The Nervous System
Part -2-

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Neurophysiology

- Neurons are highly excitable
- Action potentials, or nerve impulses, are:
  - Electrical impulses carried along the length of axons
  - The underlying functional feature of the nervous system

Electricity Definitions

- **Voltage (V)** – measure of potential energy generated by separated charge
- **Potential difference** – voltage measured between two points
- **Current (I)** – the flow of electrical (ions) between two points
- **Resistance (R)** – hindrance to charge flow
- **Insulator** – substance with high electrical resistance
- **Conductor** – substance with low electrical resistance

Electrical Current and the Body

- Reflects the flow of ions rather than electrons
- There is a potential on either side of membranes when:
  - The number of ions is different across the membrane
  - The membrane provides a resistance to ion flow

Role of Ion Channels

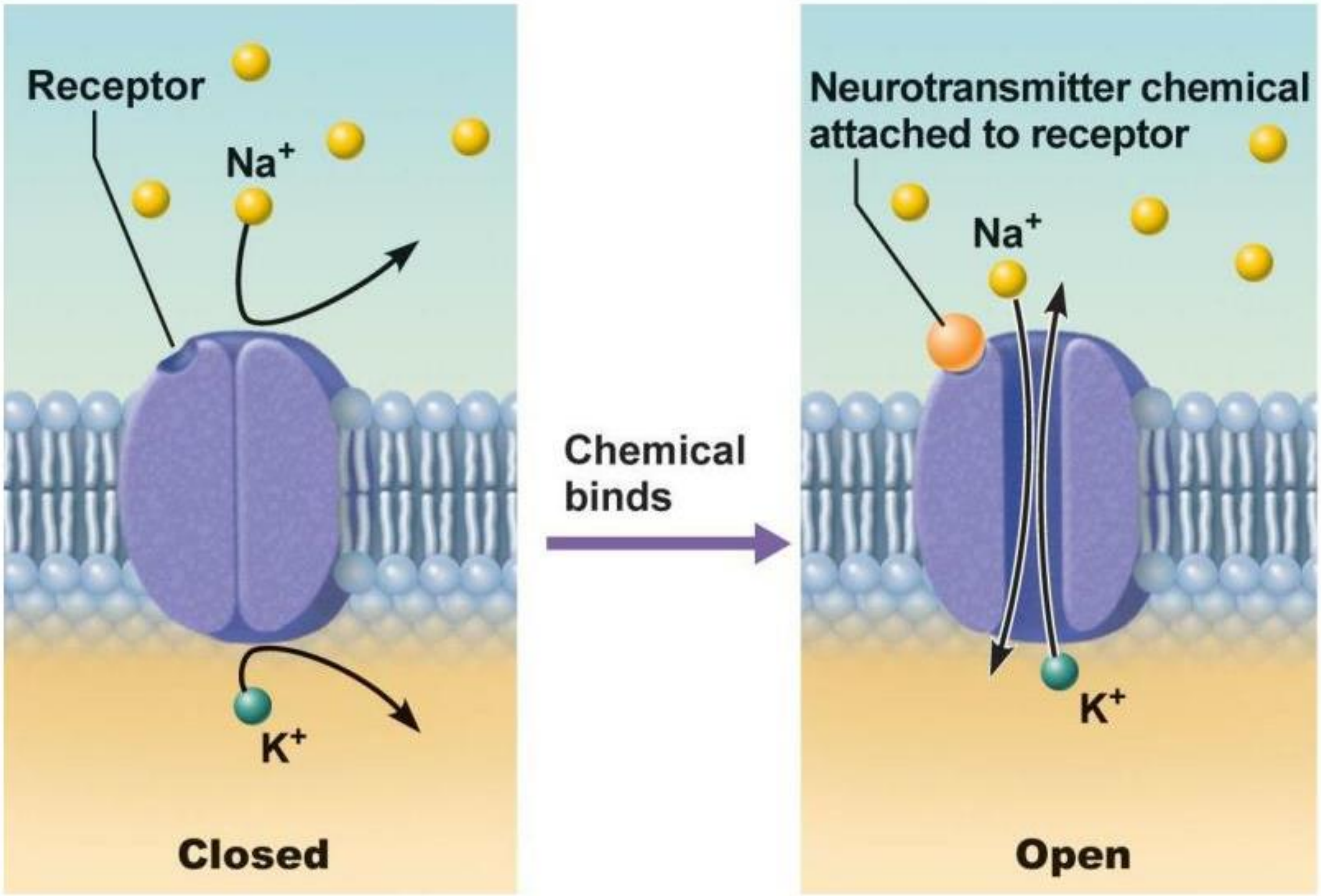
- Types of plasma membrane ion channels:
  - **Passive, or leakage, channels** – always open
  - **Gated channels –** open/close

    - **Chemically gated channels** – open with binding of a specific neurotransmitter

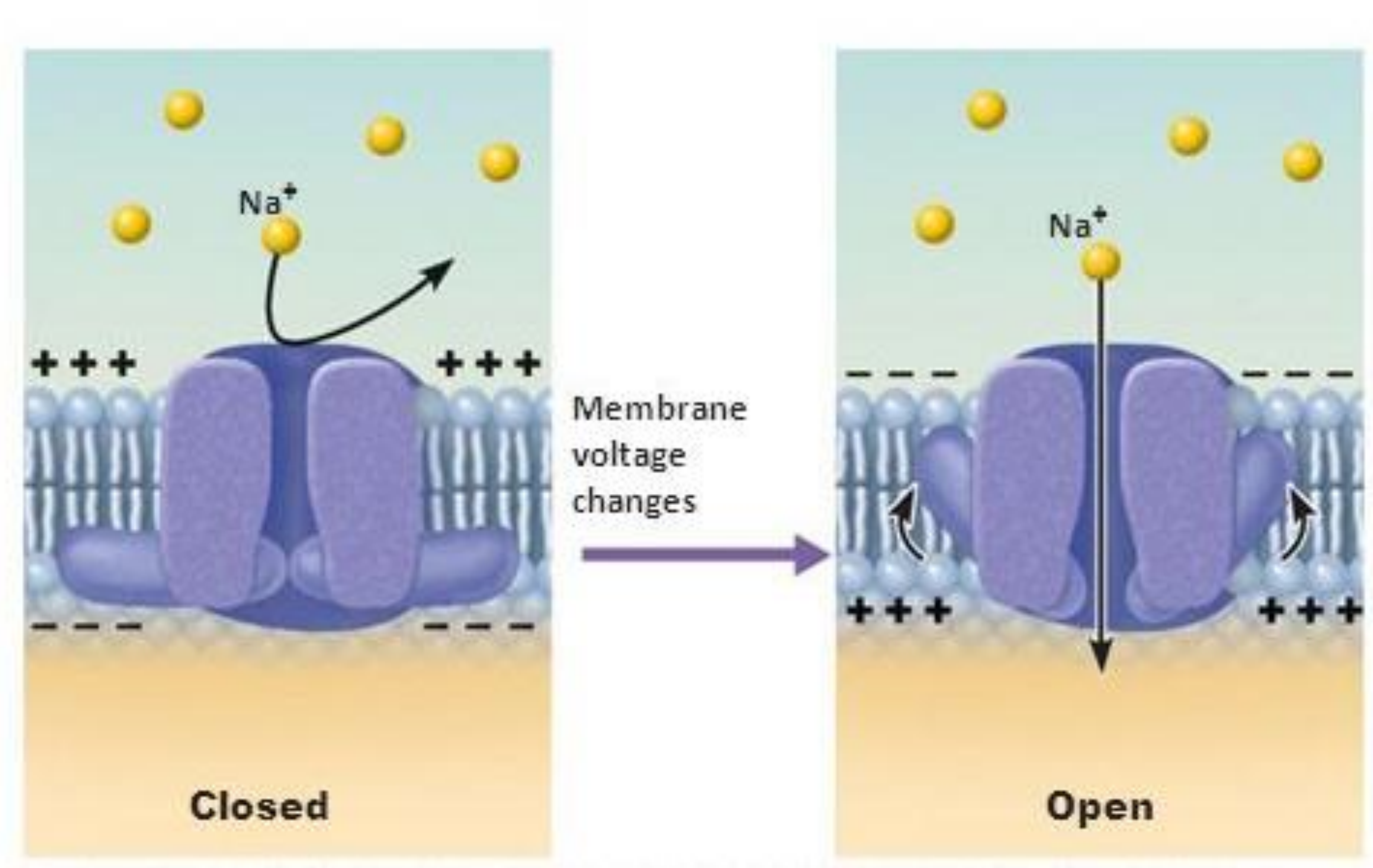
    - **Voltage-gated channels** – open and close in response to membrane potential

    - **Mechanically gated channels** – open and close in response to physical deformation of receptors

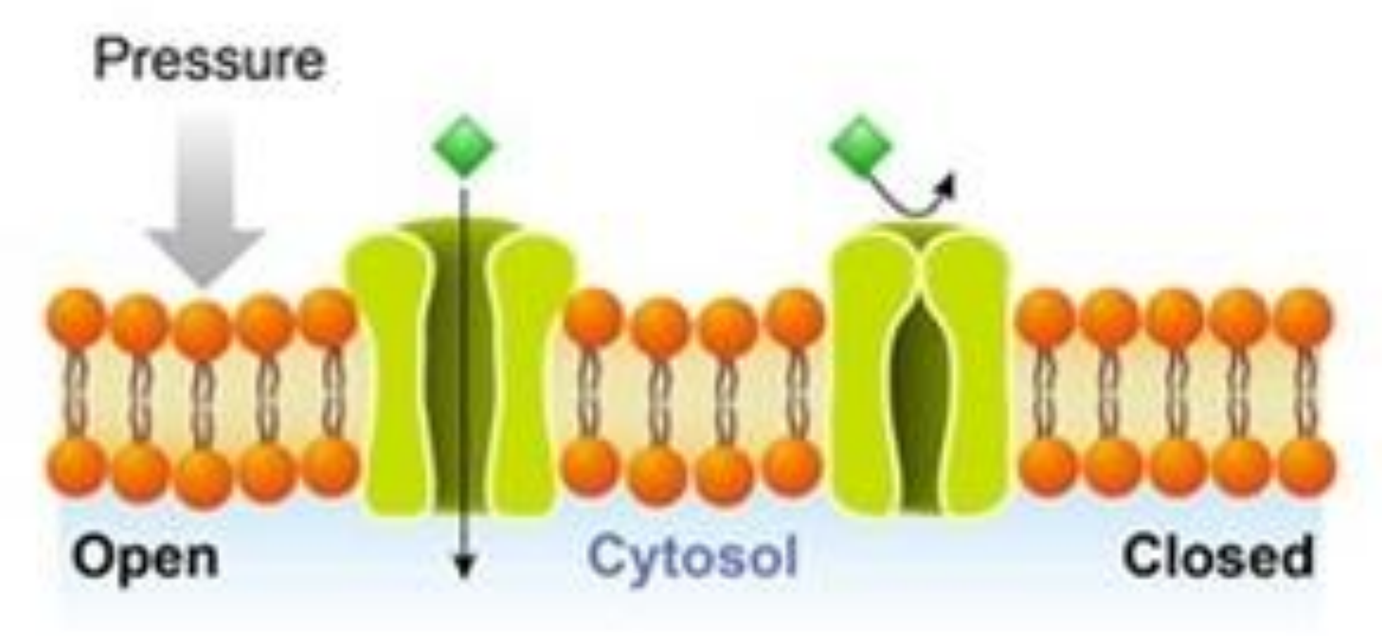
Chemically Gated Channels



Voltage-Gated Channels



Mechanically Gated Channels

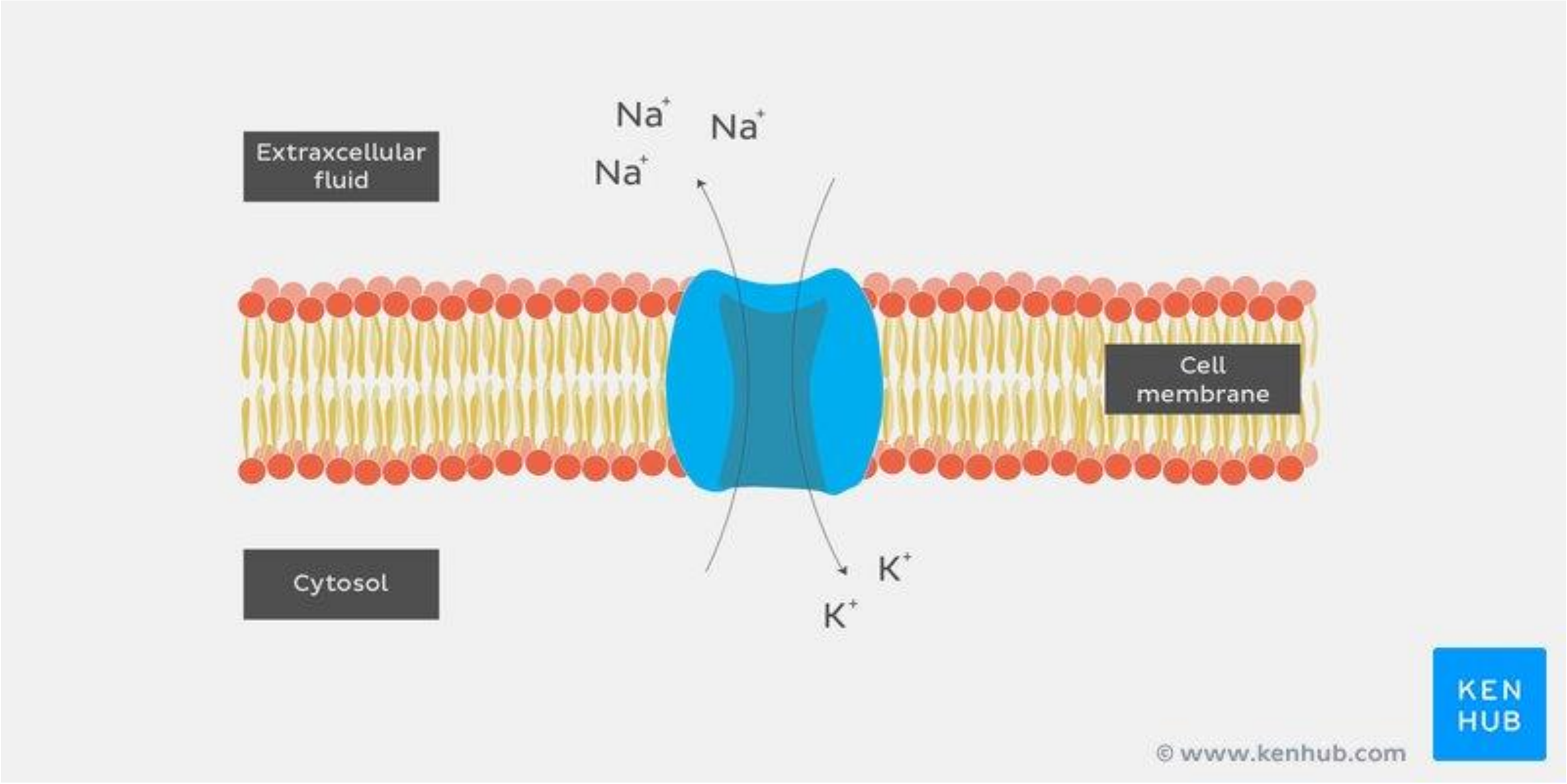


Electrochemical Gradient

- **When gated channels are open:**
- Ions flow along their chemical gradient - move from an area of high concentration to an area of low concentration
- Ions flow along their electrical gradient when they move toward an area of opposite charge
- Electrochemical gradient – the electrical and chemical gradients taken together

Membrane Potential

- Resting membrane potential
- Graded potential
- Action Potential



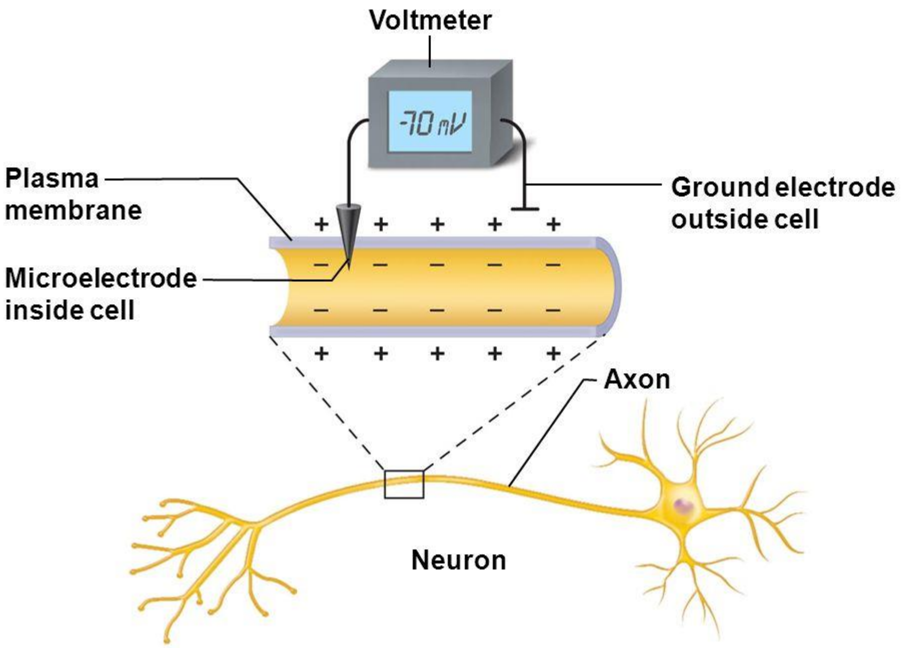
Changes in Membrane Potential

- Changes are caused by three events
  - **Depolarization** – the inside of the membrane becomes less negative
  - **Repolarization** – the membrane returns to its resting membrane potential
  - **Hyperpolarization** – the inside of the membrane becomes more negative than the resting potential

Resting Membrane Potential (V_r)

- The potential difference (–70 mV) across the membrane of a resting neuron
- It is generated by
  - Different concentrations of Na^+, K^+, Cl^-, etc.
  - Changes in membrane permeability to ions

Figure 11.7 Measuring membrane potential in neurons.



Graded Potentials

- Short-lived, localized changes in membrane potential
- Triggered by stimulus that opens gated ion channels
- Named according to location and function

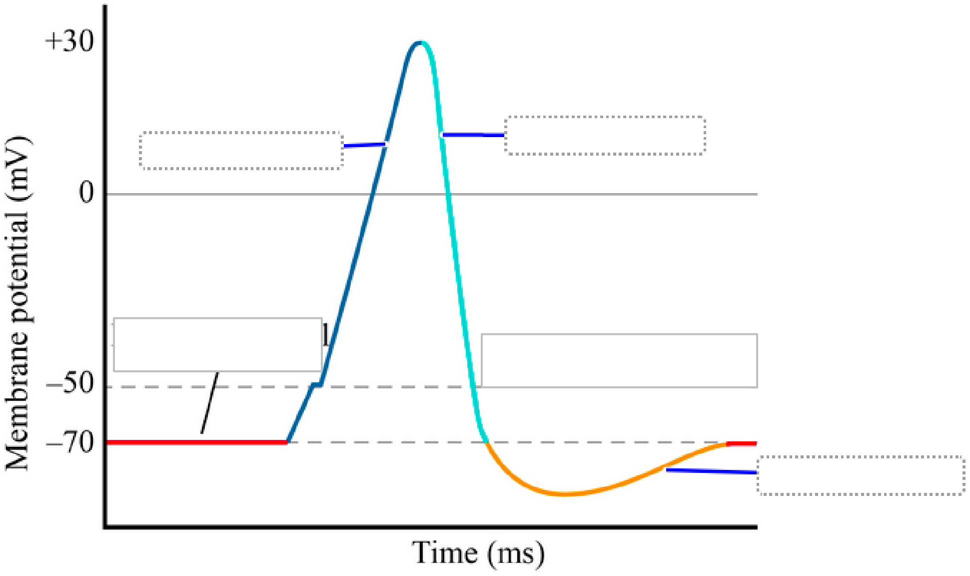
Action Potentials (APs)

- A brief reversal of membrane potential with a total amplitude of 100mV
- Principal means of neuronal communication
- Occur only in muscle cells and axons of neurons
- They do not decrease in strength over distance
- An action potential in the axon of a neuron is a nerve impulse

Generating an Action Potential

4 main steps:

- 1 – Resting state
- 2 – Depolarization phase
- 3 – Repolarization phase
- 4 – Hyperpolarization

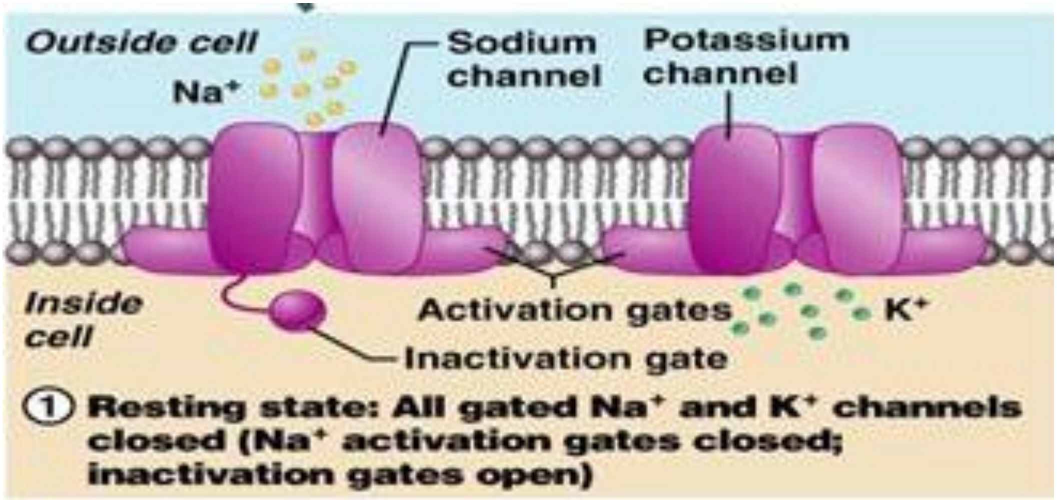


Action Potential: Resting State

- Na^+ and K^+ channels are closed

- Each Na^+ channel has two voltage-regulated gates
  - Activation gates – closed in the resting state
  - Inactivation gates – open in the resting state

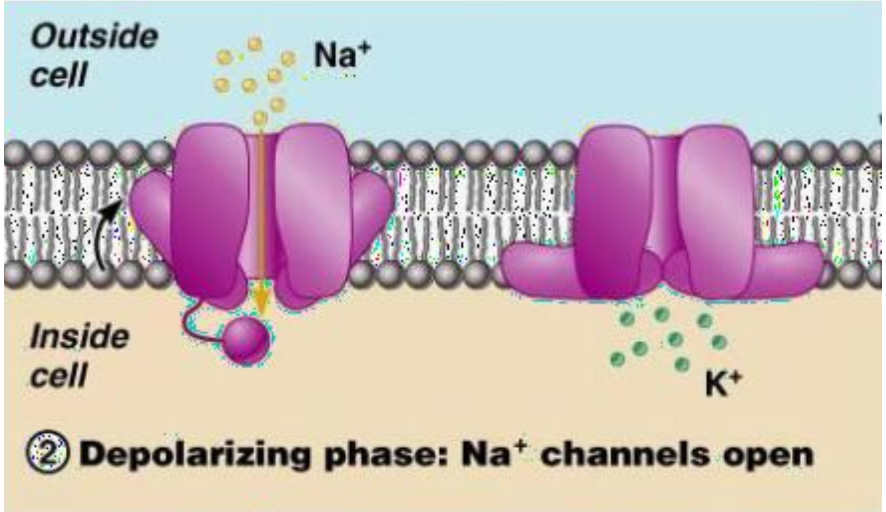
Na^+ outside, K^+ inside



Action Potential: Depolarization Phase

- Na^+ gates are **opened**; K^+ gates are **closed**
- Threshold – a critical level of depolarization (-55 to -50 mV)
- At threshold, depolarization becomes self-generating

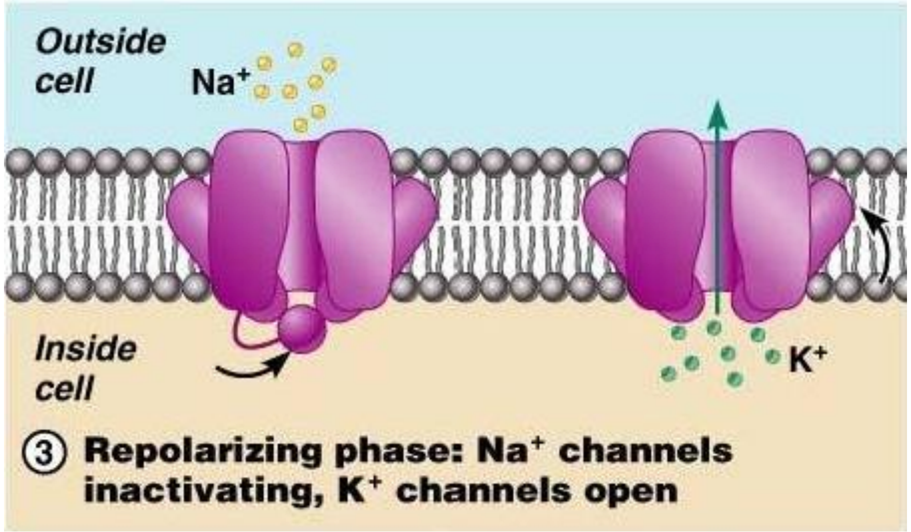
Na^+ enters



Action Potential: Repolarization Phase

- Sodium inactivation gates close
- Membrane permeability to Na^+ declines to resting levels
- As sodium gates close, voltage-sensitive K^+ gates open

K^+ exits



Action Potential: Hyperpolarization

- Potassium gates remain open, causing an excessive efflux of K^+
- This efflux causes hyperpolarization of the membrane
- Na^+ channels begin to reset

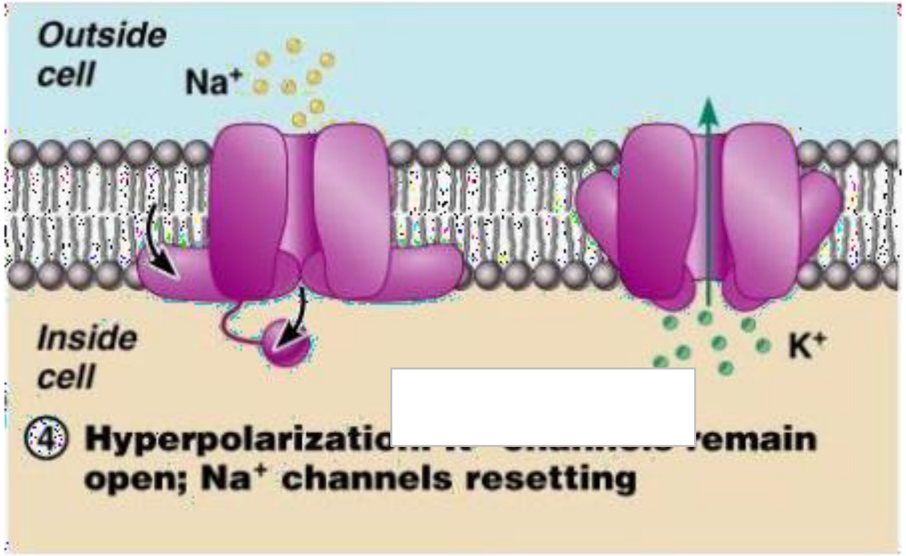
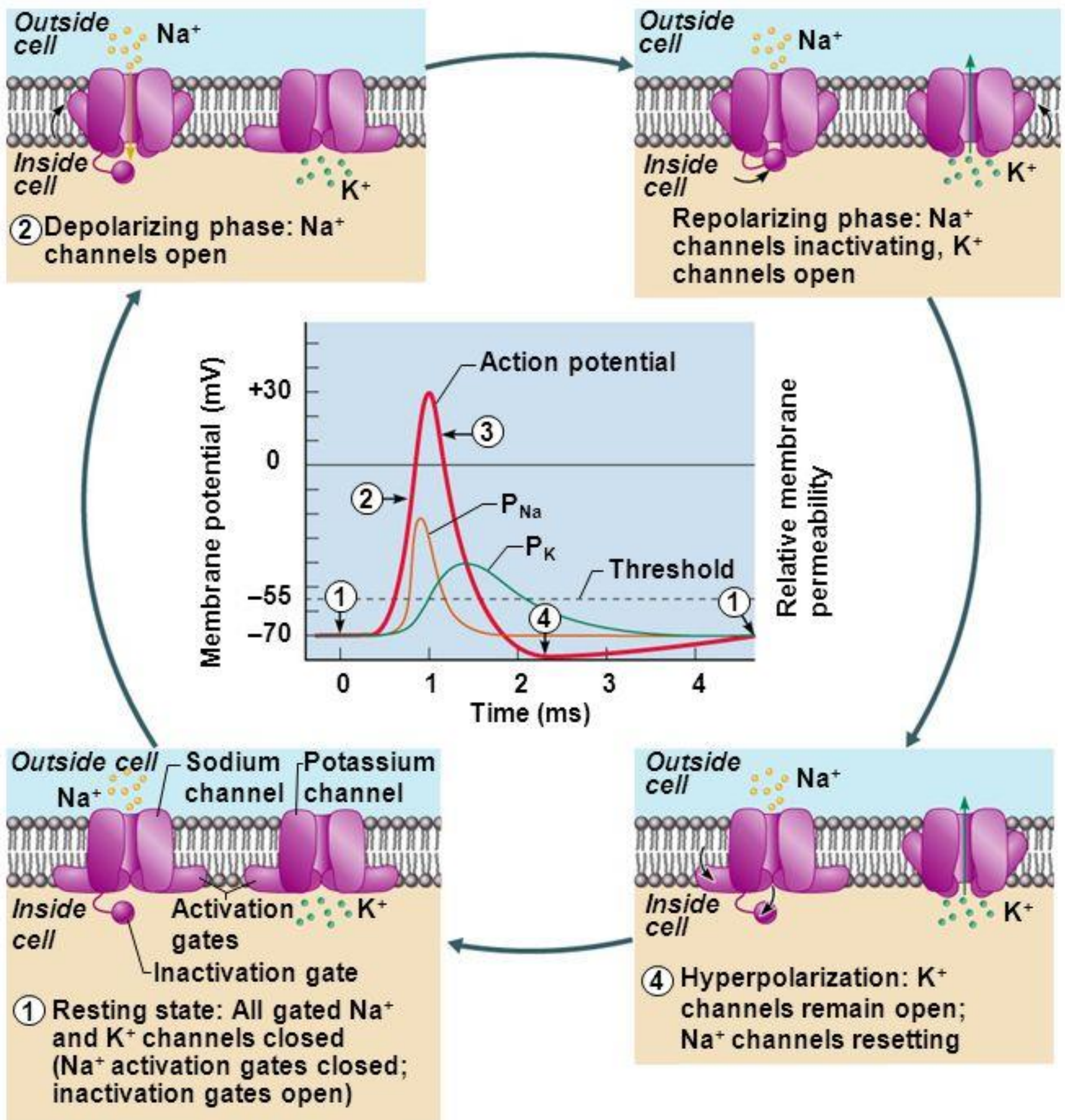
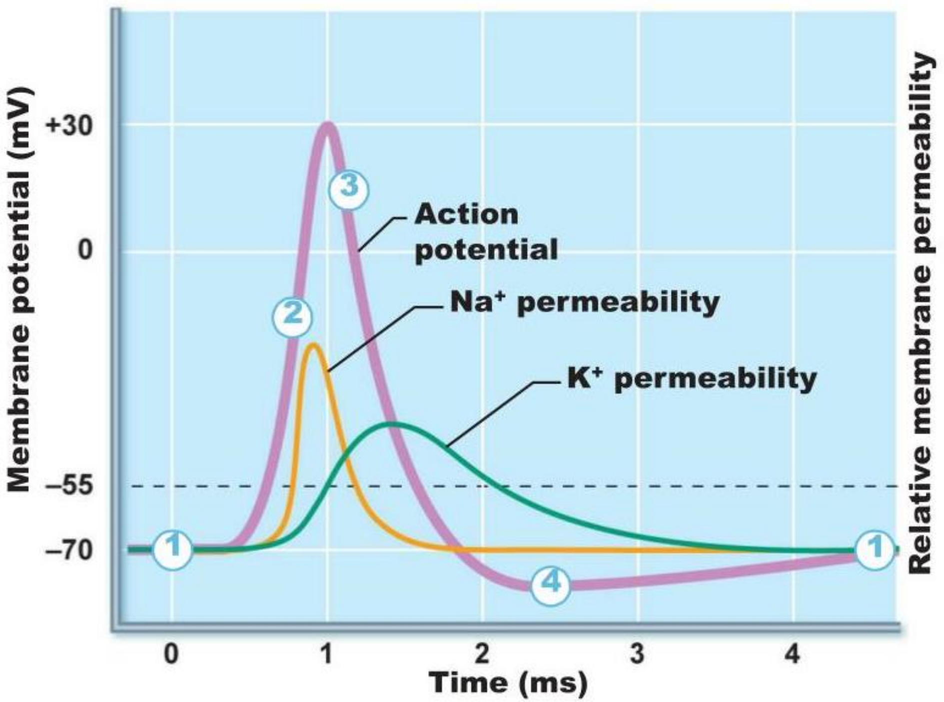


Figure 11.12: Phases of the action potential and the role of voltage-gated ion channels, p. 403.



Phases of the Action Potential

- 1 – Resting state
- 2 – Depolarization phase
- 3 – Repolarization phase
- 4 – Hyperpolarization



Threshold and Action Potentials

- Not all depolarization events produce Aps
- For an axon to “fire” depolarization must reach threshold
- **At threshold** –
  - membrane is depolarized by 15 to 20 mV
  - Na^+ permeability increases
  - Na^+ influx exceeds K^+ efflux
- **All-or-none phenomenon** – AP either happen Completely, or not at all

Refractory Periods

- Time in which neuron cannot trigger another AP
- **Two types:**
  - Absolute refractory period
  - Relative refractory period

Absolute Refractory Period

- Time from the opening of the Na^+ activation gates until the closing of inactivation gates
- The absolute refractory period:
  - Prevents the neuron from generating an action potential
  - Ensures that each action potential is separate
  - Enforces one-way transmission of nerve impulses

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Nervous System I: The Action Potential, page 14

Relative Refractory Period

- The interval following the absolute refractory period when:
  - Sodium gates are closed
  - Potassium gates are open
  - Repolarization is occurring

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Nervous System I: The Action Potential, page 15

Absolute and Relative Refractory Periods

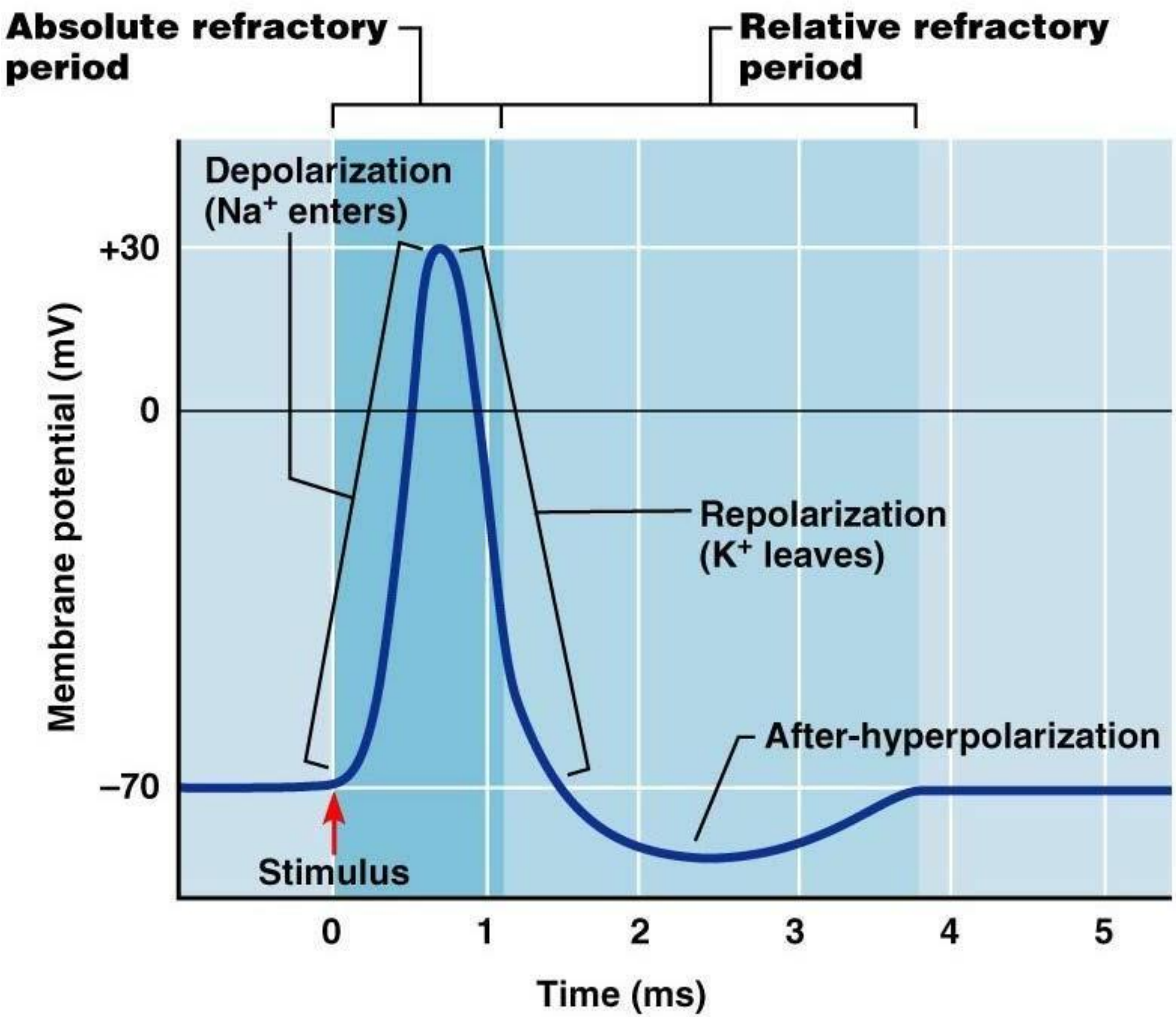

Figure 11.15

Conduction Velocities of Axons

- Conduction velocities vary widely among neurons
- Rate of impulse propagation is determined by:
  - **Axon diameter** – the larger the diameter, the faster the impulse
  - **Degree of myelination** – myelination dramatically increases impulse speed

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Nervous System I: Action Potential, page 17

Nerve Fiber Classification

- Nerve fibers are classified according to:
  - Diameter
  - Degree of myelination
  - Speed of conduction

Nerve Fiber Classification

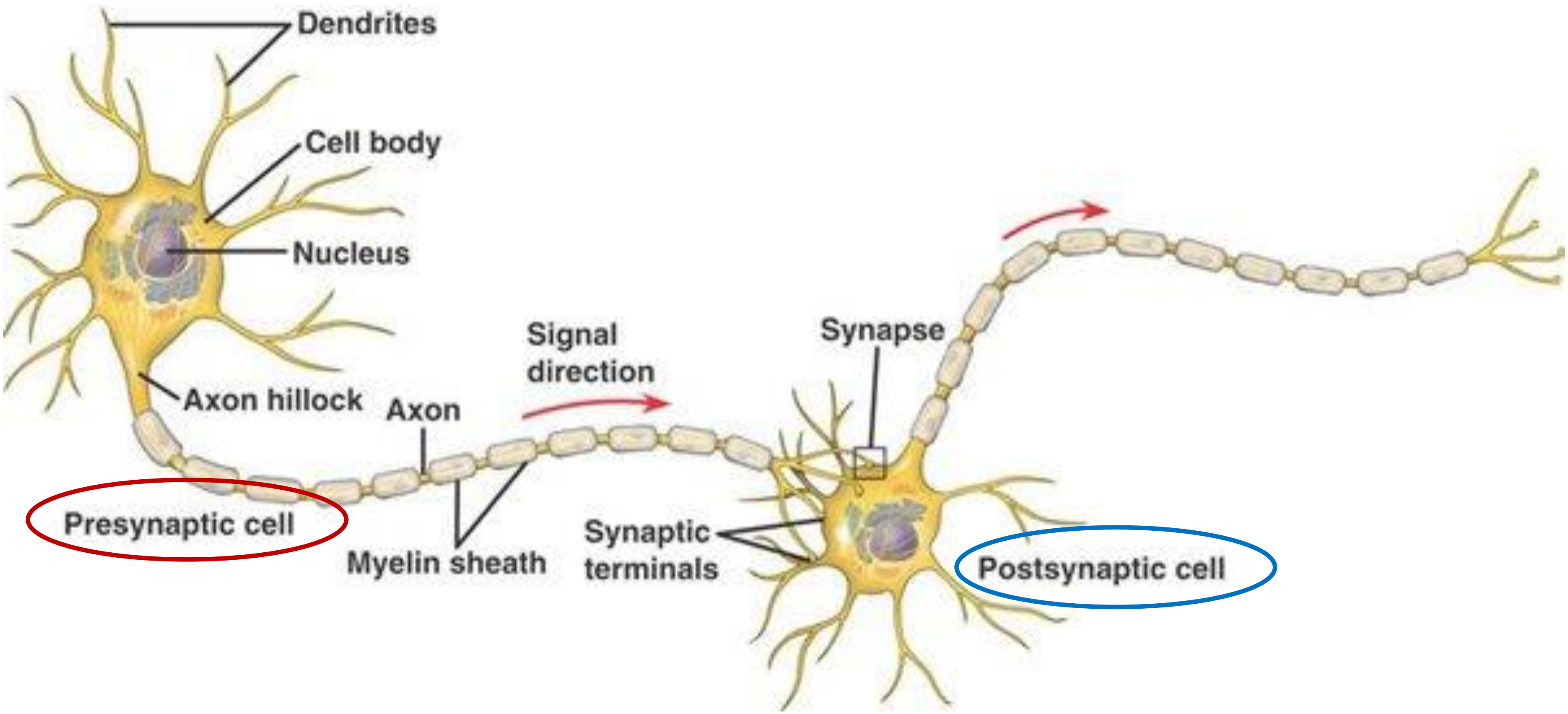
1. **Group A fibers**
   Largest diameter
   Myelinated
   Transmits at 150 m/s (~300 mph)

2. **Group B fibers**
   Intermediate diameter
   Lightly myelinated
   Transmits at 15 m/s (~30 mph)

3. **Group C fibers**
   Smallest diameter
   Unmyelinated
   Transmits at 1 m/s (~2 mph)

Synapses

- A junction that mediates information transfer from one neuron:
  - To another neuron
  - To an effector cell
- **Presynaptic neuron** – conducts impulses toward the synapse
- **Postsynaptic neuron** – transmits impulses away from the synapse


Dendrites
Cell body
Nucleus
Axon hillock
Axon
Signal direction
Synapse
Presynaptic cell
Myelin sheath
Synaptic terminals
Postsynaptic cell

Synapses

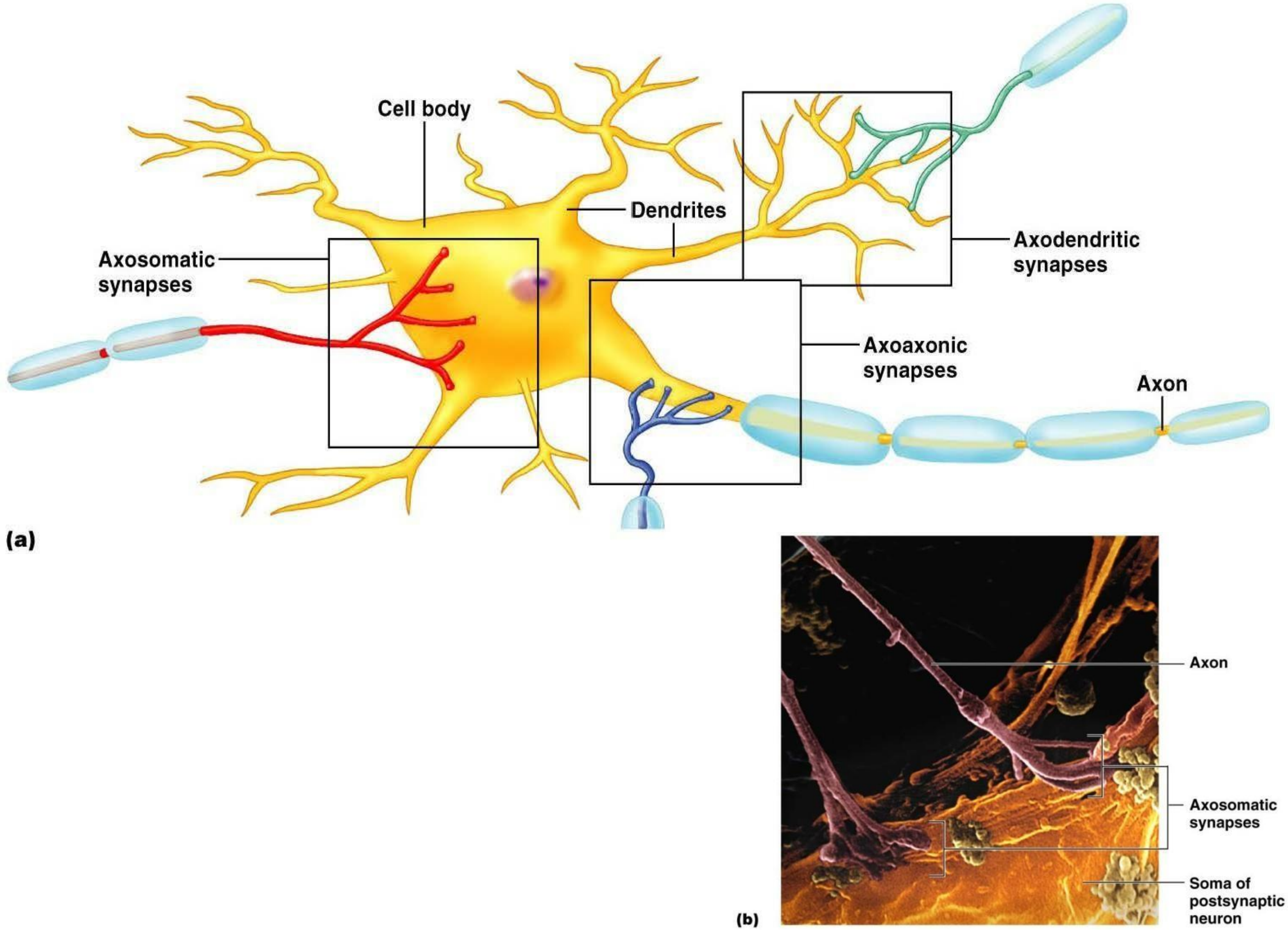


Figure 11.17

Synaptic Cleft

- Fluid-filled space separating the presynaptic and postsynaptic neurons
- Prevents nerve impulses from directly passing from one neuron to the next
- Transmission across the synaptic cleft:
  - Is a chemical event
  - Ensures unidirectional communication between neurons

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Nervous System II: Anatomy Review, page 8

Synaptic Cleft: Information Transfer

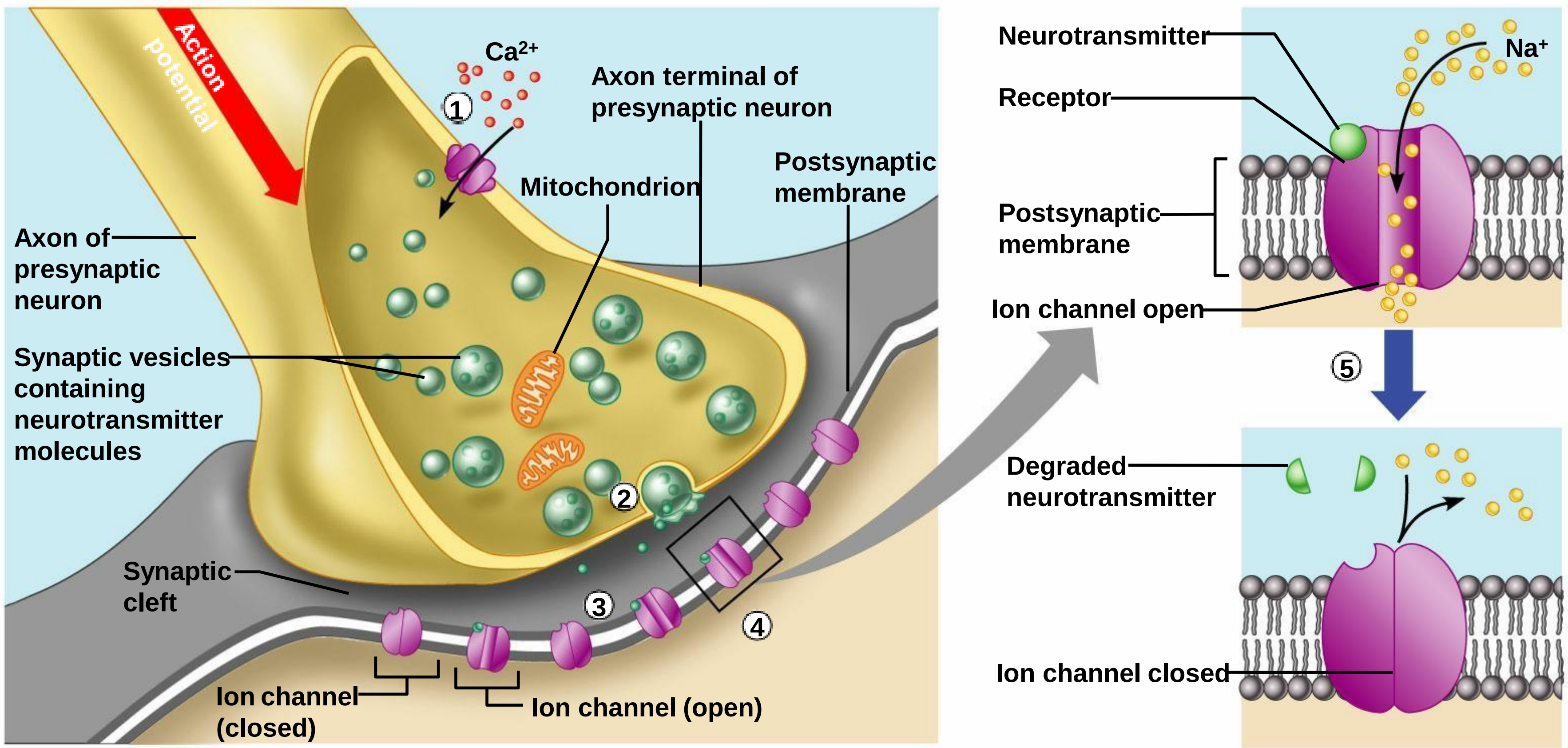

Figure 11.18

Neurotransmitters

- Chemicals used for neuronal communication with the body and the brain
- 50 different neurotransmitters have been identified
- Classified chemically and functionally

Chemical Neurotransmitters

- Acetylcholine (ACh)
- Biogenic amines
- Amino acids
- Peptides
- Novel messengers: ATP and dissolved gases NO and CO

Neurotransmitters: Acetylcholine

- First neurotransmitter identified, and best understood
- Released at the neuromuscular junction
- Synthesized and enclosed in synaptic vesicles

Neurotransmitters: Acetylcholine

- Degraded by the enzyme acetylcholinesterase (AChE)
- Released by:
  - All neurons that stimulate skeletal muscle
  - Some neurons in the autonomic nervous system

Neurotransmitters: Biogenic Amines

- Include:
  - Catecholamines – dopamine, norepinephrine (NE), and epinephrine
  - Indolamines – serotonin and histamine
- Broadly distributed in the brain
- Play roles in emotional behaviors and our biological clock

Functional Classification of Neurotransmitters

- **Two classifications**: excitatory and inhibitory
  - Excitatory neurotransmitters cause depolarizations (e.g., glutamate)
  - Inhibitory neurotransmitters cause hyperpolarizations (e.g., GABA and glycine)

Functional Classification of Neurotransmitters

- Some neurotransmitters have both excitatory and inhibitory effects
  - Determined by the receptor type of the postsynaptic neuron
  - Example: acetylcholine
    - Excitatory at neuromuscular junctions with skeletal muscle
    - Inhibitory in cardiac muscle

Neurotransmitter Receptor Mechanisms

- **Direct**: neurotransmitters that open ion channels
  - Promote rapid responses
  - Examples: ACh and amino acids
- **Indirect**: neurotransmitters that act through second messengers
  - Promote long-lasting effects
  - Examples: biogenic amines, peptides, and dissolved gases

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Nervous System II: Synaptic Transmission

Neurotransmitter Receptor Mechanism

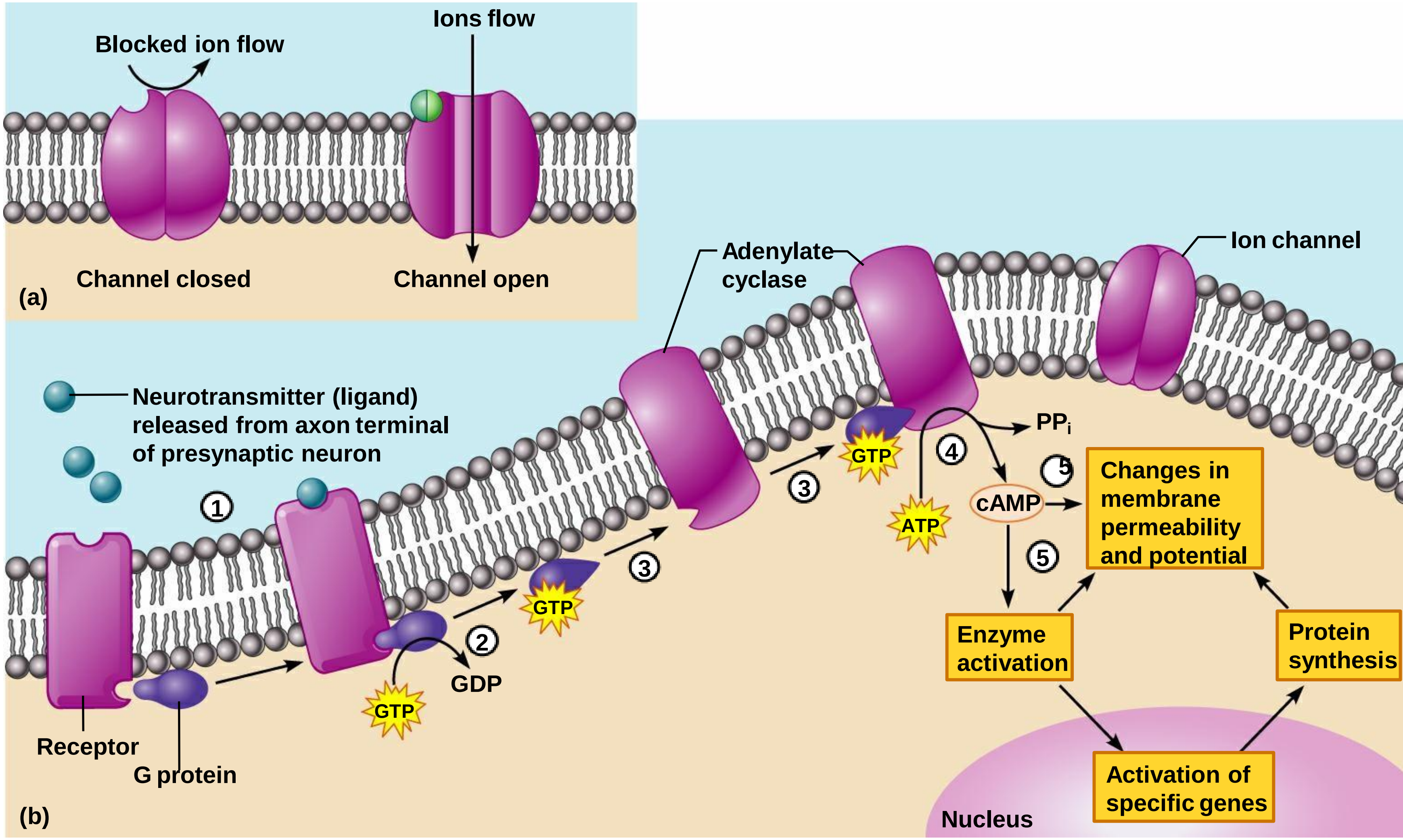

Figure 11.22b

Autonomic Nervous System (ANS)

- The ANS consists of motor neurons that:
  - Innervate smooth and cardiac muscle and glands
  - Make adjustments to ensure optimal support for body activities
  - Have viscera as most of their effectors

ANS in the Nervous System

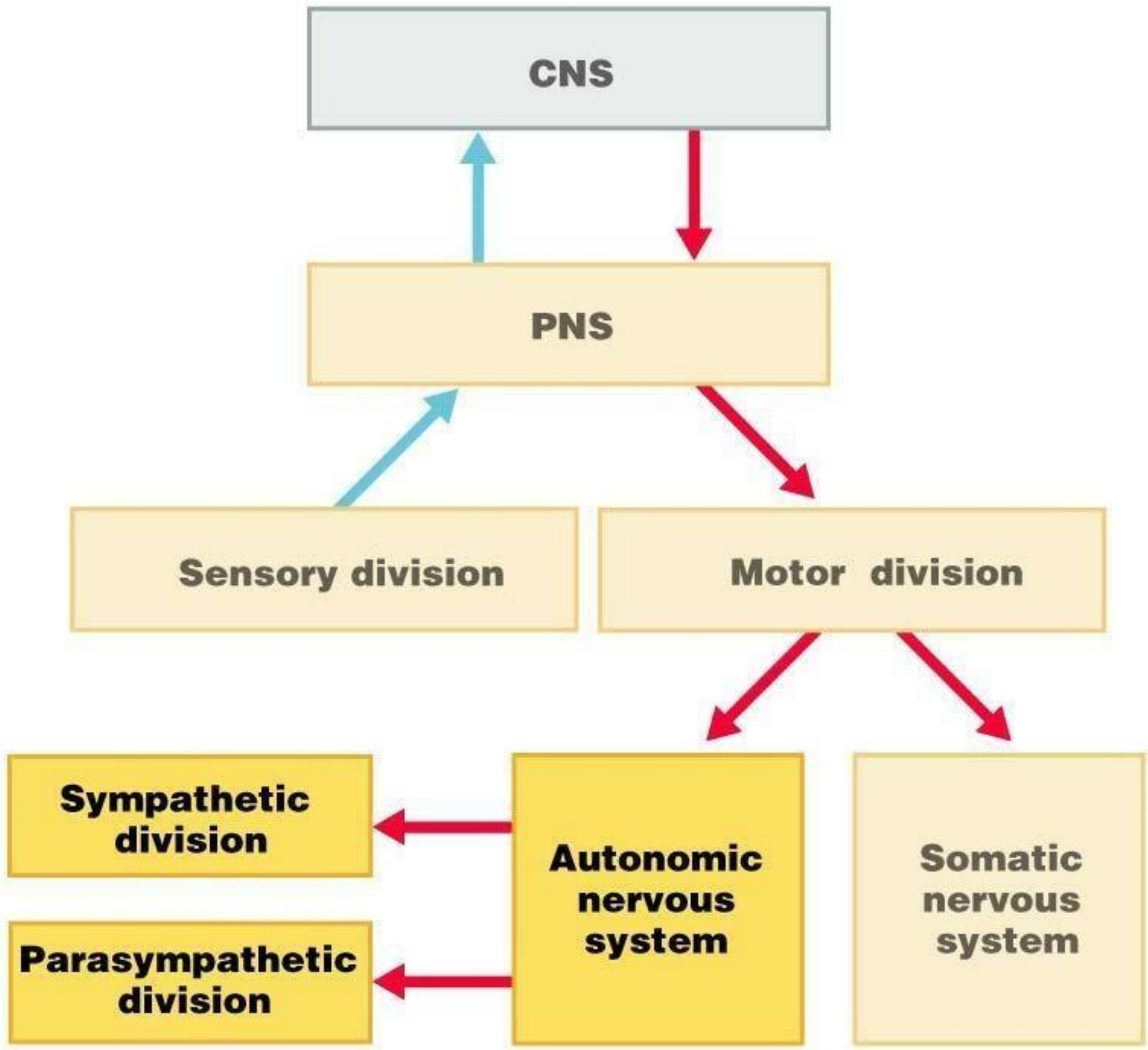

Figure 14.1

ANS Versus Somatic Nervous System (SNS)

- The ANS differs from the SNS in the following three areas
  - Effectors
  - Efferent pathways
  - Target organ responses

Comparison of Somatic and Autonomic Systems

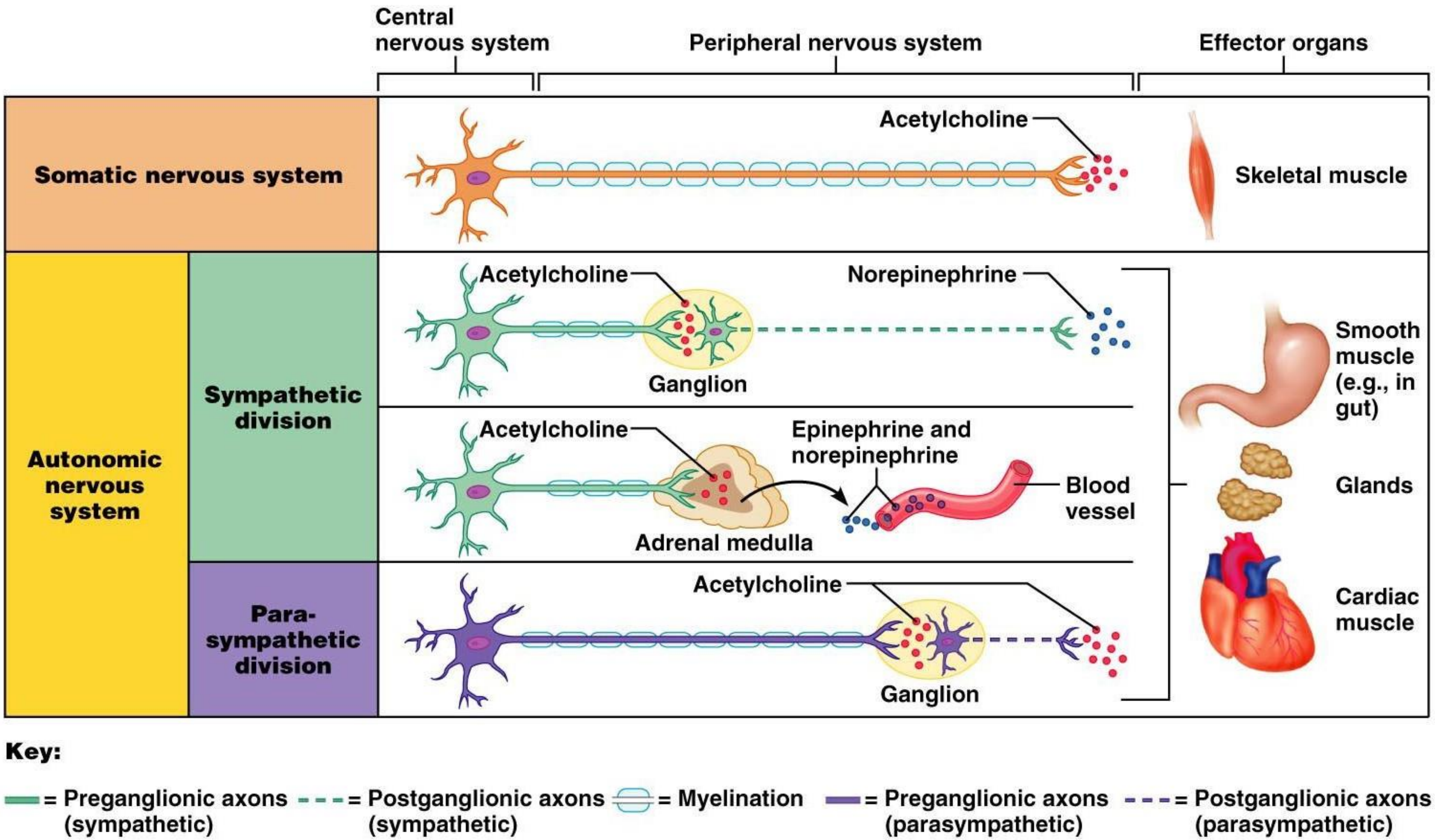

Figure 14.2

Divisions of the ANS

- ANS divisions**: sympathetic and parasympathetic**
- The **sympathetic** mobilizes the body during extreme situations
- The **parasympathetic** performs maintenance activities and conserves body energy
- The two divisions counterbalance each other

Role of the Sympathetic Division

- The sympathetic division is the “fight-or-flight” system
- Involves **E** activities – exercise, excitement, emergency, and embarrassment
- Promotes adjustments during exercise – blood flow to organs is reduced, flow to muscles is increased
- Its activity is illustrated by a person who is threatened
  - Heart rate increases, and breathing is rapid and deep
  - The skin is cold and sweaty, and the pupils dilate

Role of the Parasympathetic Division

- Concerned with keeping body energy use low
- Involves the **D** activities – digestion, defecation, and diuresis
- Its activity is illustrated in a person who relaxes after a meal
  - Blood pressure, heart rate, and respiratory rates are low
  - Gastrointestinal tract activity is high
  - The skin is warm and the pupils are constricted

Anatomy of ANS

Division	Origin of Fibers	Length of Fibers	Location of Ganglia
Sympathetic	Thoracolumbar region of the spinal cord	Short preganglionic and long postganglionic	Close to the spinal cord
Parasympathetic	Brain and sacral spinal cord	Long preganglionic and short postganglionic	In the visceral effector organs

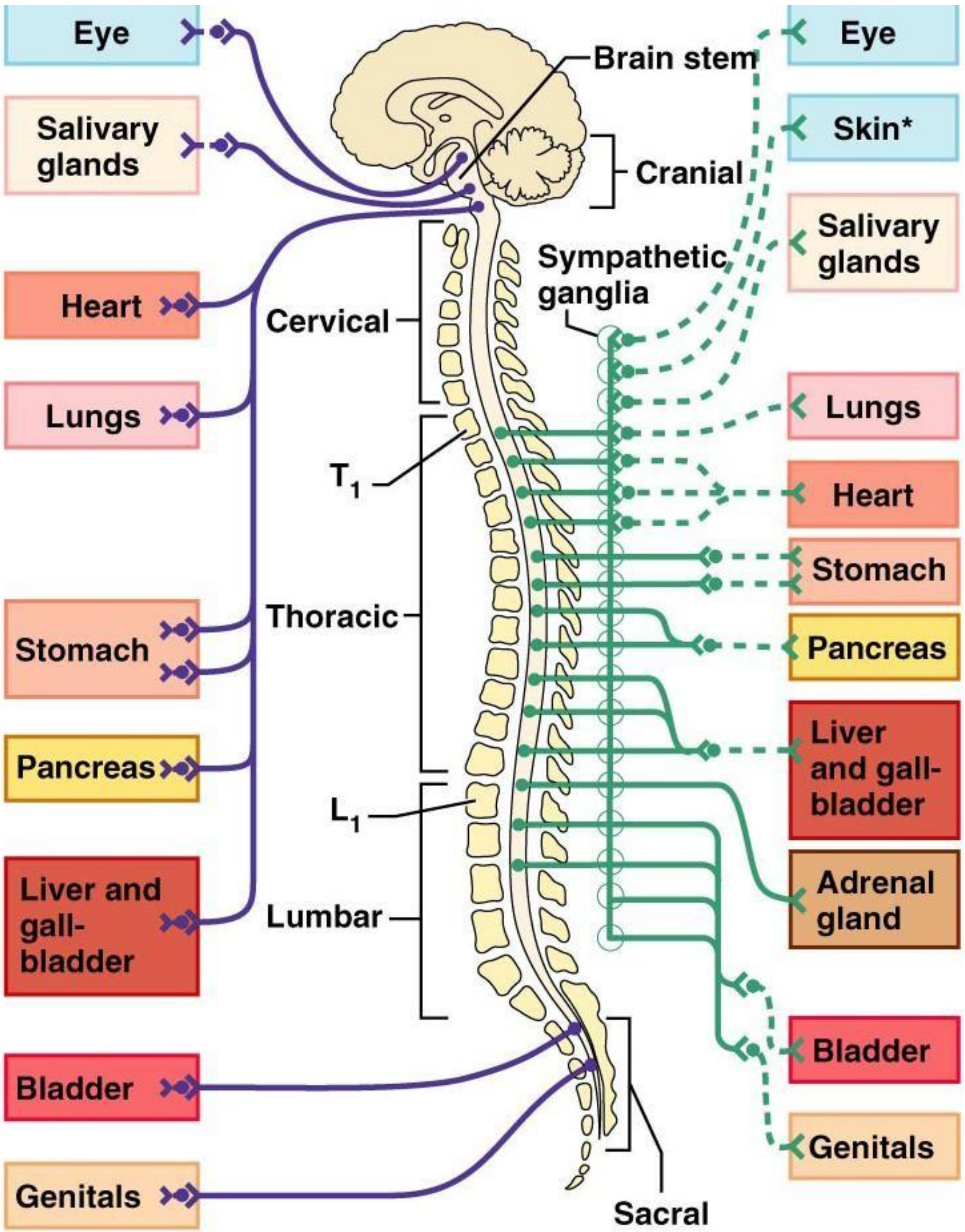
Eye
Salivary glands
Heart
Lungs
Stomach
Pancreas
Liver and gall-bladder
Bladder
Genitals
Brain stem
Cranial
Cervical
T1
Thoracic
L1
Lumbar
Sacral
Sympathetic ganglia
Eye
Skin*
Salivary glands
Lungs
Heart
Stomach
Pancreas
Liver and gall-bladder
Adrenal gland
Bladder
Genitals

Figure 14.3

Cranial Nerves

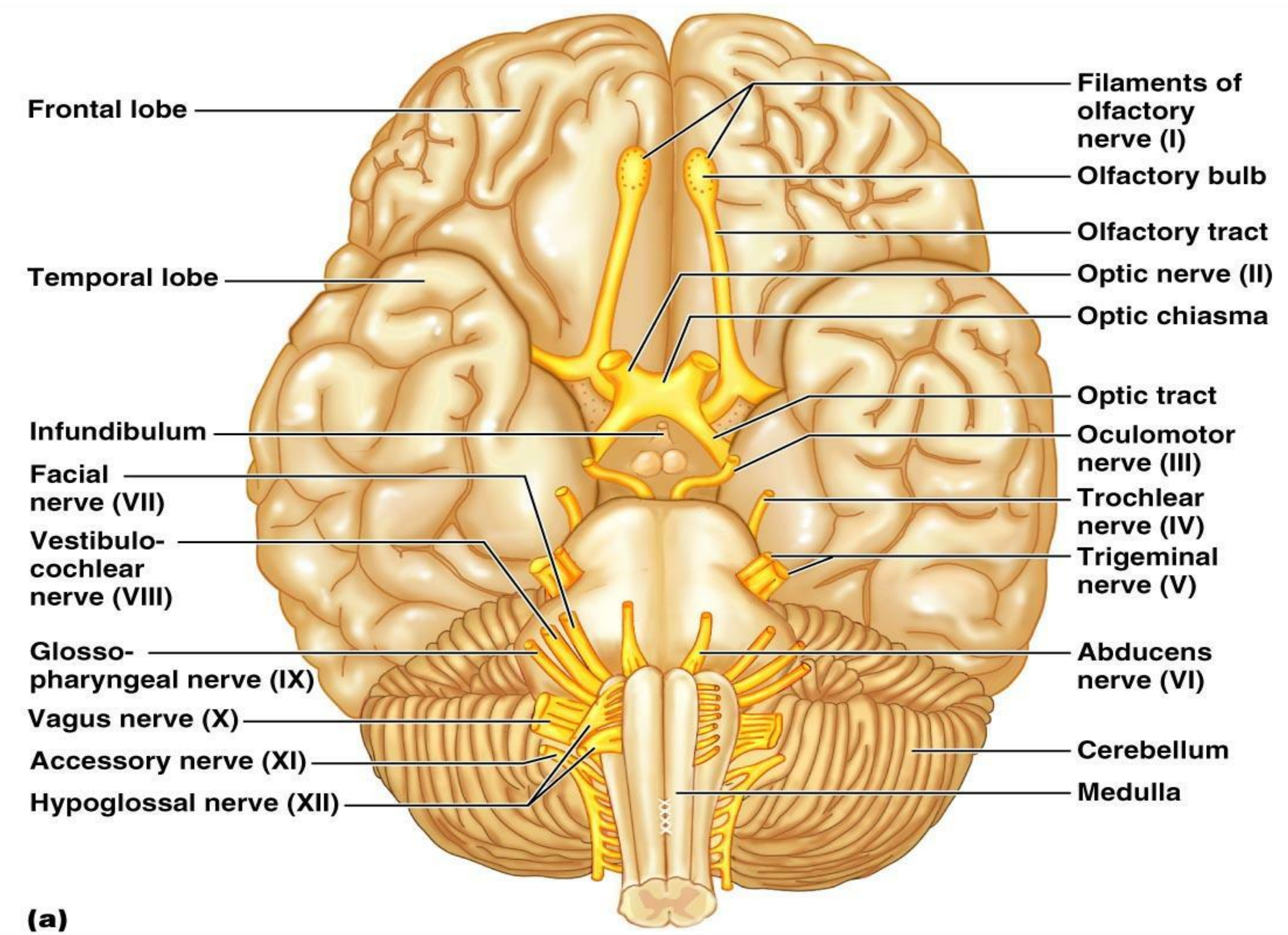

Figure 13.5a

Parasympathetic Division Outflow

Cranial Outflow	Cranial Nerve	Ganglion	Effector Organ(s)
	Occulomotor (III)	Ciliary	Eye
	Facial (VII)	Pterygopalatin Submandibular	Salivary, nasal, and lacrimal glands
	Glossopharyngeal (IX)	Otic	Parotid salivary glands
	Vagus (X)	Located within the walls of target organs	Heart, lungs, and most visceral organs
Sacral Outflow	S_2-S_4	Located within the walls of the target organs	Large intestine, urinary bladder, ureters, and reproductive organs

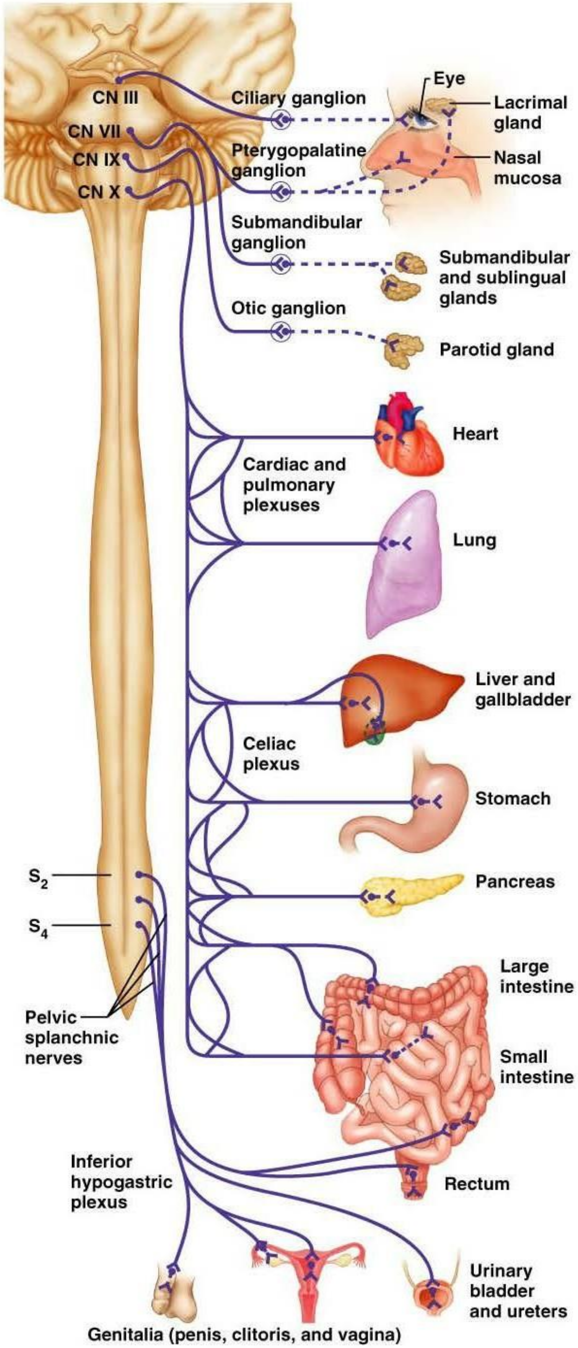
CN III
CN VII
CN IX
CN X
Ciliary ganglion
Pterygopalatine ganglion
Submandibular ganglion
Otic ganglion
Eye
Lacrimal gland
Nasal mucosa
Submandibular and sublingual glands
Parotid gland
Heart
Cardiac and pulmonary plexuses
Lung
Liver and gallbladder
Celiac plexus
Stomach
Pancreas
Large intestine
Small intestine
Rectum
S2
S4
Pelvic splanchnic nerves
Inferior hypogastric plexus
Urinary bladder and ureters
Genitalia (penis, clitoris, and vagina)

Figure 14.4

Interactions of the Autonomic Divisions

- Most visceral organs are innervated by both sympathetic and parasympathetic fibers
- This results in dynamic antagonisms that precisely control visceral activity
- Sympathetic fibers increase heart and respiratory rates, and inhibit digestion and elimination
- Parasympathetic fibers decrease heart and respiratory rates, and allow for digestion and the discarding of wastes

Thank You