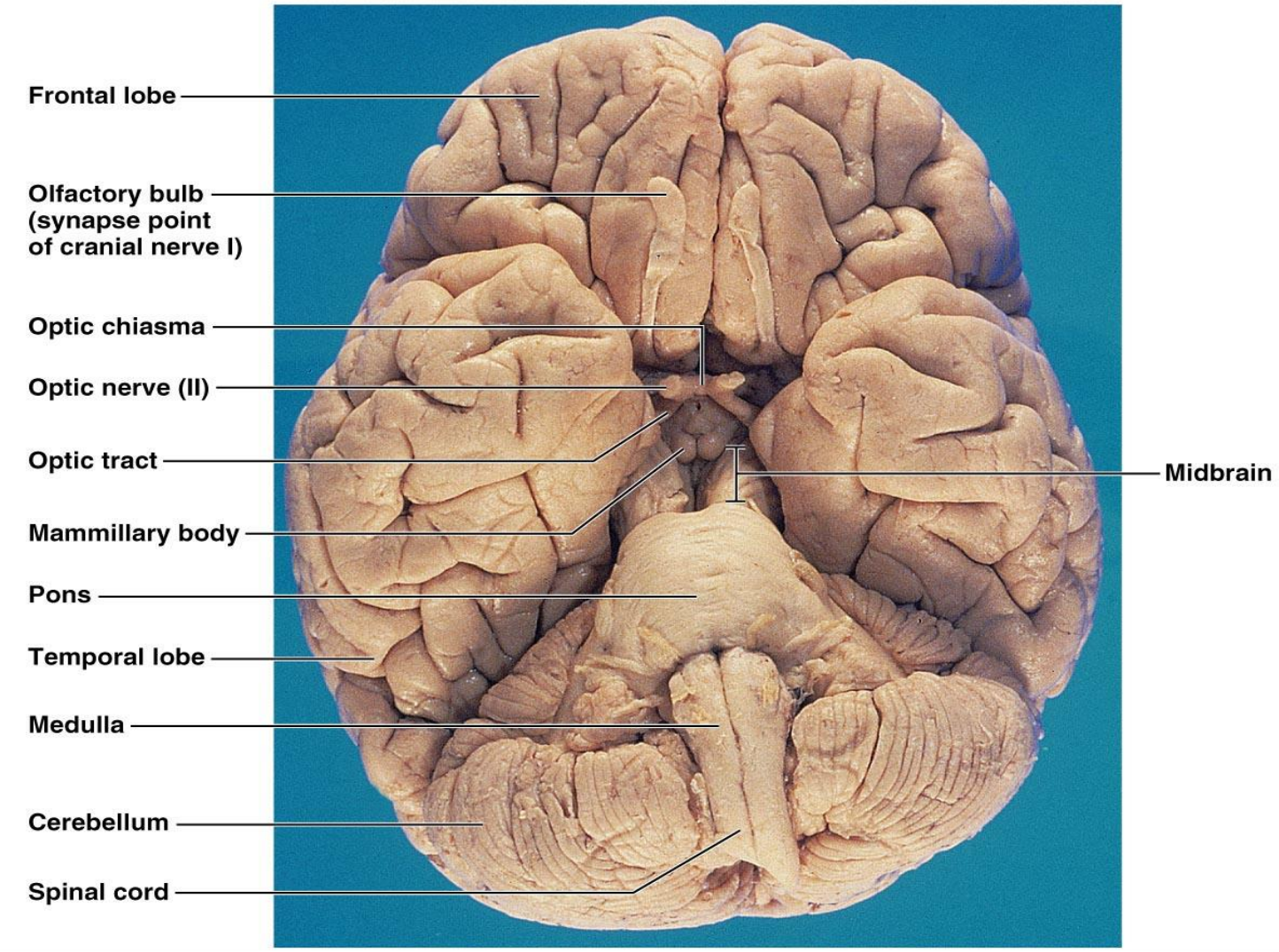
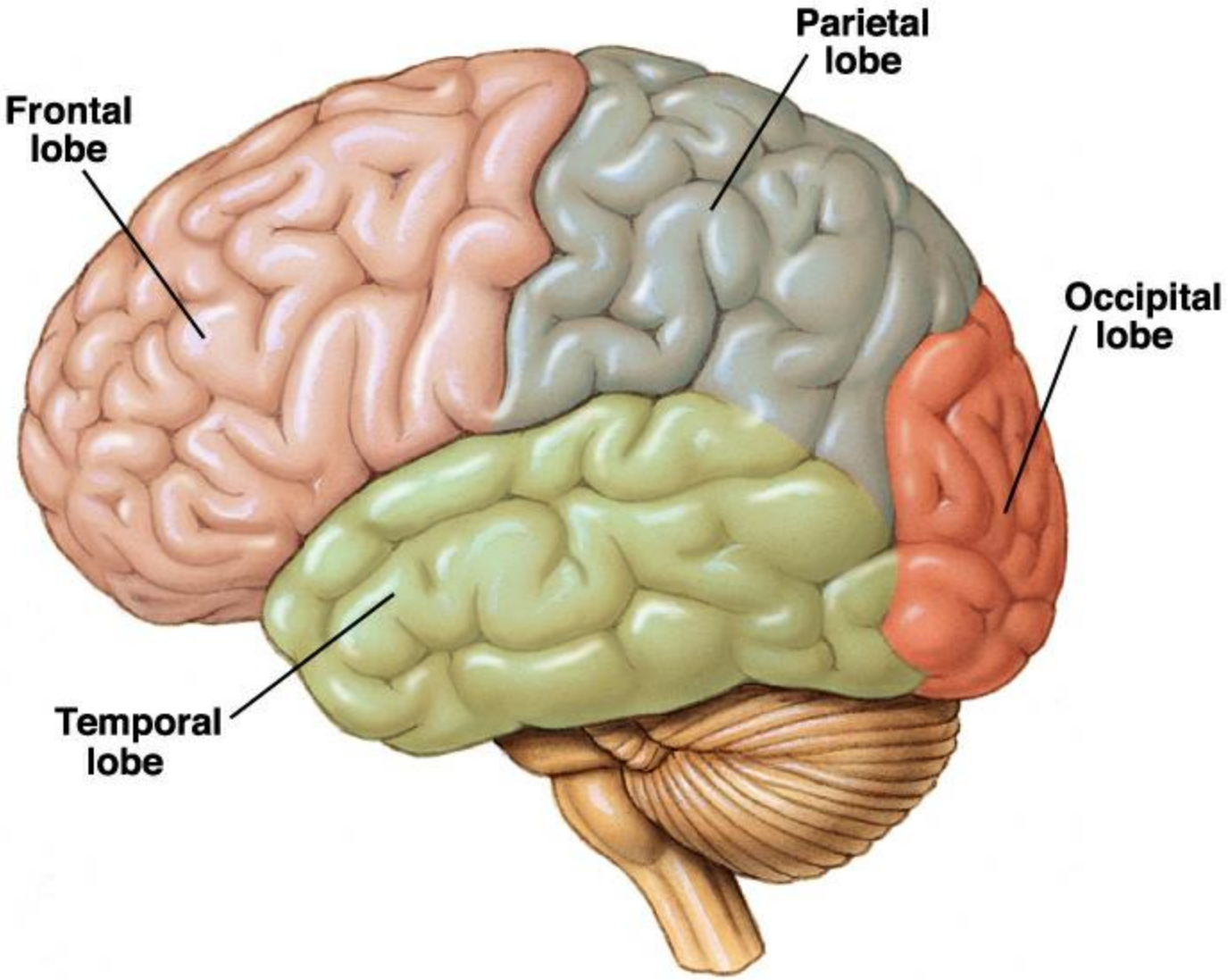
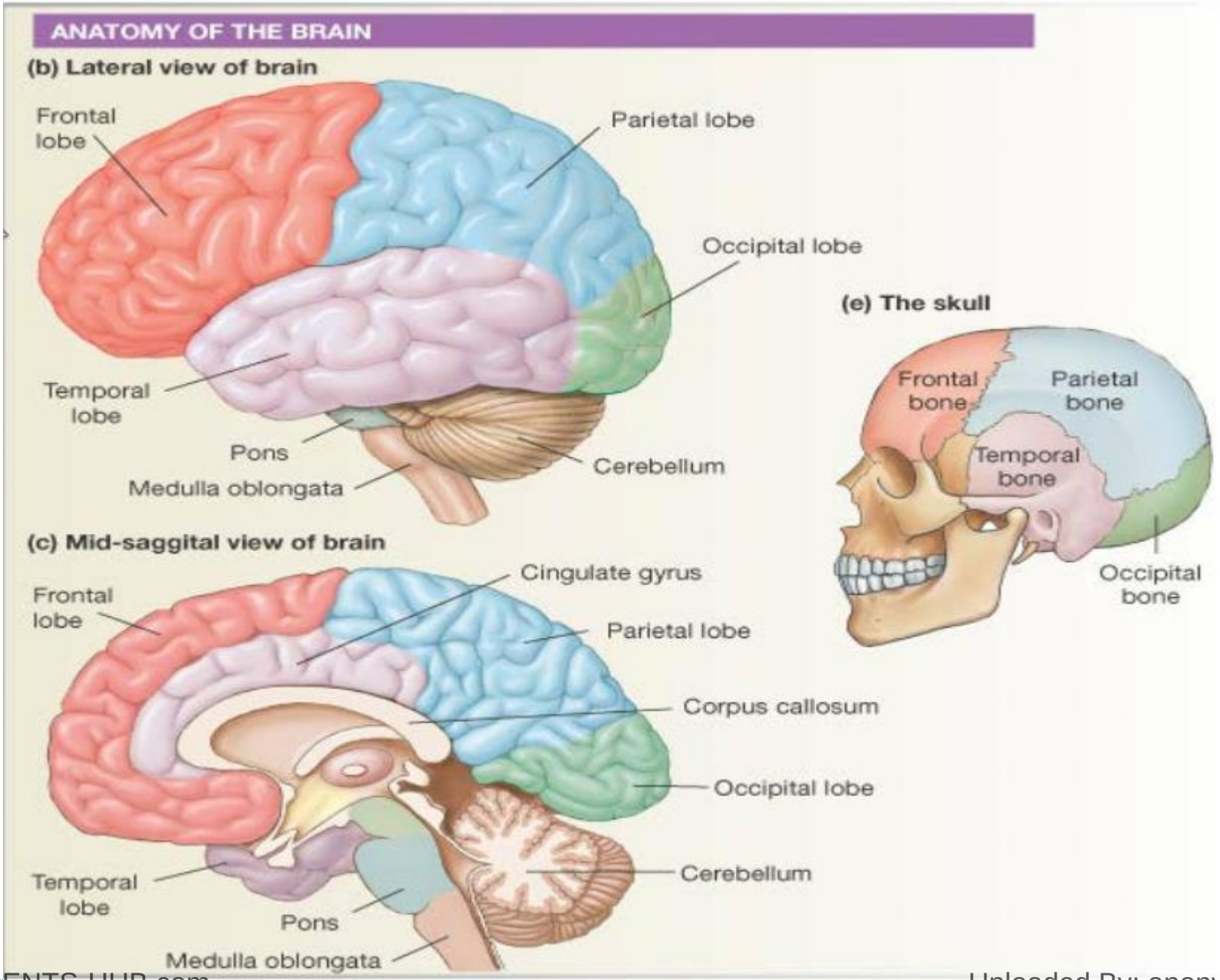
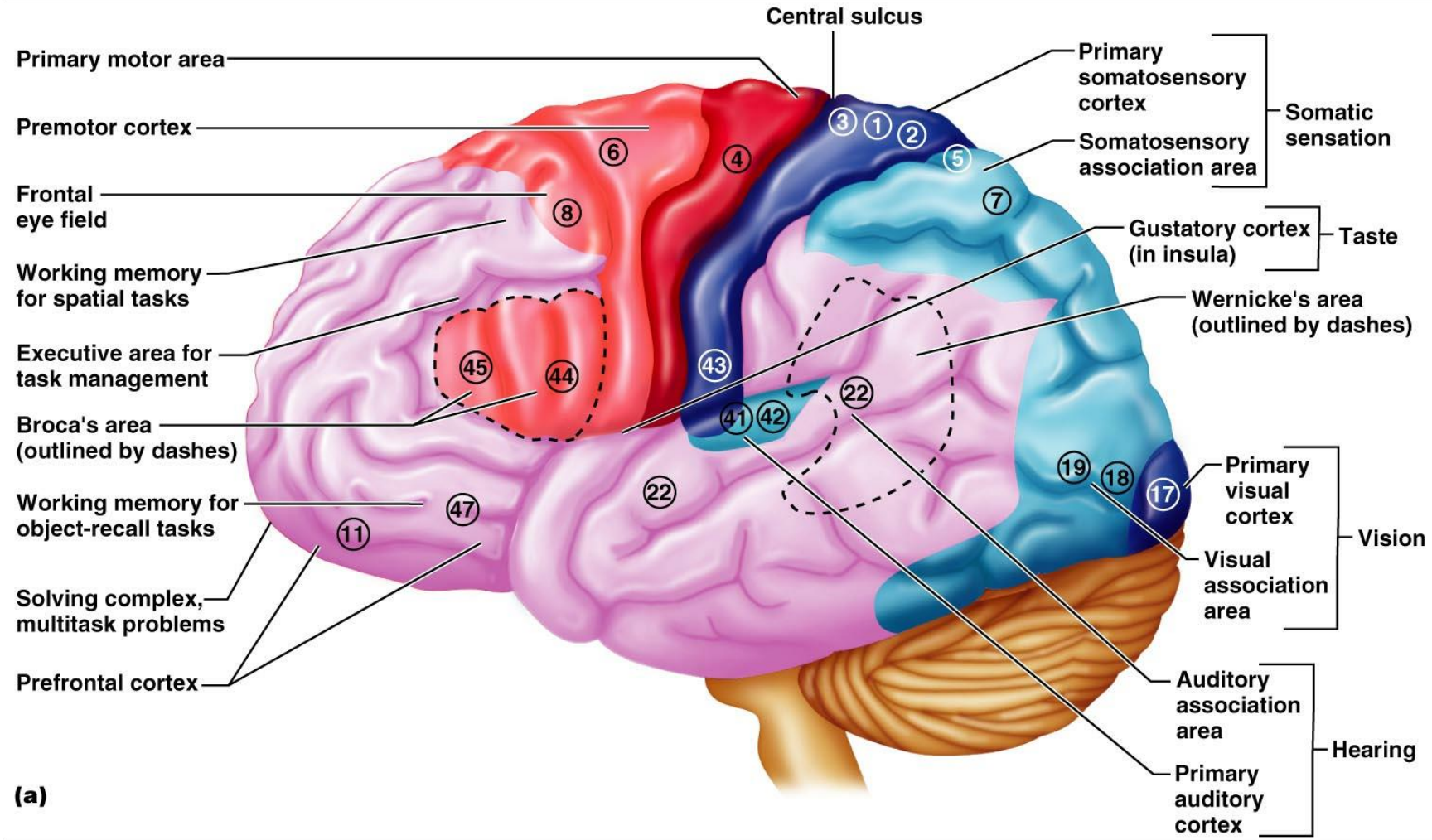
Human Brain: Ventral Aspect

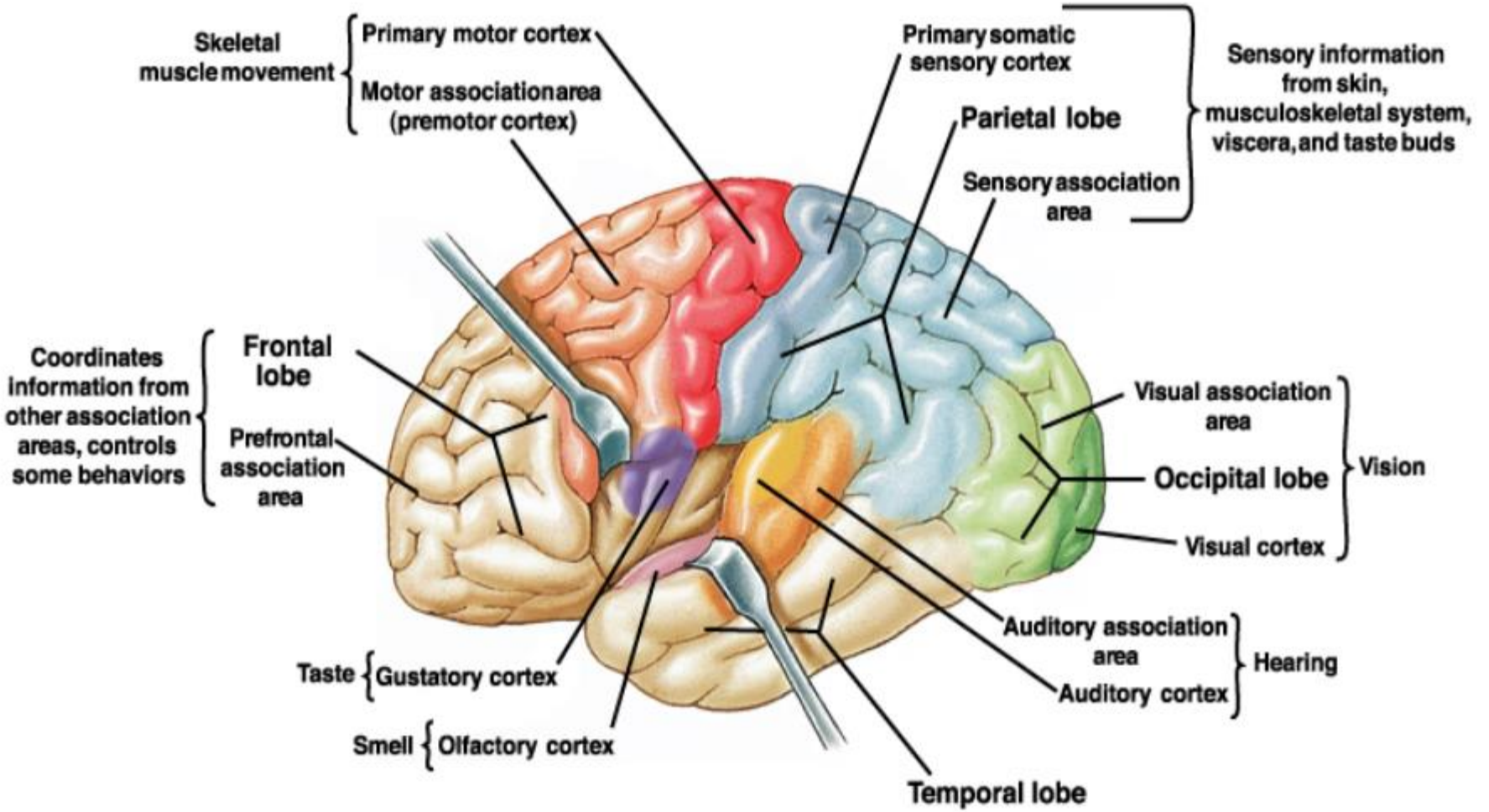


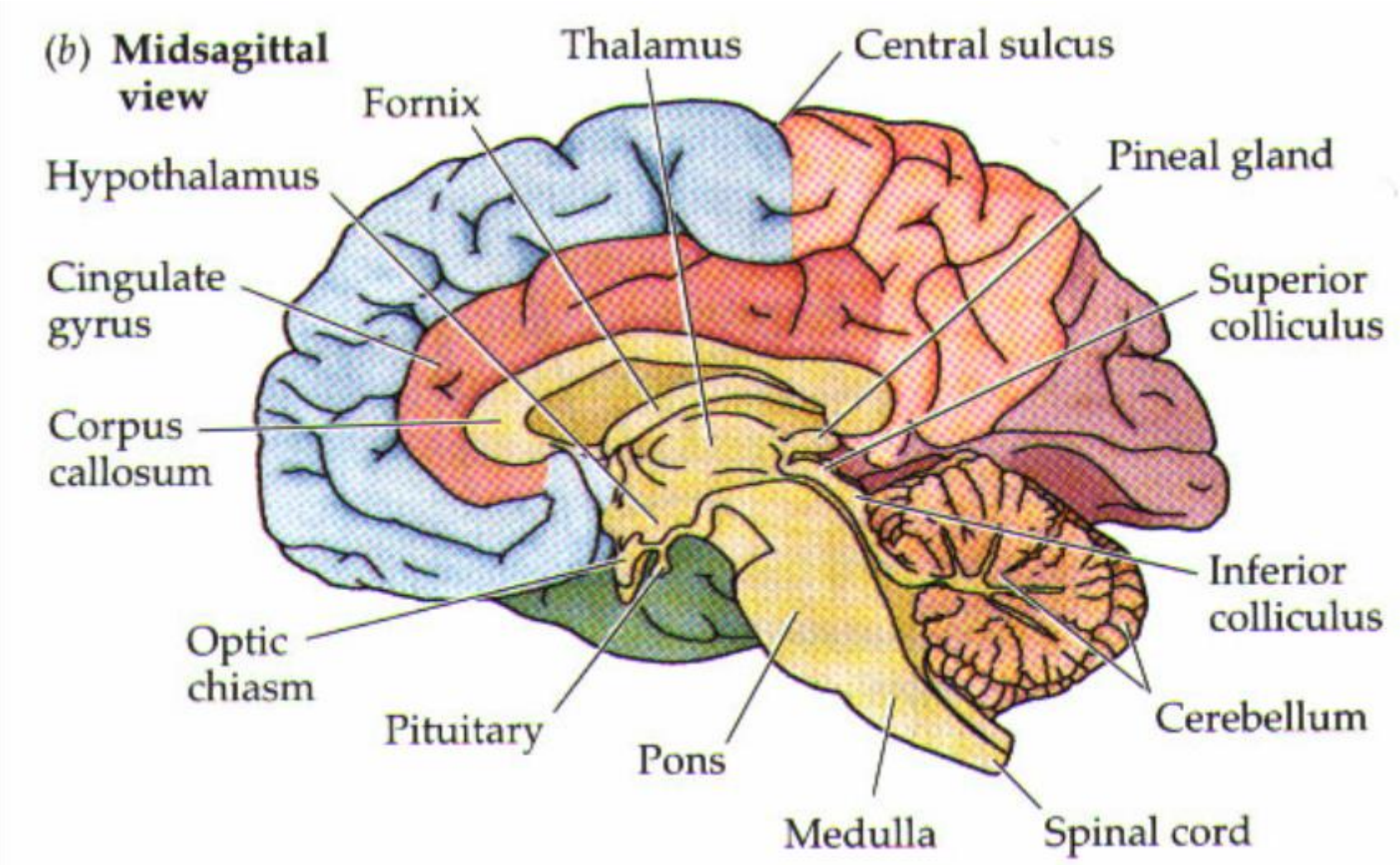


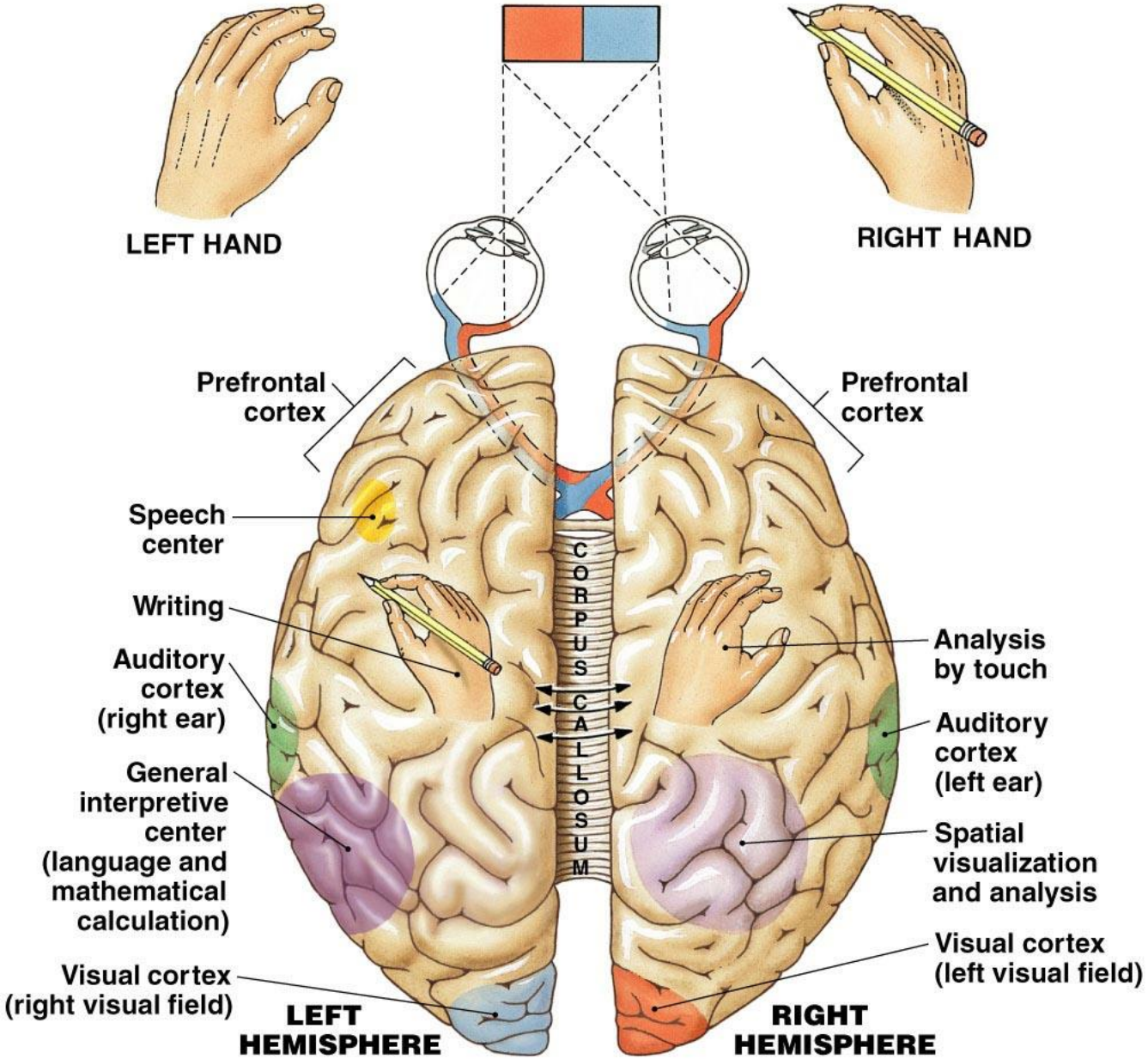


Functional Areas of the Cerebral Cortex

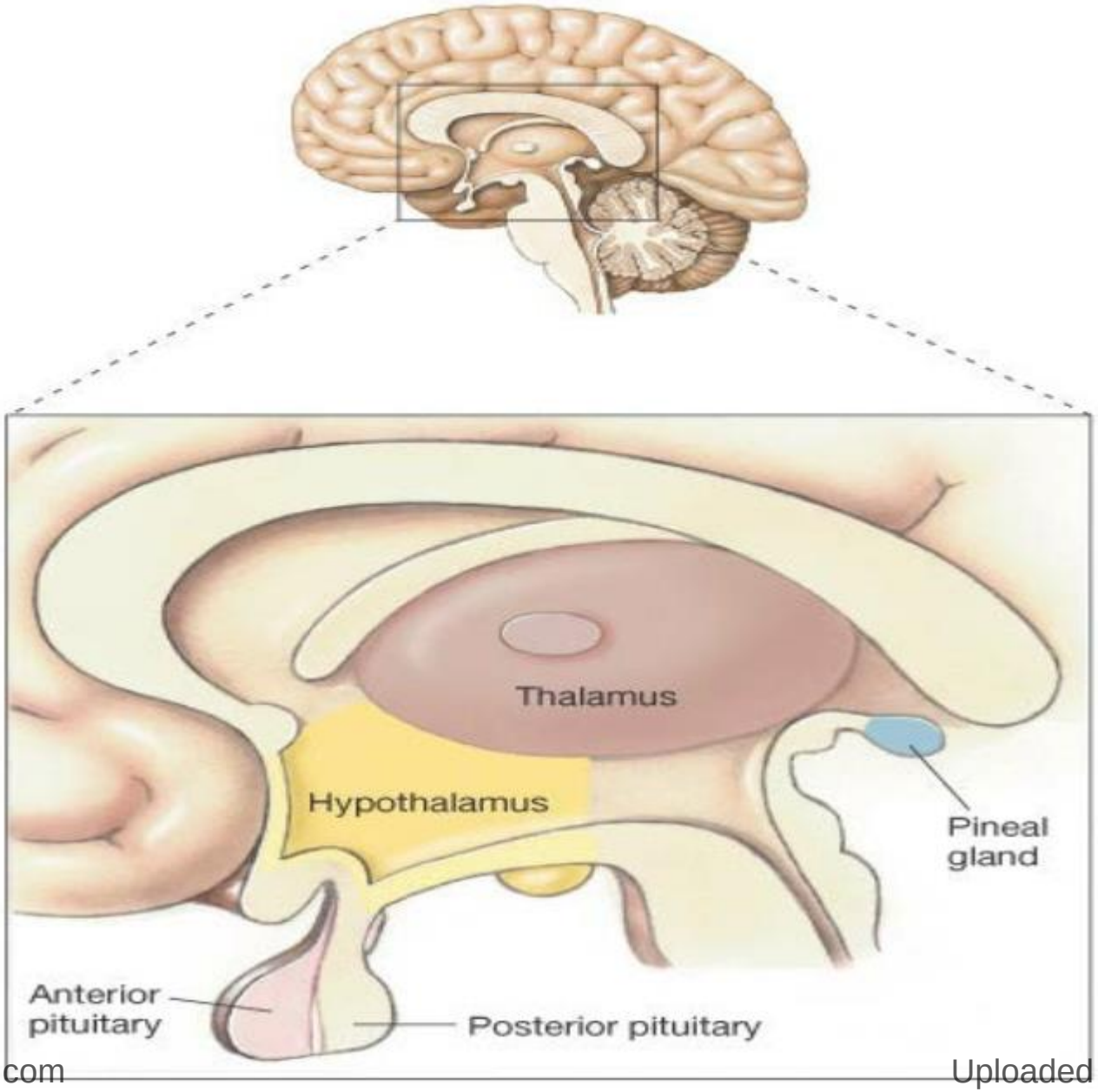


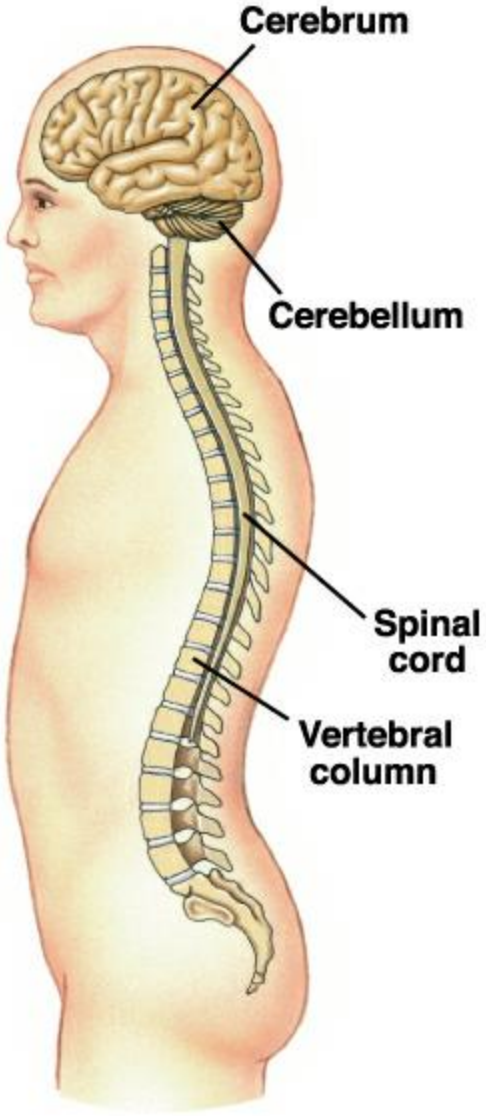




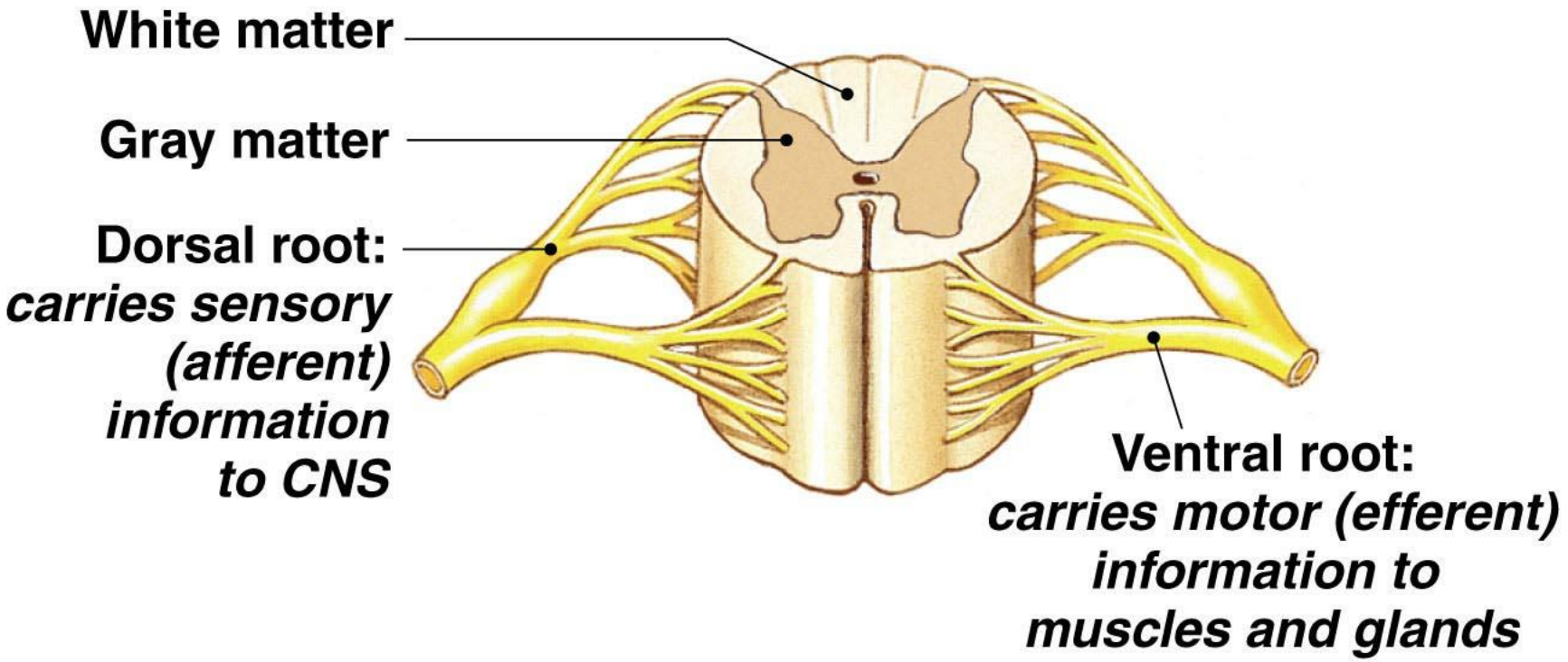


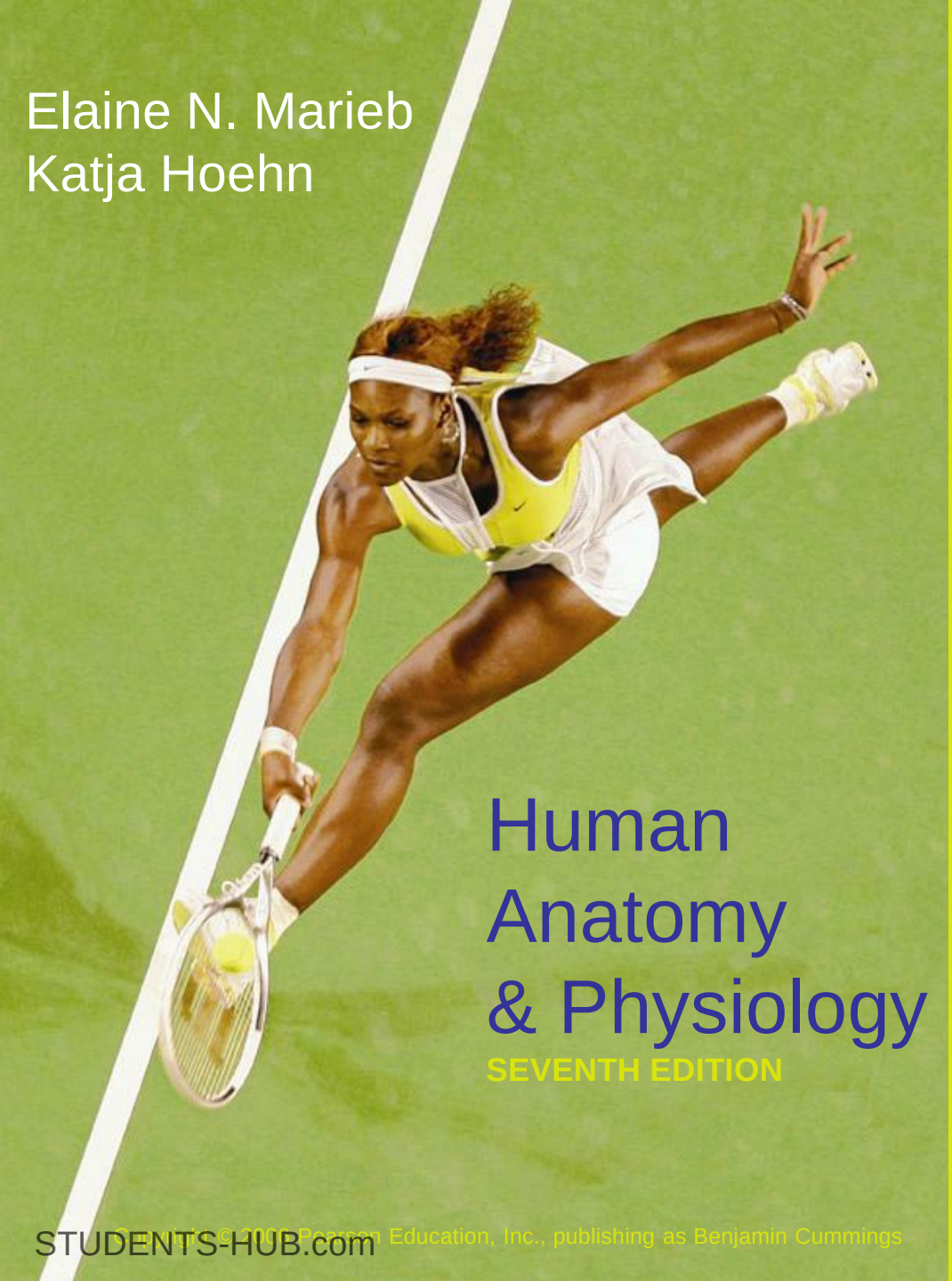
Diencephalon





(a) One segment of spinal cord, ventral view, showing its pair of nerves





Elaine N. Marieb
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Human Anatomy & Physiology

SEVENTH EDITION

PowerPoint® Lecture Slides
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Bluegrass Technical
and Community College

CHAPTER 11 PART A

Fundamentals of the Nervous System and Nervous Tissue

Nervous System

- The master controlling and communicating system of the body
- Functions
  - Sensory input – monitoring stimuli
  - Integration – interpretation of sensory input
  - Motor output – response to stimuli

Nervous System

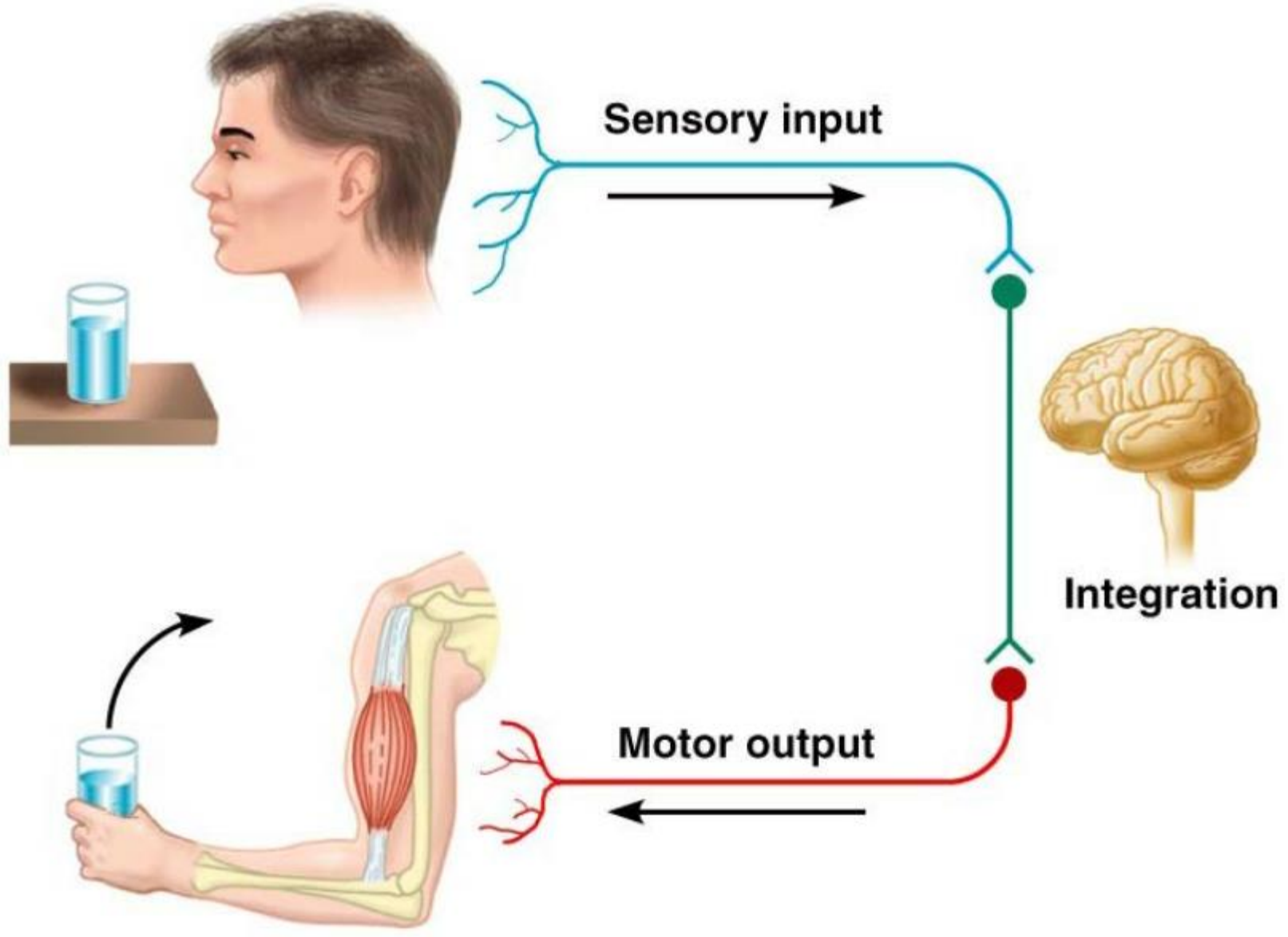


Figure 11.1

Organization of the Nervous System

- Central nervous system (CNS)
  - Brain and spinal cord
  - Integration and command center
- Peripheral nervous system (PNS)
  - Paired spinal and cranial nerves
  - Carries messages to and from the spinal cord and brain

Peripheral Nervous System (PNS): Two Functional Divisions

- Sensory (afferent) division
  - Sensory afferent fibers – carry impulses from skin, skeletal muscles, and joints to the brain
  - Visceral afferent fibers – transmit impulses from visceral organs to the brain
- Motor (efferent) division
  - Transmits impulses from the CNS to effector organs

Motor Division: Two Main Parts

- Somatic nervous system
  - Conscious control of skeletal muscles
- Autonomic nervous system (ANS)
  - Regulates smooth muscle, cardiac muscle, and glands
  - Divisions – sympathetic and parasympathetic

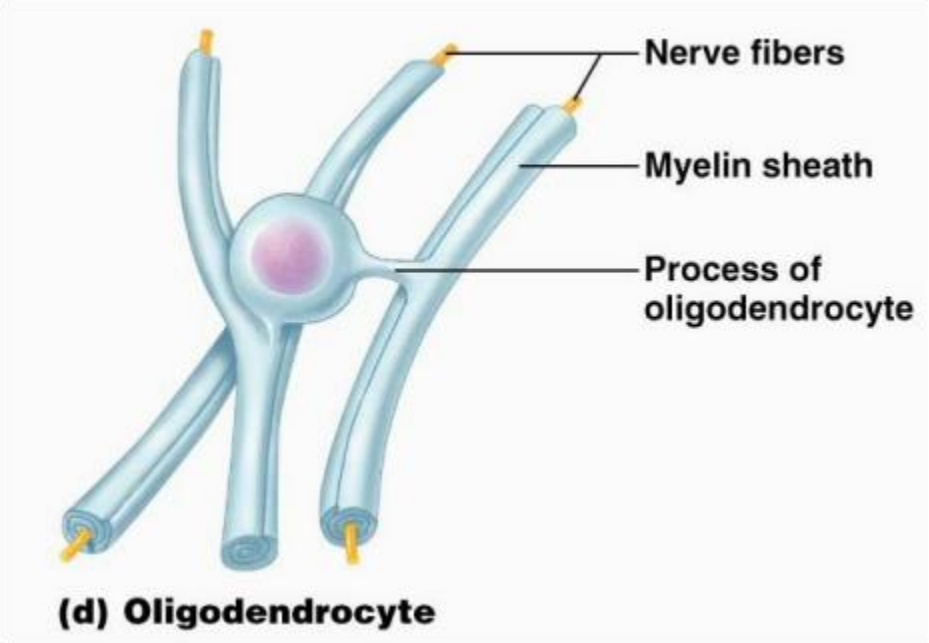
Histology of Nerve Tissue

- The two principal cell types of the nervous system are:
  - Neurons – excitable cells that transmit electrical signals
  - Supporting cells – cells that surround and wrap neurons

Oligodendrocytes, Schwann Cells, and Satellite Cells

- Oligodendrocytes – branched cells that wrap CNS nerve fibers
- Schwann cells (neurolemmocytes) – surround fibers of the PNS
- Satellite cells surround neuron cell bodies with ganglia

Oligodendrocytes, Schwann Cells, and Satellite Cells



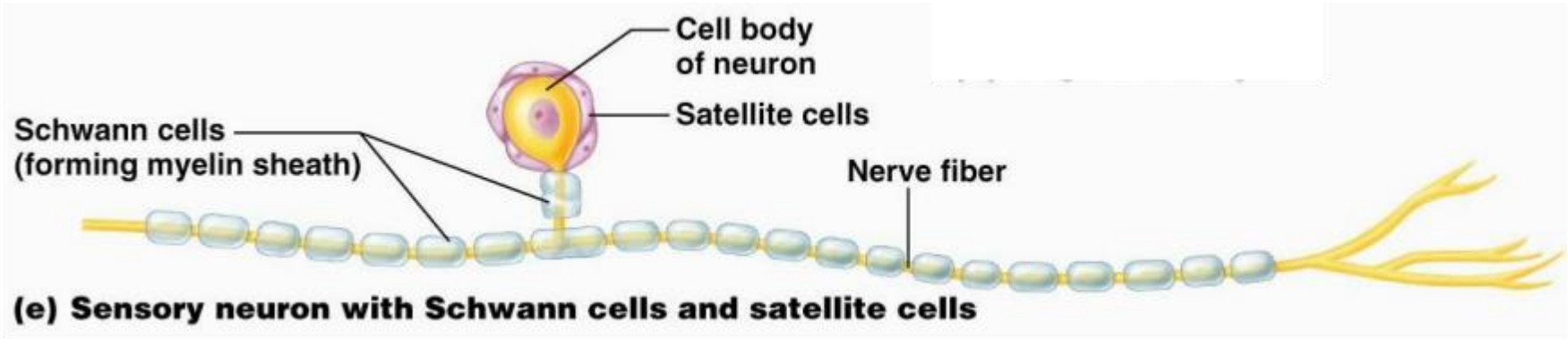


Figure 11.3d, e

Neurons (Nerve Cells)

- Structural units of the nervous system
  - Composed of a body, axon, and dendrites
  - Long-lived, amitotic (can not divide), and have a high metabolic rate
- Their plasma membrane function in:
  - Electrical signaling
  - Cell-to-cell signaling during development

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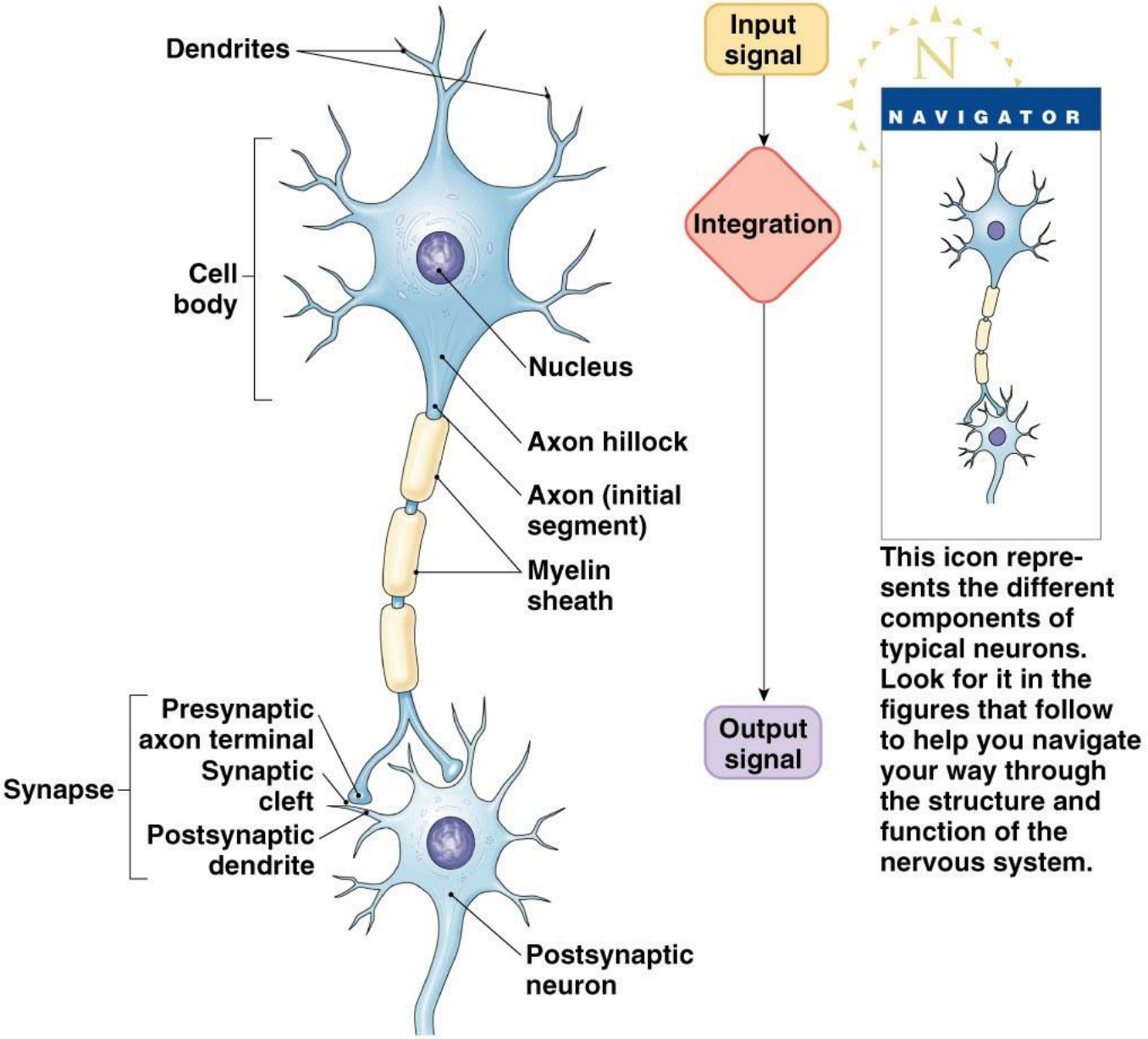

Nerve Cell Body (Soma)

- Contains the nucleus and a nucleolus
- Is the major biosynthetic center
- Is the focal point for the outgrowth of neuronal processes
- Has no centrioles (hence its amitotic nature)
- Has well-developed Nissl bodies (rough ER)
- Contains an axon hillock – cone-shaped area from which axons arise

Processes

- Armlike extensions from the soma
- Called tracts in the CNS and nerves in the PNS
- There are two types: axons and dendrites

Dendrites of Motor Neurons

- Short and diffusely branched processes
- They are the receptive, or input, regions of the neuron
- Electrical signals are conveyed as short-distance signals called graded potentials (not action potentials, i.e. nerve impulses)

Axons: Structure

- Slender processes of uniform diameter arising from the hillock
- Long axons are called nerve fibers
- Usually there is only one unbranched axon per neuron
- Rare branches, if present, are called axon collaterals
- Axonal terminal – branched terminus of an axon

Axons: Function

- Generate and transmit action potentials
- Secrete neurotransmitters from the axonal terminals
- Movement along axons occurs in two ways
  - Anterograde — toward axonal terminal
  - Retrograde — away from axonal terminal

Myelin Sheath

- Whitish, fatty (protein-lipoid), segmented sheath around most long axons
- It functions to:
  - Protect the axon
  - Electrically insulate fibers from one another
  - Increase the speed of nerve impulse transmission

Nodes of Ranvier (Neurofibral Nodes)

- Gaps in the myelin sheath between adjacent Schwann cells
- They are the sites where axon collaterals can emerge

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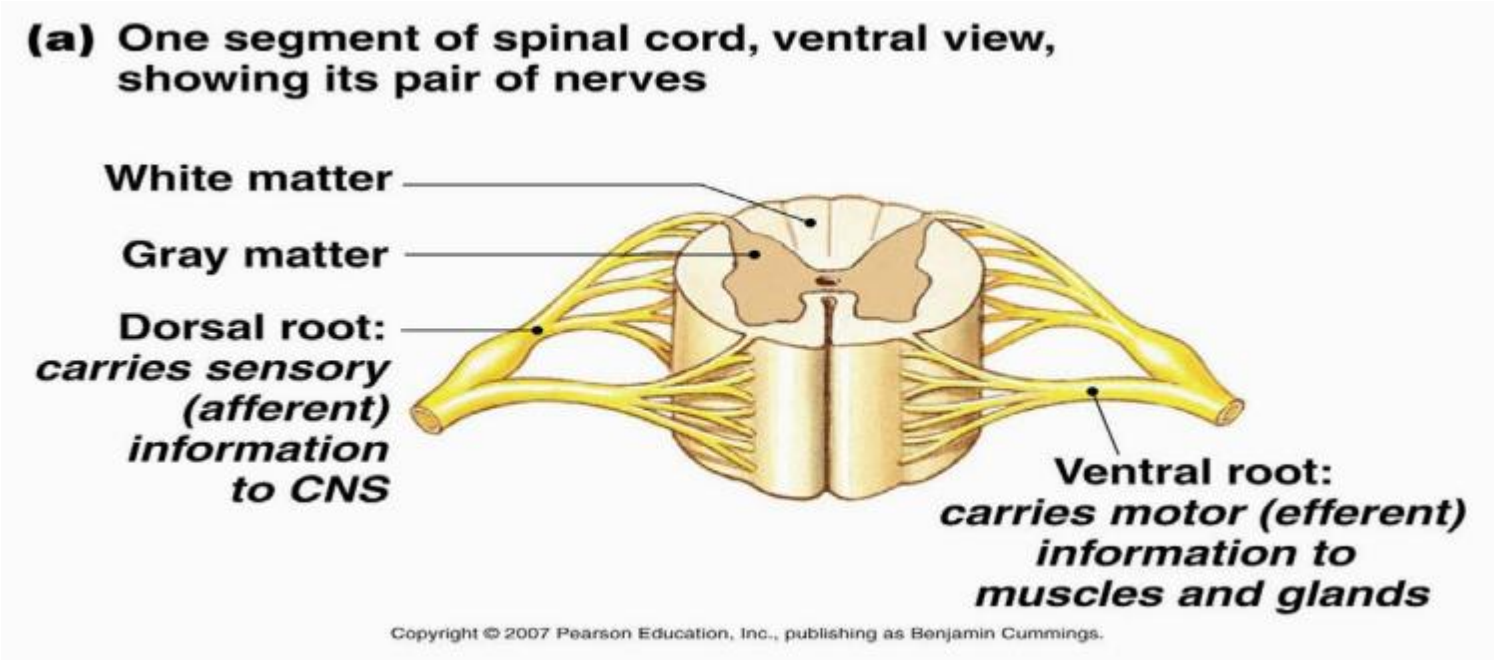
Regions of the Brain and Spinal Cord

- White matter – dense collections of myelinated fibers
- Gray matter – mostly soma and unmyelinated fibers



Neuron Classification

- Structural: based on the number of processes extending from the cell body
  - Multipolar — three or more processes (most common)
  - Bipolar — two processes (axon and dendrite) rare, found only in some special sense organs (eye, nose)
  - Unipolar — single, short process

Neuron Classification

- Functional:
  - Sensory (afferent) — transmit impulses toward the CNS
  - Motor (efferent) — carry impulses away from the CNS
  - Interneurons (association neurons) — shuttle signals through CNS pathways

Neurophysiology

- Neurons are highly irritable (angry)
- Action potentials, or nerve impulses, are:
  - Electrical impulses carried along the length of axons
  - Always the same regardless of stimulus
  - 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 charge 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
  - 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

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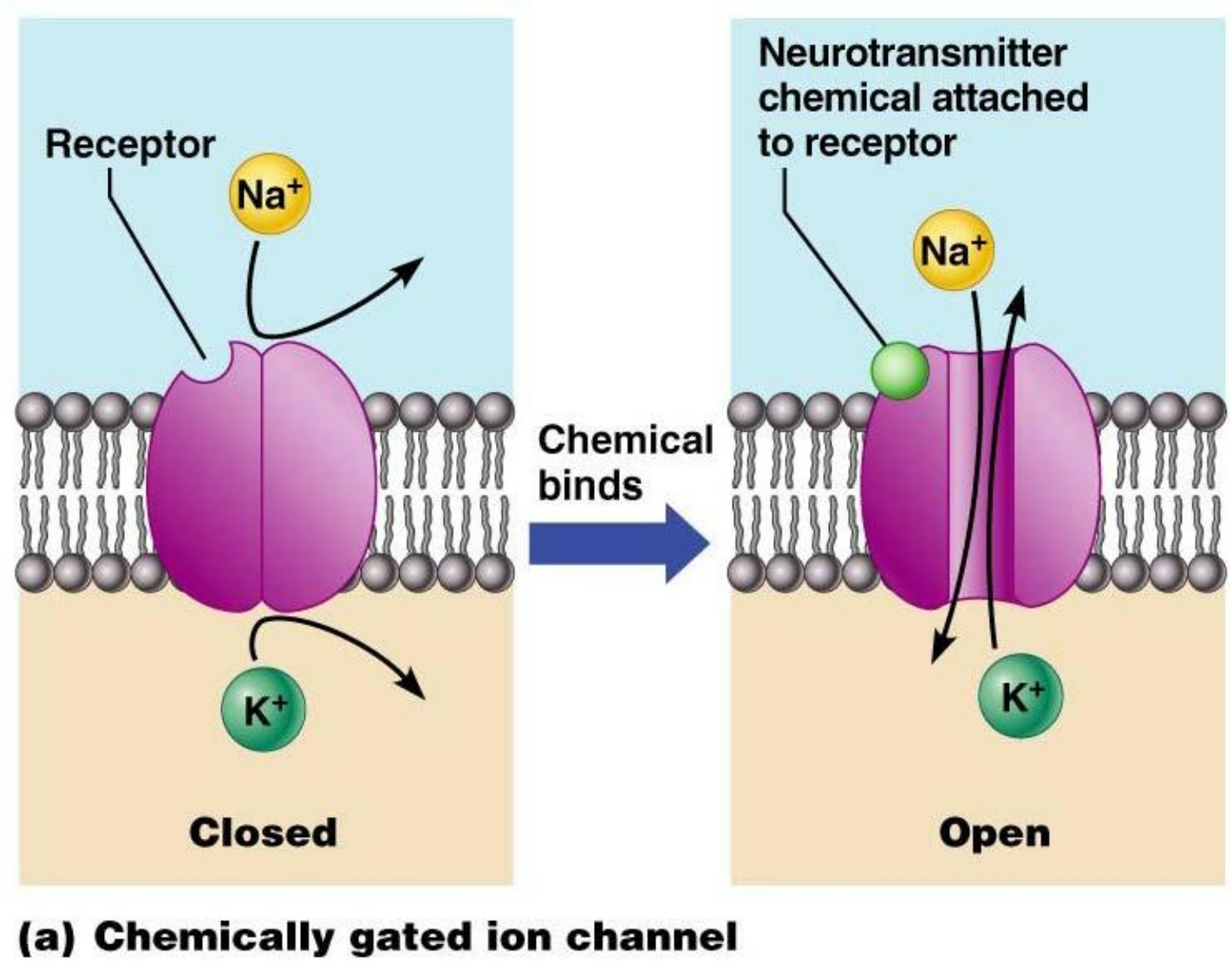
Nervous System I: Ion Channels

Operation of a Gated Channel

- Example: Na^+-K^+ gated channel
- Closed when a neurotransmitter is not bound to the extracellular receptor
  - Na^+ cannot enter the cell and K^+ cannot exit the cell
- Open when a neurotransmitter is attached to the receptor
  - Na^+ enters the cell and K^+ exits the cell

Operation of a Gated Channel



Operation of a Voltage-Gated Channel

- Example: Na^+ channel
- Closed when the intracellular environment is negative
  - Na^+ cannot enter the cell
- Open when the intracellular environment is positive
  - Na^+ can enter the cell

Operation of a Voltage-Gated Channel

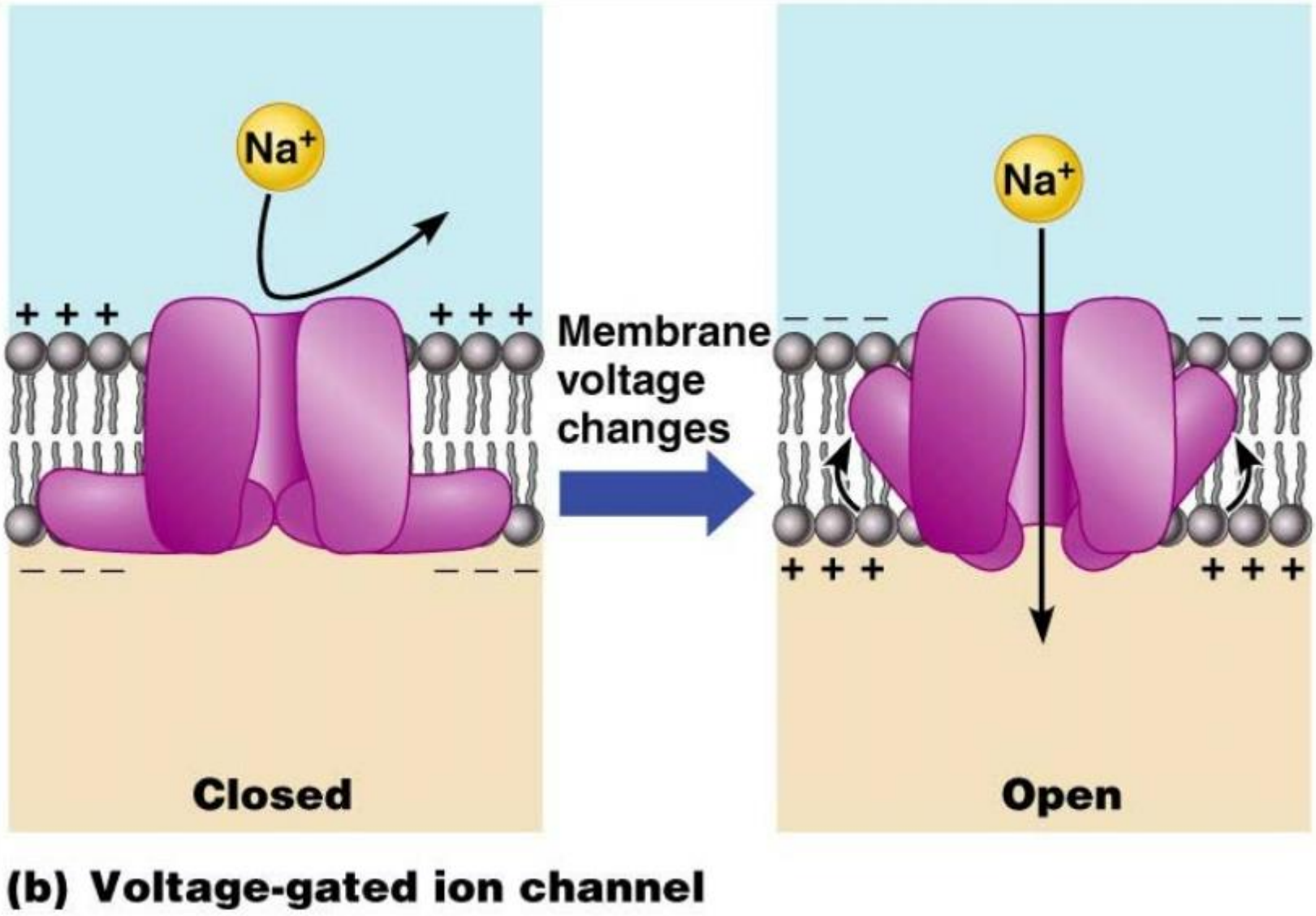


Figure 11.6b

Gated Channels

- When gated channels are open:
  - Ions move quickly across the membrane
  - Movement is along their electrochemical gradients
  - An electrical current is created
  - Voltage changes across the membrane

Electrochemical Gradient

- Ions flow along their chemical gradient when they 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

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^-, and protein anions (A^-)
- Ionic differences are the consequence of:
  - Differential permeability of the neurilemma to Na^+ and K^+
  - Operation of the sodium-potassium pump

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Nervous System I: Membrane Potential

Membrane Potentials: Signals

- Used to integrate, send, and receive information
- Membrane potential changes are produced by:
  - Changes in membrane permeability to ions
  - Alterations of ion concentrations across the membrane
- Types of signals – graded potentials and action potentials

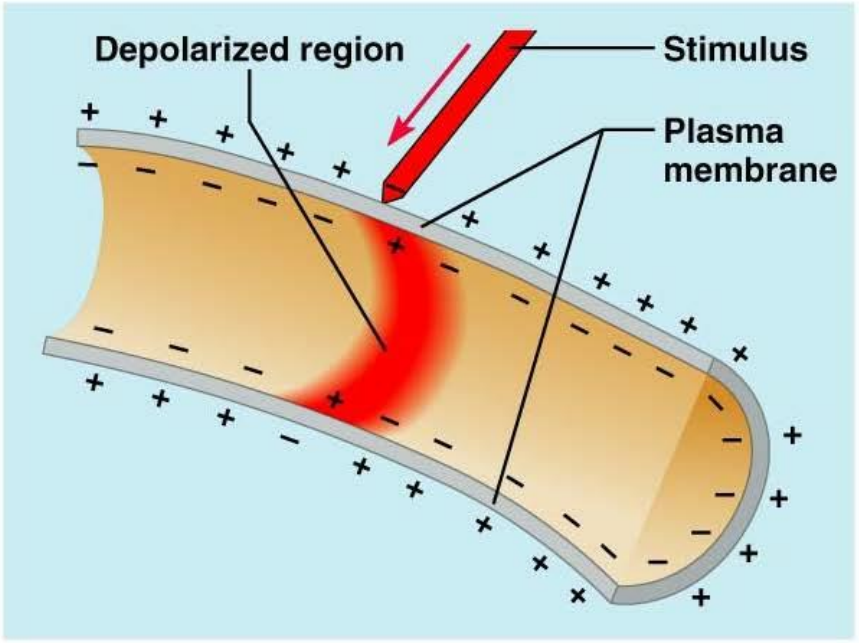
Changes in Membrane Potential

- 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

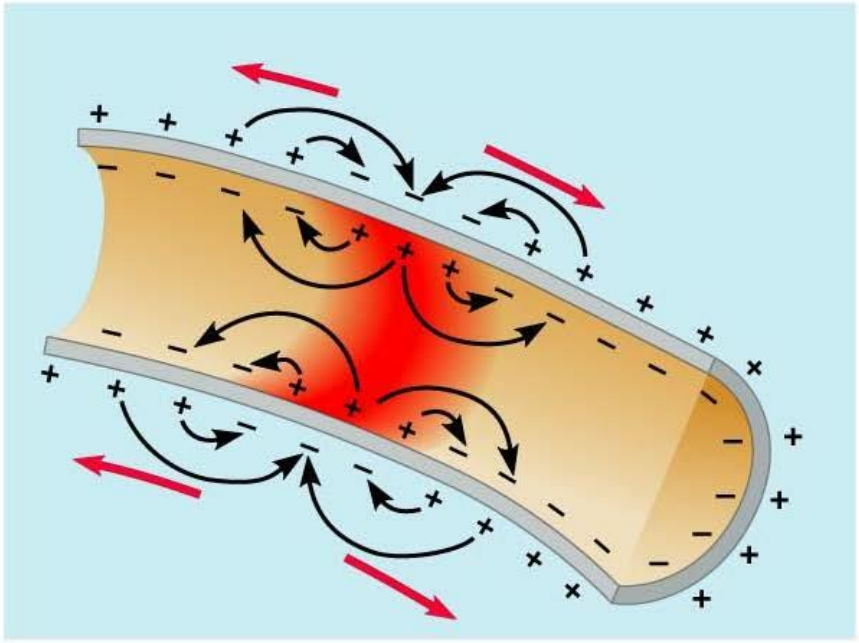
Graded Potentials

- Short-lived, local changes in membrane potential
- Decrease in intensity with distance
- Magnitude varies directly with the strength of the stimulus
- Sufficiently strong graded potentials can initiate action potentials

Graded Potentials



(a) Depolarization



(b) Spread of depolarization

Figure 11.10

Action Potentials (APs)

- A brief reversal of membrane potential with a total amplitude of 100 mV
- Action potentials are only generated by muscle cells and neurons
- They do not decrease in strength over distance
- They are the principal means of neural communication
- An action potential in the axon of a neuron is a nerve impulse

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Nervous System I: The Action Potential

Action Potential: Resting State

- Na + and K + channels are closed
- Leakage accounts for small movements of Na + and K +
- Each Na + channel has two voltage-regulated gates
  - Activation gates – closed in the resting state
  - Inactivation gates – open in the resting state

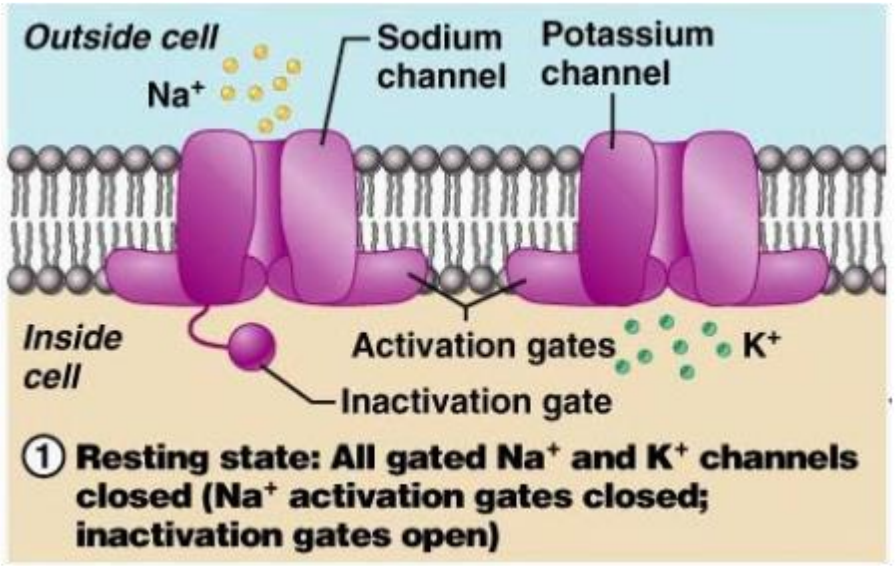

Figure 11.12a

Action Potential: Depolarization Phase

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

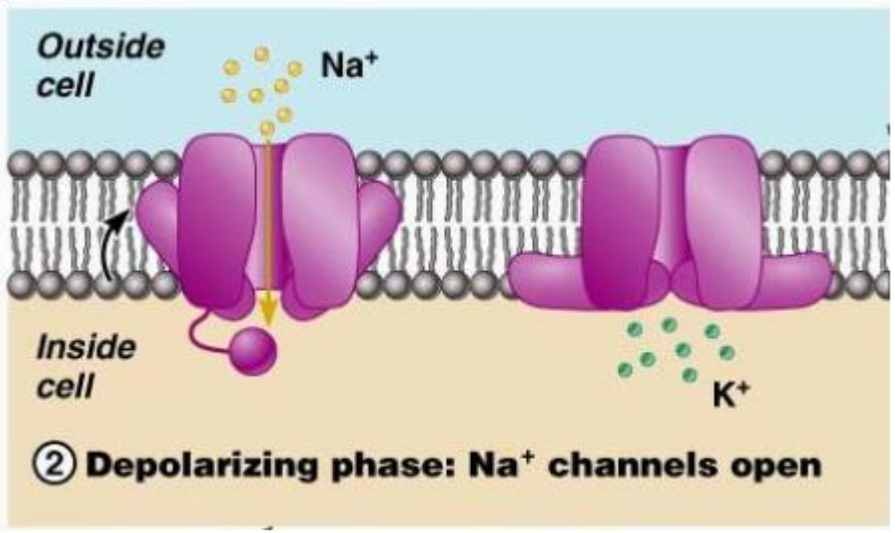

Figure 11.12.2

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 the cell and internal negativity of the resting neuron is restored

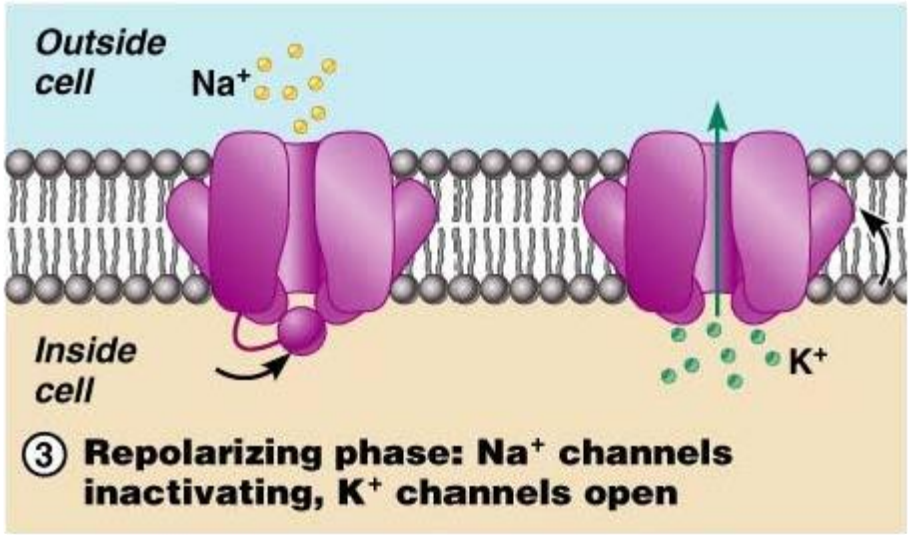

Figure 11.12.3

Action Potential: Hyperpolarization

- Potassium gates remain open, causing an excessive efflux of K^+
- This efflux causes hyperpolarization of the membrane (undershoot)
- The neuron is insensitive to stimulus and depolarization during this time

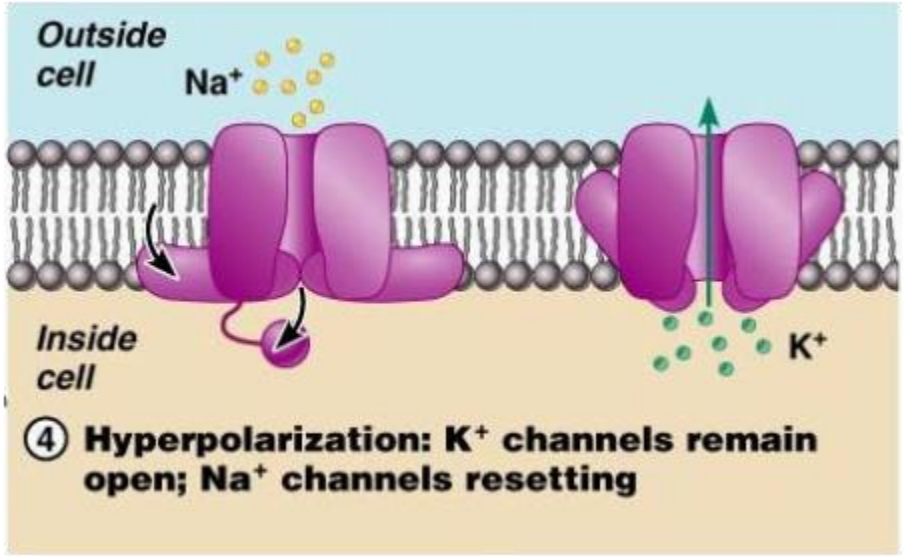

Figure 11.12d

Action Potential: Role of the Sodium-Potassium Pump

- Repolarization
  - Restores the resting electrical conditions of the neuron
  - Does not restore the resting ionic conditions
- Ionic redistribution back to resting conditions is restored by the sodium-potassium pump

Phases of the Action Potential

- 1 – resting state
- 2 – depolarization phase
- 3 – repolarization phase
- 4 – hyperpolarization

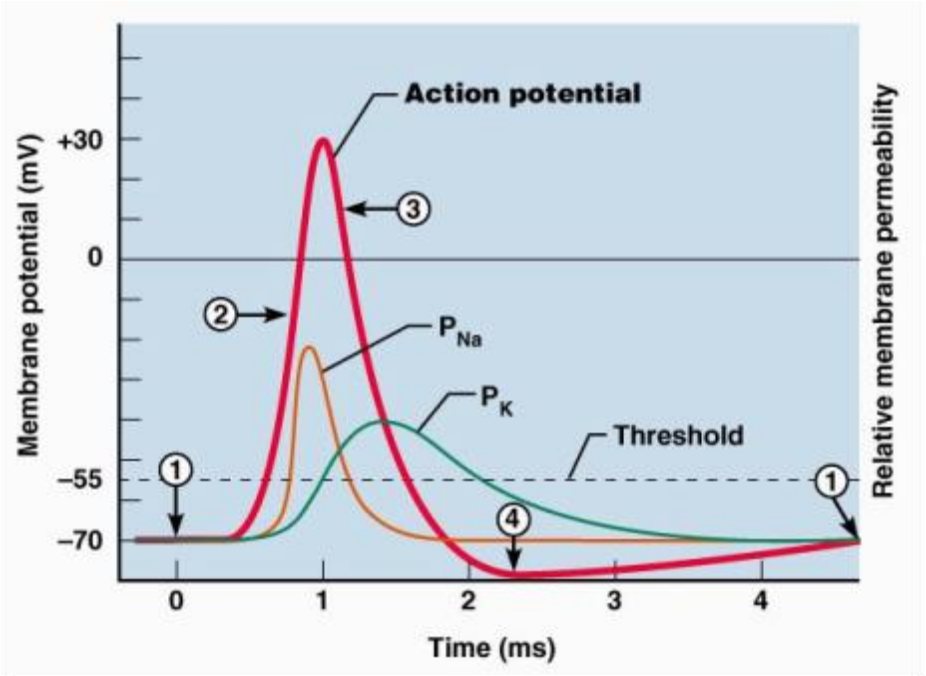

Figure 11.12

Threshold and Action Potentials

- **Threshold** – membrane is depolarized by 15 to 20 mV
- Established by the total amount of current flowing through the membrane
- Weak (subthreshold) stimuli are not relayed into action potentials
- Strong (threshold) stimuli are relayed into action potentials
- All-or-none phenomenon – action potentials either happen completely, or not at all

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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Absolute and Relative Refractory Periods

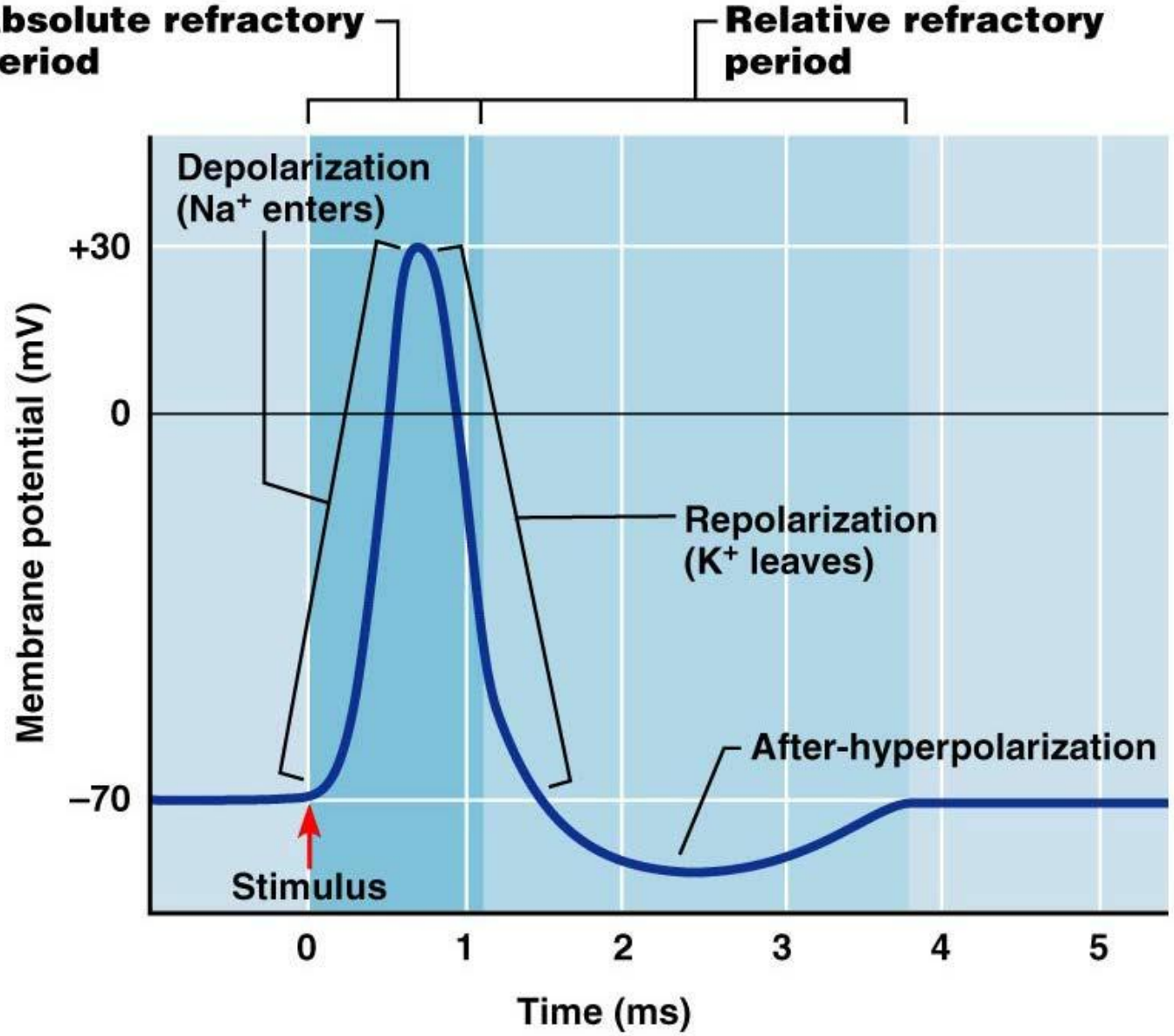

Figure 11.15

Relative Refractory Period

- The interval following the absolute refractory period when:
  - Sodium gates are closed
  - Potassium gates are open
  - Repolarization is occurring
- The threshold level is elevated, allowing strong stimuli to increase the frequency of action potential events

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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
  - **Presence of a myelin sheath** – myelination dramatically increases impulse speed

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Nerve Fiber Classification

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

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

Synapses

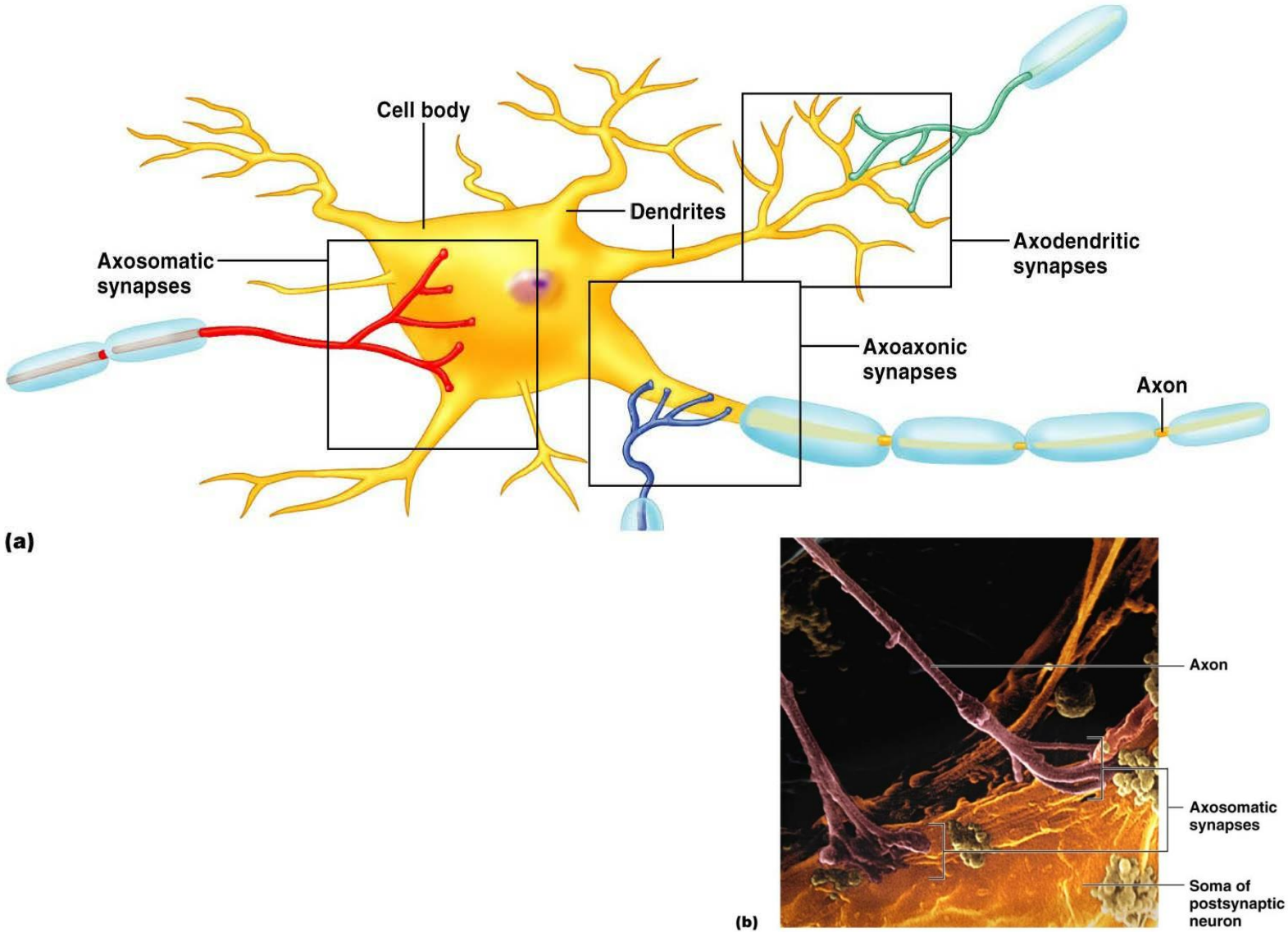

Figure 11.17

Types of Synapses

- Axodendritic – synapses between the axon of one neuron and the dendrite of another
- Axosomatic – synapses between the axon of one neuron and the soma of another
- Other types of synapses include:
  - Axoaxonic (axon to axon)
  - Dendrodendritic (dendrite to dendrite)
  - Dendrosomatic (dendrites to soma)

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Electrical Synapses

- Electrical synapses:
  - Are less common than chemical synapses
  - Correspond to gap junctions found in other cell types
  - Are important in the CNS in:
    - Arousal from sleep
    - Mental attention
    - Emotions and memory
    - Ion and water homeostasis

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Chemical Synapses

- Specialized for the release and reception of neurotransmitters
- Typically composed of two parts:
  - Axonal terminal of the presynaptic neuron, which contains synaptic vesicles
  - Receptor region on the dendrite(s) or soma of the postsynaptic neuron

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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 (as opposed to an electrical one)
  - Ensures unidirectional communication between neurons

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Synaptic Cleft: Information Transfer

- Nerve impulses reach the axonal terminal of the presynaptic neuron and open Ca^{2+} channels
- Neurotransmitter is released into the synaptic cleft via exocytosis in response to synaptotagmin
- Neurotransmitter crosses the synaptic cleft and binds to receptors on the postsynaptic neuron
- Postsynaptic membrane permeability changes, causing an excitatory or inhibitory effect

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Nervous System II: Synaptic Transmission, pages 3–6

Synaptic Cleft: Information Transfer

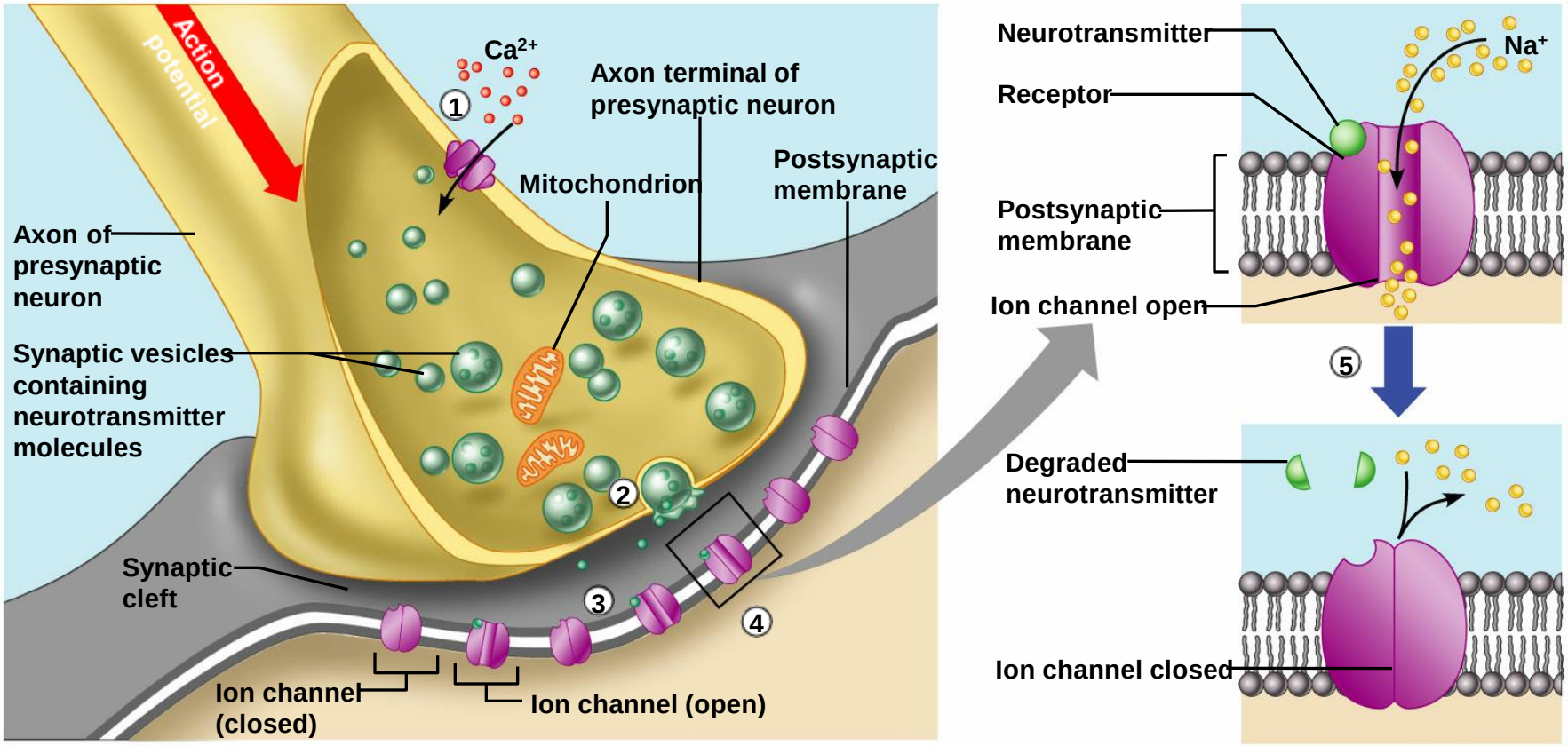

Figure 11.18

Termination of Neurotransmitter Effects

- Neurotransmitter bound to a postsynaptic neuron:
  - Produces a continuous postsynaptic effect
  - Blocks reception of additional “messages”
  - Must be removed from its receptor
- Removal of neurotransmitters occurs when they:
  - Are degraded by enzymes
  - Are reabsorbed by astrocytes or the presynaptic terminals
  - Diffuse from the synaptic cleft

Synaptic Delay

- Neurotransmitter must be released, diffuse across the synapse, and bind to receptors
- Synaptic delay – time needed to do this (0.3-5.0 ms)
- Synaptic delay is the rate-limiting step of neural transmission

Postsynaptic Potentials

- Neurotransmitter receptors mediate changes in membrane potential according to:
  - The amount of neurotransmitter released
  - The amount of time the neurotransmitter is bound to receptors
- The two types of postsynaptic potentials are:
  - EPSP – excitatory postsynaptic potentials
  - IPSP – inhibitory postsynaptic potentials

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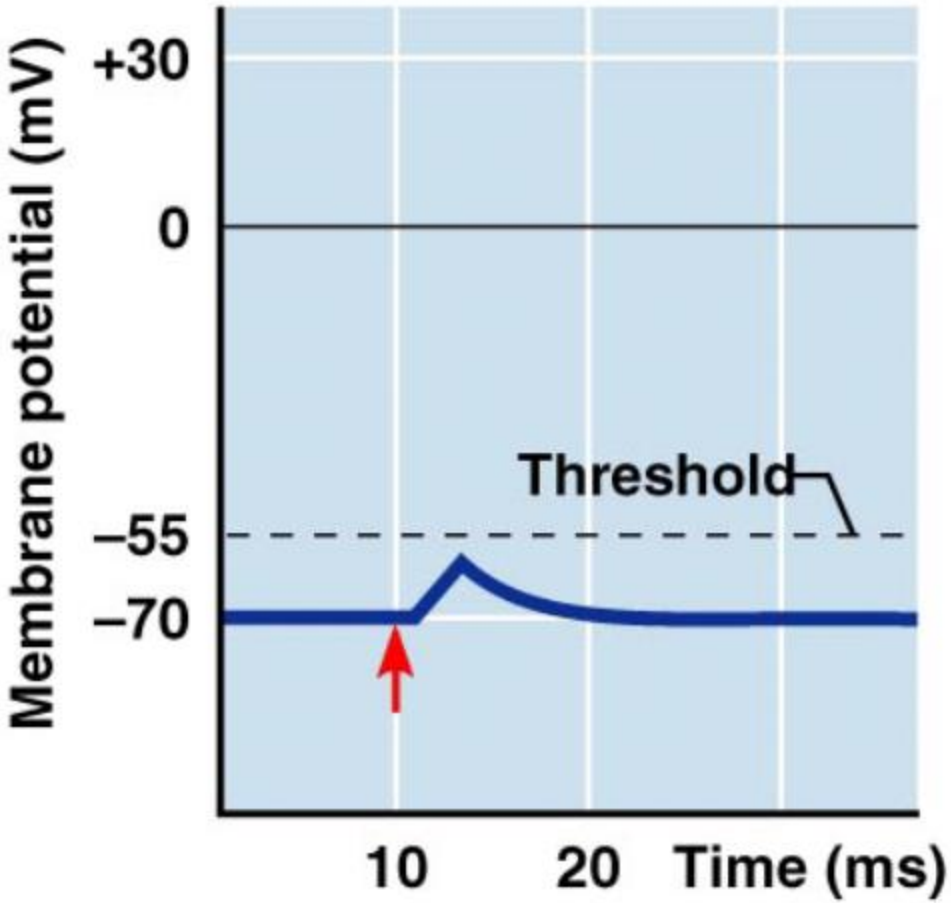
Nervous System II: Synaptic Transmission, pages 7–12

Excitatory Postsynaptic Potentials

- EPSPs are graded potentials that can initiate an action potential in an axon
  - Use only chemically gated channels
  - Na^+ and K^+ flow in opposite directions at the same time
- Postsynaptic membranes do not generate action potentials

Excitatory Postsynaptic Potential (EPSP)

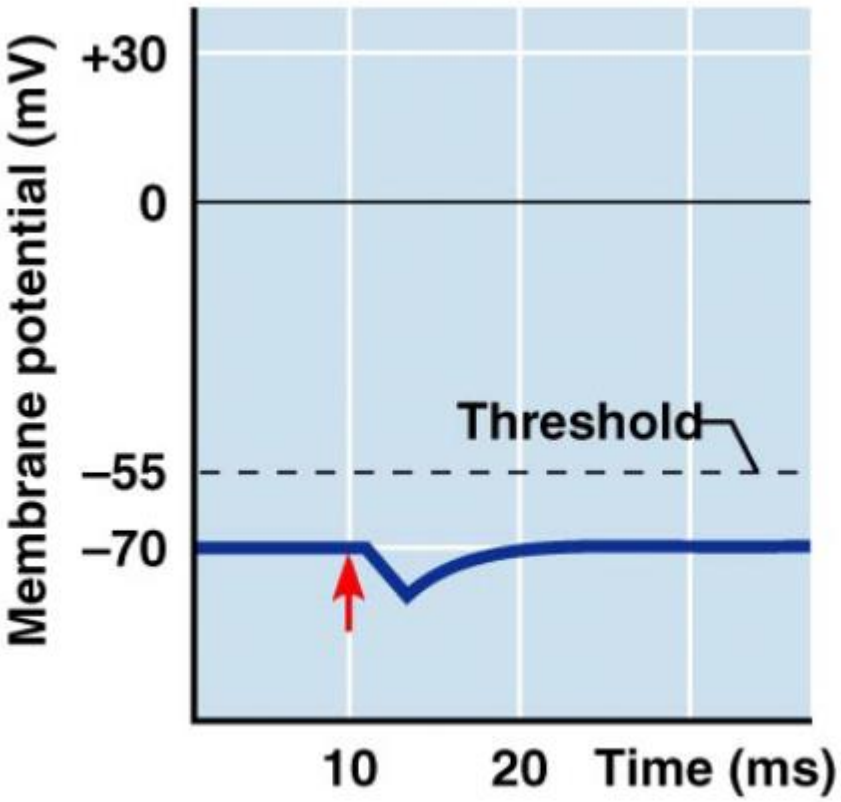


(a) Excitatory postsynaptic potential (EPSP)

Inhibitory Synapses and IPSPs

- Neurotransmitter binding to a receptor at inhibitory synapses:
  - Causes the membrane to become more permeable to potassium and chloride ions
  - Leaves the charge on the inner surface negative
  - Reduces the postsynaptic neuron's ability to produce an action potential

Inhibitory Postsynaptic (IPSP)



(b) Inhibitory postsynaptic potential (IPSP)

Figure 11.19b

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

Channel-Linked Receptors

- Composed of integral membrane protein
- Mediate direct neurotransmitter action
- Action is immediate, brief, simple, and highly localized
- Ligand binds the receptor, and ions enter the cells
- Excitatory receptors depolarize membranes
- Inhibitory receptors hyperpolarize membranes

Channel-Linked Receptors

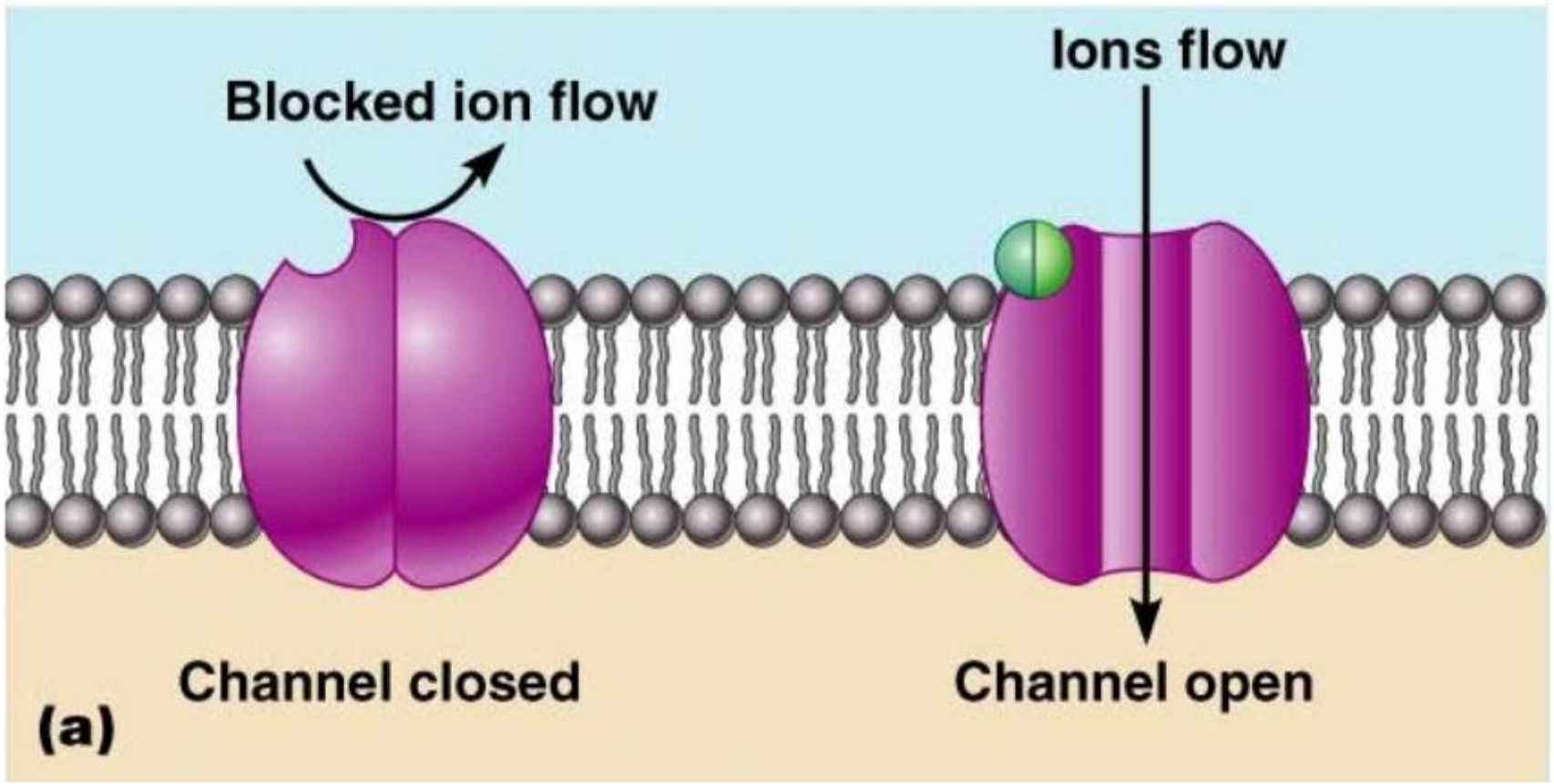


Figure 11.22a

G Protein-Linked Receptors

- Responses are indirect, slow, complex, prolonged, and often diffuse
- These receptors are transmembrane protein complexes
- Examples: muscarinic ACh receptors, neuropeptides, and those that bind biogenic amines

G Protein-Linked Receptors: Mechanism

- Neurotransmitter binds to G protein-linked receptor
- G protein is activated and GTP is hydrolyzed to GDP
- The activated G protein complex activates adenylate cyclase

G Protein-Linked Receptors: Mechanism

- Adenylate cyclase catalyzes the formation of cAMP from ATP
- cAMP, a second messenger, brings about various cellular responses

Neurotransmitter Receptor Mechanism

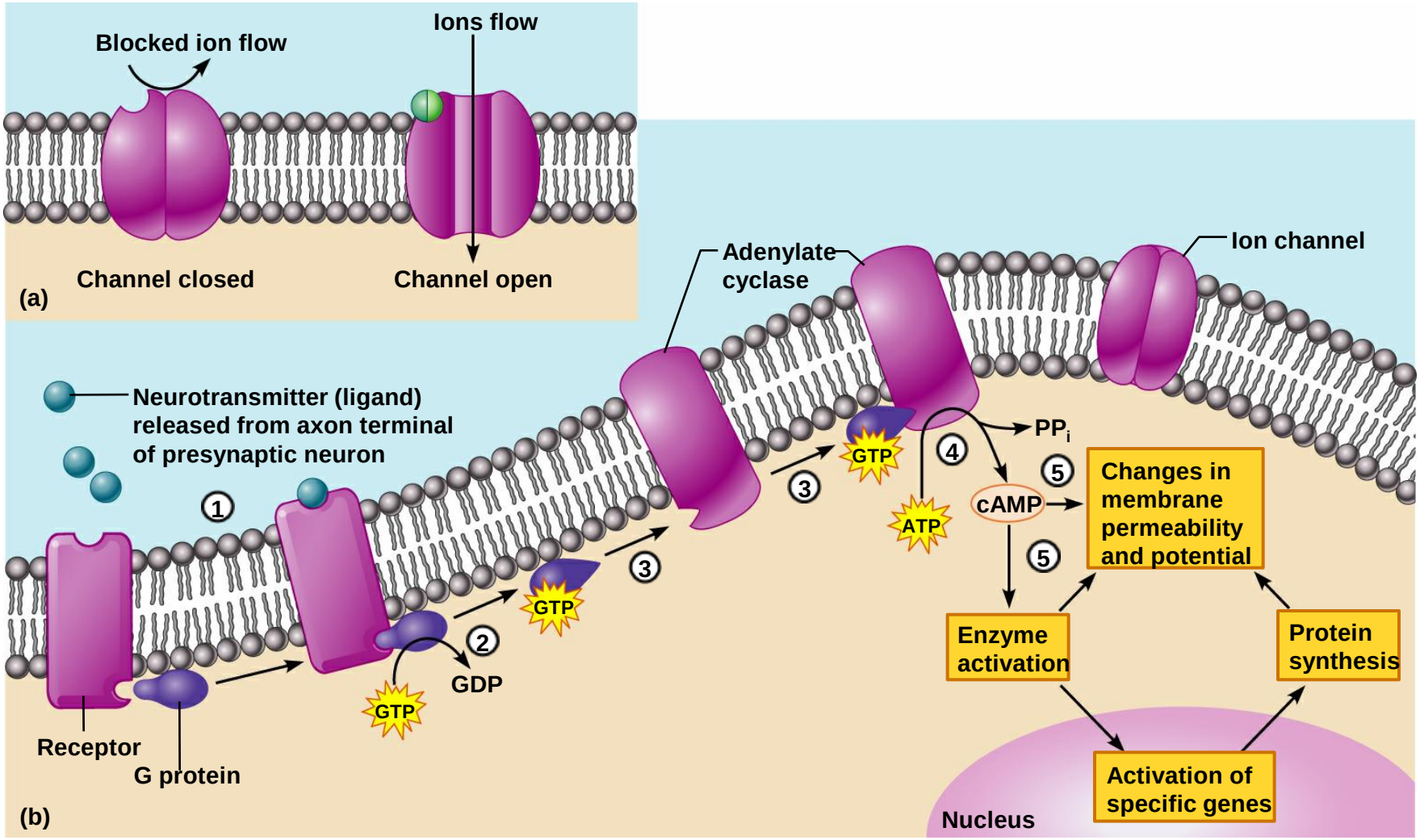


Figure 11.22b

G Protein-Linked Receptors: Effects

- G protein-linked receptors activate intracellular second messengers including Ca^{2+}, cGMP, diacylglycerol, as well as cAMP
- Second messengers:
  - Open or close ion channels
  - Activate kinase enzymes
  - Phosphorylate channel proteins
  - Activate genes and induce protein synthesis

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
  - Operate via subconscious control
  - Have viscera as most of their effectors

ANS in the Nervous System

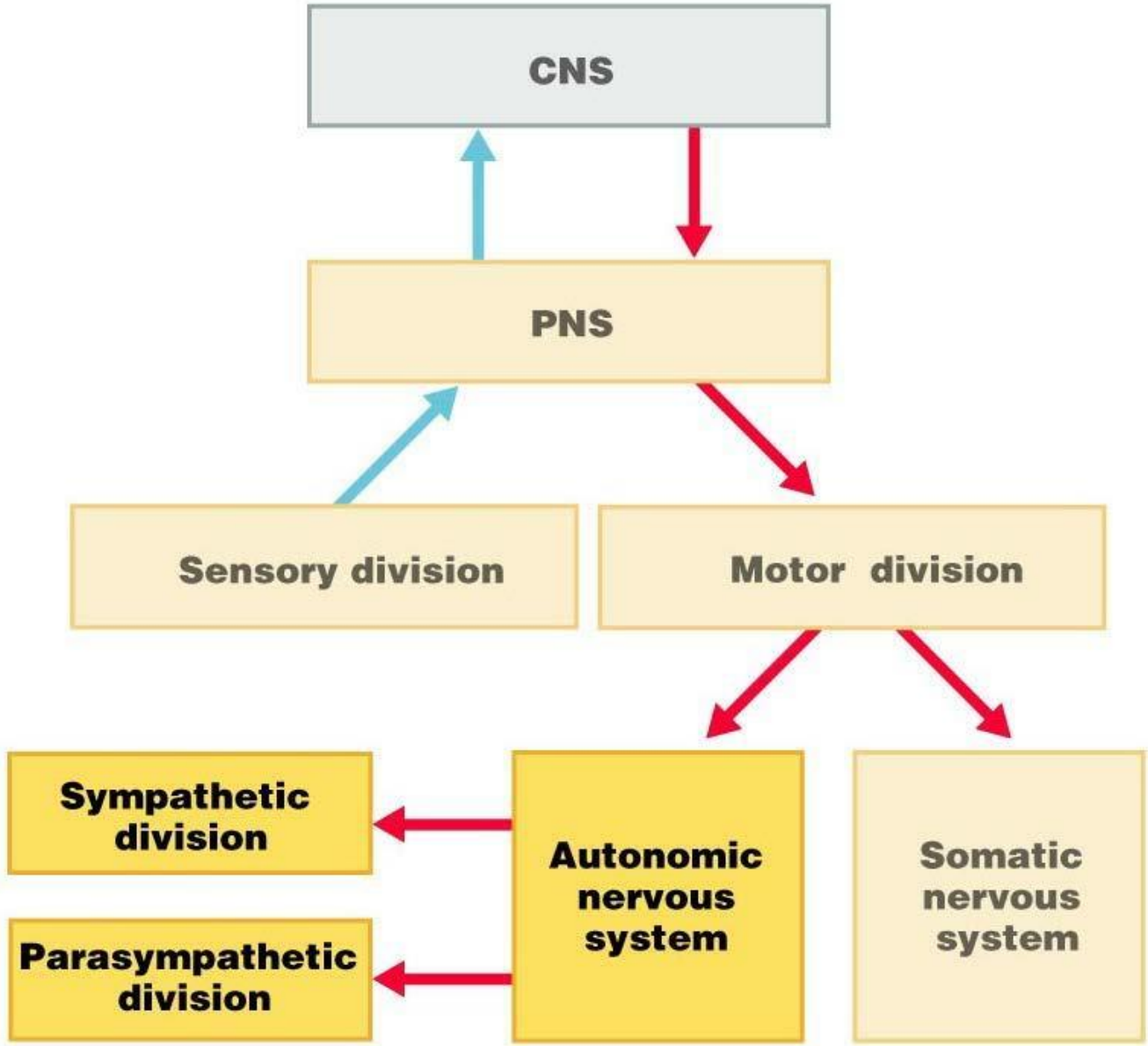


Figure 14.1

ANS Versus Somatic Nervous System (SNS)

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

Effectors

- The effectors of the SNS are skeletal muscles
- The effectors of the ANS are cardiac muscle, smooth muscle, and glands

Efferent Pathways

- Heavily myelinated axons of the somatic motor neurons extend from the CNS to the effector
- Axons of the ANS are a two-neuron chain
  - The preganglionic (first) neuron has a lightly myelinated axon
  - The ganglionic (second) neuron extends to an effector organ

Neurotransmitter Effects

- All somatic motor neurons release Acetylcholine (ACh), which has an excitatory effect
- In the ANS:
  - Preganglionic fibers release ACh
  - Postganglionic fibers release norepinephrine or ACh and the effect is either stimulatory or inhibitory
  - ANS effect on the target organ is dependent upon the neurotransmitter released and the receptor type of the effector

Comparison of Somatic and Autonomic Systems

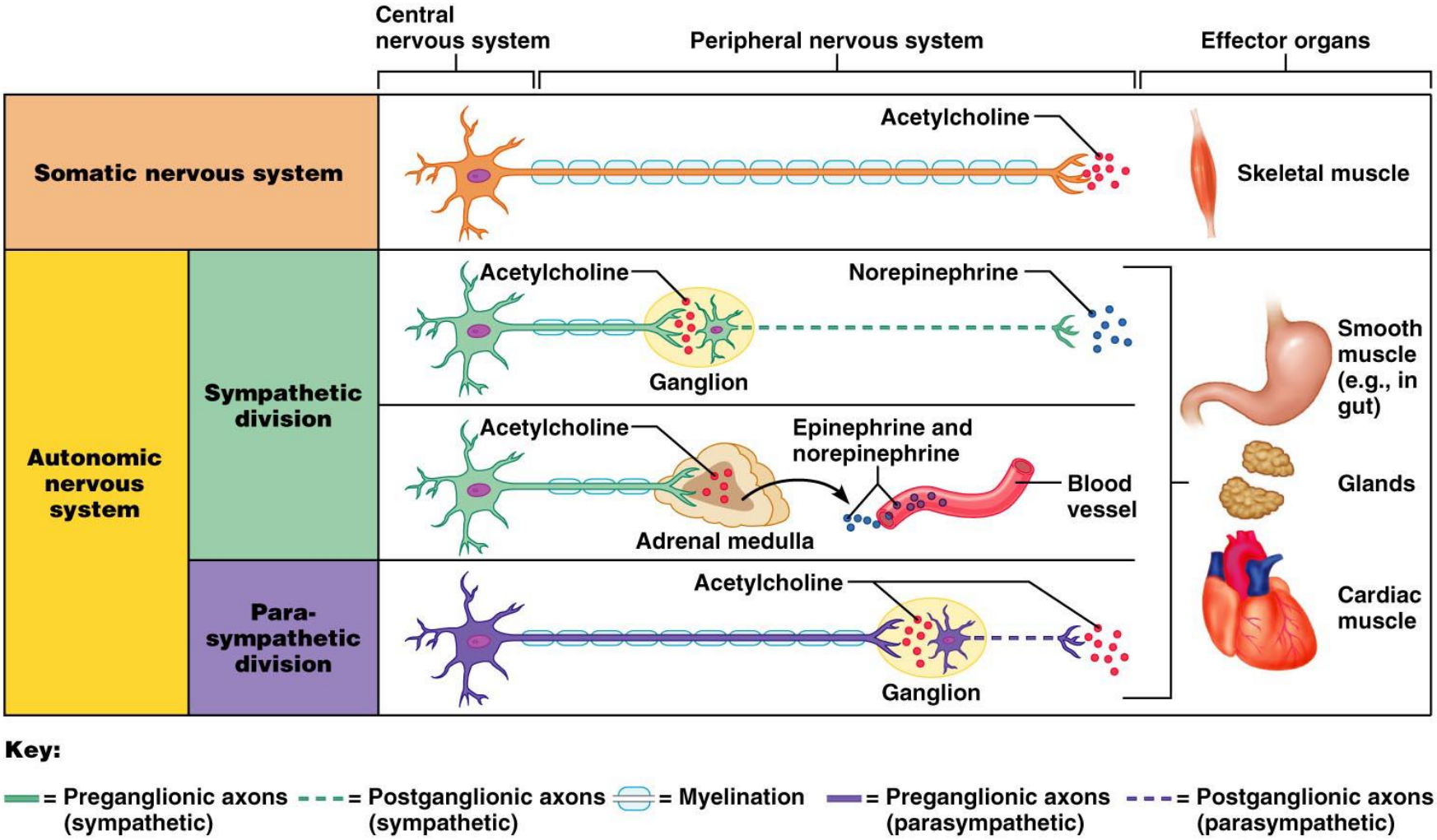


Figure 14.2

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 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

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

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

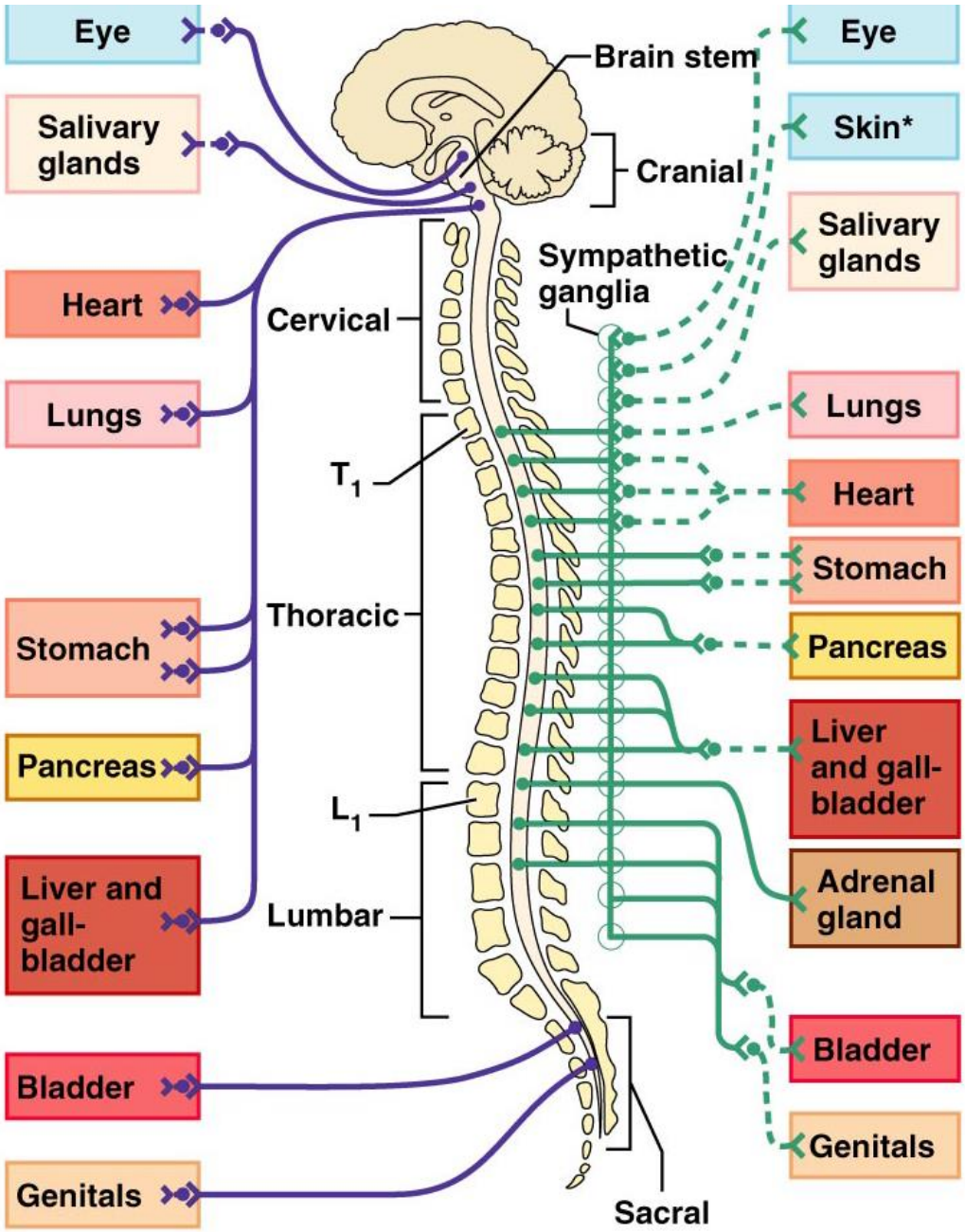
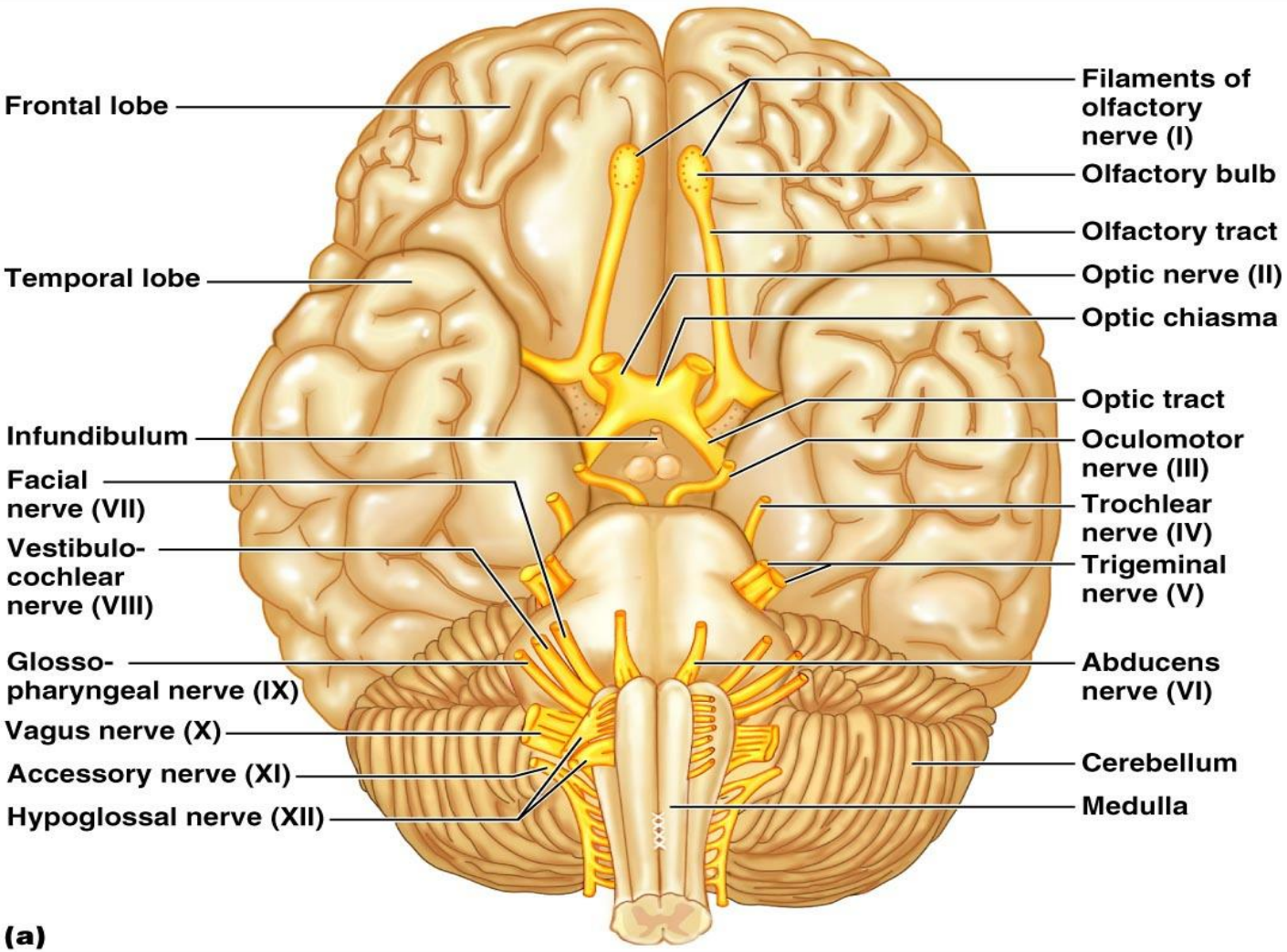


Figure 14.3

Cranial Nerves



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

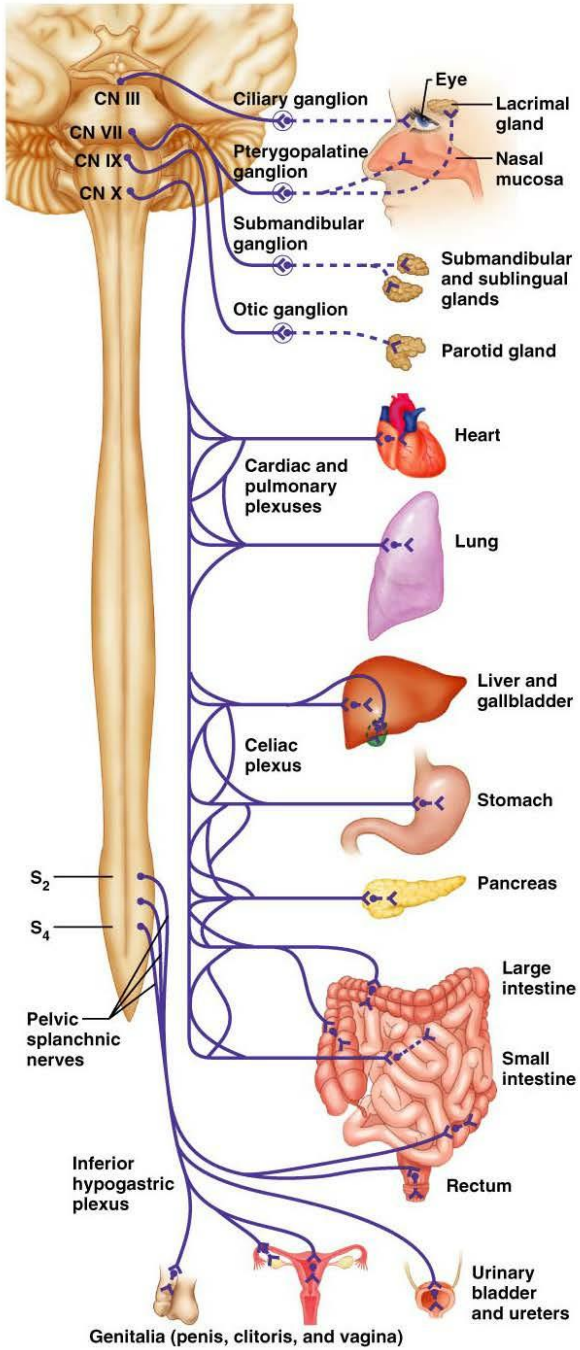


Figure 14.4

Visceral Reflexes

- Visceral reflexes have the same elements as somatic reflexes
- They are always polysynaptic pathways
- Afferent fibers are found in spinal and autonomic nerves

Visceral Reflexes

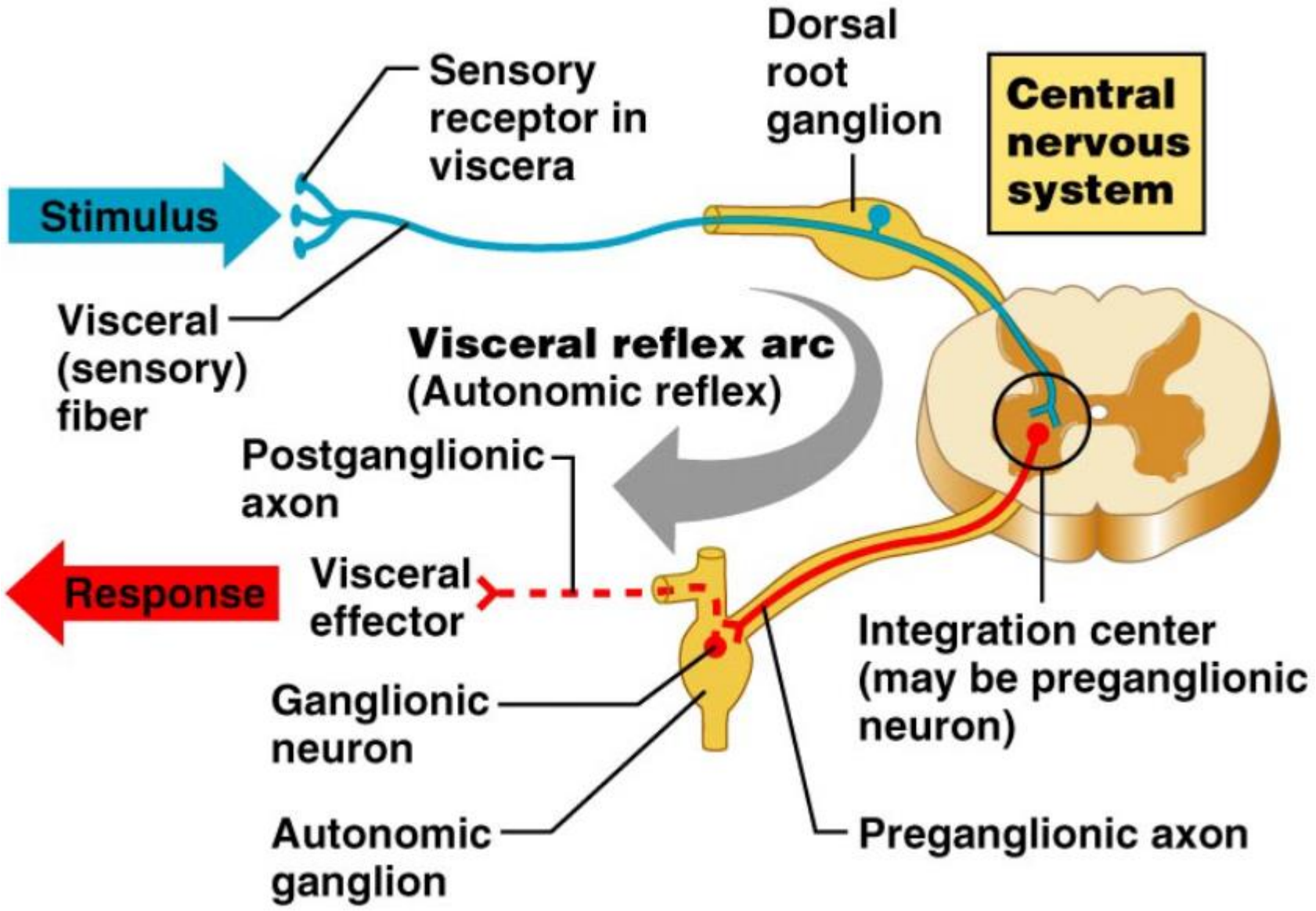


Figure 14.7

Neurotransmitters and Receptors

- Acetylcholine (ACh) and norepinephrine (NE) are the two major neurotransmitters of the ANS
- ACh is released by all preganglionic axons and all parasympathetic postganglionic axons
- Cholinergic fibers – ACh-releasing fibers
- Adrenergic fibers – sympathetic postganglionic axons that release NE
- Neurotransmitter effects can be excitatory or inhibitory depending upon the receptor type

Cholinergic Receptors

- The two types of receptors that bind ACh are nicotinic and muscarinic
- These are named after drugs that bind to them and mimic ACh effects

Nicotinic Receptors

- Nicotinic receptors are found on:
  - Motor end plates (somatic targets)
  - All ganglionic neurons of both sympathetic and parasympathetic divisions
  - The hormone-producing cells of the adrenal medulla
- The effect of ACh binding to nicotinic receptors is always stimulatory

Muscarinic Receptors

- Muscarinic receptors occur on all effector cells stimulated by postganglionic cholinergic fibers
- The effect of ACh binding:
  - Can be either inhibitory or excitatory
  - Depends on the receptor type of the target organ

Adrenergic Receptors

- The two types of adrenergic receptors are alpha and beta
- Each type has two or three subclasses (α1, α2, β1, β2 , β3)
- Effects of NE binding to:
  - α receptors is generally stimulatory
  - β receptors is generally inhibitory
- A notable exception – NE binding to β receptors of the heart is stimulatory

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Nervous System II: Synaptic Transmission, pages 8–9

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

Unique Roles of the Sympathetic Division

- Regulates many functions not subject to parasympathetic influence
- These include the activity of the adrenal medulla, sweat glands, arrector pili muscles, kidneys, and most blood vessels
- The sympathetic division controls:
  - Thermoregulatory responses to heat
  - Release of renin from the kidneys
  - Metabolic effects

Thermoregulatory Responses to Heat

- Applying heat to the skin causes reflex dilation of blood vessels
- Systemic body temperature elevation results in widespread dilation of blood vessels
- This dilation brings warm blood to the surface and activates sweat glands to cool the body
- When temperature falls, blood vessels constrict and blood is retained in deeper vital organs

Release of Renin from the Kidneys

- Sympathetic impulses activate the kidneys to release renin
- Renin is an enzyme that promotes increased blood pressure

Metabolic Effects

- The sympathetic division promotes metabolic effects that are not reversed by the parasympathetic division
  - Increases the metabolic rate of body cells
  - Raises blood glucose levels
  - Mobilizes fat as a food source
  - Stimulates the reticular activating system (RAS) of the brain, increasing mental alertness

Localized Versus Diffuse Effects

- The parasympathetic division exerts short-lived, highly localized control
- The sympathetic division exerts long-lasting, diffuse effects

Effects of Sympathetic Activation

- Sympathetic activation is long-lasting because NE:
  - Is inactivated more slowly than ACh
  - Is an indirectly acting neurotransmitter, using a second-messenger system
  - And epinephrine are released into the blood and remain there until destroyed by the liver