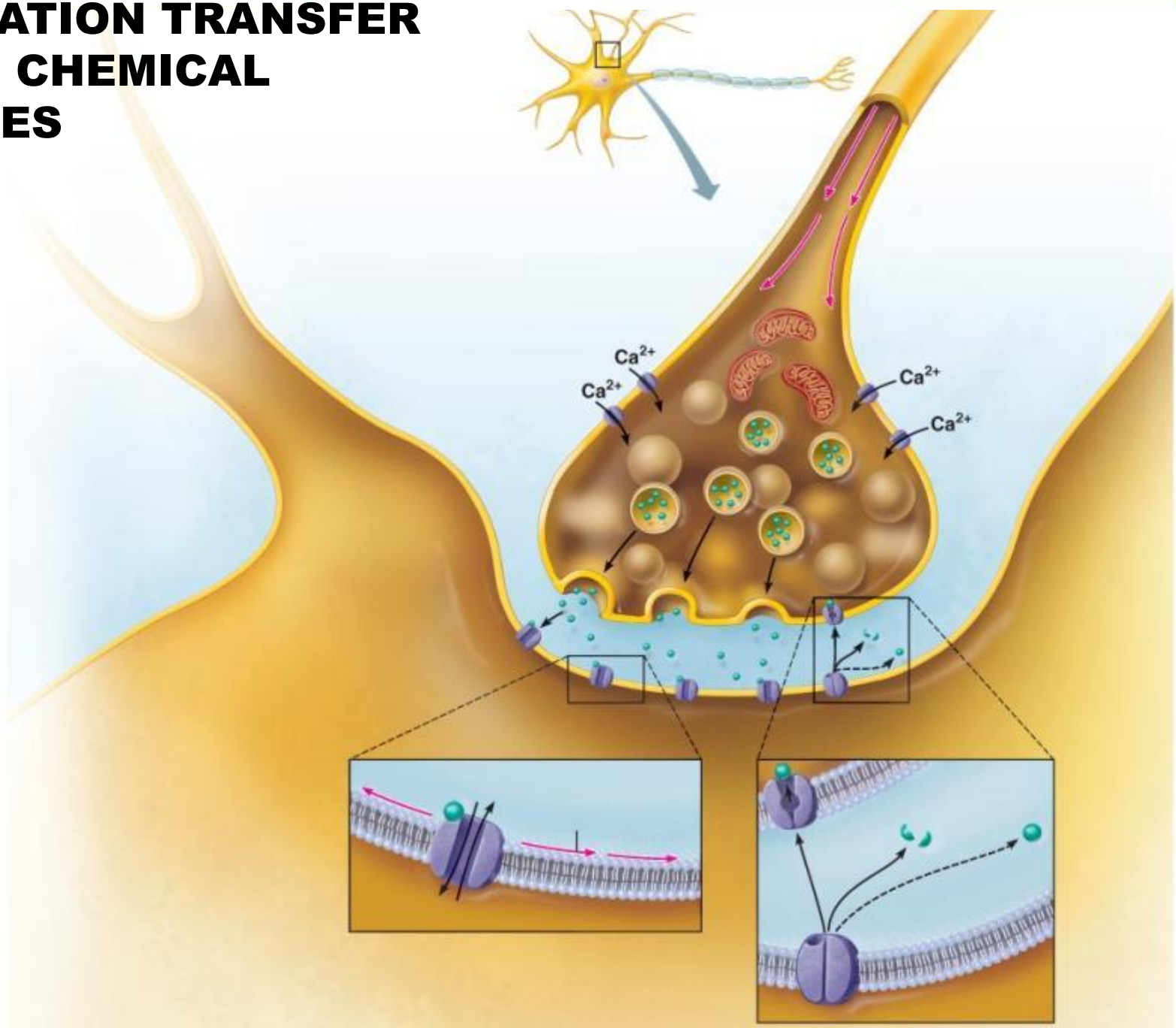


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

CHEMICAL SYNAPSE (1/3)

1- Action potential arrives at axon terminal.

2- Voltage-gated Ca^{2+} channels open and Ca^{2+} enters the axon terminal.

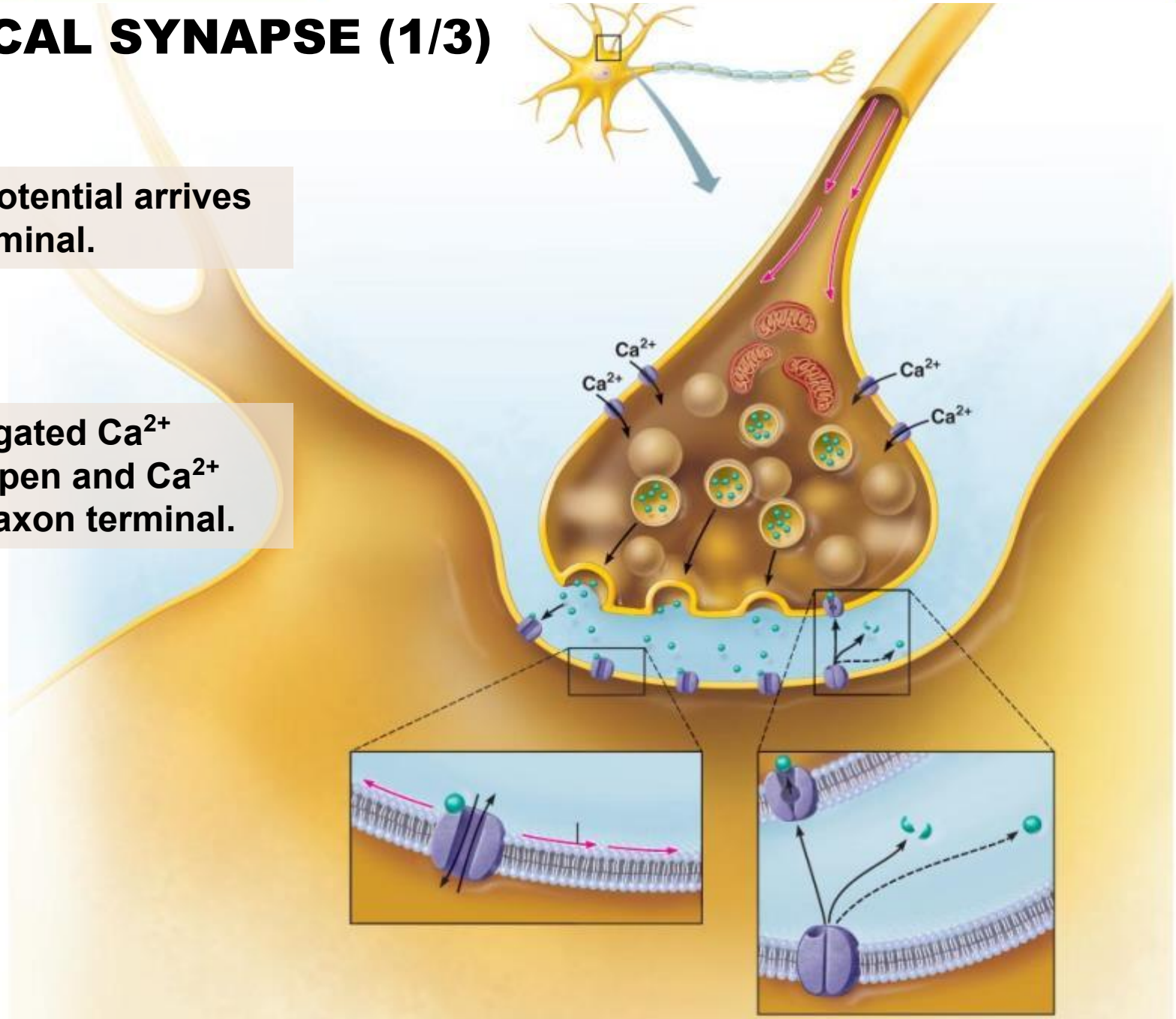


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

CHEMICAL SYNAPSE (2/3)

3- Ca^{2+} entry (binding to synaptotagmin) causes synaptic vesicles to release neurotransmitter by exocytosis

4- Neurotransmitter diffuses across the synaptic cleft and binds to specific receptors on the postsynaptic membrane.

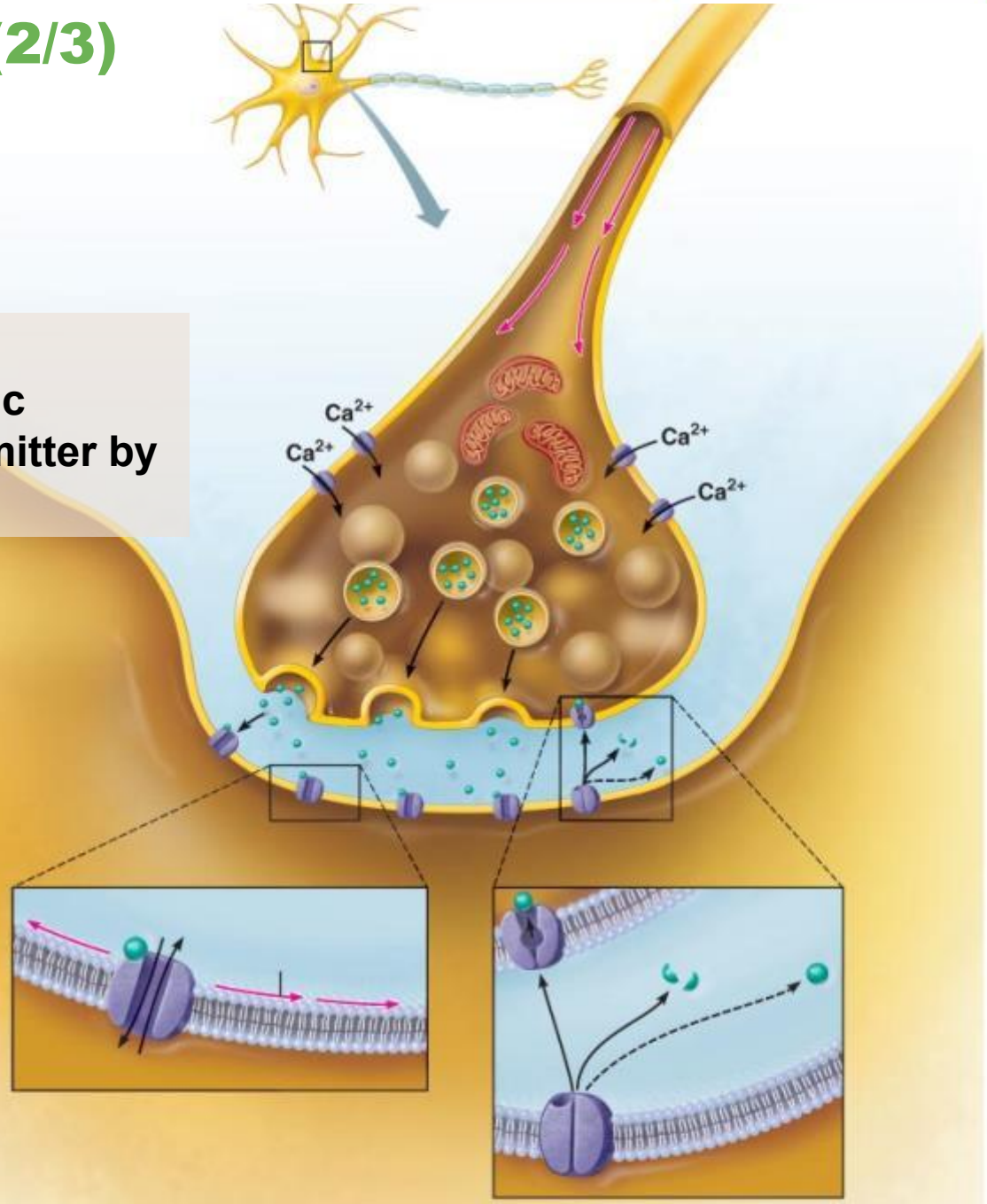
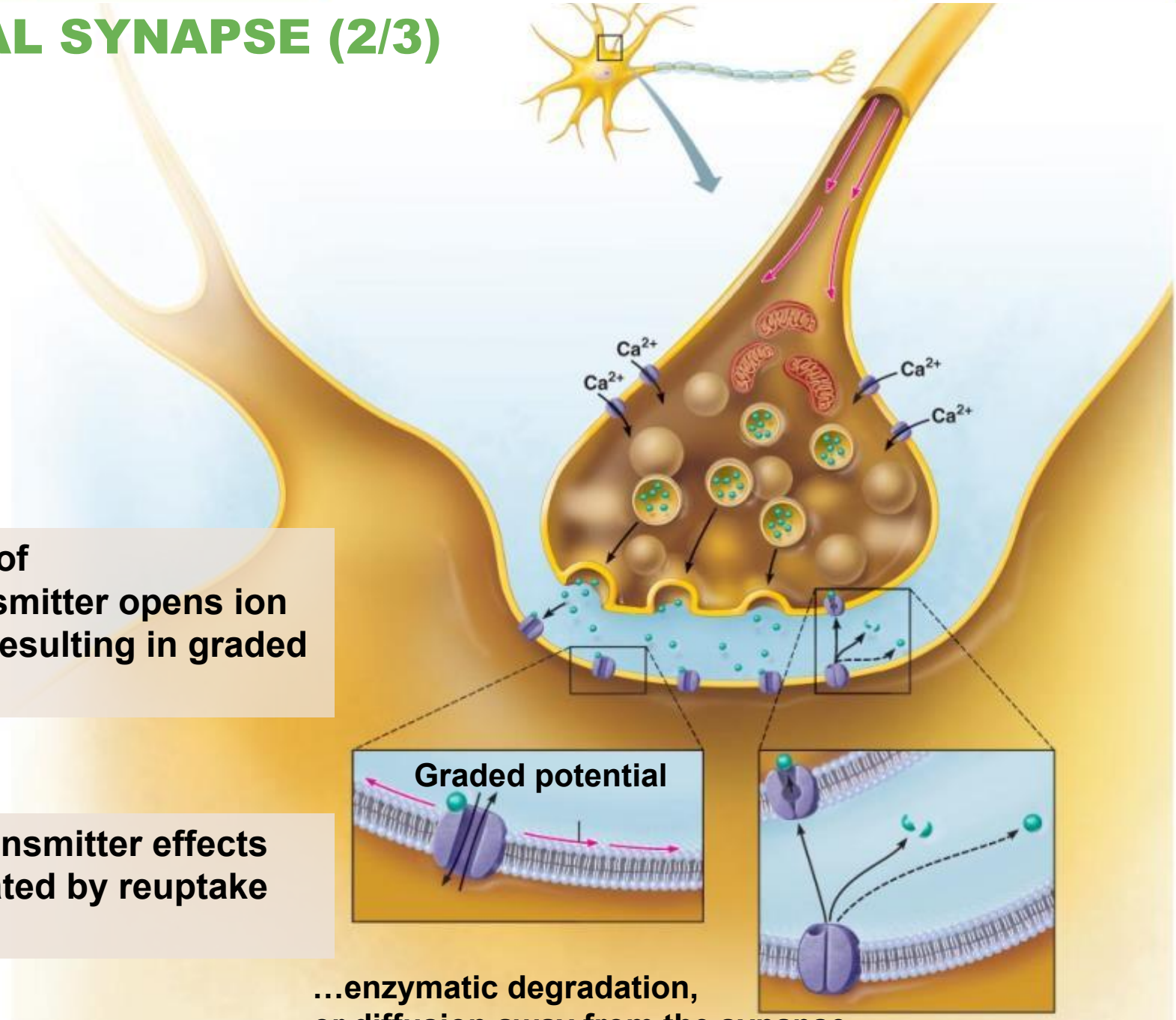


Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

CHEMICAL SYNAPSE (2/3)



5- Binding of neuro-transmitter opens ion channels, resulting in graded potentials.

6- Neurotransmitter effects are terminated by reuptake through…

…enzymatic degradation, or diffusion away from the synapse.

Image source: As before.

FIGURE 12.28

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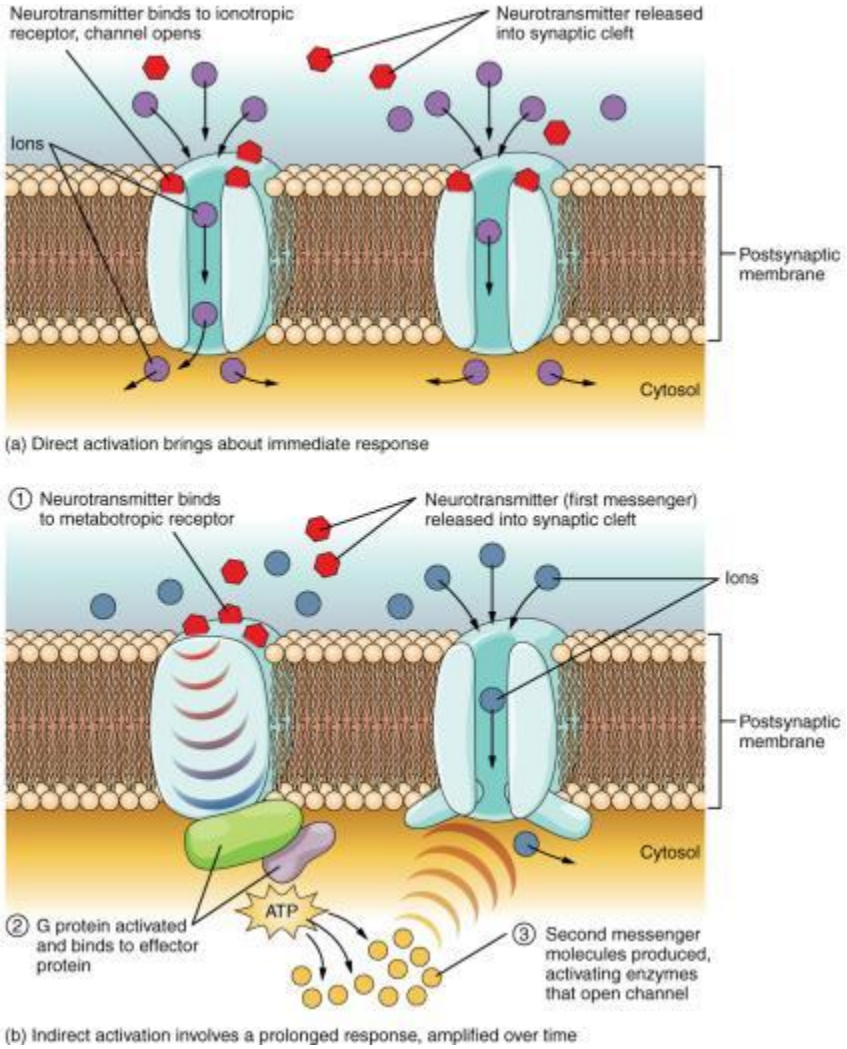
Receptor Types

(a) An ionotropic receptor is a channel that opens when the neurotransmitter binds to it.

(b) A metabotropic receptor is a complex that causes metabolic changes in the cell when the neurotransmitter binds to it (1). After binding, the G protein hydrolyzes GTP and moves to the effector protein (2). When the G protein contacts the effector protein, a second messenger is generated, such as cAMP (3). The second messenger can then go on to cause changes in the neuron, such as opening or closing ion channels, metabolic changes, and changes in gene transcription.



MODIFIED TABLE 12.3

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Characteristics of Selected Neurotransmitters

Type	Example(s)	Receptors	Postsynaptic effect(s)
Cholinergic	• Acetylcholine (ACh)	• Nicotinic (I) • Muscarinic (I)	• "E" at nicotinic receptors • "E" or "I" at muscarinic receptors
Amino acids	• Glutamate • GABA	• Glu receptors (I) • GABA receptors (I)	• "E" - mostly • "I" - mostly
Biogenic amines	• Serotonin • Dopamine Norepinephrin (noradrenaline) • Epinephrin (adrenalin)	• 5-HT receptors (M) • D1, D2 receptors (M) • Alpha- and beta-adrenergic receptors (M)	• Varied("E" or "I"
Gasotransmitters	• Nitric oxide (NO)	• Multiple receptors (M)	• Varied.
Neuro-peptides	• Substance P • Beta-endorphin	• Specific receptors (M)	• Varied.

Legend: (I), ionotropic or direct signaling; (M) metabotropic or indirect signaling; "E", excitatory; "I", inhibitory.

EVERYDAY CONNECTIONS

- **Potassium Concentration and Astrocytes**
  - Glial cells, especially astrocytes, are responsible for maintaining the chemical environment of the CNS tissue. If the balance of ions is upset, drastic outcomes are possible.
  - Normally the concentration of K+ is higher inside the neuron than outside. After the repolarizing phase of the action potential, K+ leakage channels and the Na+/K+ pump ensure that the ions return to their original locations.
  - Following a stroke or other ischemic event, extracellular K+ levels are elevated. The astrocytes in the area are equipped to clear excess K+ to aid the pump. But when the level is far out of balance, the effects can be irreversible.
  - Astrocytes and other glial cells enlarge and their processes swell. They lose their K+ buffering ability and the function of the pump is affected, or even reversed. This Na+/K+ imbalance negatively affects the internal chemistry of cells, preventing glial cells and neurons from functioning normally.

DISORDERS & HOMEOSTATIC IMBALANCES

- **Demyelination Disorders**
  - Diseases of genetic, infectious or autoimmune origins can cause a demyelination of axons. As the myelin insulation of axons is compromised, electrical signaling becomes slower.
  - **Multiple sclerosis (MS)** is an example of an autoimmune disease. The antibodies produced by lymphocytes (a type of white blood cell) mark CNS myelin as something that should not be in the body. This causes inflammation and the destruction of the myelin in the central nervous system. Scarring – sclerosis – occurs in the white matter of the brain and spinal cord. The symptoms of MS include both somatic and autonomic deficits. Control of the musculature is compromised, as is control of organs such as the bladder.
  - **Guillain-Barré syndrome** is an example of a demyelinating disease of the PNS. It is also the result of an autoimmune reaction, but the inflammation is in peripheral nerves. Sensory symptoms or motor deficits are common, and autonomic failures can lead to changes in the heart rhythm or a drop in blood pressure, especially when standing, which causes dizziness.

DISORDERS & HOMEOSTATIC IMBALANCES

- **Proteopathies**

  For proteins to function correctly, their linear sequence of amino acids must fold into a three-dimensional shape that is based on the interactions between and among those amino acids.

  When the folding is disturbed, and proteins take on a different shape, they stop functioning correctly. Symptoms can arise as a result of the functional loss of these proteins, but often also because the accumulation of these altered proteins is toxic.

  - Alzheimer's Disease
    - One of the strongest theories of what causes Alzheimer's disease is based on the accumulation of beta-amyloid plaques, dense conglomerations of a protein that is not functioning correctly.
  - Creutzfeld-Jacob Disease
    - Creutzfeld-Jacob disease, the human variant of the prion disease known as mad cow disease, also involves the accumulation of amyloid plaques, similar to Alzheimer's. Cerebral neurons die in small clusters, creating a "spongiform encephalopathy".
  - Parkinson's Disease
    - Parkinson's disease is linked to an increase in a protein known as alpha-synuclein that is toxic to the **dopamine**-secreting neurons of the substantia nigra nucleus (midbrain).

INTERACTIVE LINKS

- Visit the Nobel Prize web site http://openstaxcollege.org/l/nobel_2 to play an interactive game that demonstrates the use of Magnetic Resonance Imaging (MRI) and compares it with other types of imaging technologies.
- Visit this site http://openstaxcollege.org/l/troublewstairs to read about a woman that notices that her daughter is having trouble walking up the stairs. This leads to the discovery of a hereditary condition that affects the brain and spinal cord. The electromyography and MRI tests indicated deficiencies in the spinal cord and cerebellum, both of which are responsible for controlling coordinated movements.
- Visit this site http://openstaxcollege.org/l/nervetissue3 to learn about how nervous tissue is composed of neurons and glial cells.
- View an electron micrograph of a cross-section of a myelinated nerve fiber at http://openstaxcollege.org/l/nervefiber (U. of Michigan).
- View this animation http://openstaxcollege.org/l/dynamic1 of what happens across the membrane of an electrically active cell.

INTERACTIVE LINKS

- FYI - Visit this site http://openstaxcollege.org/l/neurolab to see a virtual neurophysiology lab, and to observe electrophysiological processes in the nervous system.
- Watch this video http://openstaxcollege.org/l/summation to learn about summation.
- Watch this video http://openstaxcollege.org/l/neurotrans to learn about the release of a neurotransmitter.

ERRORS IN KEY TERMS

Error p. 542:
Choroid plexus: specialized structure containing ependymal cells that ~~line~~ **cover the outside of** blood capillaries and filter blood to produce CSF in the four ventricles of the brain

Add p.543:
Ependymal cell: glial cell type in the CNS, **bearing cilia, which lines the internal cavities of the CNS**; responsible for producing cerebrospinal fluid **in choroid plexuses**

Error p. 543:
Leakage channel: ion channel that ~~opens randomly and~~ **remains open** as it is not gated to a specific event, also known as a non-gated channel

Add p.545:
Synaptic end bulb: also known as "terminal bouton" - swelling at the end of an axon where neurotransmitter molecules are released onto a target cell across a synapse

END

Last modified: 09/2017 / Dr. F. Jolicoeur

GRADED POTENTIALS VS. ACTION POTENTIALS (1/2)

	GRADED POTENTIAL (GP)	ACTION POTENTIAL (AP)
Location of event	Cell body and dendrites, typically	Axon hillock and axon
Distance traveled	Short distance—typically within cell body to axon hillock (0.1–1.0 mm)	Long distance—from trigger zone at axon hillock through entire length of axon (a few mm to over a meter)
Amplitude (size)	Various sizes (graded); decays with distance	Always the same size (all-or-none); does not decay with distance
Stimulus for opening ion channels	Chemical (neurotransmitter) or sensory stimulus (e.g., light, pressure, temperature)	Voltage (depolarization, triggered by GP reaching threshold)

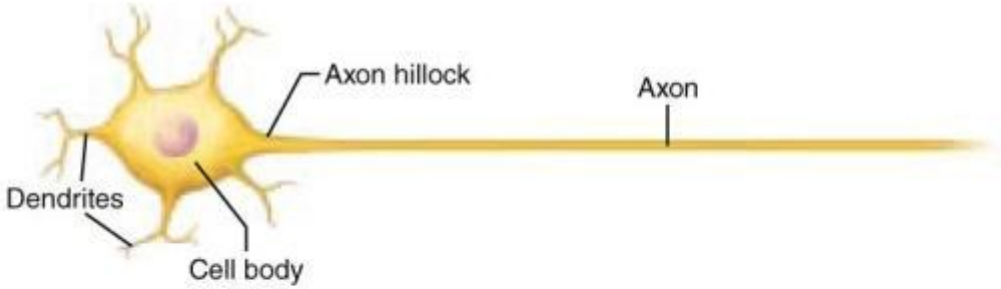

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

GRADED POTENTIALS VS. ACTION POTENTIALS (2/2)

	GRADED POTENTIAL (GP)		ACTION POTENTIAL (AP)
Positive feed-back cycle	Absent		Present
Repolarization	Voltage independent; occurs when stimulus is no longer present		Voltage regulated; occurs when Na^+ channels inactivate and K^+ channels open
Summation	Stimulus responses can summate to increase amplitude of graded potential		Does not occur; an all-or-none phenomenon
	 Temporal: increased frequency of stimuli	 Spatial: stimuli from multiple sources	
	POSTSYNAPTIC POTENTIAL (A TYPE OF GP)		
	EXCITATORY (EPSP)	**INHIBITORY (IPSP)**	
Function	Short-distance signaling; depolarization that spreads to axon hillock; moves membrane potential *toward* threshold for generating an AP	Short-distance signaling; hyperpolarization that spreads to axon hillock; moves membrane potential *away* from threshold for generating an AP	Long-distance signaling; constitutes the nerve impulse

Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.