Department of Veterinary Physiology

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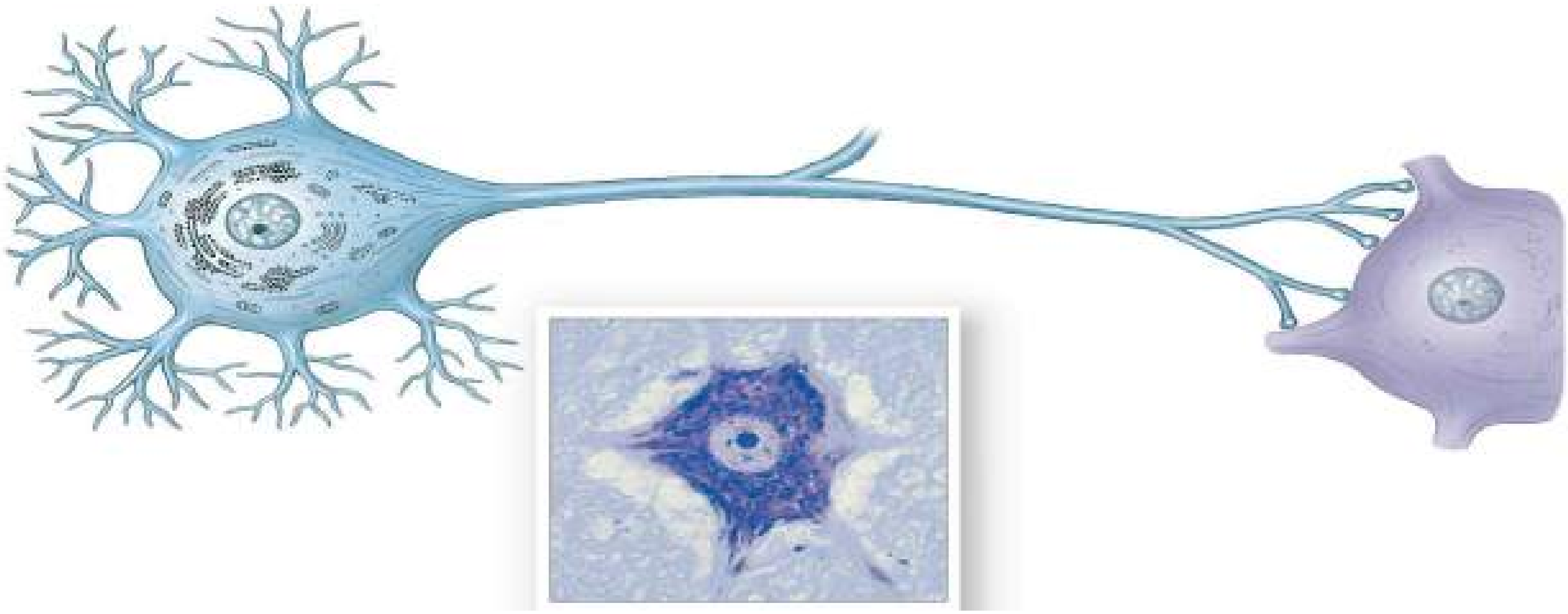
B.V.Sc. & A.H.

1st Year (2023-24)

The Nervous System



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The Nervous System and the Endocrine System (Introduction)

- The nervous system and endocrine system coordinate other organ systems to maintain homeostasis
- The nervous system is fast, short acting
- The endocrine system is slower, but longer lasting
- The nervous system is the most complex system in the body

Functions of the Nervous System (8-1)

- Monitors the body's internal and external environments
- Integrates sensory information
- Coordinates voluntary and involuntary responses

Divisions of the Nervous System (8-1)

- Anatomical divisions are:
  - The **central nervous system (CNS)**
    - Made up of the brain and spinal cord
    - Integrates and coordinates input and output
  - The **peripheral nervous system (PNS)**
    - All the neural tissues outside of the CNS
    - The connection between the CNS and the organs

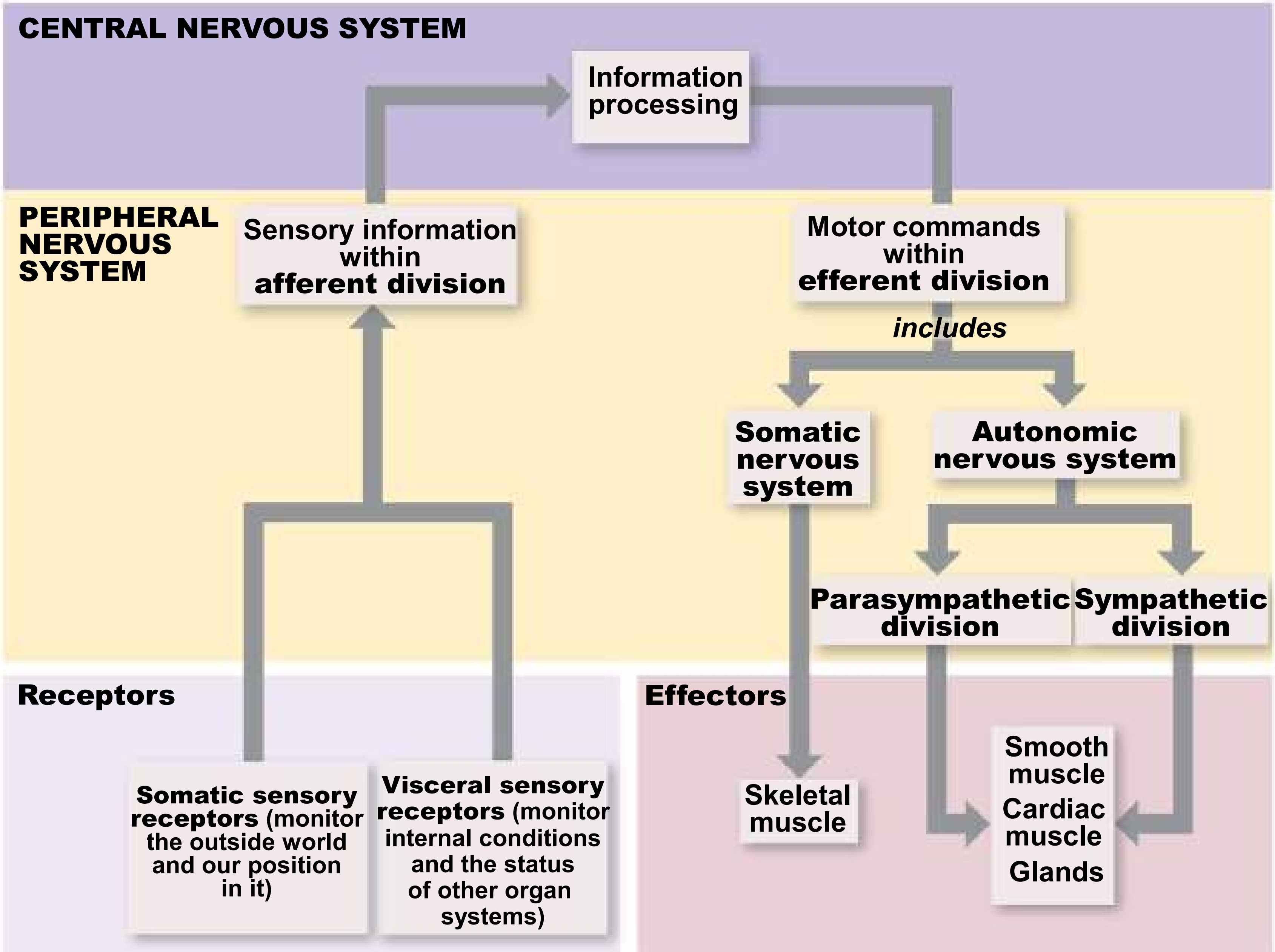
Divisions of the Nervous System (8-1)

- Functional divisions are:
  - The **afferent division**
    - Includes sensory receptors and neurons that send information to the CNS
  - The **efferent division**
    - Includes neurons that send information to the effectors, which are the muscles and glands

Efferent Division of the Nervous System (8-1)

- Further divided into:
  - The **somatic nervous system (SNS)**
    - Controls skeletal muscle
  - The **autonomic nervous system (ANS)**
    - Controls smooth and cardiac muscle, and glands
    - Has two parts
      1. *Sympathetic division*
      2. *Parasympathetic division*

Figure 8-1 A Functional Overview of the Nervous System.



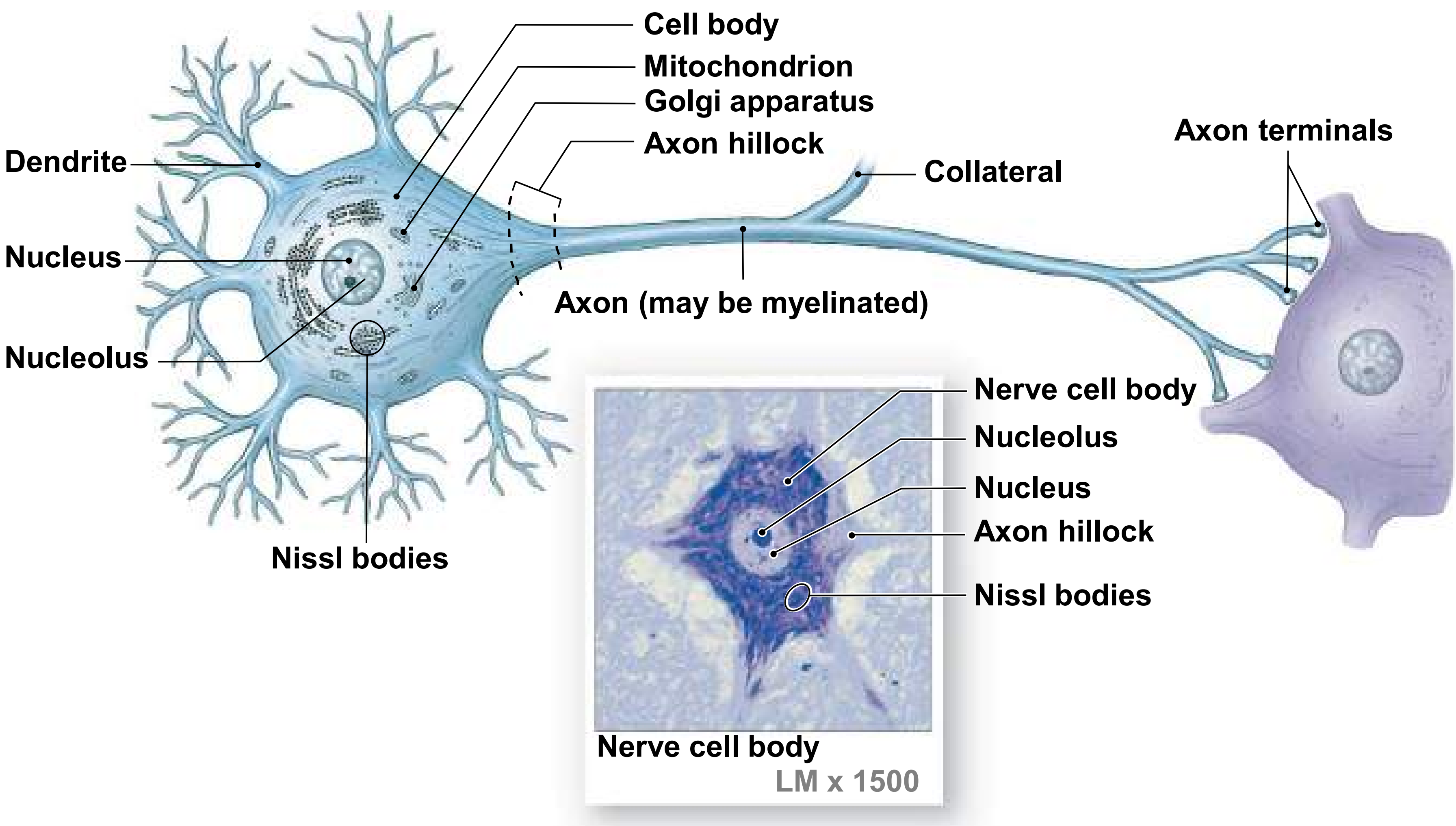
Neurons (8-2)

- Cells that communicate with one another and other cells
- Associated with neuroglia – regulate environment around the neurons
- Basic structure of a neuron includes:
  - Cell body
  - **Dendrites**
    - Which receive signals
  - **Axons**
    - Which carry signals to the next cell
  - **Axon terminals**
    - Bulb-shaped endings that form a **synapse** with the next cell

Neurons (8-2)

- Have a very limited ability to regenerate when damaged or destroyed
- Cell bodies contain:
  - Mitochondria, free and fixed ribosomes, and rough endoplasmic reticulum
    - Free ribosomes and RER form **Nissl bodies** and give the tissue a gray color (gray matter)
  - The **axon hillock**
    - Where electrical signal begins

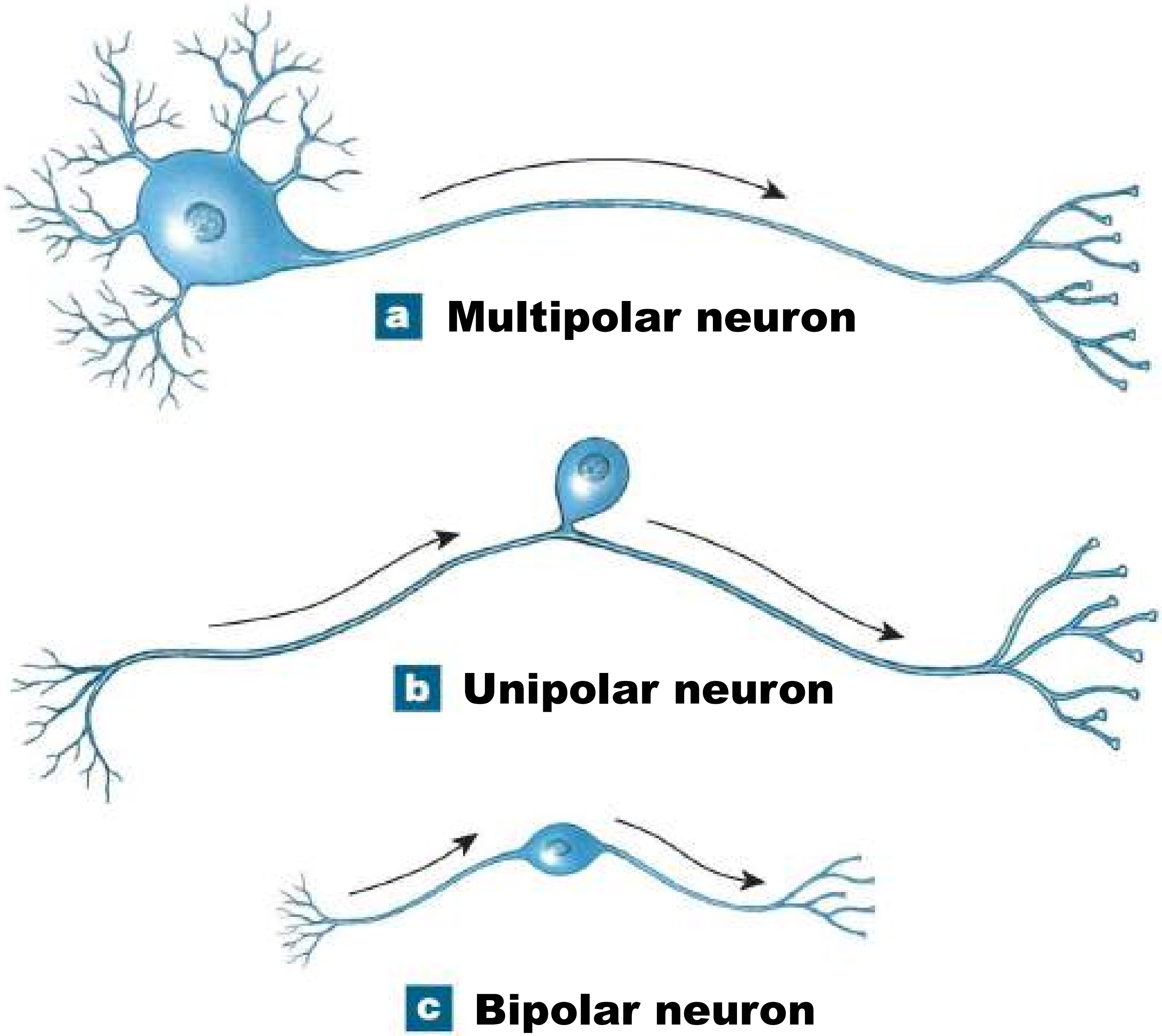
Figure 8-2 The Anatomy of a Representative Neuron.



Structural Classification of Neurons (8-2)

- Based on the relationship of the dendrites to the cell body
  - **Multipolar neurons**
    - Are the most common in the CNS and have two or more dendrites and one axon
  - **Unipolar neurons**
    - Have the cell body off to one side, most abundant in the afferent division
  - **Bipolar neurons**
    - Have one dendrite and one axon with the cell body in the middle, and are rare

Figure 8-3 A Structural Classification of Neurons.



Sensory Neurons (8-2)

- Also called *afferent neurons*
- Total 10 million or more
- Receive information from sensory receptors
  - **Somatic sensory receptors**
    - Detect stimuli concerning the outside world, in the form of **external receptors**
      - And our position in it, in the form of **proprioceptors**
  - **Visceral** or **internal receptors**
    - Monitor the internal organs

Motor Neurons (8-2)

- Also called *efferent neurons*
- Total about half a million in number
- Carry information to peripheral targets called *effectors*
  - **Somatic motor neurons**
    - Innervate skeletal muscle
  - **Visceral motor neurons**
    - Innervate cardiac muscle, smooth muscle, and glands

Interneurons (8-2)

- Also called *association neurons*
- By far the most numerous type at about 20 billion
- Are located in the CNS
- Function as links between sensory and motor processes
- Have higher functions
  - Such as memory, planning, and learning

Neuroglial Cells (8-2)

- Are supportive cells and make up about half of all neural tissue
- Four types are found in the CNS
  1. **Astrocytes**
  2. **Oligodendrocytes**
  3. **Microglia**
  4. **Ependymal cells**
- Two types in the PNS
  1. **Satellite cells**
  2. **Schwann cells**

Astrocytes (8-2)

- Large and numerous neuroglia in the CNS
- Maintain the *blood–brain barrier (isolates CNS from general circulation)*
- Create structural framework for CNS neurons
- Perform repairs in damaged neural tissues

Oligodendrocytes (8-2)

- Found in the CNS
- Produce an insulating membranous wrapping around axons called **myelin**
  - Small gaps between the wrappings called nodes of Ranvier
- **Myelinated** axons constitute the **white matter** of the CNS
  - Where cell bodies are **gray matter**
  - Some axons are **unmyelinated**

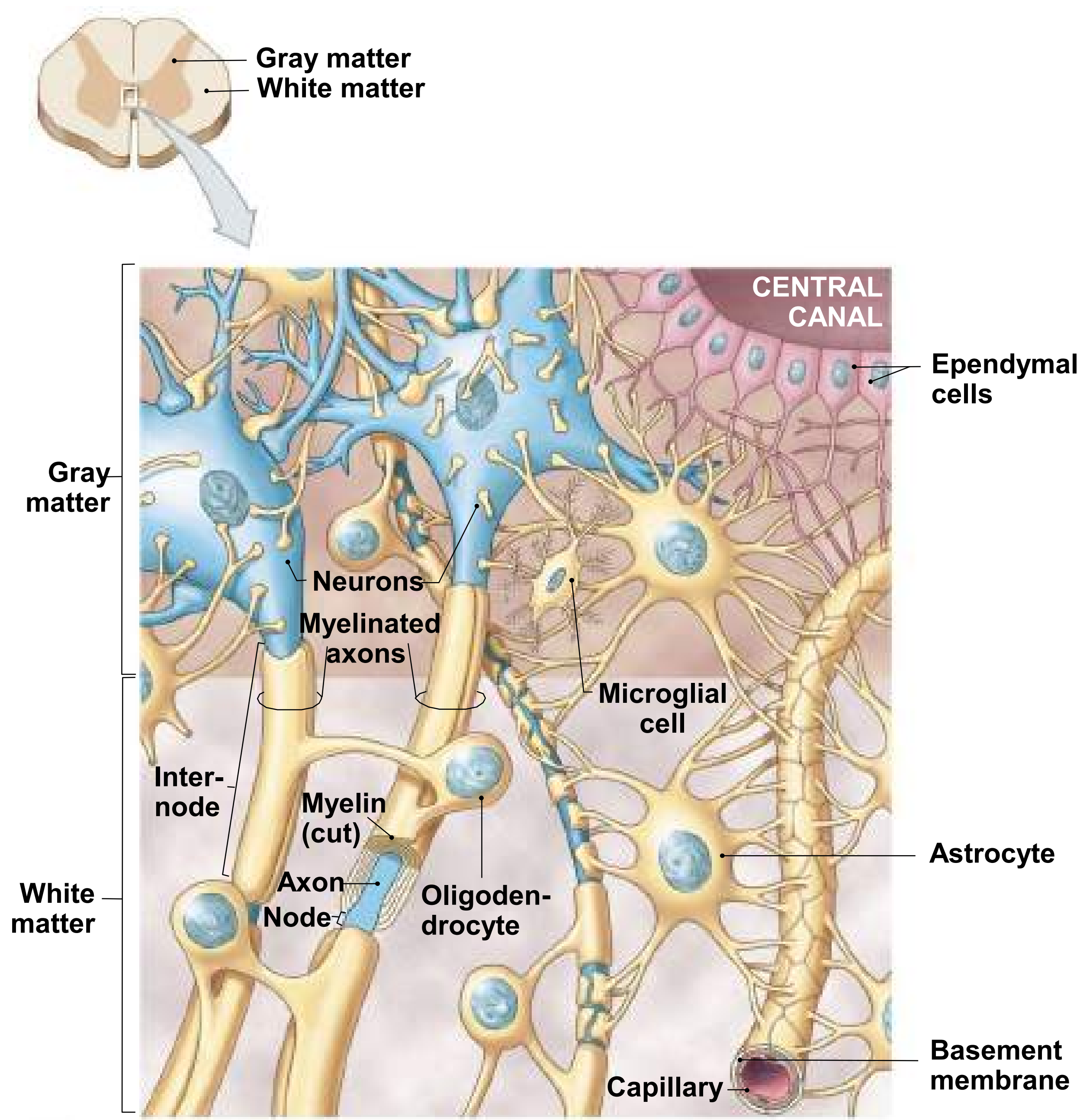
Microglia (8-2)

- The smallest and least numerous
- Phagocytic cells derived from white blood cells
- Perform essential protective functions such as engulfing pathogens and cellular waste

Ependymal Cells (8-2)

- Line the fluid-filled central canal of the spinal cord and the ventricles of the brain
- The endothelial lining is called the **ependyma**
- It is involved in producing and circulating cerebrospinal fluid around the CNS

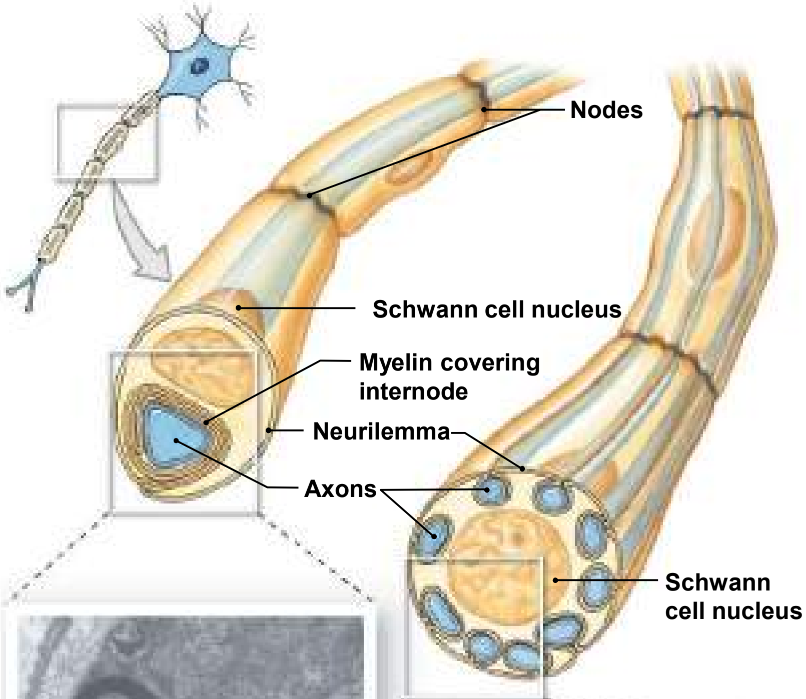
Figure 8-4 Neuroglia in the CNS.



Neuroglial Cells in PNS (8-2)

- **Satellite cells**
  - Surround and support neuron cell bodies
  - Similar in function to the astrocytes in the CNS
- **Schwann cells**
  - Cover every axon in PNS
  - The surface is the neurilemma
  - Produce myelin

Figure 8-5 Schwann Cells and Peripheral Axons.



a A myelinated axon in the PNS is covered by several Schwann cells, each of which forms a myelin sheath around a portion of the axon. This arrangement differs from the way myelin forms in the CNS; compare with Figure 8-4.

b A single Schwann cell can encircle several unmyelinated axons. Every axon in the PNS is completely enclosed by Schwann cells.

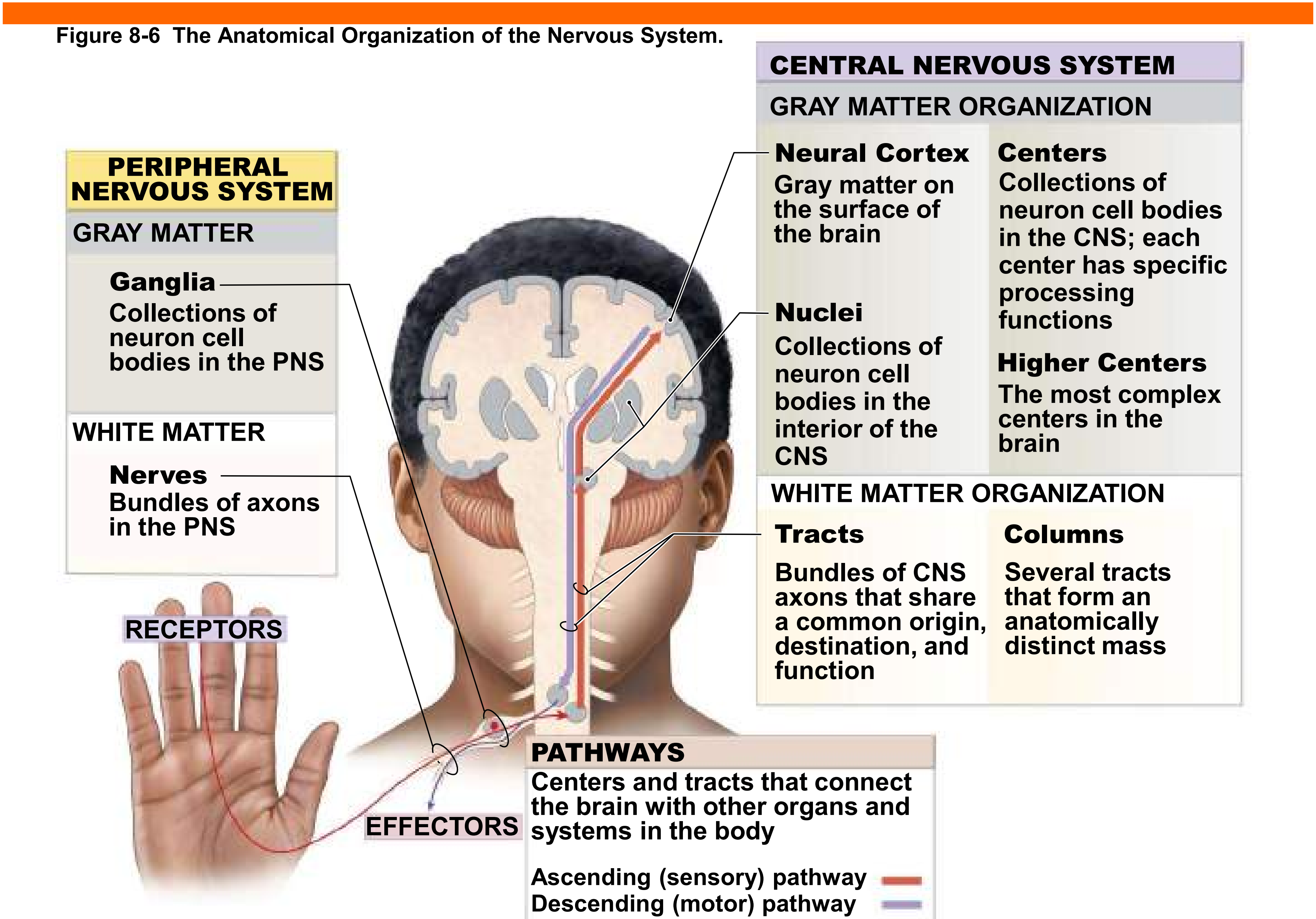
Organization of the Nervous System (8-2)

- In the PNS:
  - Collections of nerve cell bodies are **ganglia**
  - Bundled axons are **nerves**
  - Including spinal nerves and cranial nerves
  - Can have both sensory and motor components

Organization of the Nervous System (8-2)

- In the CNS:
  - Collections of neuron cell bodies are found in **centers**, or **nuclei**
  - **Neural cortex** is a thick layer of gray matter
  - White matter in the CNS is formed by bundles of axons called **tracts**, and in the spinal cord, form **columns**
  - **Pathways** are either **sensory** or ascending tracts, or **motor** or descending tracts

Figure 8-6 The Anatomical Organization of the Nervous System.



The Membrane Potential (8-3)

- A membrane potential exists because of:
  - Excessive positive ionic charges on the outside of the cell
  - Excessive negative charges on the inside, creating a polarized membrane
  - An undisturbed cell has a **resting membrane potential** measured in the inside of the cell in *millivolts*
  - The resting membrane potential of neurons is –70 mV

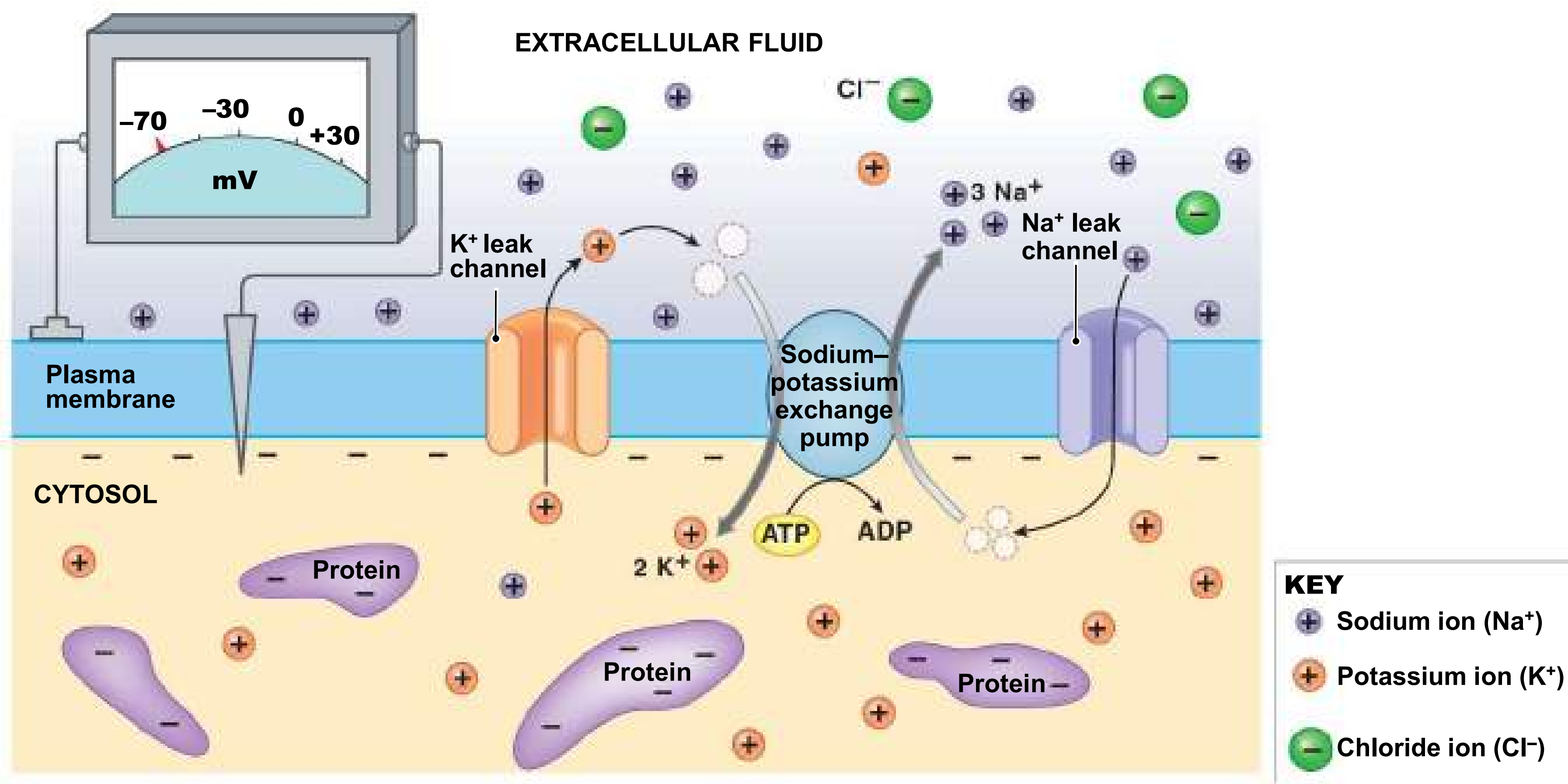
Factors Determining Membrane Potential (8-3)

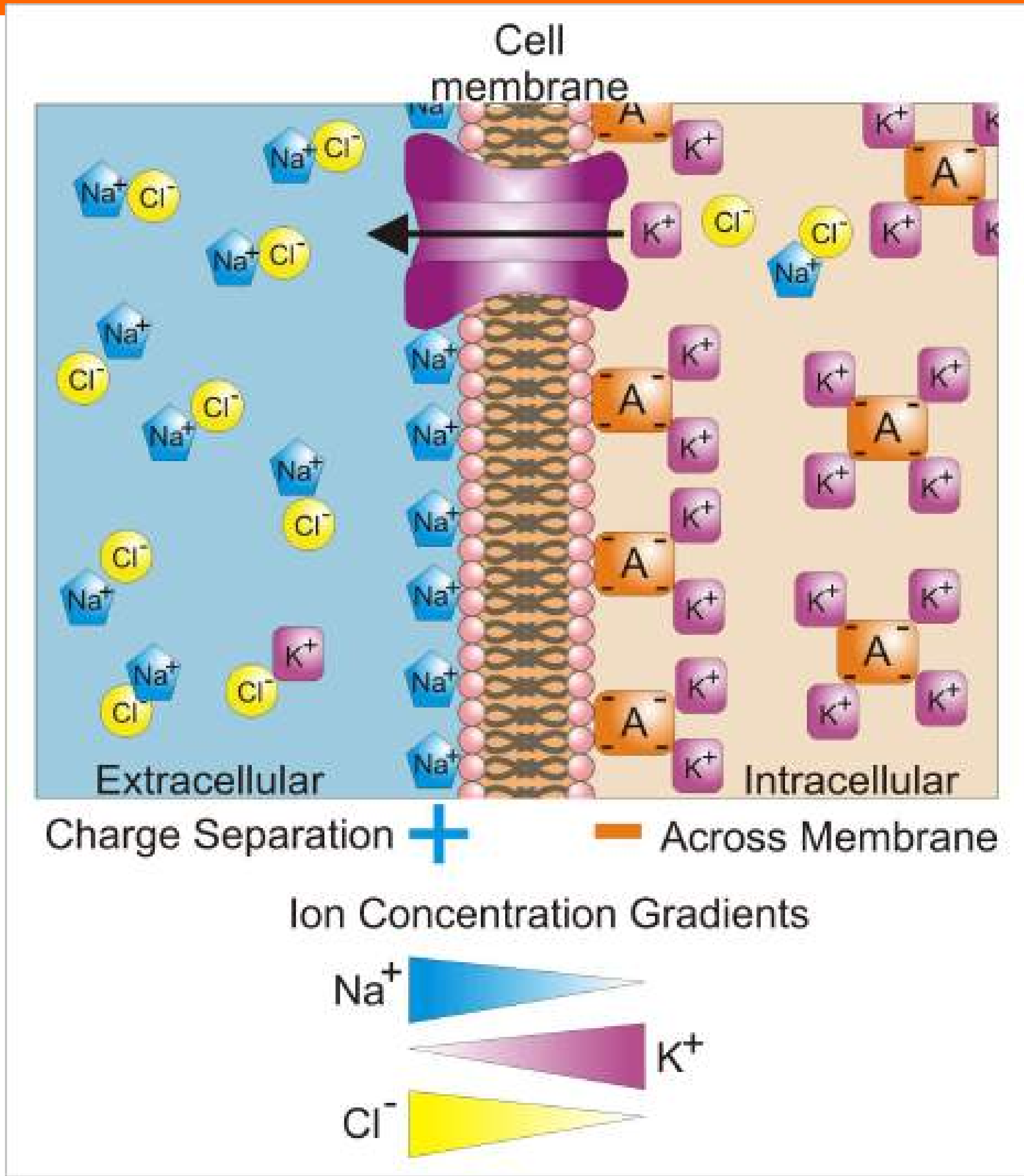
- Extracellular fluid (ECF) is high in Na^+ and Cl^-
- Intracellular fluid (ICF) is high in K^+ and negatively charged proteins (Pr^-)
- Proteins are non-permeating, staying in the ICF
- Some ion channels are always open
  - Called *leak channels*
- Some are open or closed
  - Called *gated channels*

Factors Determining Membrane Potential (8-3)

- Na^+ can leak in
  - But the membrane is more permeable to K^+
    - Allowing K^+ to leak out faster
- Na^+/K^+ exchange pump exchanges 3 Na^+ for every 2 K^+
  - Moving Na^+ out as fast as it leaks in
- Cell experiences a net loss of positive ions
  - Resulting in a resting membrane charge of –70 mV

Figure 8-7 The Resting Potential Is the Membrane Potential of an Undisturbed Cell.



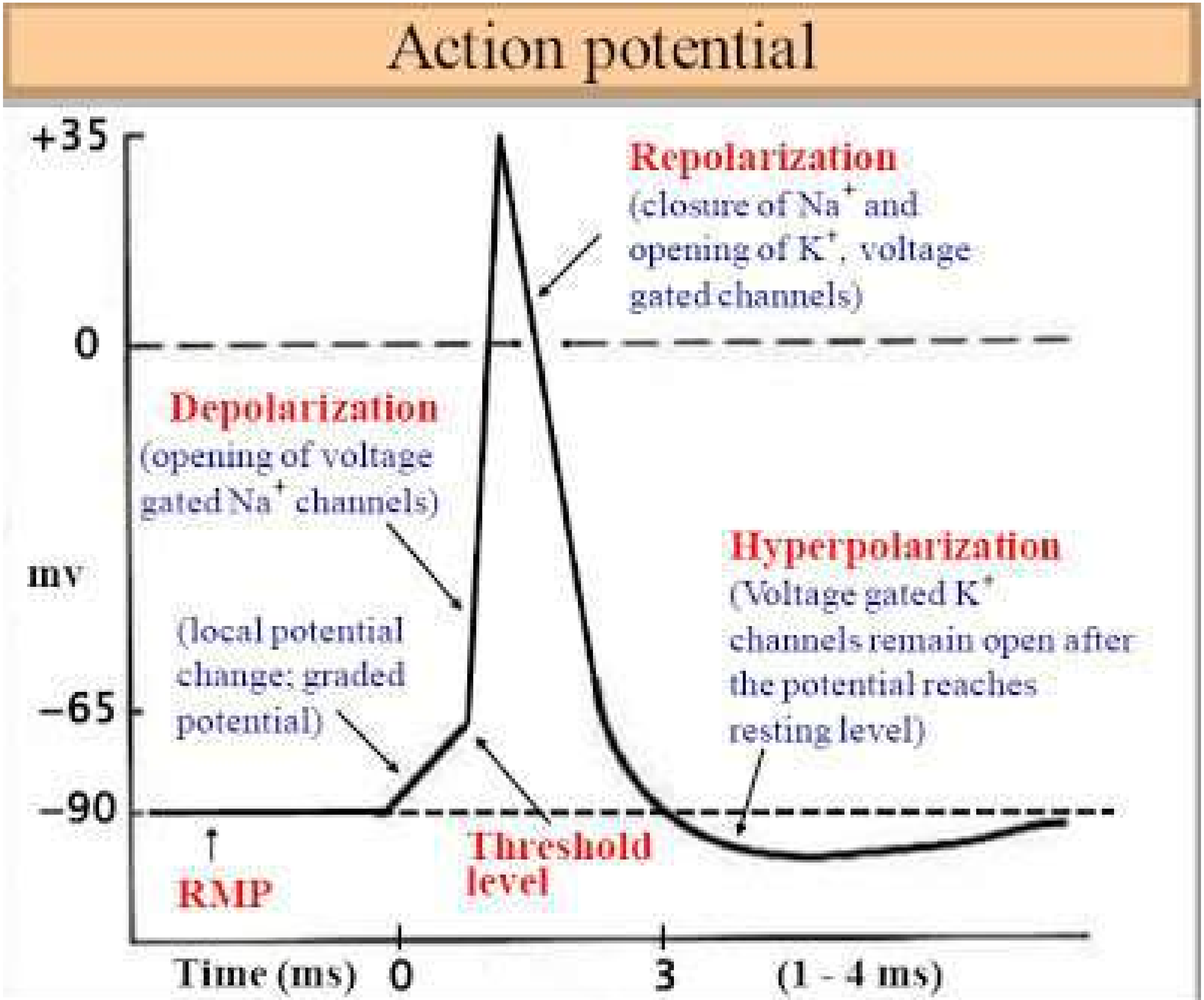

Cell membrane
Extracellular
Intracellular
Charge Separation + − Across Membrane
Ion Concentration Gradients
Na+
K+
Cl-

Changes in Membrane Potential (8-3)

- Stimuli alter membrane permeability to Na^+ or K^+
  - Or alter activity of the exchange pump
  - Types include:
    - Cellular exposure to chemicals
    - Mechanical pressure
    - Temperature changes
    - Changes in the ECF ion concentration
    - Result is opening of a gated channel
      - Increasing the movement of ions across the membrane

Changes in Membrane Potential (8-3)

- Opening of Na^+ channels results in an influx of Na^+
  - Moving the membrane toward 0 mV, a shift called **depolarization**
- Opening of K^+ channels results in an efflux of K^+
  - Moving the membrane further away from 0 mV, a shift called **hyperpolarization**
- Return to resting from depolarization: **repolarizing**


Action potential
+35
0
mv
-65
-90
Repolarization
(closure of Na+ and opening of K+, voltage gated channels)
Depolarization
(opening of voltage gated Na+ channels)
(local potential change; graded potential)
Hyperpolarization
(Voltage gated K+ channels remain open after the potential reaches resting level)
RMP
Threshold level
Time (ms) 0
3
(1 - 4 ms)

Graded Potentials (8-3)

- Local changes in the membrane that fade over distance
- All cells experience graded potentials when stimulated
  - And can result in the activation of smaller cells
- Graded potentials by themselves cannot trigger activation of large neurons and muscle fibers
  - Referred to as having excitable membranes

Action Potentials (8-3)

- A change in the membrane that travels the entire length of neurons
  - A **nerve impulse**
- If a combination of graded potentials causes the membrane to reach a critical point of depolarization, it is called the **threshold**
  - Then an action potential will occur

Action Potentials (8-3)

- Are **all-or-none** and will propagate down the length of the neuron
- From the time the voltage-gated channels open until **repolarization** is finished:
  - The membrane cannot respond to further stimulation
- This period of time is the **refractory period**
  - And limits the rate of response by neurons

Figure 8-8 The Generation of an Action Potential

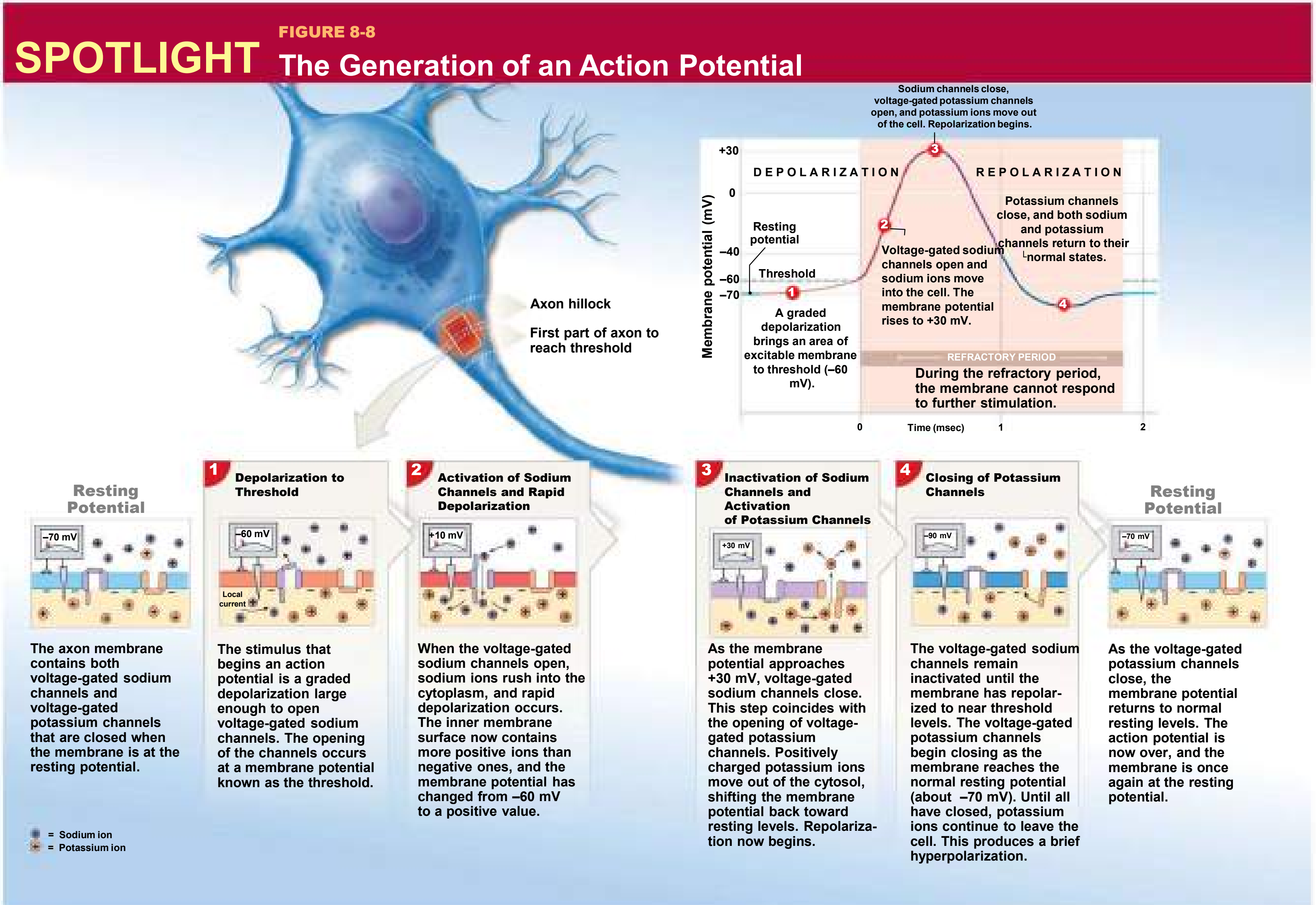


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Figure 8-8 The Generation of an Action Potential

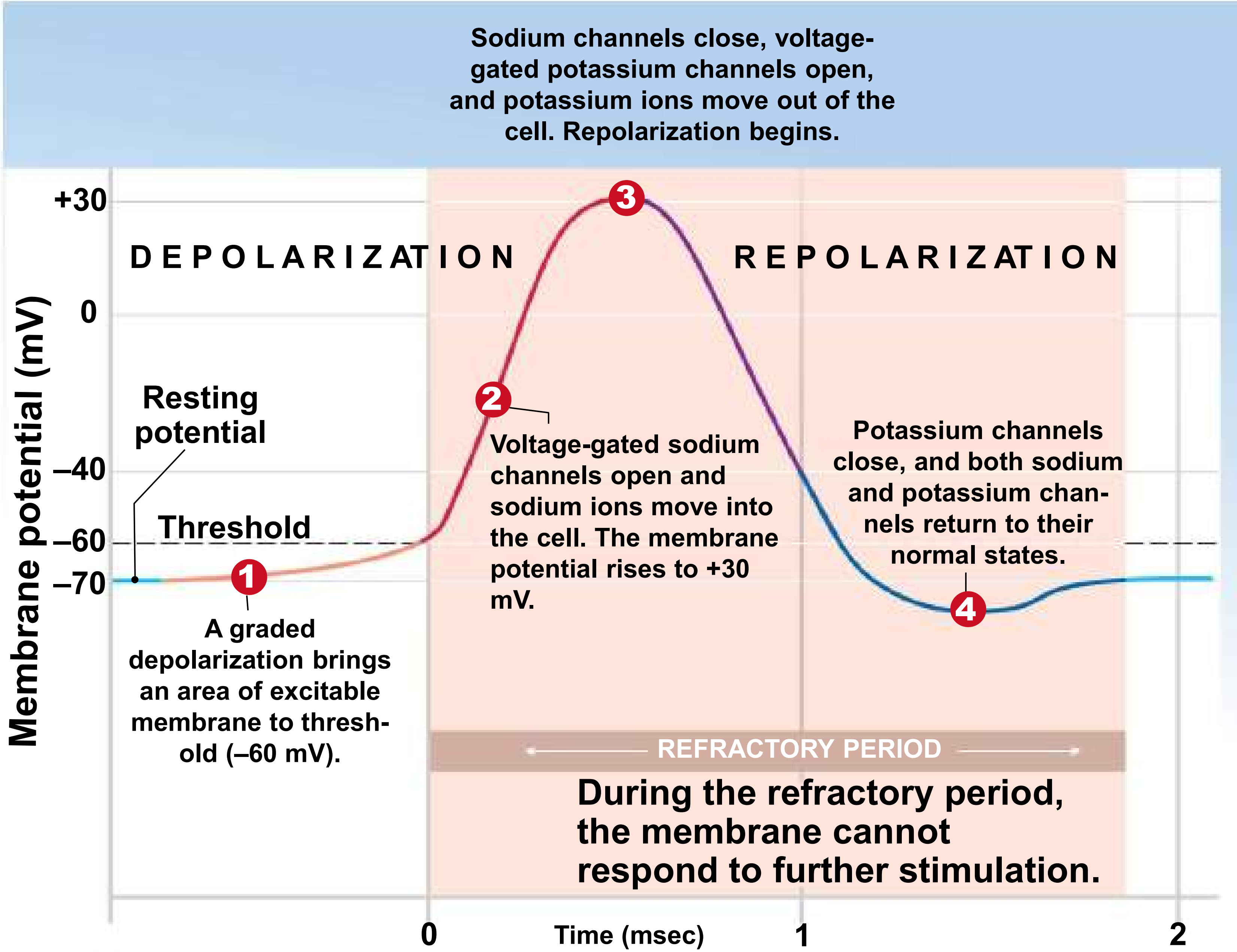
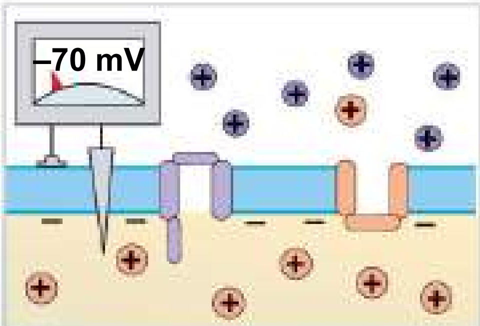


Figure 8-8 The Generation of an Action Potential

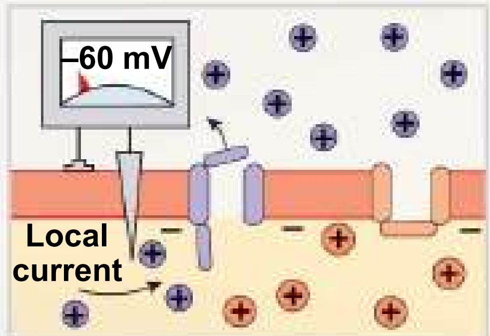
Resting Potential



The axon membrane contains both voltage-gated sodium channels and voltage-gated potassium channels that are closed when the membrane is at the resting potential.

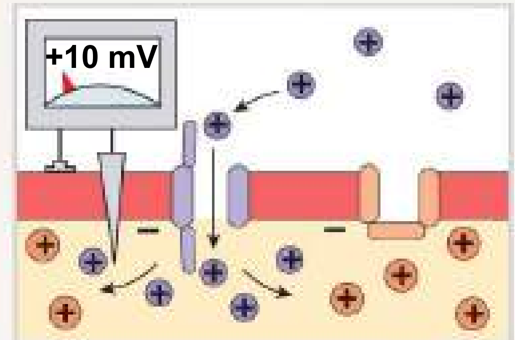
⊕ = Sodium ion
⊕ = Potassium ion

1 Depolarization to Threshold



The stimulus that begins an action potential is a graded depolarization large enough to open voltage-gated sodium channels. The opening of the channels occurs at a membrane potential known as the threshold.

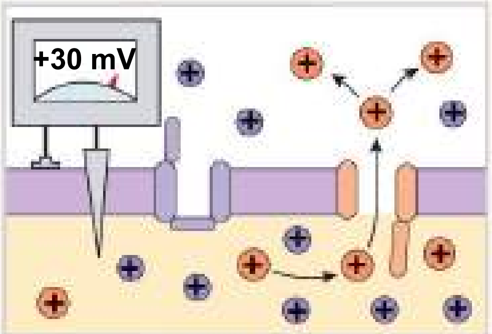
2 Activation of Sodium Channels and Rapid Depolarization



When the voltage-gated sodium channels open, sodium ions rush into the cytoplasm, and rapid depolarization occurs. The inner membrane surface now contains more positive ions than negative ones, and the membrane potential has changed from –60 mV to a positive value.

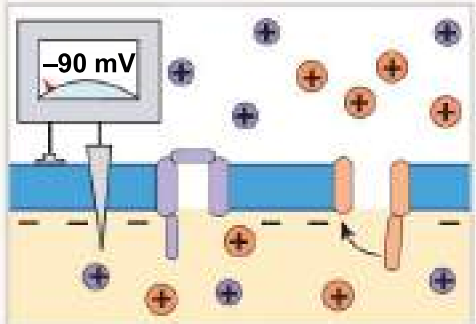
Figure 8-8 The Generation of an Action Potential

3 Inactivation of Sodium Channels and Activation of Potassium Channels



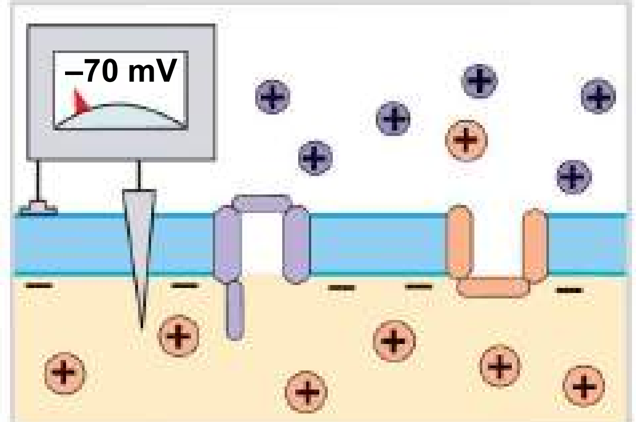
As the membrane potential approaches +30 mV, voltage-gated sodium channels close. This step coincides with the opening of voltage-gated potassium channels. Positively charged potassium ions move out of the cytosol, shifting the membrane potential back toward resting levels. Repolarization now begins.

4 Closing of Potassium Channels



The voltage-gated sodium channels remain inactivated until the membrane has repolarized to near threshold levels. The voltage-gated potassium channels begin closing as the membrane reaches the normal resting potential (about –70 mV). Until all have closed, potassium ions continue to leave the cell. This produces a brief hyperpolarization.

Resting Potential

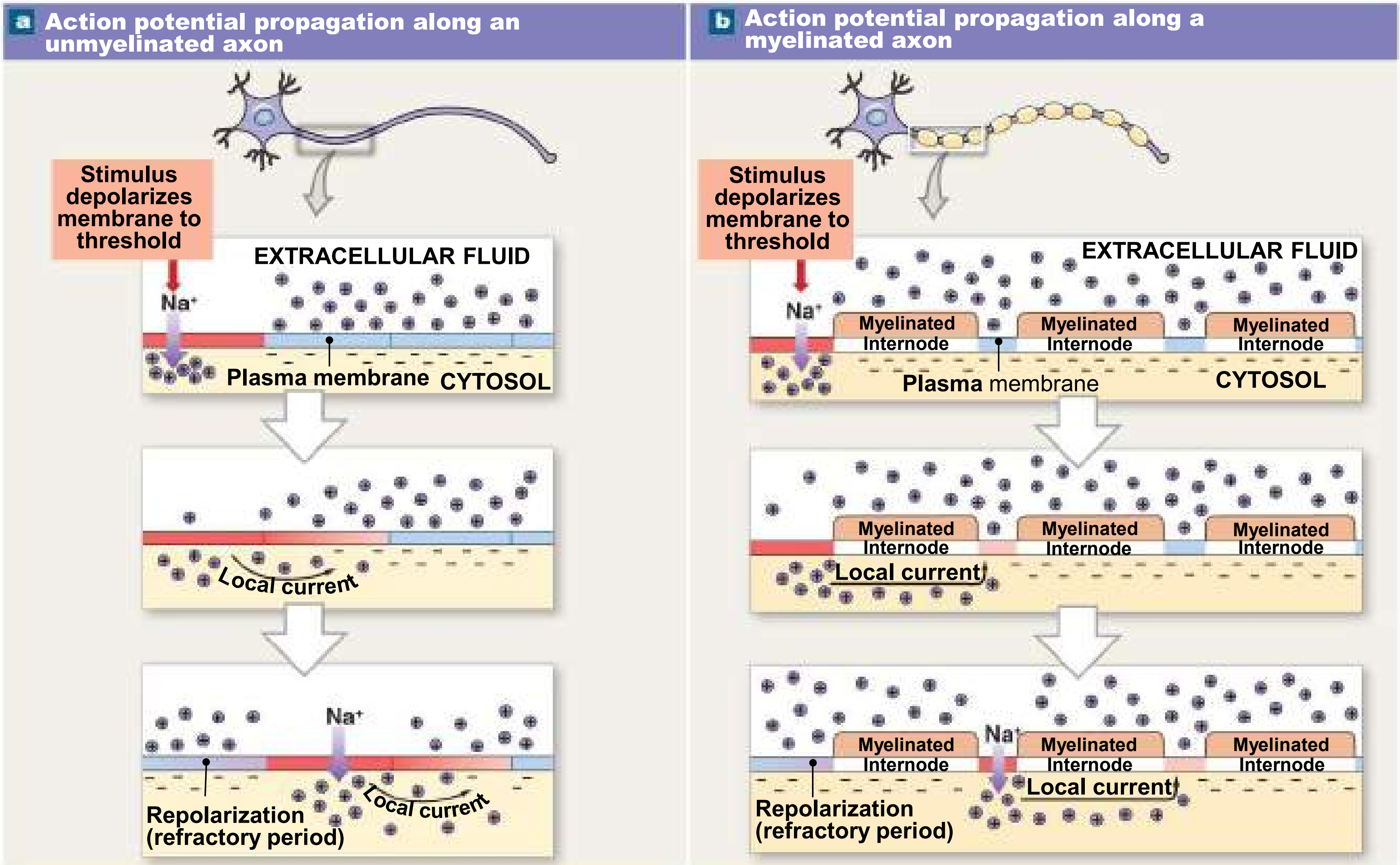


As the voltage-gated potassium channels close, the membrane potential returns to normal resting levels. The action potential is now over, and the membrane is once again at the resting potential.

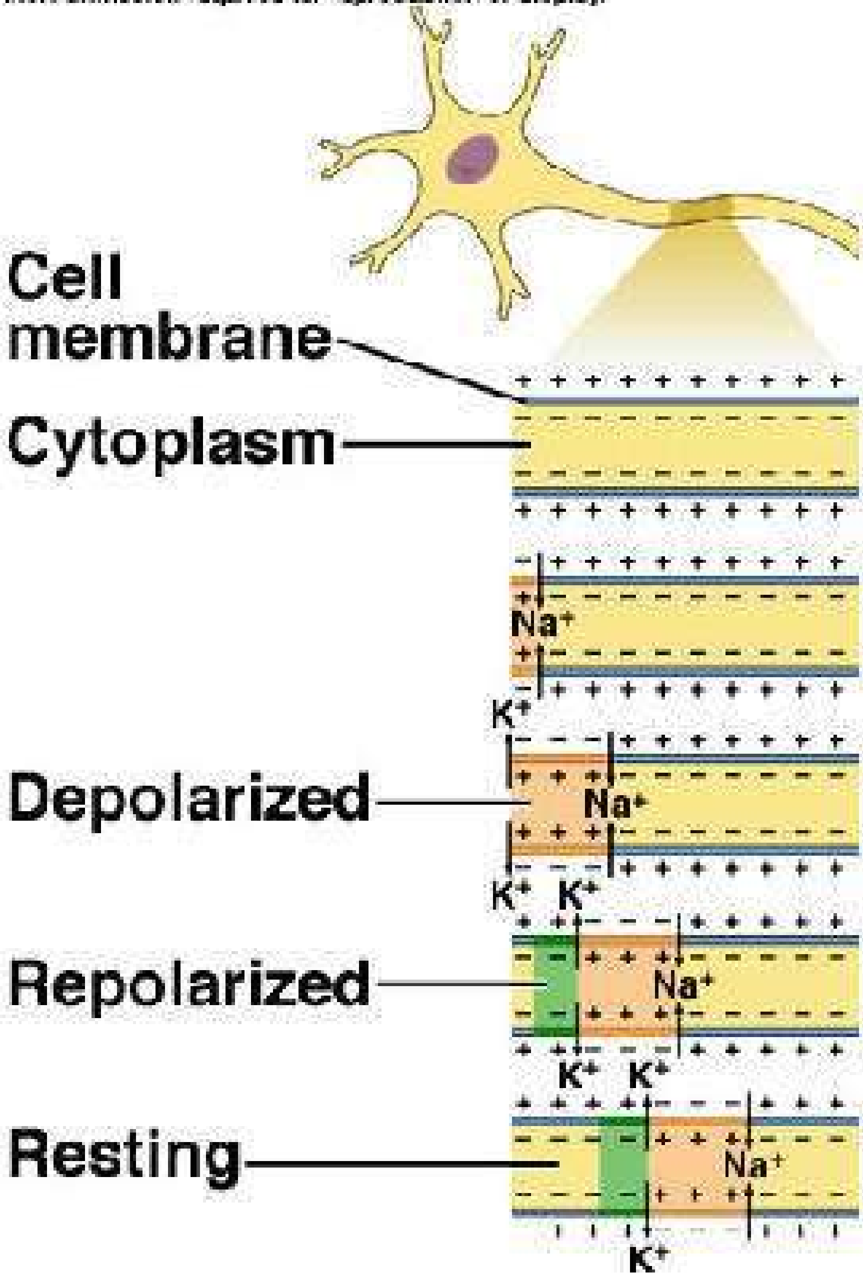
Propagation of an Action Potential (8-3)

- Occurs when local changes in the membrane in one site:
  - Result in the activation of voltage-gated channels in the next adjacent site of the membrane
- This causes a wave of membrane potential changes
- **Continuous propagation**
  - Occurs in unmyelinated fibers and is relatively slow
- **Saltatory propagation**
  - Is in myelinated axons and is faster

Figure 8-9 The Propagation of Action Potentials over Unmyelinated and Myelinated Axons.



Action Potential Propagation



The Synapse (8-4)

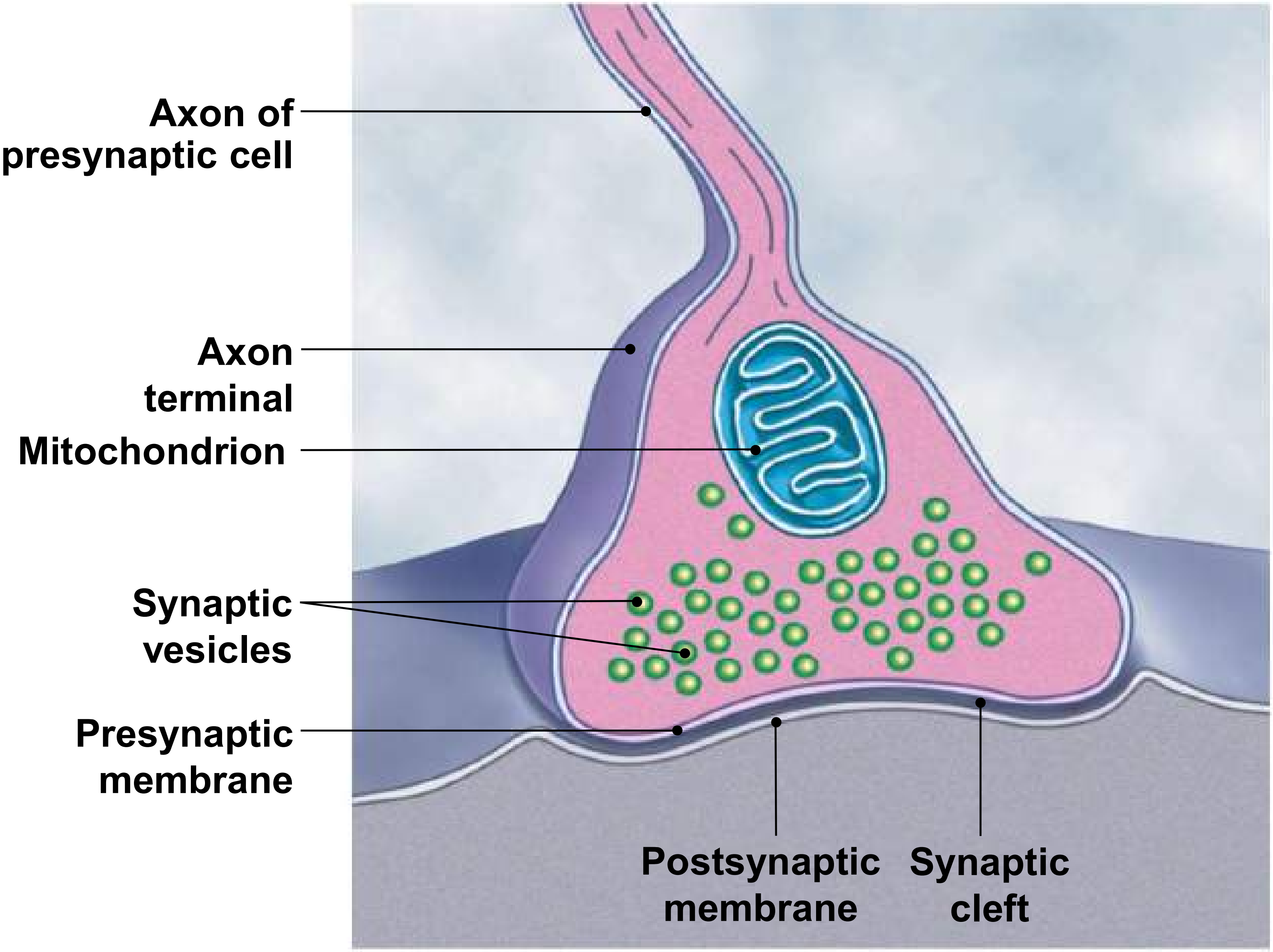
- A junction between a neuron and another cell
- Occurs because of chemical messengers called **neurotransmitters**
- Communication happens in one direction only
- Between a neuron and another cell type is a **neuroeffector junction**
  - Such as the *neuromuscular junction* or *neuroglandular junction*

A Synapse between Two Neurons (8-4)

- Occurs:
  - Between the axon terminals of the **presynaptic neuron**
  - Across the **synaptic cleft**
  - To the dendrite or cell body of the **postsynaptic neuron**
- Neurotransmitters
  - Stored in vesicles of the axon terminals
  - Released into the cleft and bind to receptors on the postsynaptic membrane

PLAY *ANIMATION* **Neurophysiology: Synapse**

Figure 8-10 The Structure of a Typical Synapse.



The Neurotransmitter ACh (8-4)

- Activates **cholinergic synapses** in four steps
  1. Action potential arrives at the axon terminal
  2. ACh is released and diffuses across synaptic cleft
  3. ACh binds to receptors and triggers depolarization of the postsynaptic membrane
  4. ACh is removed by AChE (acetylcholinesterase)

Figure 8-11 The Events at a Cholinergic Synapse.

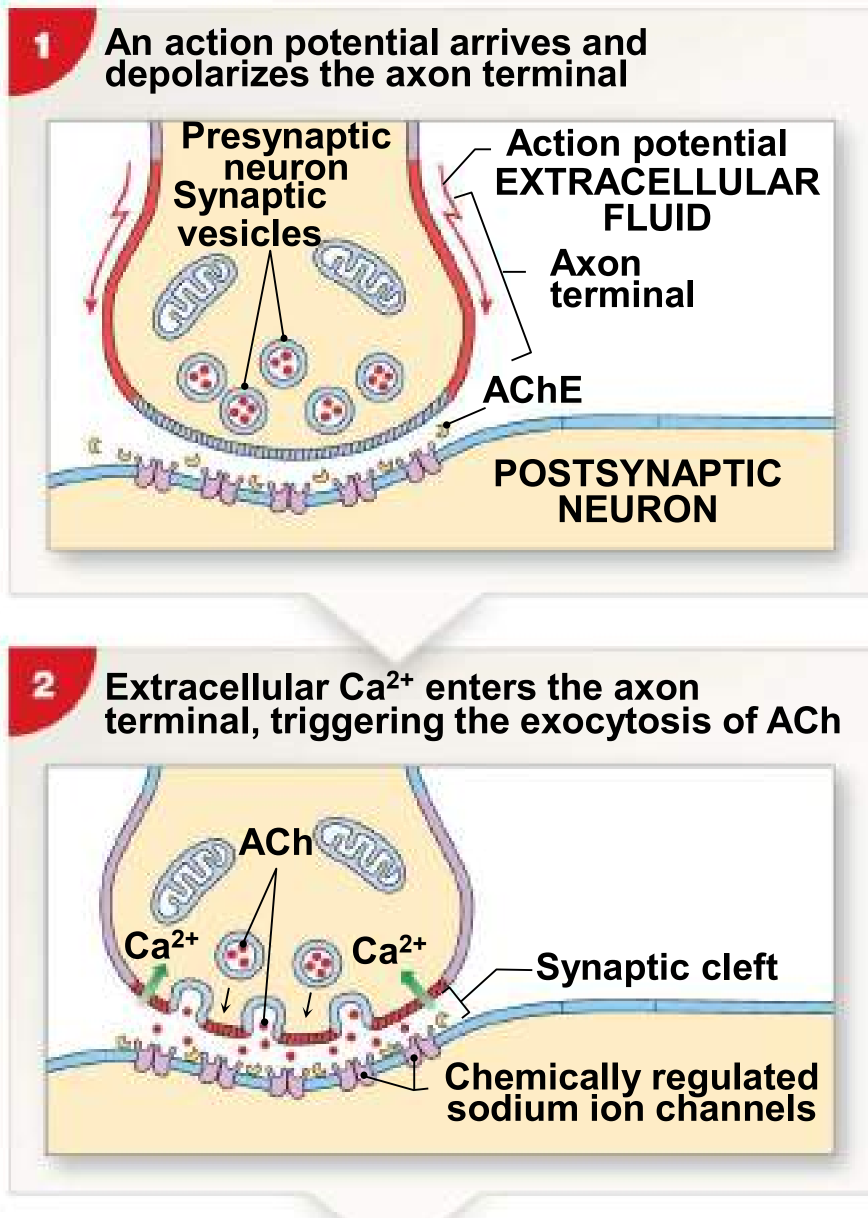


Figure 8-11 The Events at a Cholinergic Synapse.

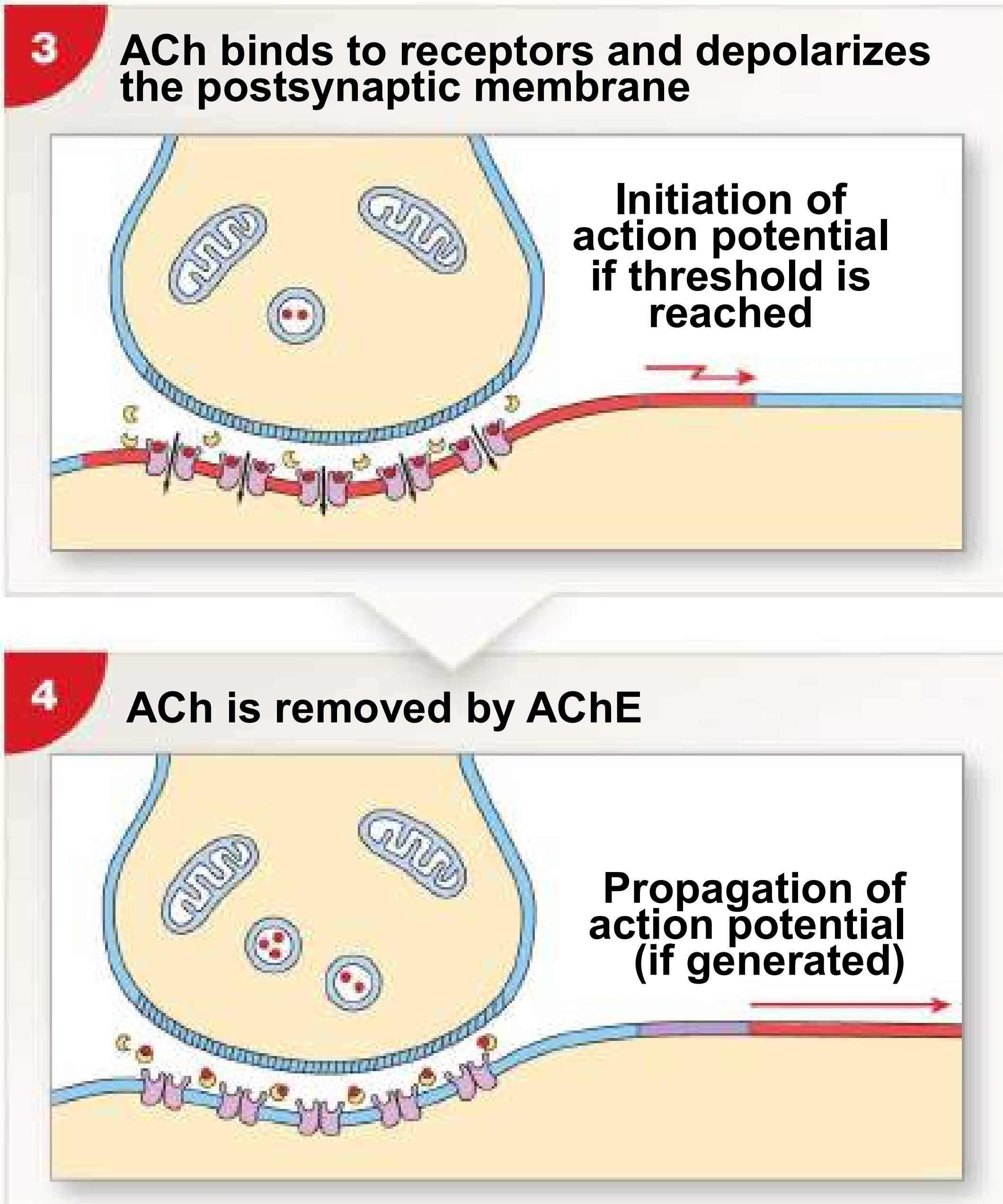


Table 8-1 The Sequence of Events at a Typical Cholinergic Synapse

Table 8-1 The Sequence of Events at a Typical Cholinergic Synapse

Step 1:

- An arriving action potential depolarizes the axon terminal and the presynaptic membrane.

Step 2:

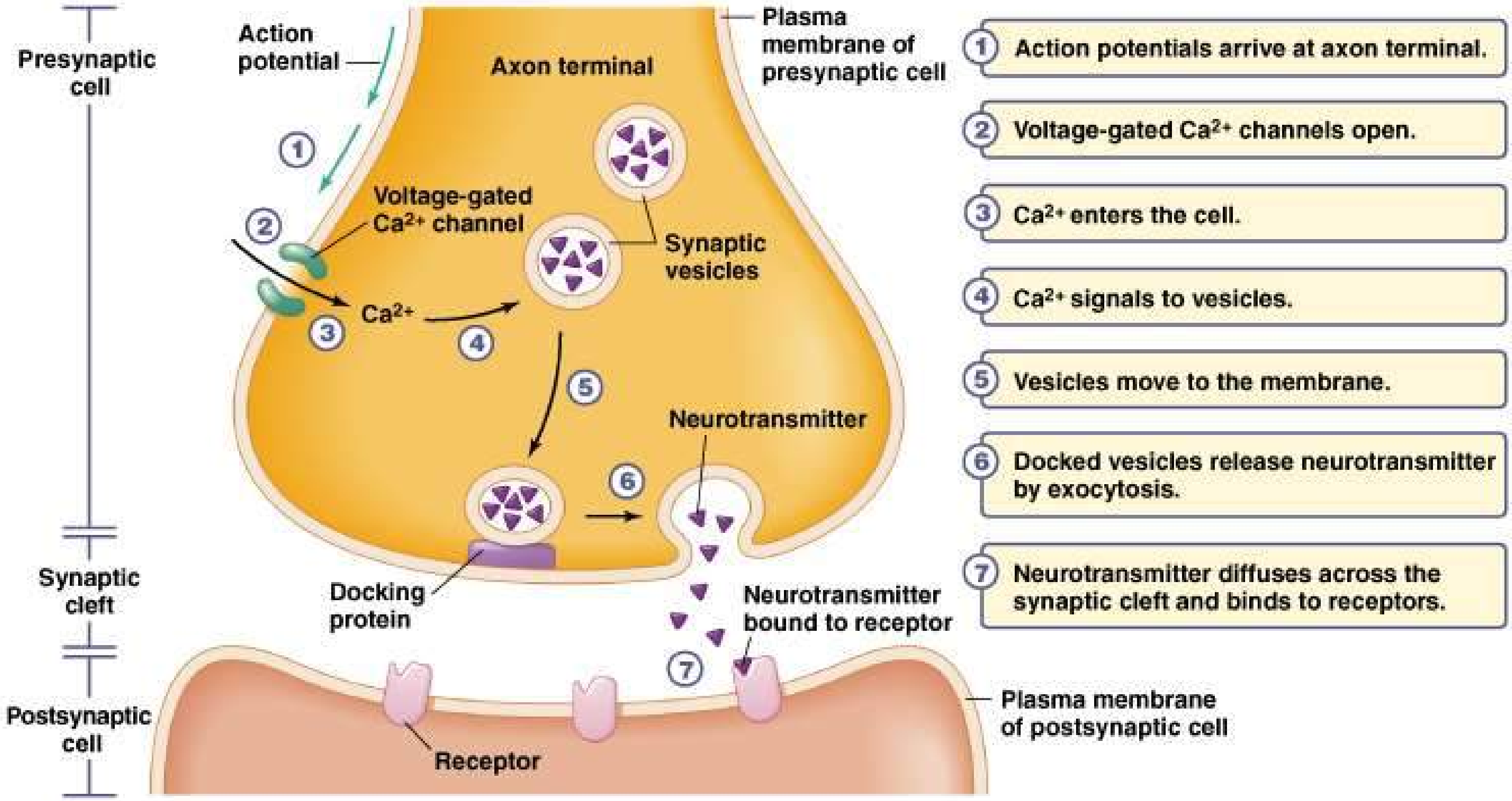
- Calcium ions enter the cytoplasm of the axon terminal.
- ACh release occurs through exocytosis of neurotransmitter vesicles.

Step 3:

- ACh diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane.
- Sodium channels on the postsynaptic surface are activated, producing a graded depolarization.
- ACh release stops because calcium ions are removed from the cytoplasm of the axon terminal.

Step 4:

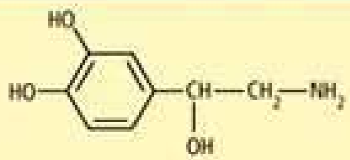
- The depolarization ends as ACh is broken down into acetate and choline by AChE.
- The axon terminal reabsorbs choline from the synaptic cleft and uses it to resynthesize ACh.


Presynaptic cell
Synaptic cleft
Postsynaptic cell
Action potential
Axon terminal
Plasma membrane of presynaptic cell
Voltage-gated Ca^{2+} channel
Synaptic vesicles
Ca^{2+}
Neurotransmitter
Docking protein
Neurotransmitter bound to receptor
Receptor
Plasma membrane of postsynaptic cell
1 Action potentials arrive at axon terminal.
2 Voltage-gated Ca^{2+} channels open.
3 Ca^{2+} enters the cell.
4 Ca^{2+} signals to vesicles.
5 Vesicles move to the membrane.
6 Docked vesicles release neurotransmitter by exocytosis.
7 Neurotransmitter diffuses across the synaptic cleft and binds to receptors.

Other Important Neurotransmitters (8-4)

- **Norepinephrine (NE)**
  - In the brain and part of the ANS, is found in **adrenergic** synapses
- **Dopamine**, **GABA**, and **serotonin**
  - Are CNS neurotransmitters
- At least 50 less-understood neurotransmitters
- **NO** and **CO**
  - Are gases that act as neurotransmitters

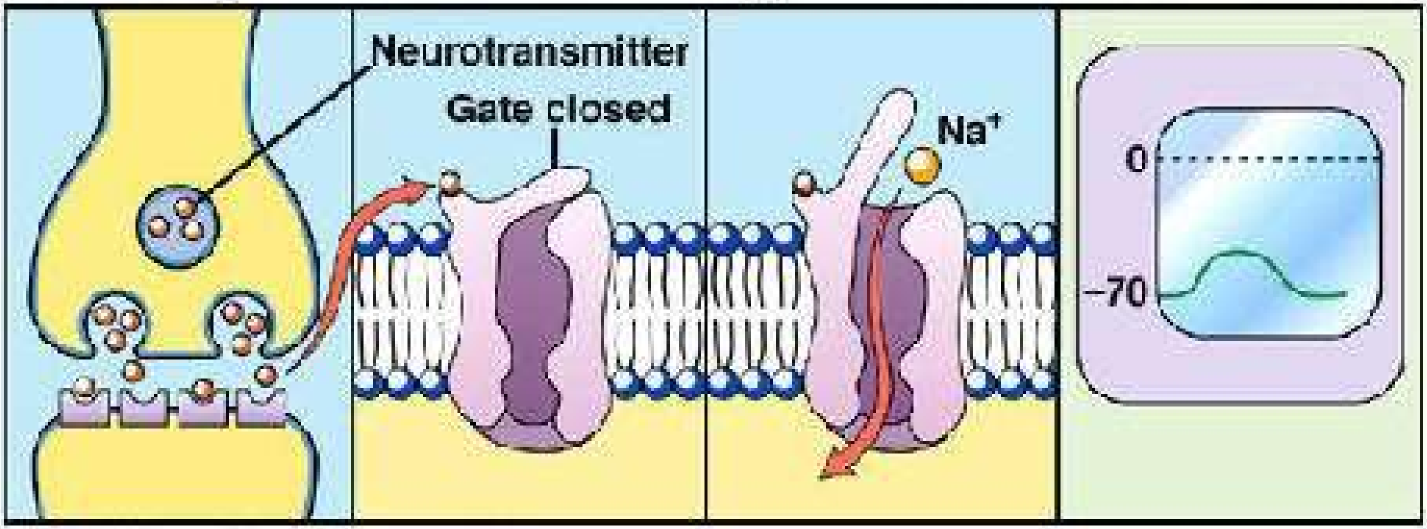
Table 48.1 Major Neurotransmitters

Neurotransmitter	Structure	Functional Class	Secretion Sites
Acetylcholine	$H_3C-\overset{O}{\overset{\parallel}{C}}-O-CH_2-CH_2-N^+-(CH_3)_3$	Excitatory to vertebrate skeletal muscles; excitatory or inhibitory at other sites	CNS; PNS; vertebrate neuromuscular junction
Biogenic Amines			
Norepinephrine		Excitatory or inhibitory	CNS; PNS
Dopamine		Generally excitatory; may be inhibitory at some sites	CNS; PNS
Serotonin		Generally inhibitory	CNS
Amino Acids			
GABA (gamma aminobutyric acid)	$H_2N-CH_2-CH_2-CH_2-COOH$	Inhibitory	CNS; invertebrate neuromuscular junction
Glycine	H_2N-CH_2-COOH	Inhibitory	CNS
Glutamate	$H_2N-\underset{COOH}{\underset{\mid}{CH}}-CH_2-CH_2-COOH$	Excitatory	CNS; invertebrate neuromuscular junction
Aspartate	$H_2N-\underset{COOH}{\underset{\mid}{CH}}-CH_2-COOH$	Excitatory	CNS
Neuropeptides (a very diverse group, only two of which are shown)			
Substance P	Arg—Pro—Lys—Pro—Gln—Gln—Phe—Phe—Gly—Leu—Met	Excitatory	CNS; PNS
Met-enkephalin (an endorphin)	Tyr—Gly—Gly—Phe—Met	Generally inhibitory	CNS

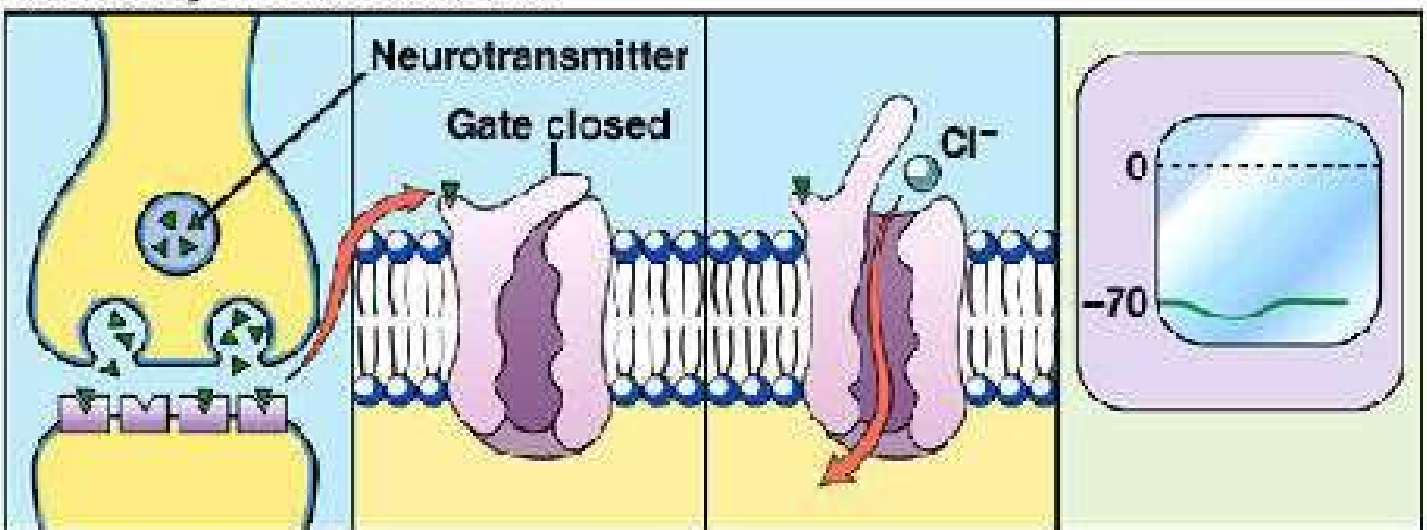
Excitatory vs. Inhibitory Synapses (8-4)

- Usually, ACh and NE trigger depolarization
  - An excitatory response
  - With the potential of reaching threshold
- Usually, dopamine, GABA, and serotonin trigger hyperpolarization
  - An inhibitory response
  - Making it farther from threshold

Excitatory and Inhibitory Neurotransmitters



Excitatory Neurotransmitter



Inhibitory Neurotransmitter

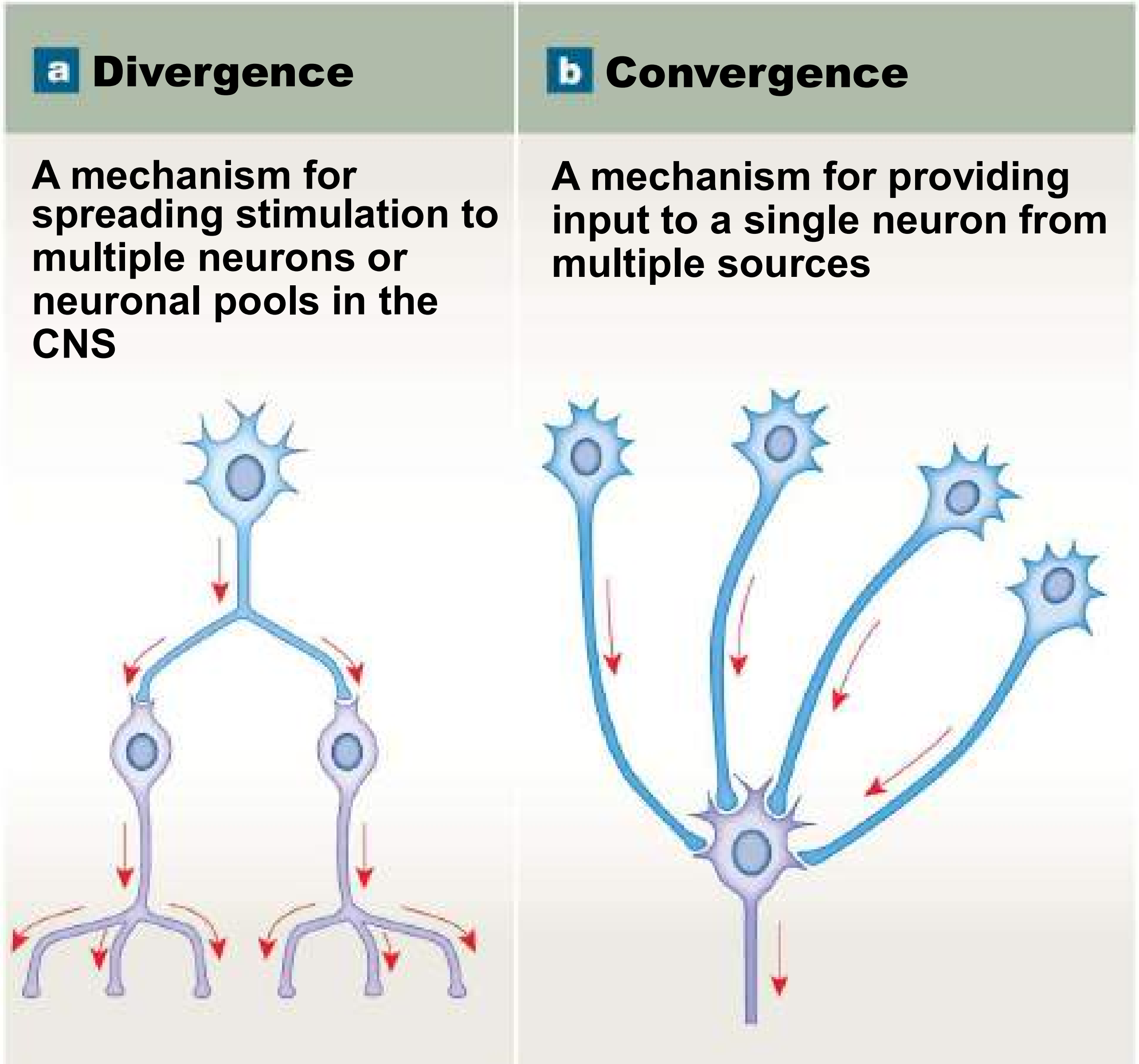
Neuronal Pools (8-4)

- Multiple presynaptic neurons can synapse with one postsynaptic neuron
  - If they all release excitatory neurotransmitters:
    - Then an action potential can be triggered
  - If they all release an inhibitory neurotransmitter:
    - Then no action potential can occur
  - If half release excitatory and half inhibitory neurotransmitters:
    - They cancel, resulting in no action

Neuronal Pools (8-4)

- A term that describes the complex grouping of neural pathways or circuits
- **Divergence**
  - Is a pathway that spreads information from one neuron to multiple neurons
- **Convergence**
  - Is when several neurons synapse with a single postsynaptic neuron

Figure 8-12 Two Common Types of Neuronal Pools.



The Meninges (8-5)

- The neural tissue in the CNS is protected by three layers of specialized membranes

1. **Dura mater**
2. **Arachnoid**
3. **Pia mater**

The Dura Mater (8-5)

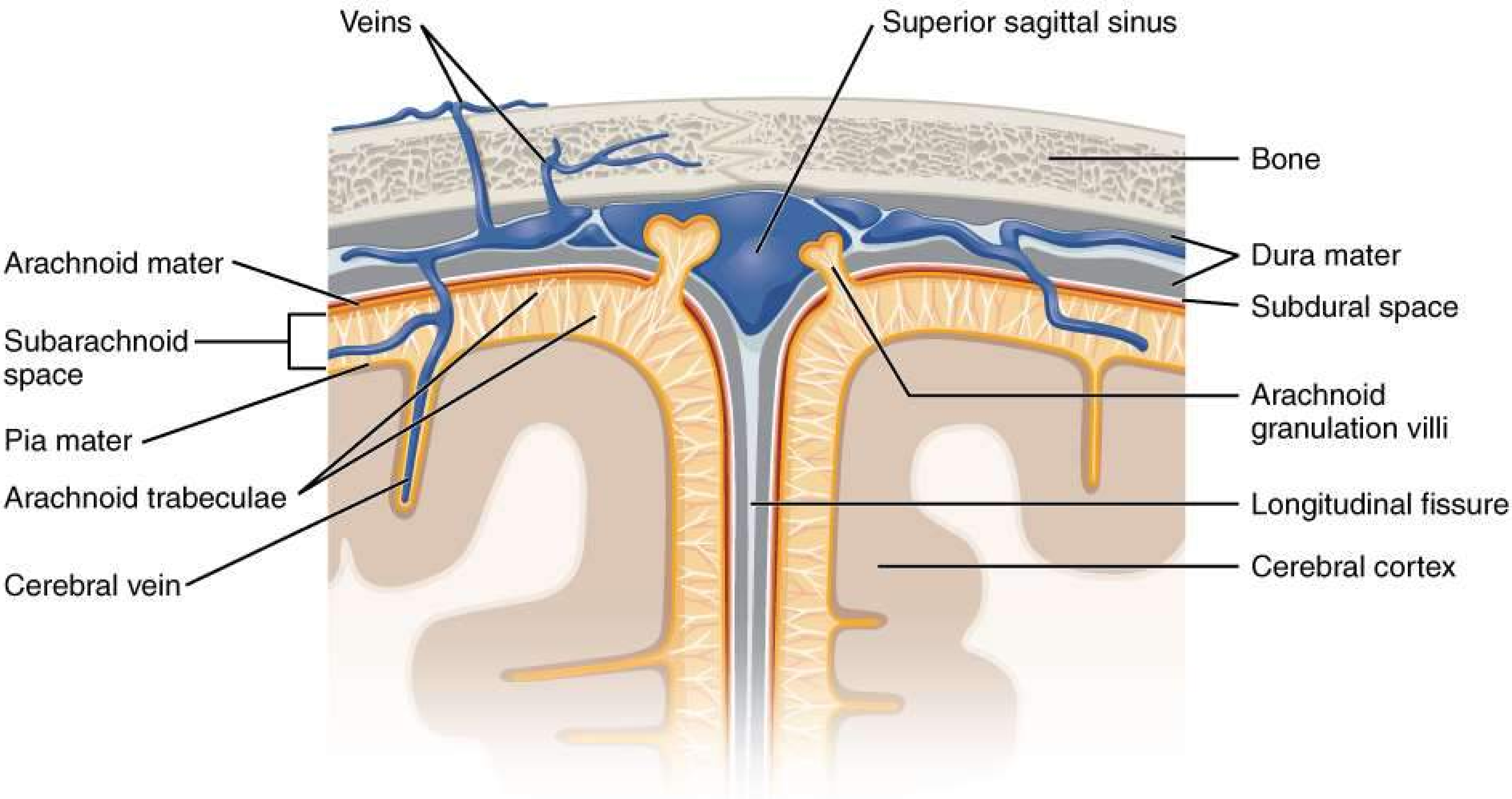
- Is the outer, very tough covering
  - The dura mater has two layers, with the outer layer fused to the periosteum of the skull
  - *Dural folds* contain large veins, the *dural sinuses*
  - In the spinal cord the dura mater is separated from the bone by the **epidural space**

The Arachnoid

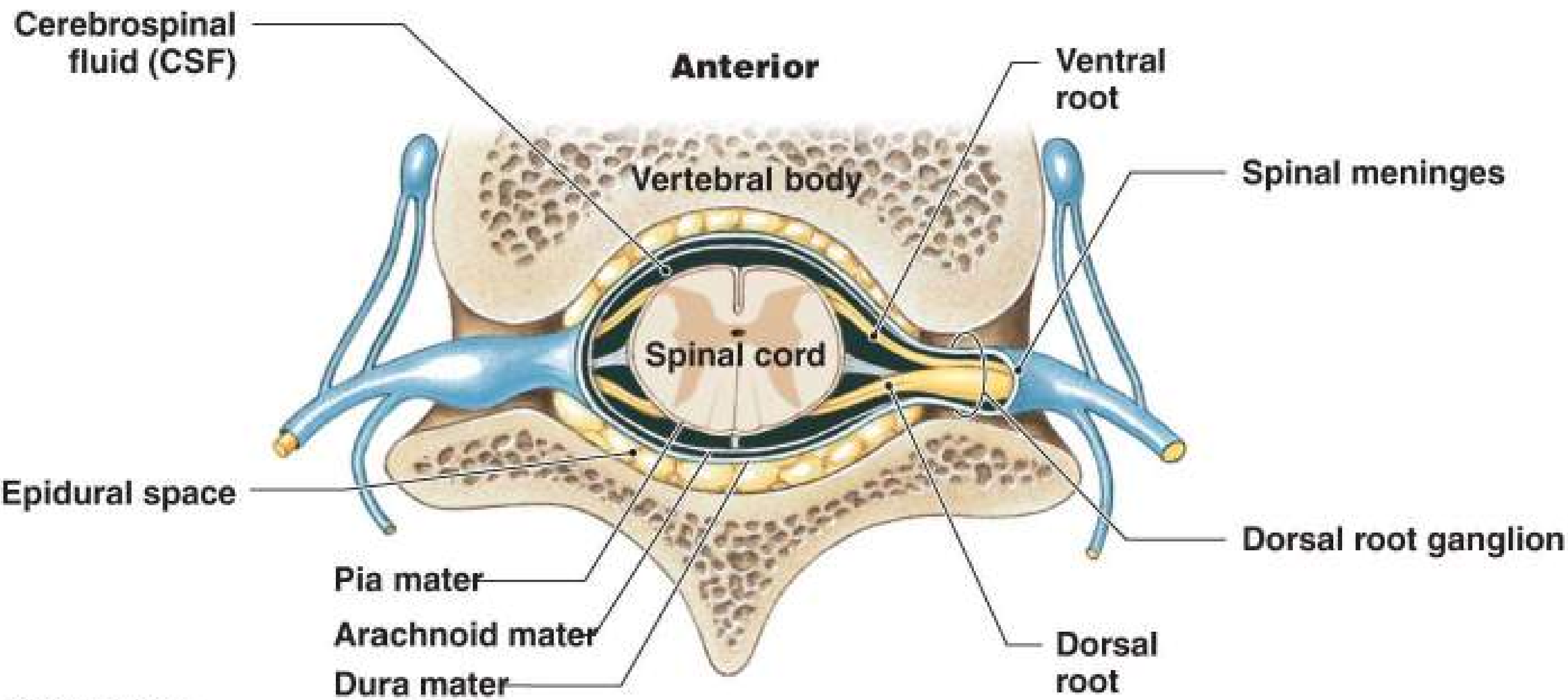
- Is separated from the dura mater by the **subdural space**
  - That contains a little lymphatic fluid
- Below the epithelial layer is **arachnoid space**
  - Created by a web of collagen fibers
  - Contains cerebrospinal fluid

The Pia Mater

- Is the innermost layer
  - Firmly bound to the neural tissue underneath
  - Highly vascularized
    - Providing needed oxygen and nutrients


Veins
Superior sagittal sinus
Bone
Arachnoid mater
Dura mater
Subdural space
Subarachnoid space
Pia mater
Arachnoid granulation villi
Arachnoid trabeculae
Longitudinal fissure
Cerebral cortex
Cerebral vein

A cross-sectional view showing the structures surrounding the spinal cord and the spaces between the meningeal layers



Spinal Cord Structure (8-6)

- The major neural pathway between the brain and the PNS
- Can also act as an integrator in the spinal reflexes
  - Involving the 31 pairs of spinal nerves
- Consistent in diameter except for the cervical enlargement and lumbar enlargement
  - Where numerous nerves supply upper and lower limbs

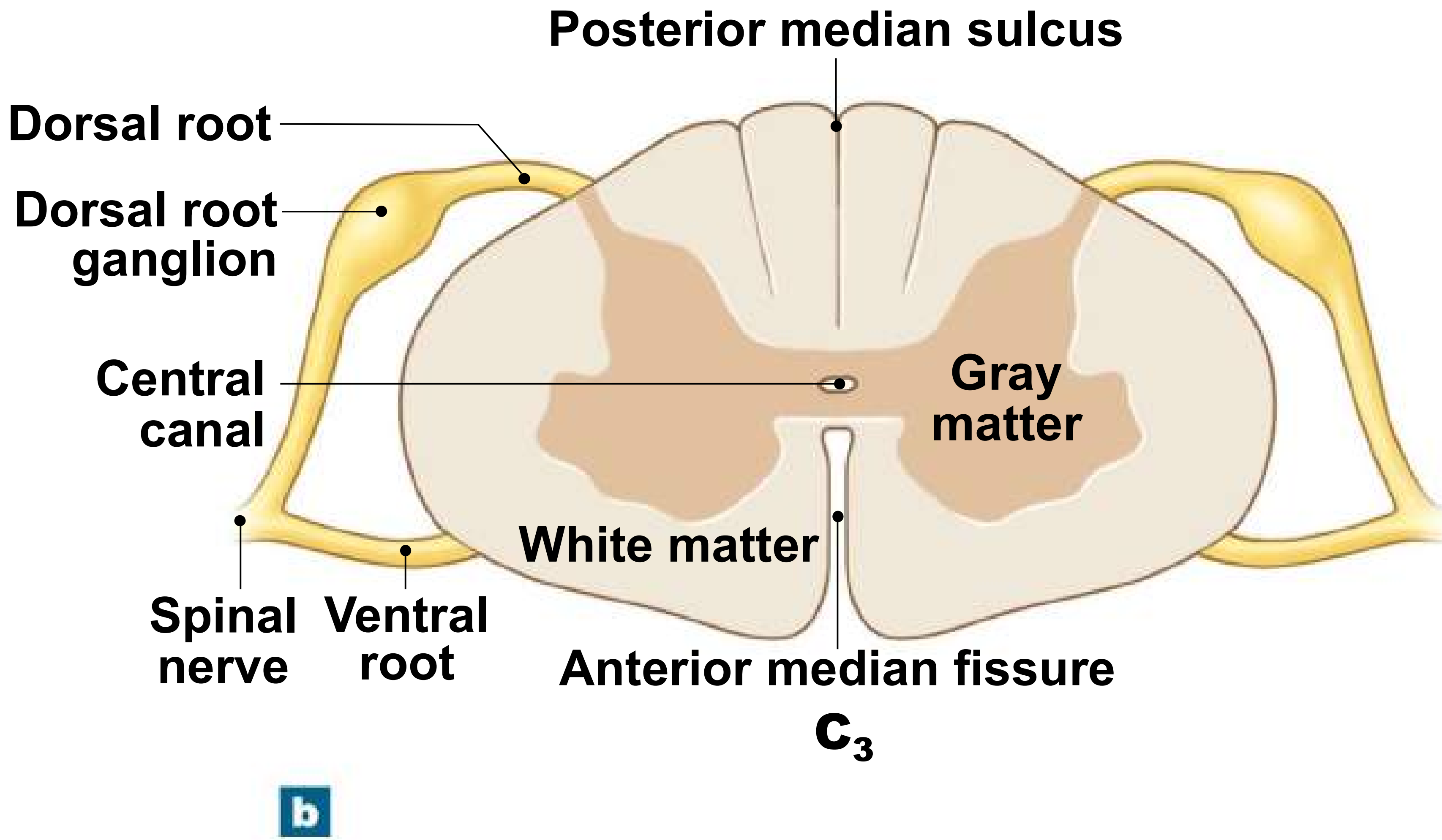
Spinal Cord Structure (8-6)

- **Central canal**
  - A narrow passage containing cerebrospinal fluid
- Surface of the spinal cord is indented by the:
  - *Posterior median sulcus*
  - Deeper *anterior median fissure*

31 Spinal Segments (8-6)

- Identified by a letter and number relating to the nearby vertebrae
- Each has a pair of **dorsal root ganglia**
  - Containing the cell bodies of sensory neurons with axons in **dorsal root**
- **Ventral roots** contain motor neuron axons
  - Roots are contained in one **spinal nerve**

Figure 8-14b Gross Anatomy of the Spinal Cord.

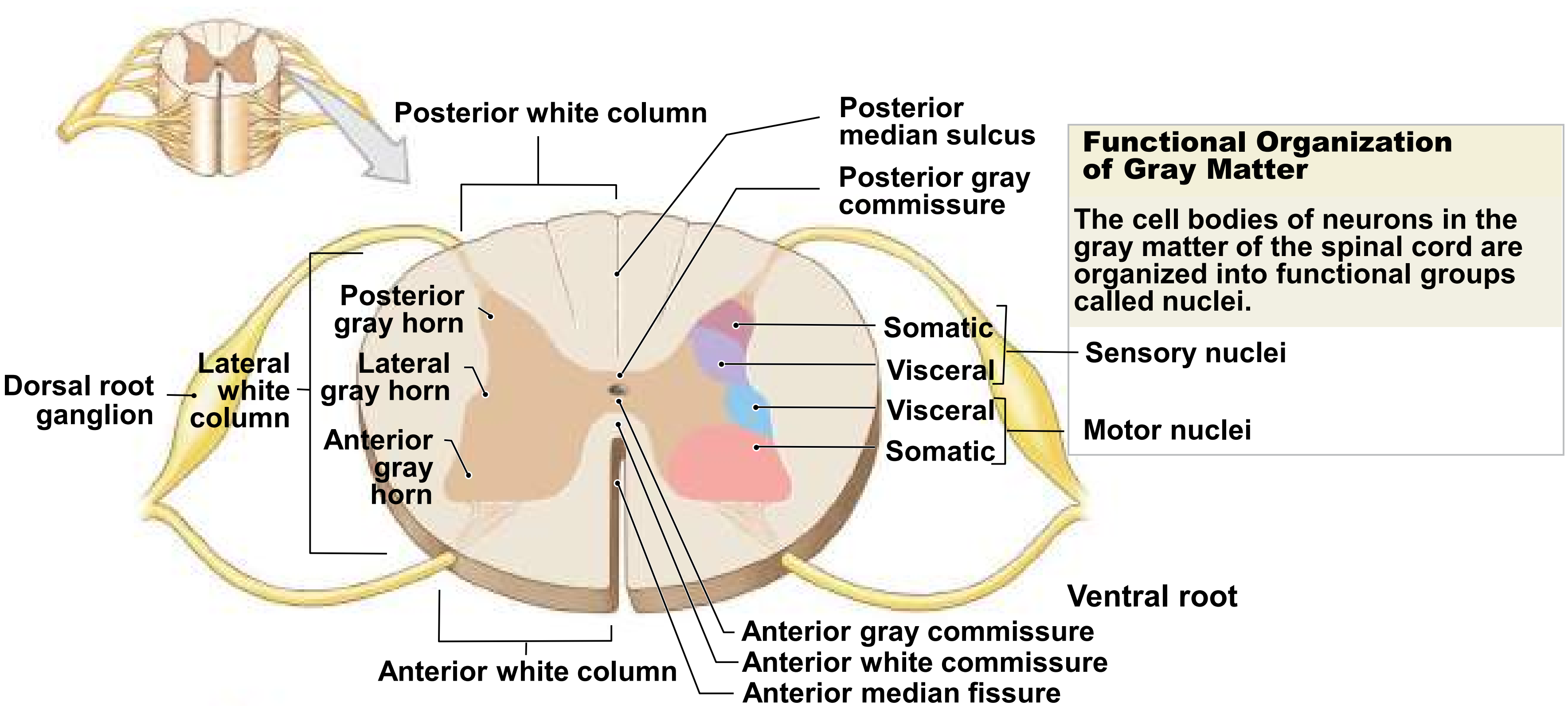


This cross section through the cervical region of the spinal cord shows some prominent features and the arrangement of gray matter and white matter.

Sectional Anatomy of the Spinal Cord (8-6)

- The central *gray matter* is made up of glial cells and nerve cell bodies
- Projections of gray matter are called **horns**
  - Which extend out into the *white matter*
- White matter is myelinated and unmyelinated axons
- The location of cell bodies in specific nuclei of the gray matter relate to their function

Figure 8-15a Sectional Anatomy of the Spinal Cord.

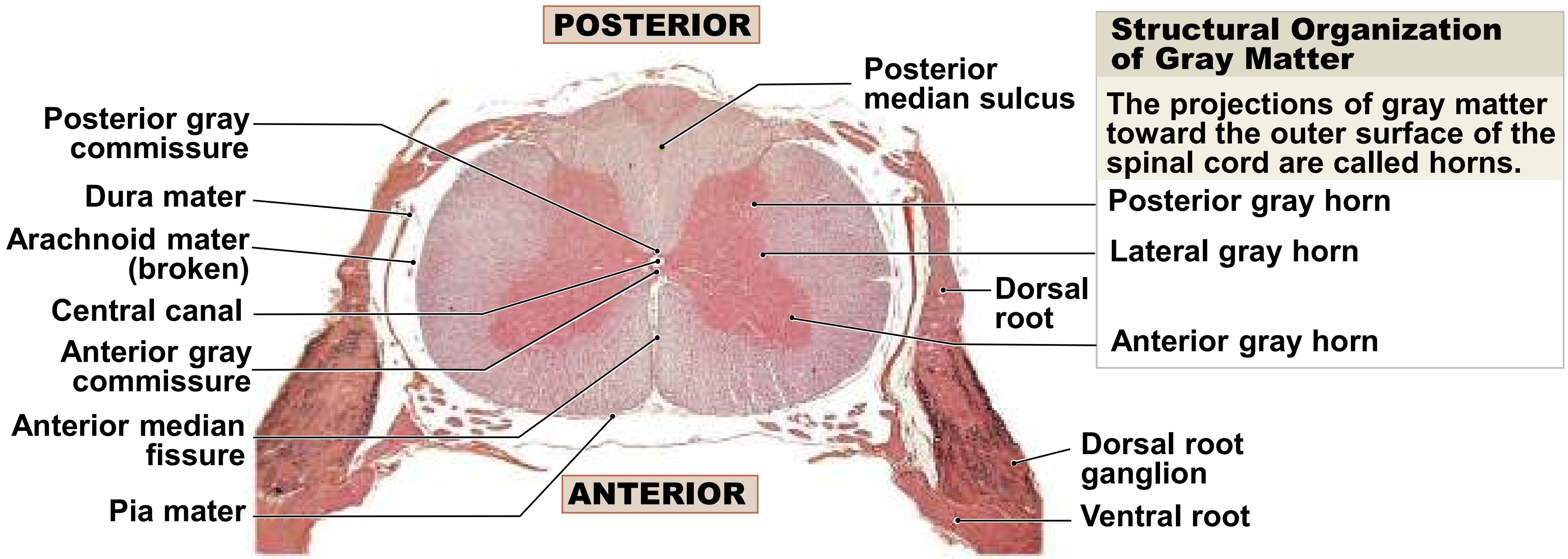


Functional Organization of Gray Matter

The cell bodies of neurons in the gray matter of the spinal cord are organized into functional groups called nuclei.

a The left half of this sectional view shows important anatomical landmarks, including the three columns of white matter. The right half indicates the functional organization of the nuclei in the anterior, lateral, and posterior gray horns.

Figure 8-15b Sectional Anatomy of the Spinal Cord.



b A micrograph of a section through the spinal cord, showing major landmarks in and surrounding the cord.

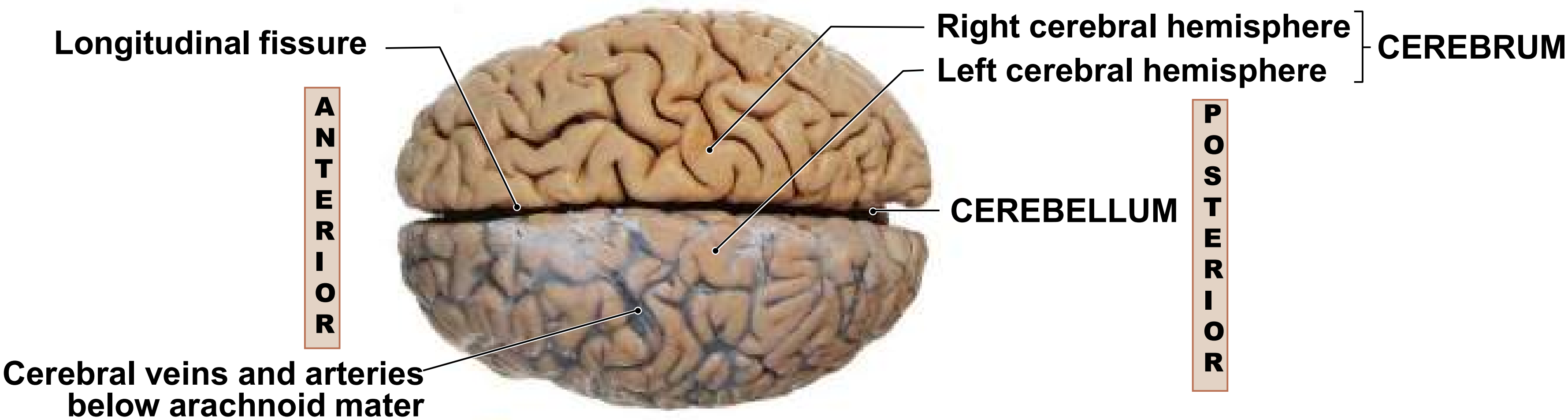
Six Major Regions of the Brain (8-7)

1. The *cerebrum*
2. The *diencephalon*
3. The *midbrain*
4. The *pons*
5. The *medulla oblongata*
6. The *cerebellum*

Major Structures of the Brain (8-7)

- The **cerebrum**
  - Is divided into paired **cerebral hemispheres**
- Deep to the cerebrum is the **diencephalon**
  - Which is divided into the **thalamus,** the **hypothalamus,** and the **epithalamus**
- The **brain stem**
  - Contains the **midbrain, pons,** and **medulla oblongata**
- The **cerebellum**
  - Is the most inferior/posterior part

Figure 8-16a The Brain.



a Superior view

Figure 8-16b The Brain.

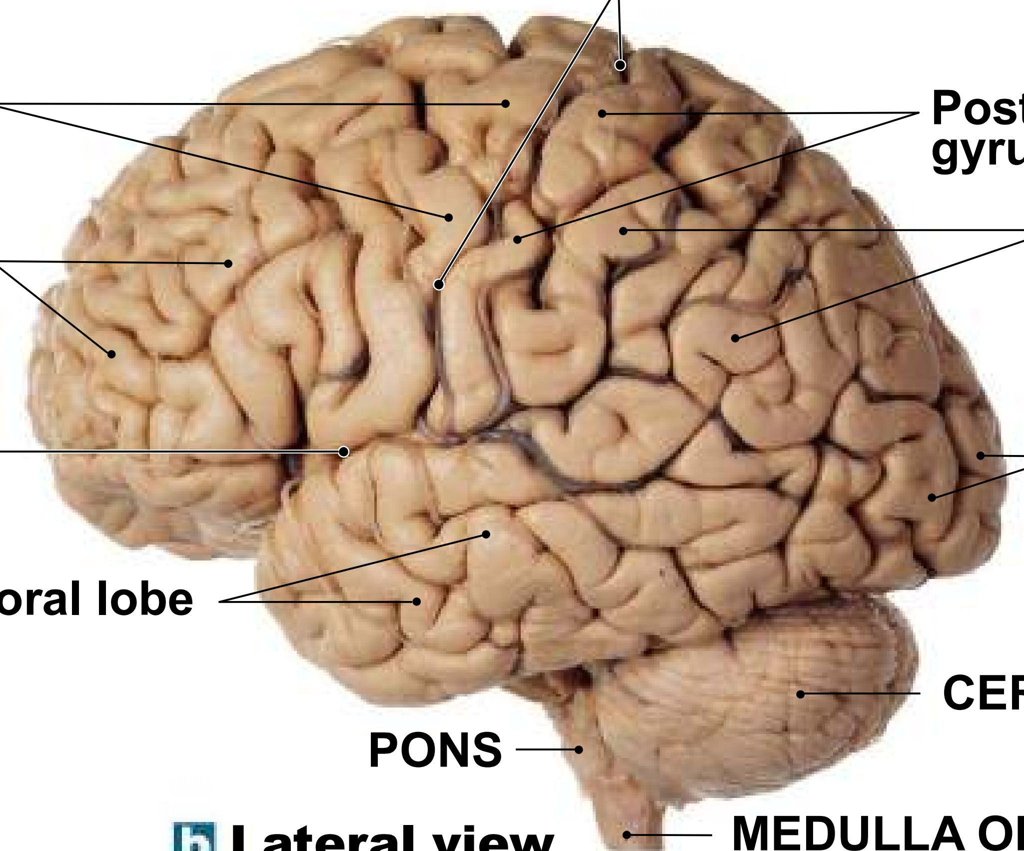
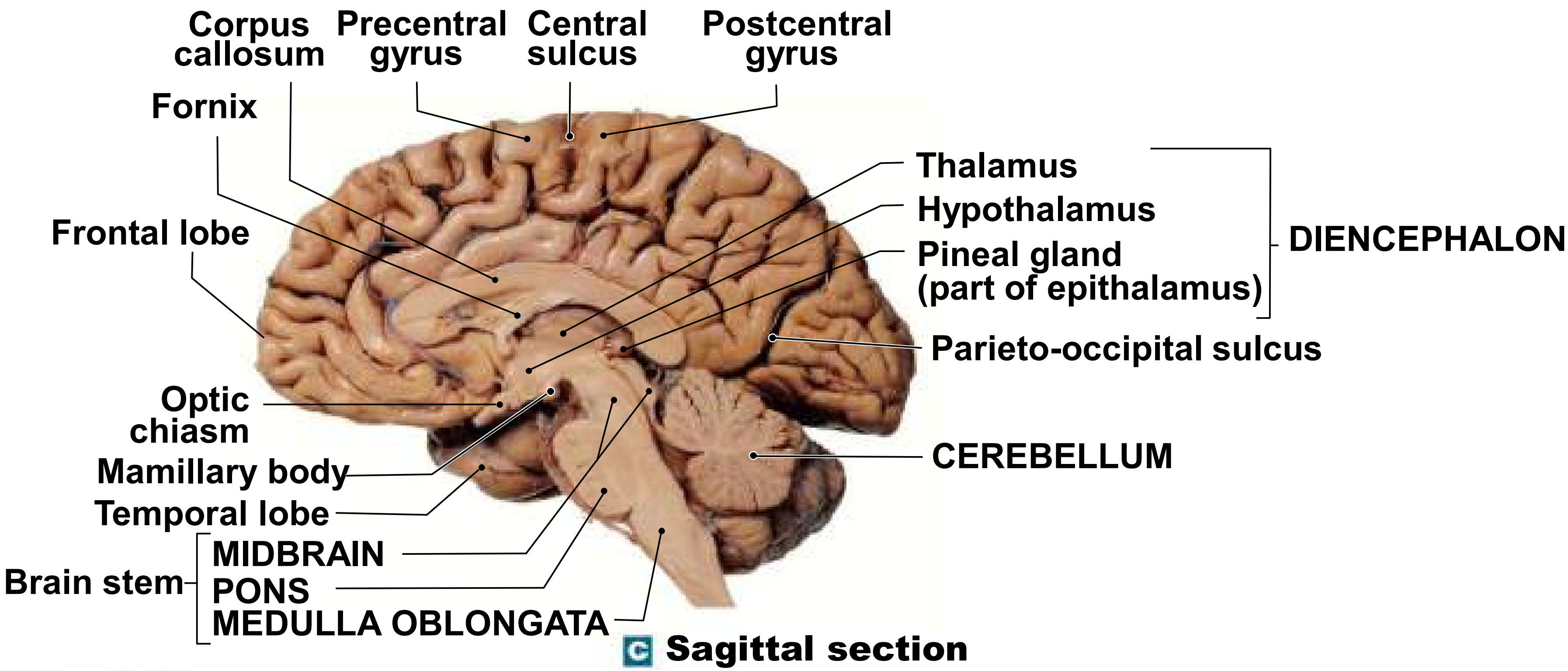
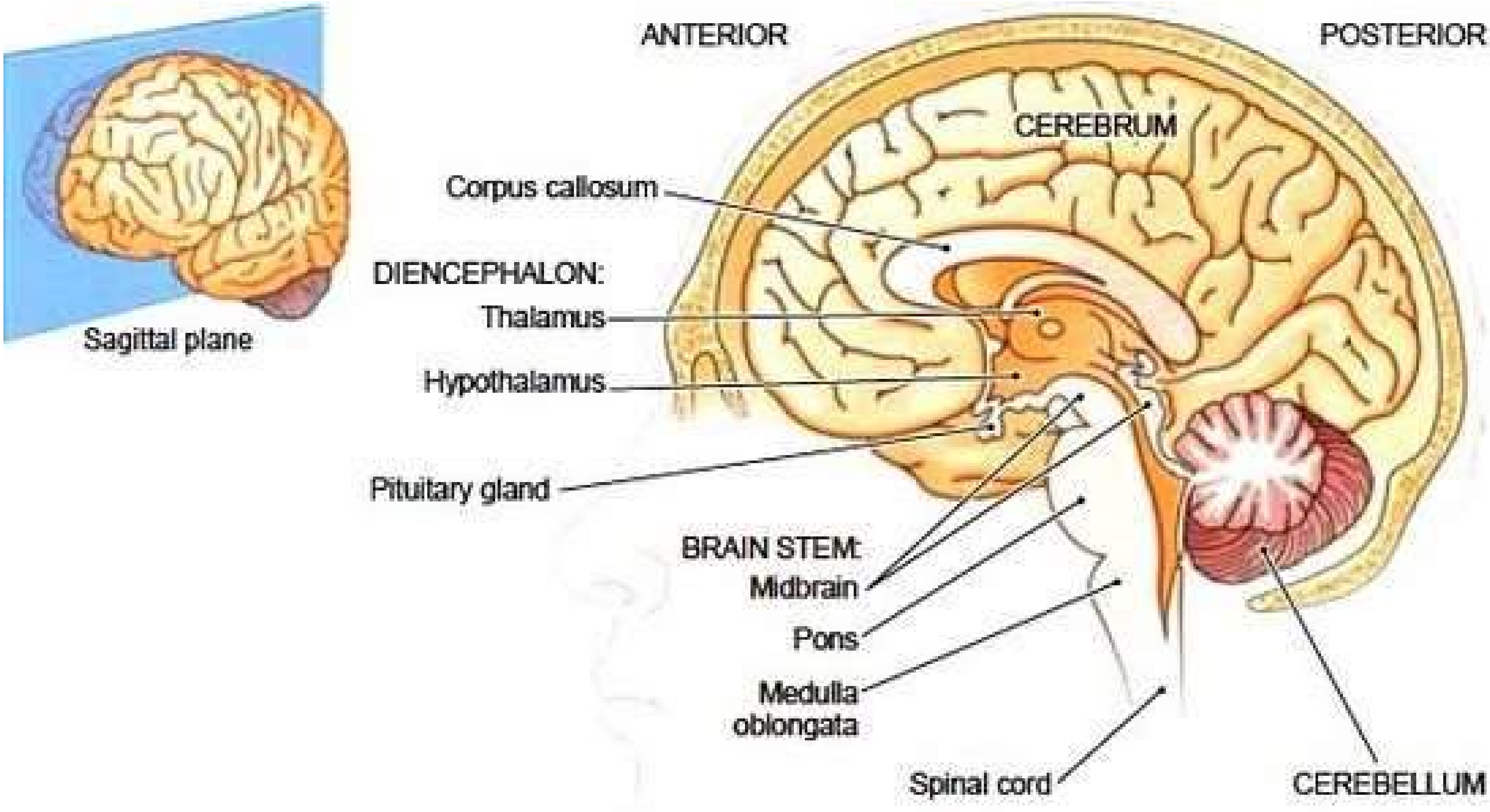


Figure 8-16c The Brain.



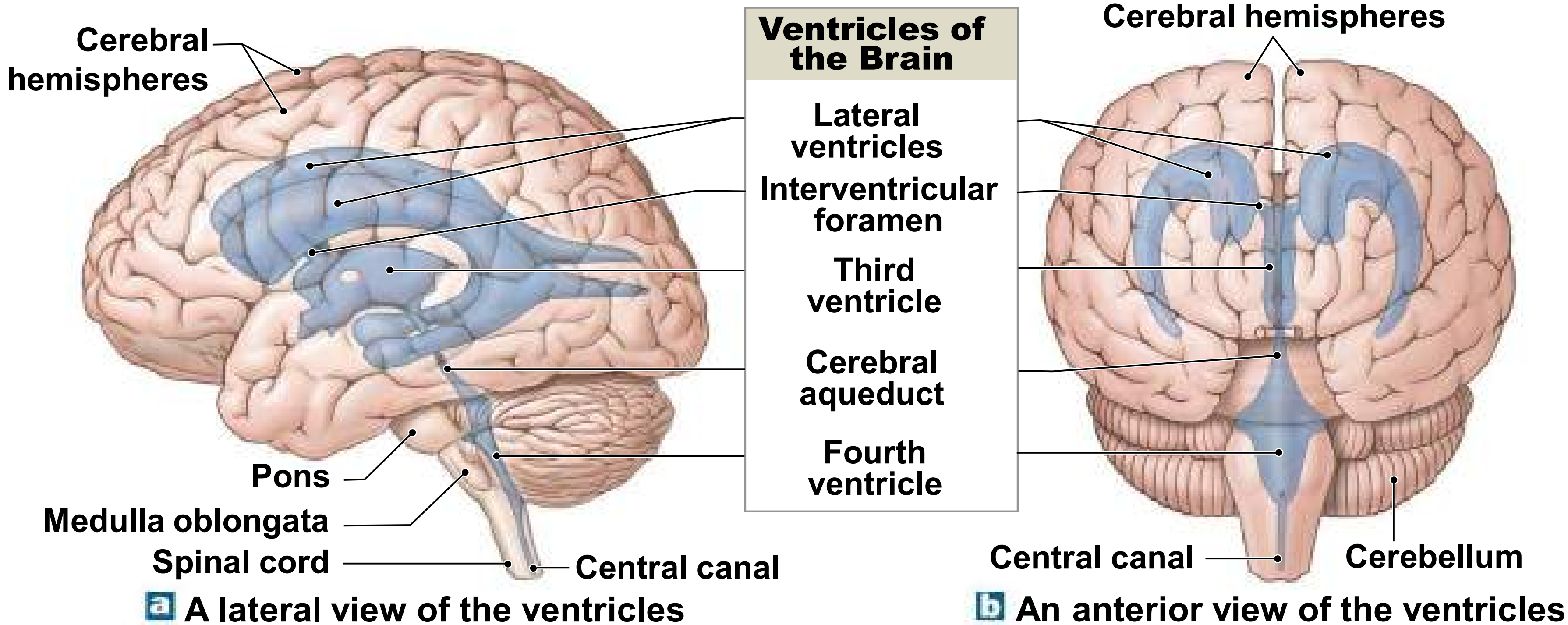


www.pinirest.com.

The Ventricles of the Brain (8-7)

- Filled with cerebrospinal fluid and lined with ependymal cells
  - The two **lateral ventricles** within each cerebral hemisphere drain through the:
  - *Interventricular foramen* into the:
  - **Third ventricle** in the diencephalon, which drains through the *cerebral aqueduct* into the:
  - **Fourth ventricle,** which drains into the central canal

Figure 8-17 The Ventricles of the Brain.



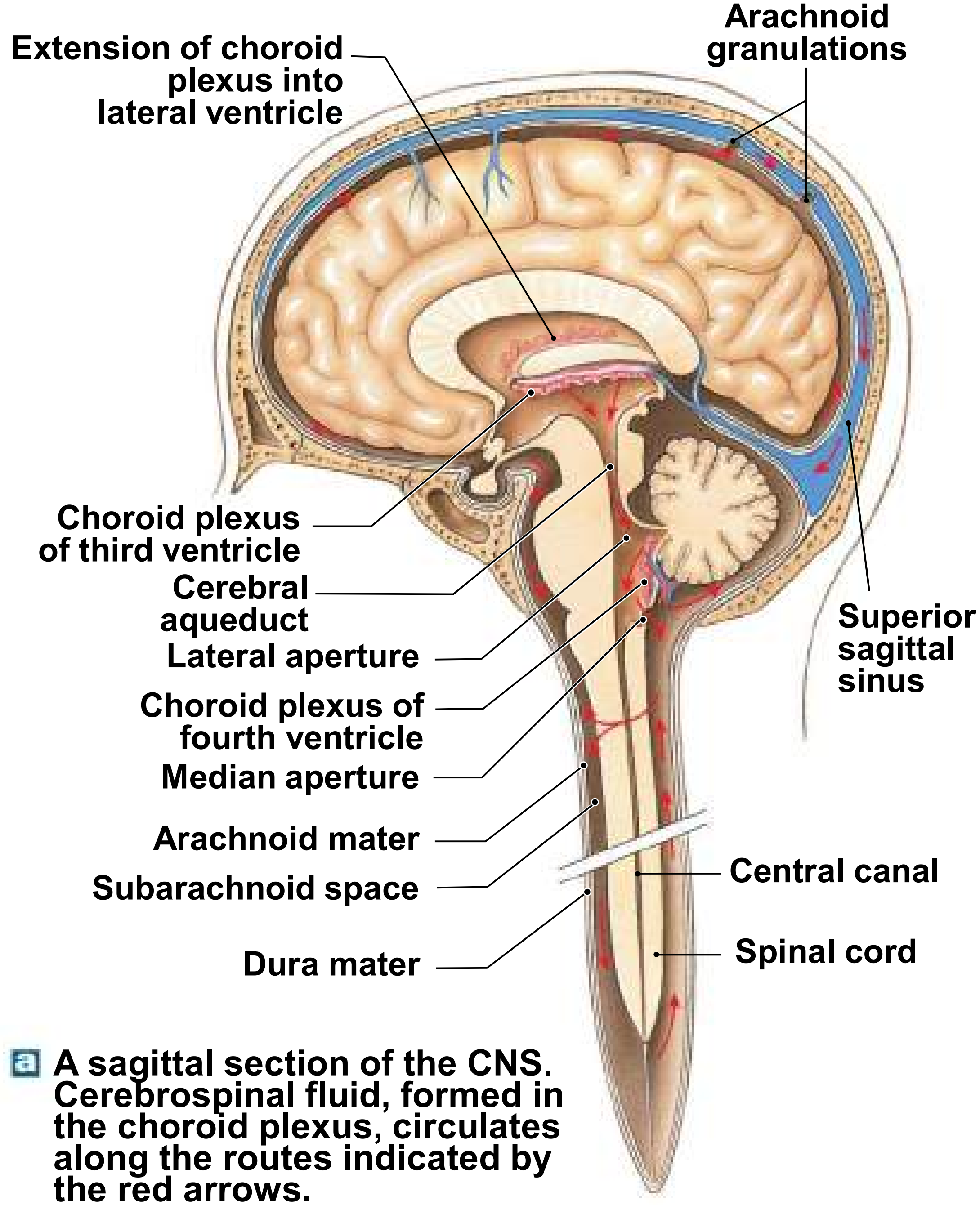
a A lateral view of the ventricles

b An anterior view of the ventricles

Cerebrospinal Fluid (8-7)

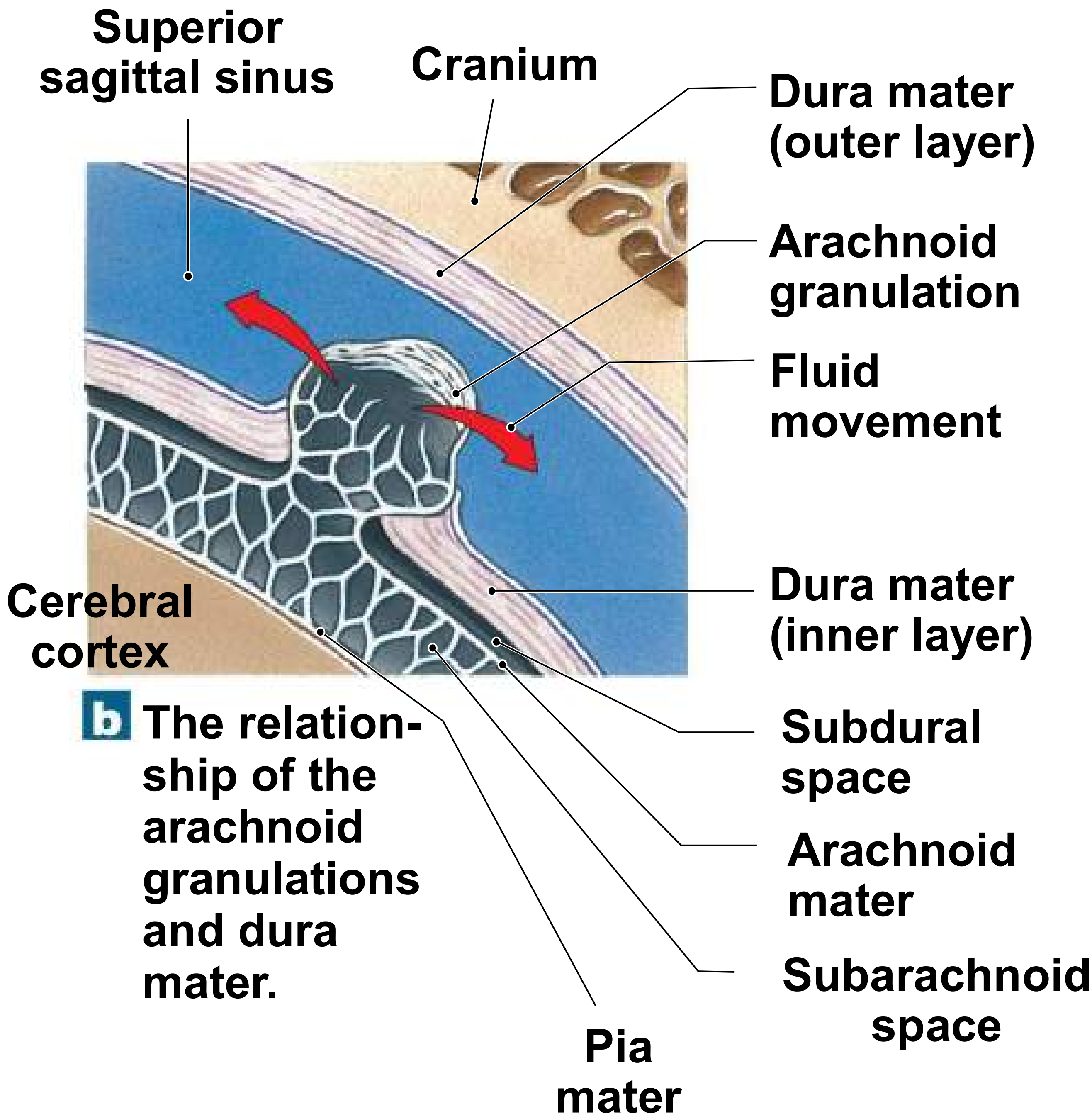
- CSF
  - Surrounds and bathes the exposed surfaces of the CNS
  - Floats the brain
  - Transports nutrients, chemicals, and wastes
  - Is produced by the **choroid plexus**
  - Continually secreted and replaced three times per day
  - Circulation from the fourth ventricle into the subarachnoid space into the dural sinuses

Figure 8-18a The Formation and Circulation of Cerebrospinal Fluid.



a A sagittal section of the CNS. Cerebrospinal fluid, formed in the choroid plexus, circulates along the routes indicated by the red arrows.

Figure 8-18b The Formation and Circulation of Cerebrospinal Fluid.



b The relationship of the arachnoid granulations and dura mater.

The Cerebrum (8-7)

- Contains an outer gray matter called the **cerebral cortex**
  - Deep gray matter in the cerebral nuclei and white matter of myelinated axons beneath the cortex and around the nuclei
- The surface of the cerebrum
  - Folds into **gyri**
  - Separated by depressions called **sulci** or deeper grooves called **fissures**

The Cerebral Hemispheres (8-7)

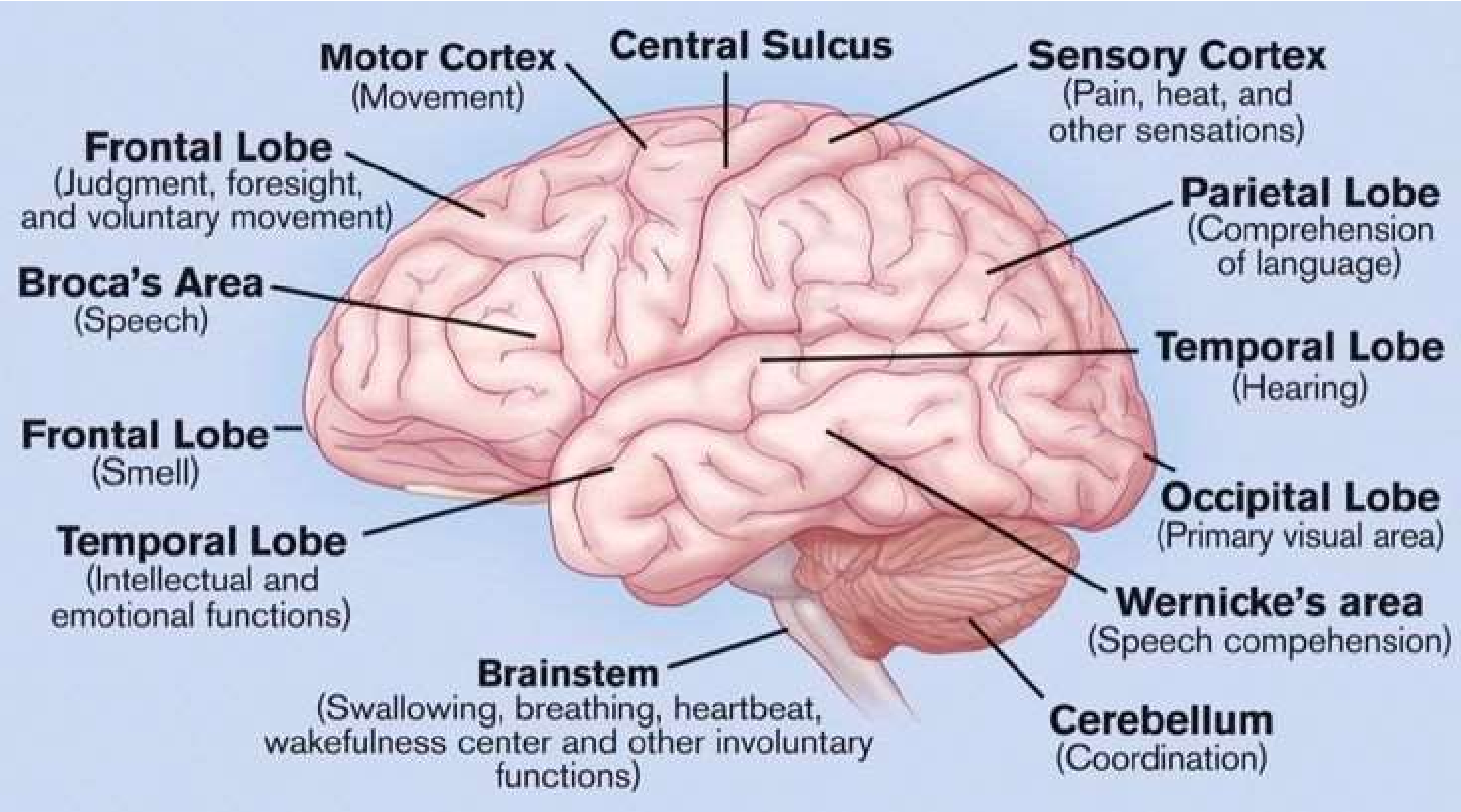
- Are separated by the **longitudinal fissure**
- The **central sulcus**
  - Extends laterally from the longitudinal fissure
- The **frontal lobe**
  - Is anterior to the central sulcus
  - Is bordered inferiorly by the **lateral sulcus**

The Cerebral Hemispheres (8-7)

- The **temporal lobe**
  - Inferior to the lateral sulcus
  - Overlaps the **insula**
- The **parietal lobe**
  - Extends between the central sulcus and the **parieto-occipital sulcus**

The Cerebral Hemispheres (8-7)

- The **occipital lobe**
  - Located most posteriorly
- The lobes are named for the cranial bone above it
- Each lobe has sensory regions and motor regions
- Each hemisphere sends and receives information from the opposite side of the body



Motor Cortex
(Movement)
Central Sulcus
Sensory Cortex
(Pain, heat, and other sensations)
Frontal Lobe
(Judgment, foresight, and voluntary movement)
Parietal Lobe
(Comprehension of language)
Broca's Area
(Speech)
Temporal Lobe
(Hearing)
Frontal Lobe
(Smell)
Occipital Lobe
(Primary visual area)
Temporal Lobe
(Intellectual and emotional functions)
Wernicke's area
(Speech compehension)
Brainstem
(Swallowing, breathing, heartbeat, wakefulness center and other involuntary functions)
Cerebellum
(Coordination)

Motor and Sensory Areas of the Cortex (8-7)

- Are divided by the central sulcus
- The **precentral gyrus** of the frontal lobe
  - Contains the **primary motor cortex**
- The **postcentral gyrus** of the parietal lobe
  - Contains the **primary sensory cortex**

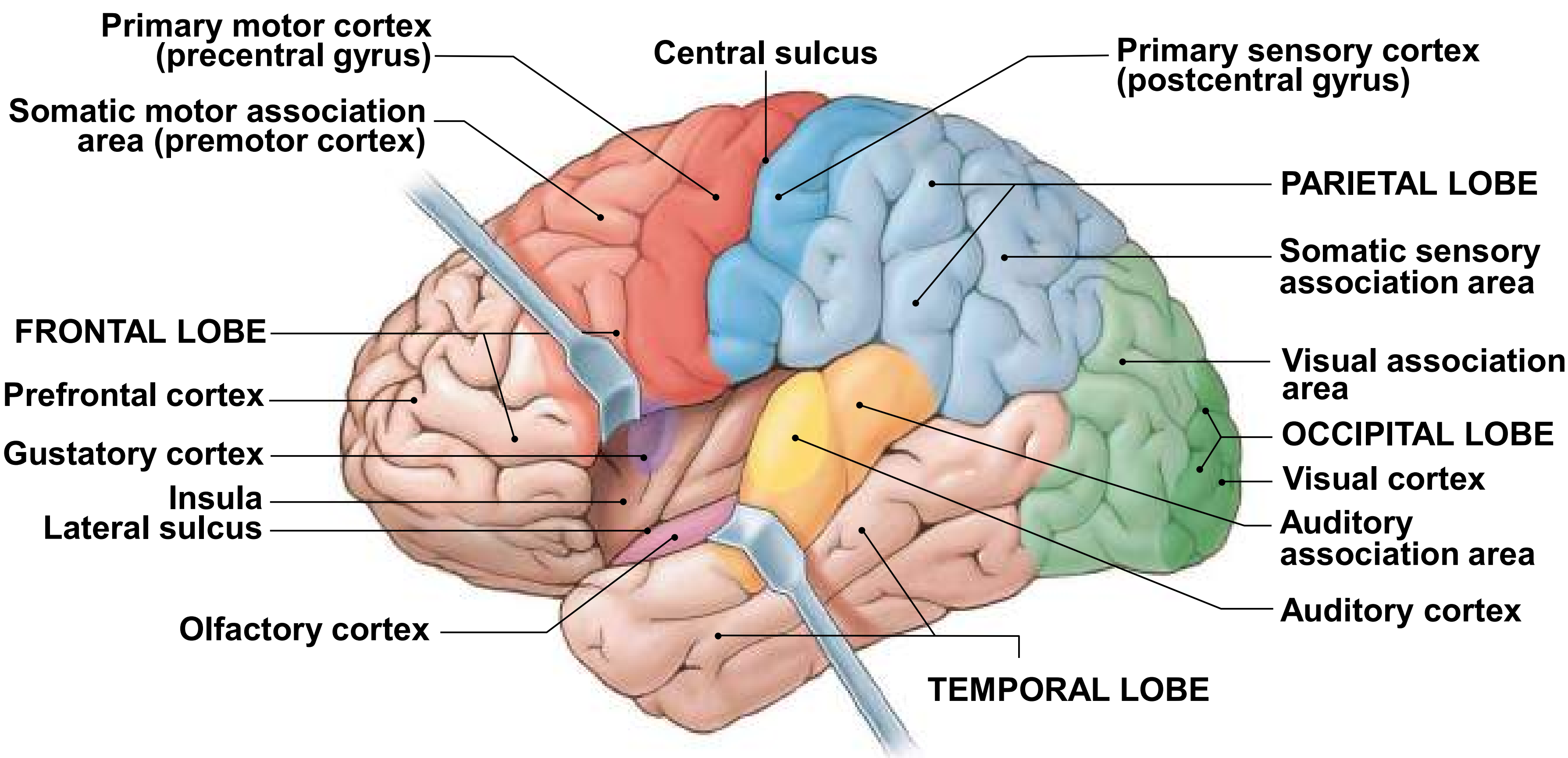
Motor and Sensory Areas of Cortex (8-7)

- The **visual cortex** is in the occipital lobe
- The **gustatory, auditory,** and **olfactory** cortexes are in the temporal lobe

Association Areas (8-7)

- Interpret incoming information
- Coordinate a motor response, integrating the sensory and motor cortexes
- The **somatic sensory association area**
  - Helps to recognize touch
- The **somatic motor association area**
  - Is responsible for coordinating movement

Figure 8-19 The Surface of the Cerebral Hemispheres.



Cortical Connections (8-7)

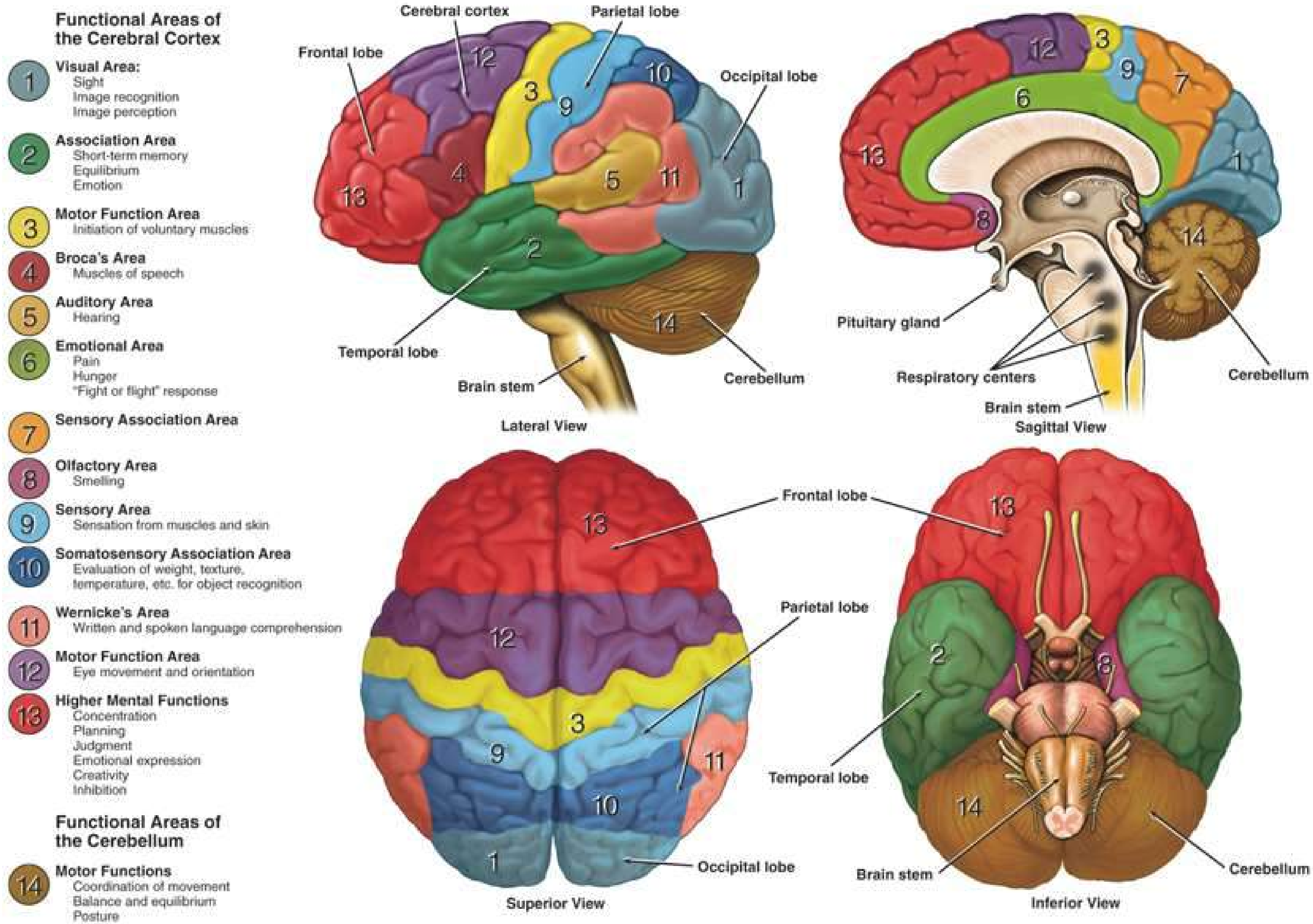
- Regions of the cortex are linked by the deeper white matter
- The left and right hemispheres are linked across the **corpus callosum**
- Other axons link the cortex with:
  - The diencephalon, brain stem, cerebellum, and spinal cord

Higher-Order Centers (8-7)

- Integrative areas, usually only in the left hemisphere
- The **general interpretive area** or *Wernicke's area*
  - Integrates sensory information to form visual and auditory memory
- The **speech center** or *Broca's area*
  - Regulates breathing and vocalization, the motor skills needed for speaking

The Prefrontal Cortex (8-7)

- In the frontal lobe
- Coordinates information from the entire cortex
  - Skills such as:
    - Predicting time lines
    - Making judgments
  - Feelings such as:
    - Frustration, tension, and anxiety

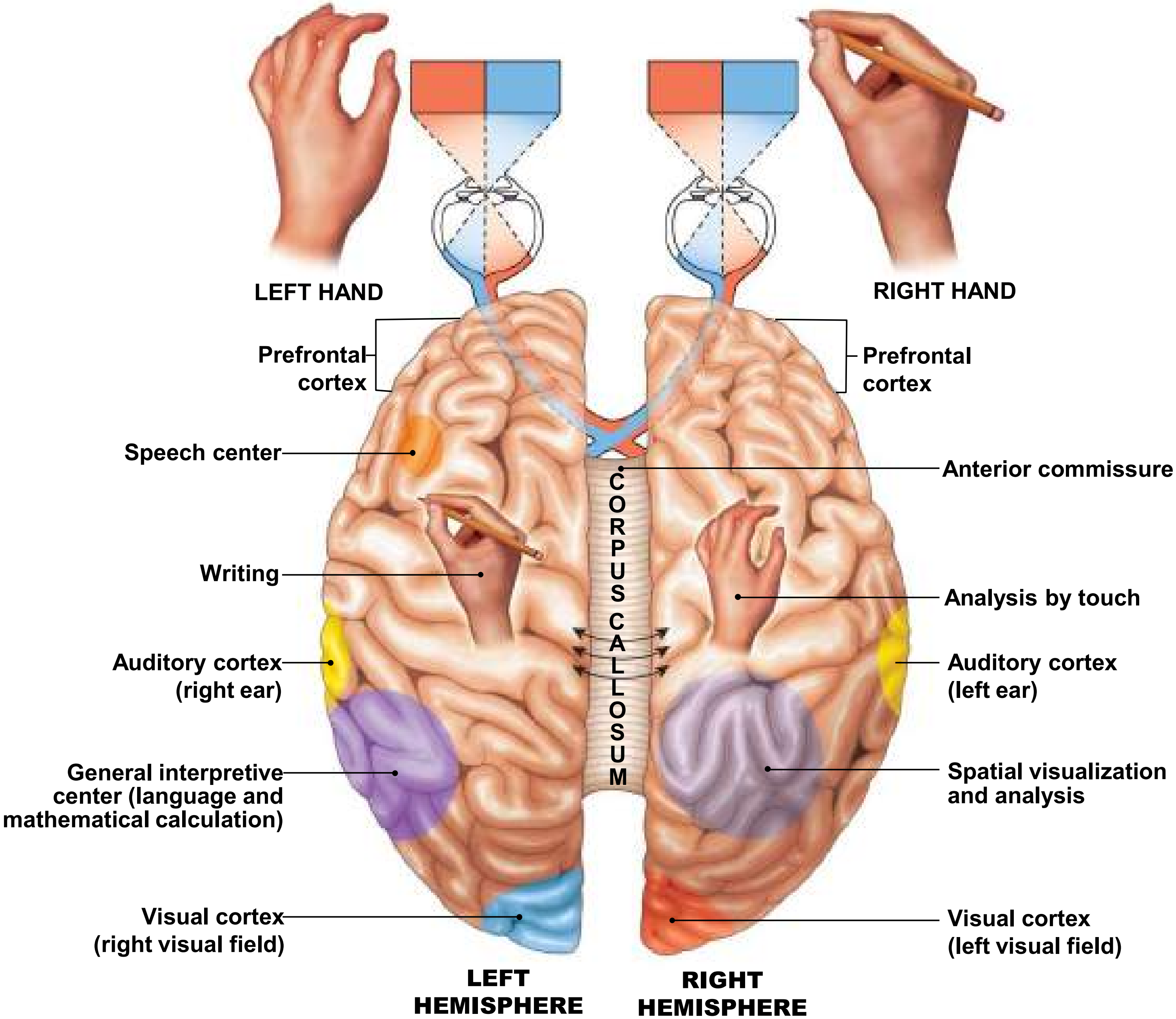


. https://cern-foundation.org/wp-content/uploads/2013/02/Brain-Anatomy-Function.jpg

Hemispheric Lateralization (8-7)

- The concept that different brain functions can and do occur on one side of the brain
  - The left hemisphere tends to be involved in language skills, analytical tasks, and logic
  - The right hemisphere tends to be involved in analyzing sensory input and relating it to the body, as well as analyzing emotional content

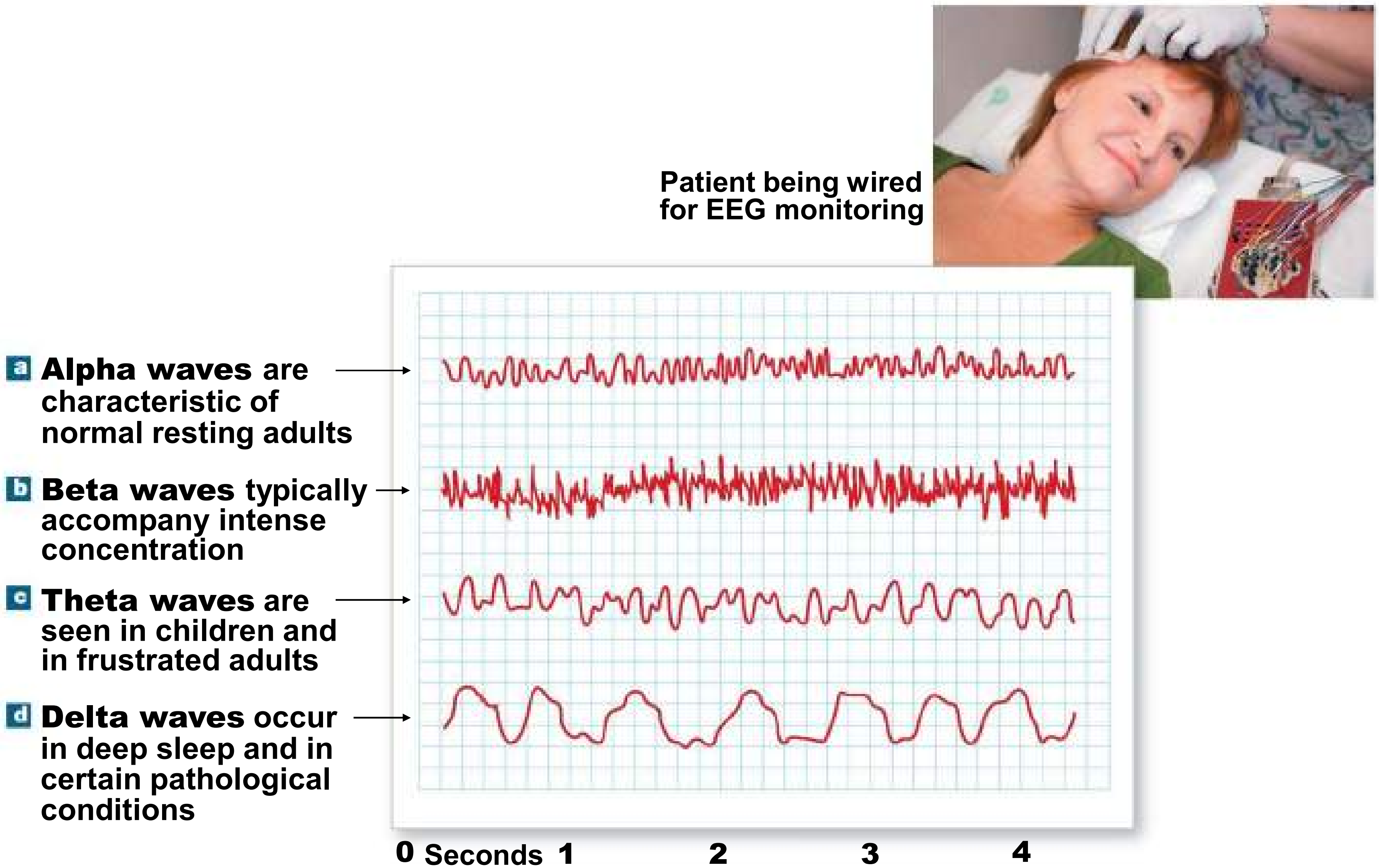
Figure 8-20 Hemispheric Lateralization.



The Electroencephalogram (8-7)

- EEG
- A printed record of **brain wave** activity
  - Can be interpreted to diagnose brain disorders
- More modern techniques
  - Brain imaging, using the PET scan and MRIs, has allowed extensive "mapping" of the brain's functional areas

Figure 8-21 Brain Waves.



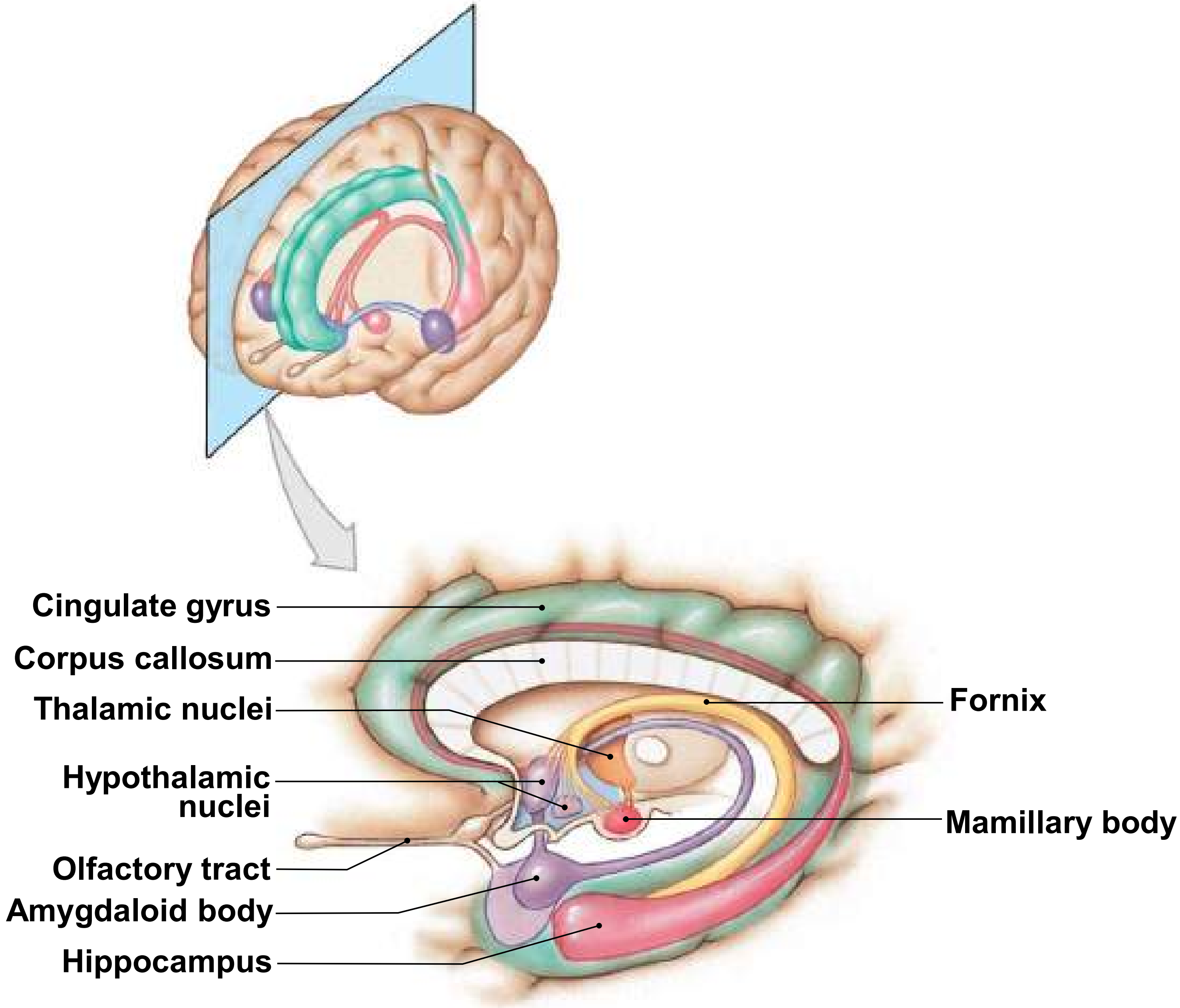
Memory (8-7)

- **Fact memory**
  - The recall of bits of information
- **Skill memory**
  - Learned motor skill that can become incorporated into unconscious memory
- **Short-term memory**
  - Doesn't last long unless rehearsed
  - Converting into *long-term memory* through memory consolidation
- **Long-term memory**
  - Remains for long periods, sometimes an entire lifetime
- **Amnesia**
  - Memory loss as a result of disease or trauma

The Limbic System (8-7)

- Includes the olfactory cortex, basal nuclei, gyri, and tracts between the cerebrum and diencephalon
- A functional grouping, rather than an anatomical one
- Establishes the emotional states
- Links the conscious with the unconscious
- Aids in long-term memory with help of the **hippocampus**

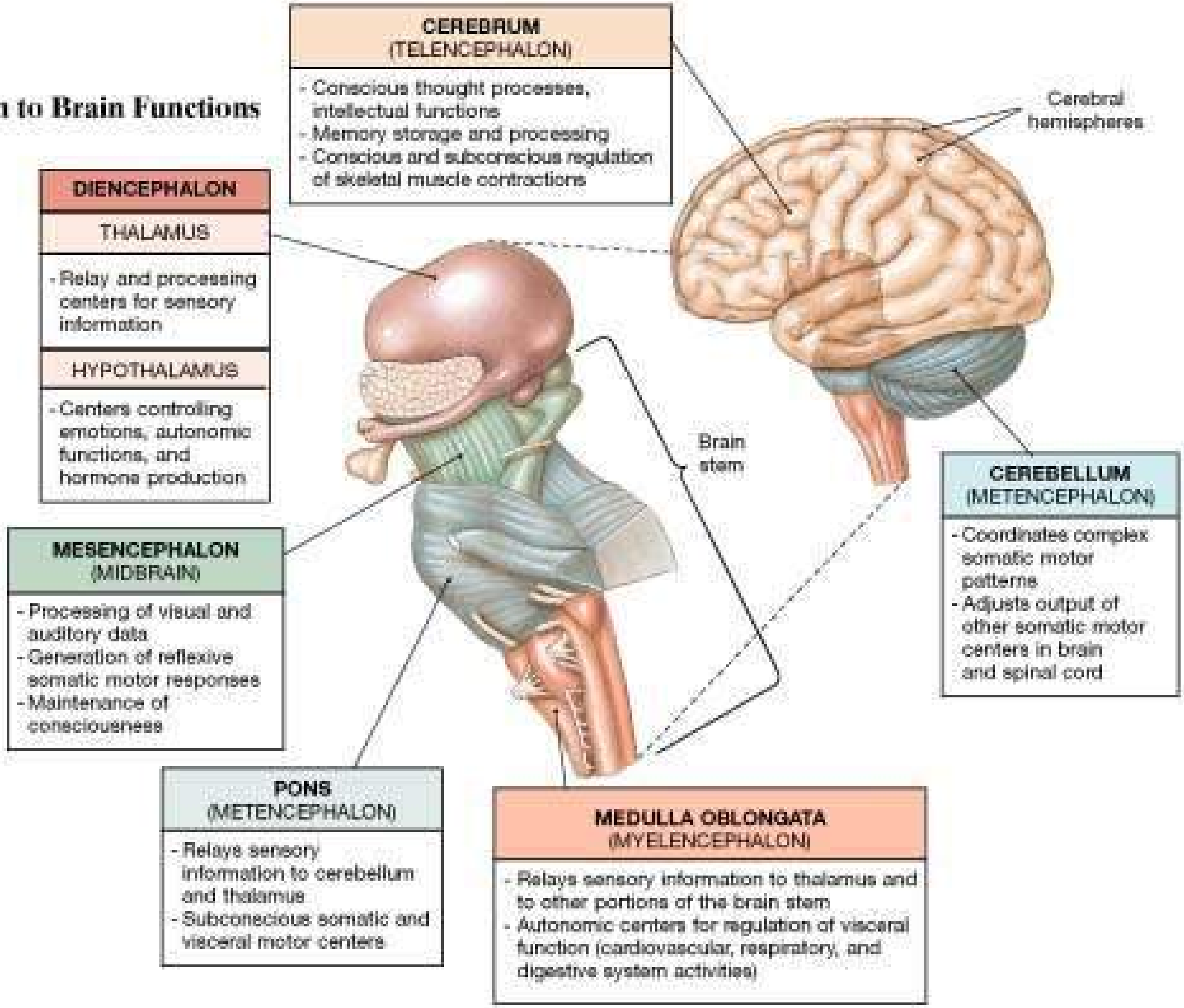
Figure 8-23 The Limbic System.



The Diencephalon (8-7)

- Contains switching and relay centers
- Centers integrate conscious and unconscious sensory information and motor commands
- Surround third ventricle
- Three components
    1. Epithalamus
    2. Thalamus
    3. Hypothalamus

• FIGURE 14-2
An Introduction to Brain Functions



The Epithalamus (8-7)

- Lies superior to the third ventricle and forms the roof of the diencephalon
- The anterior part contains choroid plexus
- The posterior part contains the **pineal gland** that is endocrine and secretes *melatonin*

The Thalamus (8-7)

- The left and right **thalamus** are separated by the third ventricle
- The final relay point for sensory information
- Only a small part of this input is sent on to the primary sensory cortex

The Hypothalamus (8-7)

- Lies inferior to the third ventricle
- The subconscious control of skeletal muscle contractions is associated with strong emotion
- Adjusts the pons and medulla functions
- Coordinates the nervous and endocrine systems

The Hypothalamus (8-7)

- Secretes hormones
- Produces sensations of thirst and hunger
- Coordinates voluntary and ANS function
- Regulates body temperature
- Coordinates daily cycles

The Midbrain (8-7)

- Contains various nuclei
  - Two pairs involved in visual and auditory processing, the *colliculi*
- Contains motor nuclei for cranial nerves III and IV
- **Cerebral peduncles** contain descending fibers
- **Reticular formation** is a network of nuclei related to the state of wakefulness
- The *substantia nigra* influence muscle tone

The Pons (8-7)

- Links the cerebellum with the midbrain, diencephalon, cerebrum, and spinal cord
- Contains sensory and motor nuclei for cranial nerves V, VI, VII, and VIII
- Other nuclei influence rate and depth of respiration

The Cerebellum (8-7)

- An automatic processing center
  - Which adjusts postural muscles to maintain balance
- Programs and fine-tunes movements
- The **cerebellar peduncles**
  - Are tracts that link the cerebral cortex, basal nuclei, and brain stem
- *Ataxia*
  - Is disturbance of coordination
  - Can be caused by damage to the cerebellum

The Medulla Oblongata (8-7)

- Connects the brain with the spinal cord
- Contains sensory and motor nuclei for cranial nerves VIII, IX, X, XI, and XII
- Contains reflex centers
    - **Cardiovascular centers**
        - Adjust heart rate and arteriolar diameter
    - **Respiratory rhythmicity centers**
        - Regulate respiratory rate

Figure 8-24a The Diencephalon and Brain Stem.

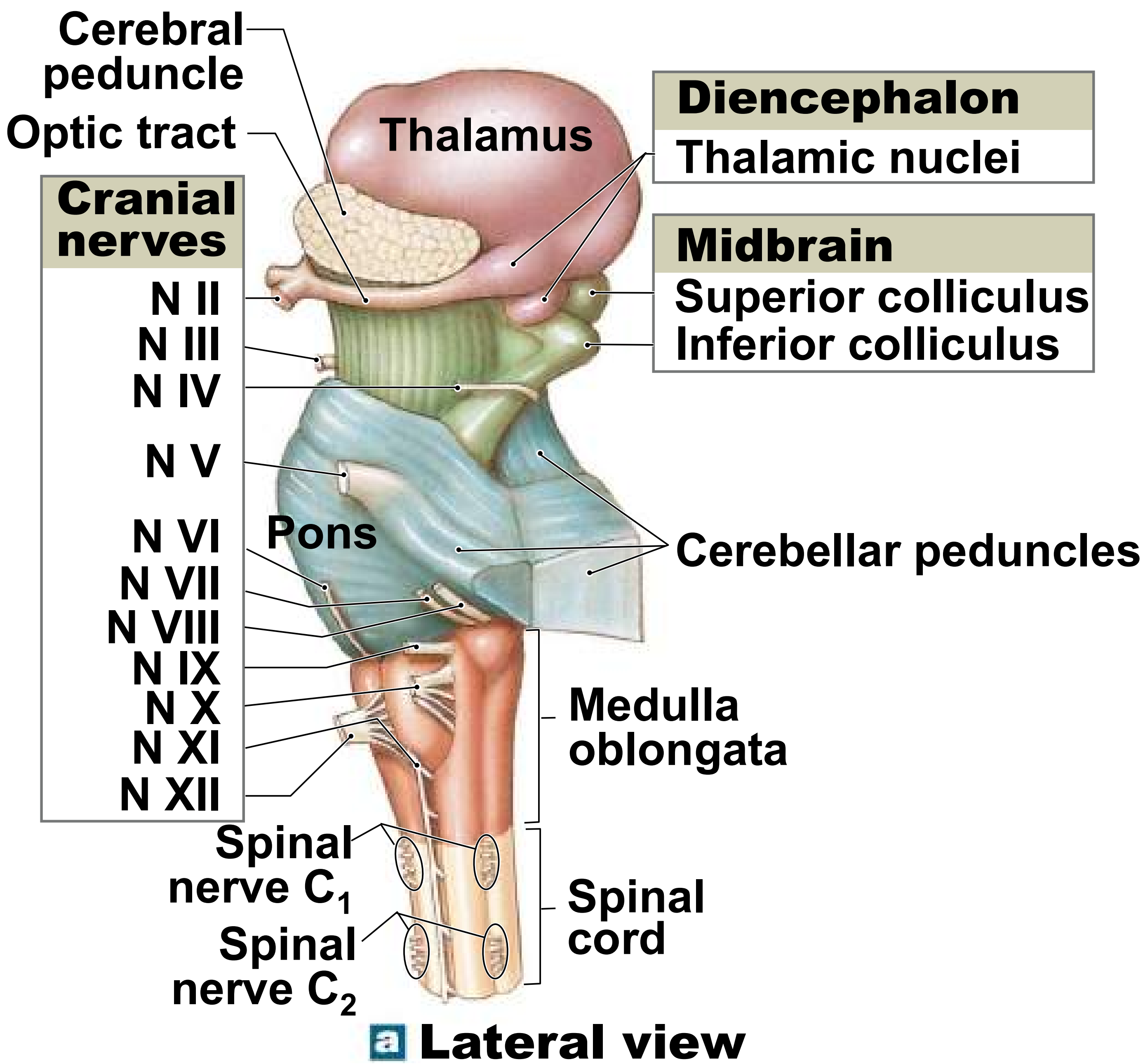
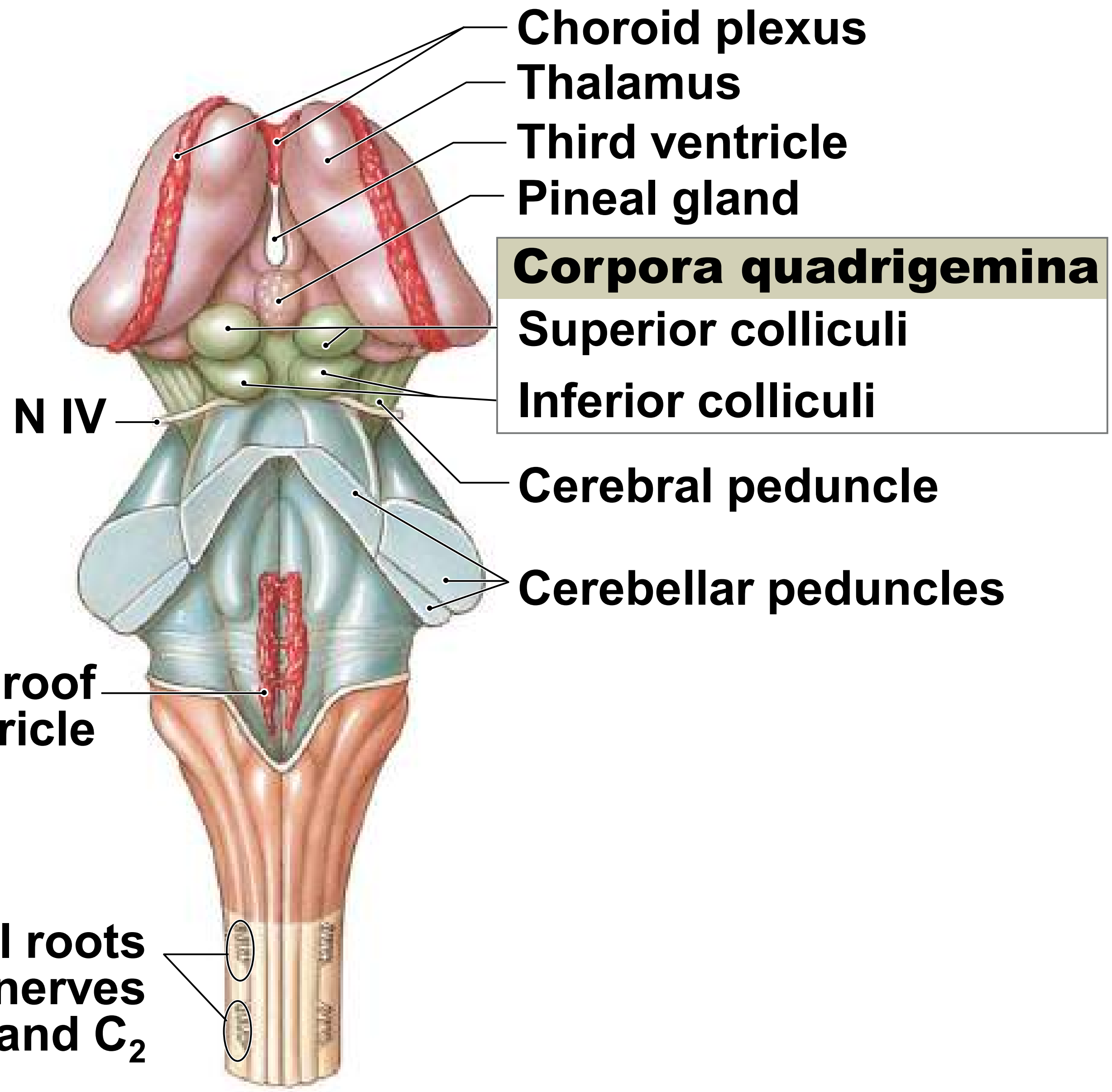
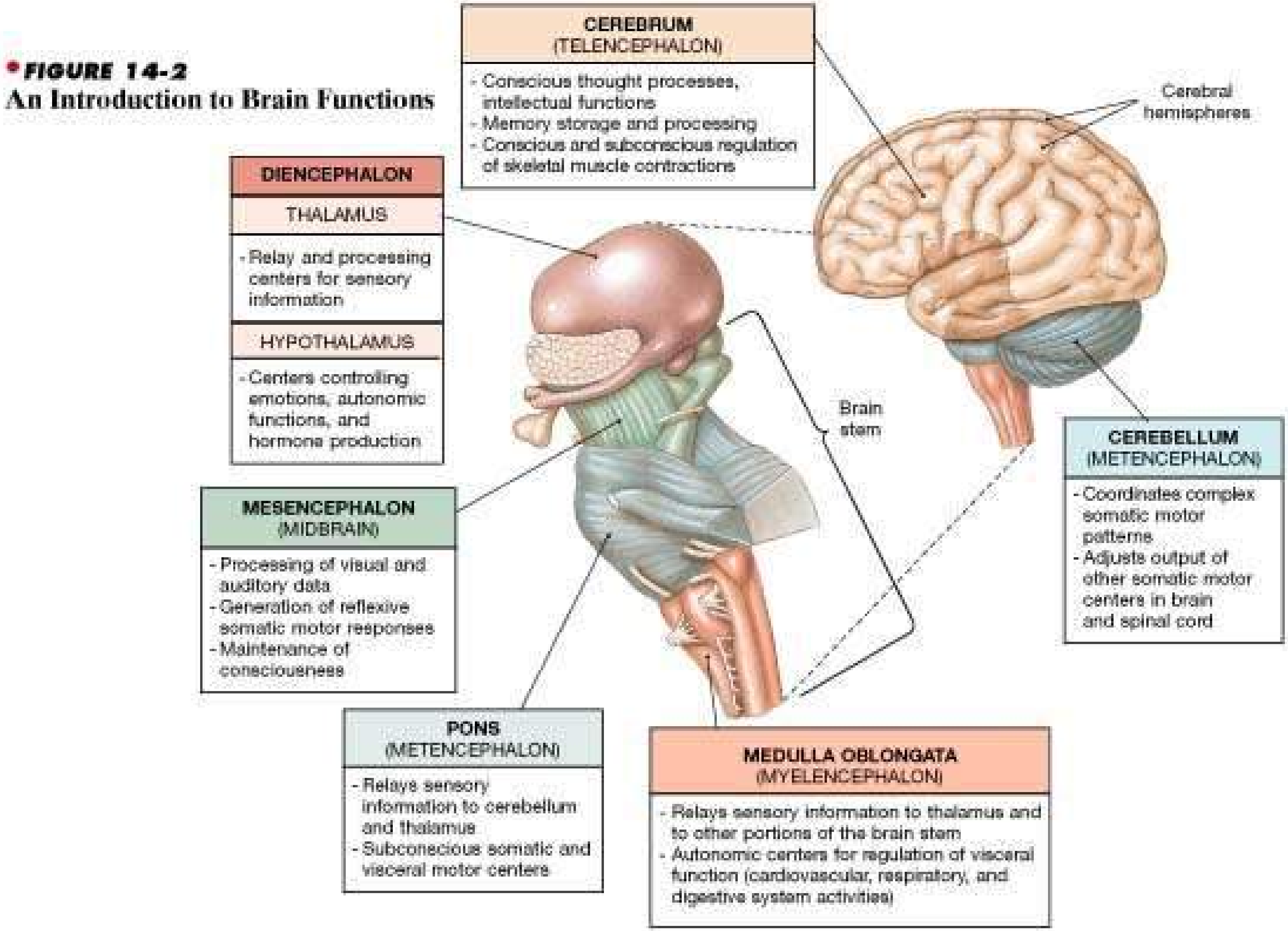


Figure 8-24b The Diencephalon and Brain Stem.



b Posterior view



• FIGURE 14-2
An Introduction to Brain Functions
CEREBRUM
(TELENCEPHALON)
- Conscious thought processes, intellectual functions
- Memory storage and processing
- Conscious and subconscious regulation of skeletal muscle contractions
Cerebral hemispheres
DIENCEPHALON
THALAMUS
- Relay and processing centers for sensory information
HYPOTHALAMUS
- Centers controlling emotions, autonomic functions, and hormone production
Brain stem
MESENCEPHALON
(MIDBRAIN)
- Processing of visual and auditory data
- Generation of reflexive somatic motor responses
- Maintenance of consciousness
CEREBELLUM
(METENCEPHALON)
- Coordinates complex somatic motor patterns
- Adjusts output of other somatic motor centers in brain and spinal cord
PONS
(METENCEPHALON)
- Relays sensory information to cerebellum and thalamus
- Subconscious somatic and visceral motor centers
MEDULLA OBLONGATA
(MYELENCEPHALON)
- Relays sensory information to thalamus and to other portions of the brain stem
- Autonomic centers for regulation of visceral function (cardiovascular, respiratory, and digestive system activities)

Peripheral Nervous System (8-8)

- Links the CNS to the rest of the body through **peripheral nerves**
- They include the **cranial nerves** and the **spinal nerves**
- The cell bodies of sensory and motor neurons are contained in the **ganglia**

The Cranial Nerves (8-8)

- 12 pairs, noted as Roman numerals I through XII
- Some are:
  - Only motor pathways
  - Only sensory pathways
  - Mixed having both sensory and motor neurons
- Often remembered with a mnemonic
  - "Oh, Once One Takes The Anatomy Final, Very Good Vacations Are Heavenly"

The Cranial Nerves (8-8)

- The **olfactory nerves (N I)**
  - Are connected to the cerebrum
  - Carry information concerning the sense of smell
- The **optic nerves** (**N II**)
  - Carry visual information from the eyes, through the **optic foramina** of the orbits to the **optic chiasm**
  - Continue as the optic tracts to the nuclei of the thalamus

The Cranial Nerves (8-8)

- The **oculomotor nerves** (**N III**)
  - Motor only, arising in the midbrain
  - Innervate four of six extrinsic eye muscles and the intrinsic eye muscles that control the size of the pupil
- The **trochlear nerves** (**N IV**)
  - Smallest, also arise in the midbrain
  - Innervate the superior oblique extrinsic muscles of the eyes

The Cranial Nerves (8-8)

- The **trigeminal nerves** (**N V**)
  - Have nuclei in the pons, are the largest cranial nerves
  - Have three branches
    1. The *ophthalmic*
       - From the orbit, sinuses, nasal cavity, skin of forehead, nose, and eyes
    2. The *maxillary*
       - From the lower eyelid, upper lip, cheek, nose, upper gums, and teeth
    3. The *mandibular*
       - From salivary glands and tongue

The Cranial Nerves (8-8)

- The **abducens nerves** (**N VI**)
  - Innervate only the lateral rectus extrinsic eye muscle, with the nucleus in the pons
- The **facial nerves** (**N VII**)
  - Mixed, and emerge from the pons
  - Sensory fibers monitor proprioception in the face
  - Motor fibers provide facial expressions; control tear and salivary glands

The Cranial Nerves (8-8)

- The **vestibulocochlear nerves** (**N VIII**)
  - Respond to sensory receptors in the inner ear
  - There are two components
    1. The **vestibular nerve**
       - Conveys information about balance and position
    2. The **cochlear nerve**
       - Responds to sound waves for the sense of hearing
    - Their nuclei are in the pons and medulla oblongata

The Cranial Nerves (8-8)

- The **glossopharyngeal nerves** (**N IX**)
  - Mixed nerves innervating the tongue and pharynx
  - Their nuclei are in the medulla oblongata
  - The sensory portion monitors taste on the posterior third of the tongue and monitors BP and blood gases
  - The motor portion controls pharyngeal muscles used in swallowing, and fibers to salivary glands

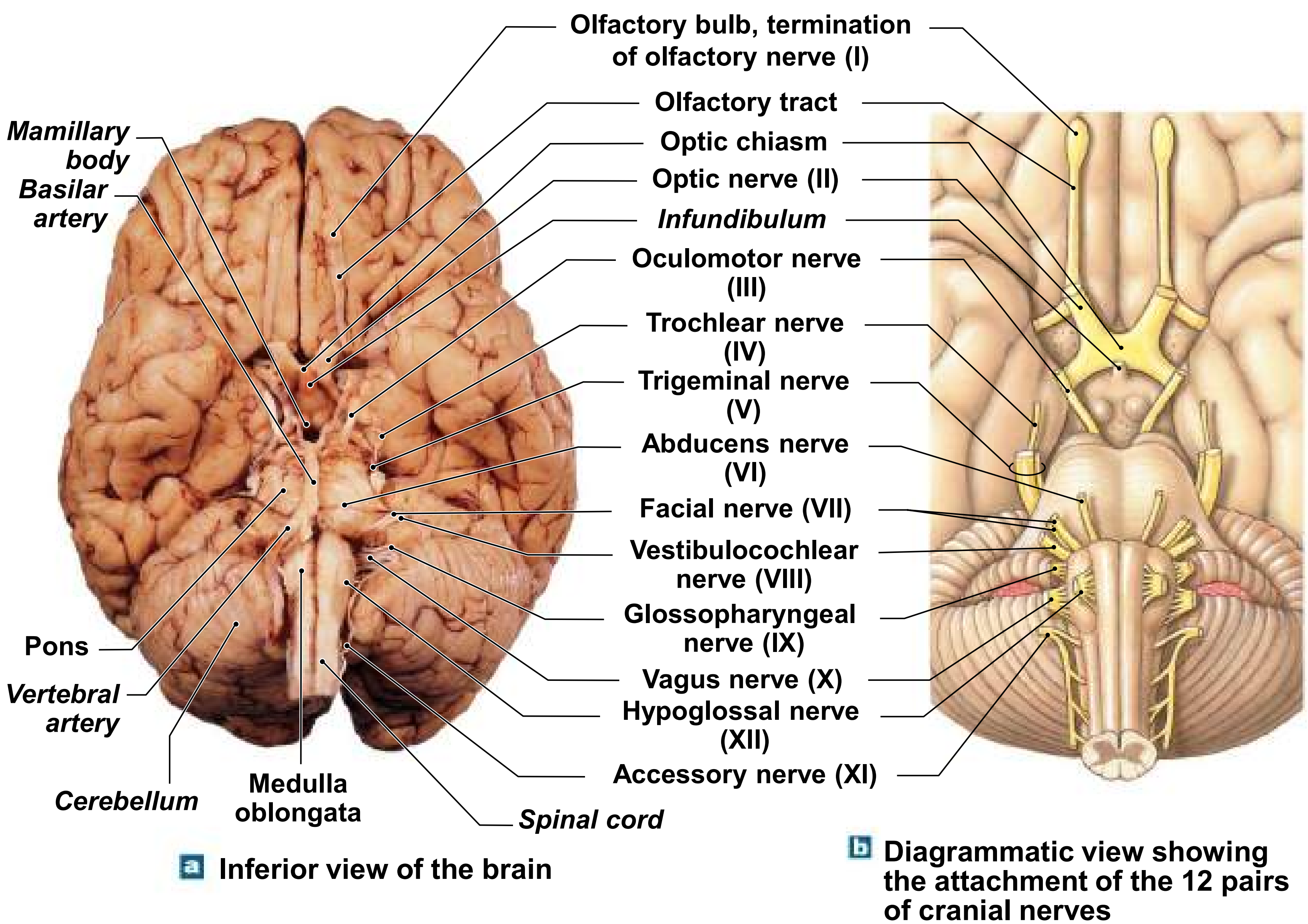
The Cranial Nerves (8-8)

- The **vagus nerves** (**N X**)
  - Have sensory input vital to autonomic control of the viscera
  - Motor control includes the soft palate, pharynx, and esophagus
  - Are a major pathway for ANS output to cardiac muscle, smooth muscle, and digestive glands

The Cranial Nerves (8-8)

- The **accessory nerves** (**N XI**)
  - Have fibers that originate in the medulla oblongata
  - Also in the lateral gray horns of the first five cervical segments of the spinal cord
- The **hypoglossal nerves** (**N XII**)
  - Provide voluntary motor control over the tongue

Figure 8-25 The Cranial Nerves.



a Inferior view of the brain

b Diagrammatic view showing the attachment of the 12 pairs of cranial nerves

Table 8-2 The Cranial Nerves

Cranial Nerves (Number)	Primary Function	Innervation
Olfactory (N I)	Special sensory	Olfactory epithelium
Optic (N II)	Special sensory	Retina of eye
Oculomotor (N III)	Motor	Inferior, medial, superior rectus, inferior oblique, and intrinsic muscles of eye
Trochlear (N IV)	Motor	Superior oblique muscle of eye
Trigeminal (N V)	Mixed	*Sensory*:orbital structures, nasal cavity, skin of forehead, eyelids, eyebrows, nose, lips, gums and teeth; cheek, palate, pharynx, and tongue *Motor*:chewing muscles (temporalis, masseter, pterygoids)
Abducens (N VI)	Motor	Lateral rectus muscle of eye
Facial (N VII)	Mixed	*Sensory*:taste receptors on the anterior 2/3 of tongue *Motor*:muscles of facial expression, lacrimal (tear) gland, and submandibular and sublingual salivary glands
Vestibulocochlear (N VIII)	Special sensory	Cochlea (receptors for hearing) Vestibule (receptors for motion and balance)
Glossopharyngeal (N IX)	Mixed	*Sensory*:posterior 1/3 of tongue; pharynx and palate (part); receptors for blood pressure, pH, oxygen, and carbon dioxide concentrations *Motor*:pharyngeal muscles, parotid salivary glands
Vagus (N X)	Mixed	*Sensory*:pharynx, auricle and external acoustic meatus, diaphragm, visceral organs inthoracic and abdominopelvic cavities *Motor*:palatal and pharyngeal muscles and visceral organs in thoracic and abdominopelvic cavities
Accessory (Spinal Accessory) (N XI)	Motor	Voluntary muscles of palate, pharynx, and larynx (with vagus nerve); sternocleidomastoid and trapezius muscles
Hypoglossal (N XII)	Motor	Tongue muscles

The Spinal Nerves (8-8)

- Found in 31 pairs grouped according to the region of the vertebral column
  - 8 pairs of cervical nerves, C_1–C_8
  - 12 pairs of thoracic nerves, T_1–T_{12}
  - 5 pairs of lumbar nerves, L_1–L_5
  - 5 pairs of sacral nerves, S_1–S_5
  - 1 pair of coccygeal nerves, Co_1

Nerve Plexuses (8-8)

- The origin of major nerve trunks of the PNS
  - The **cervical plexus**
    - Innervates the muscles of the head and neck and the diaphragm
  - The **brachial plexus**
    - Innervates the shoulder girdle and upper limb
  - The **lumbar plexus** and the **sacral plexus**
    - Innervate the pelvic girdle and lower limb

Dermatome (8-8)

- A clinically important area monitored by a specific spinal nerve

Table 8-3 Nerve Plexuses and Major Nerves

Table 8-3 Nerve Plexuses and Major Nerves

Plexus	Major Nerve	Distribution
Cervical Plexus ($C_1 - C_5$)	Phrenic nerve	Diaphragm
	Other branches	Muscles of the neck; skin of upper chest, neck, and ears
Brachial Plexus ($C_5 - T_1$)	Axillary nerve	Deltoid and teres minor muscles; skin of shoulder
	Musculocutaneous nerve	Flexor muscles of arm and forearm; skin on lateral surface of forearm
	Median nerve	Flexor muscles of forearm and hand; skin over lateral surface of hand
	Radial nerve	Extensor muscles of arm, forearm, and hand; skin over posterolateral surface of the arm
	Ulnar nerve	Flexor muscles of forearm and small digital muscles; skin over medial surface of hand
Lumbosacral Plexus		
Lumbar Plexus (T_{12}-L_4)	Femoral nerve	Flexors and adductors of hip, extensors of knee; skin over medial surfaces of thigh, leg, and foot
	Obturator nerve	Adductors of hip; skin over medial surface of thigh
	Saphenous nerve	Skin over medial surface of leg
Sacral Plexus (L_4-S_4)	Gluteal nerve	Abductors and extensors of hip; skin over posterior surface of thigh
	Sciatic nerve	Flexors of knee and ankle, flexors and extensors of toes; skin over anterior and posterior surfaces of leg and foot

Reflexes (8-9)

- Rapid, automatic, unlearned motor response to a stimulus
- Usually removes or opposes the original stimulus
- **Monosynaptic reflexes**
  - For example, the **stretch reflex**
    - Which responds to **muscle spindles,** is the simplest with only one synapse
    - The best known stretch reflex is probably the **knee jerk reflex**

Simple Reflexes (8-9)

- Are wired in a **reflex arc**
  - A stimulus activates a sensory receptor
  - An action potential travels down an afferent neuron
  - Information processing occurs with the interneuron
  - An action potential travels down an efferent neuron
  - The effector organ responds

Figure 8-28 The Components of a Reflex Arc.

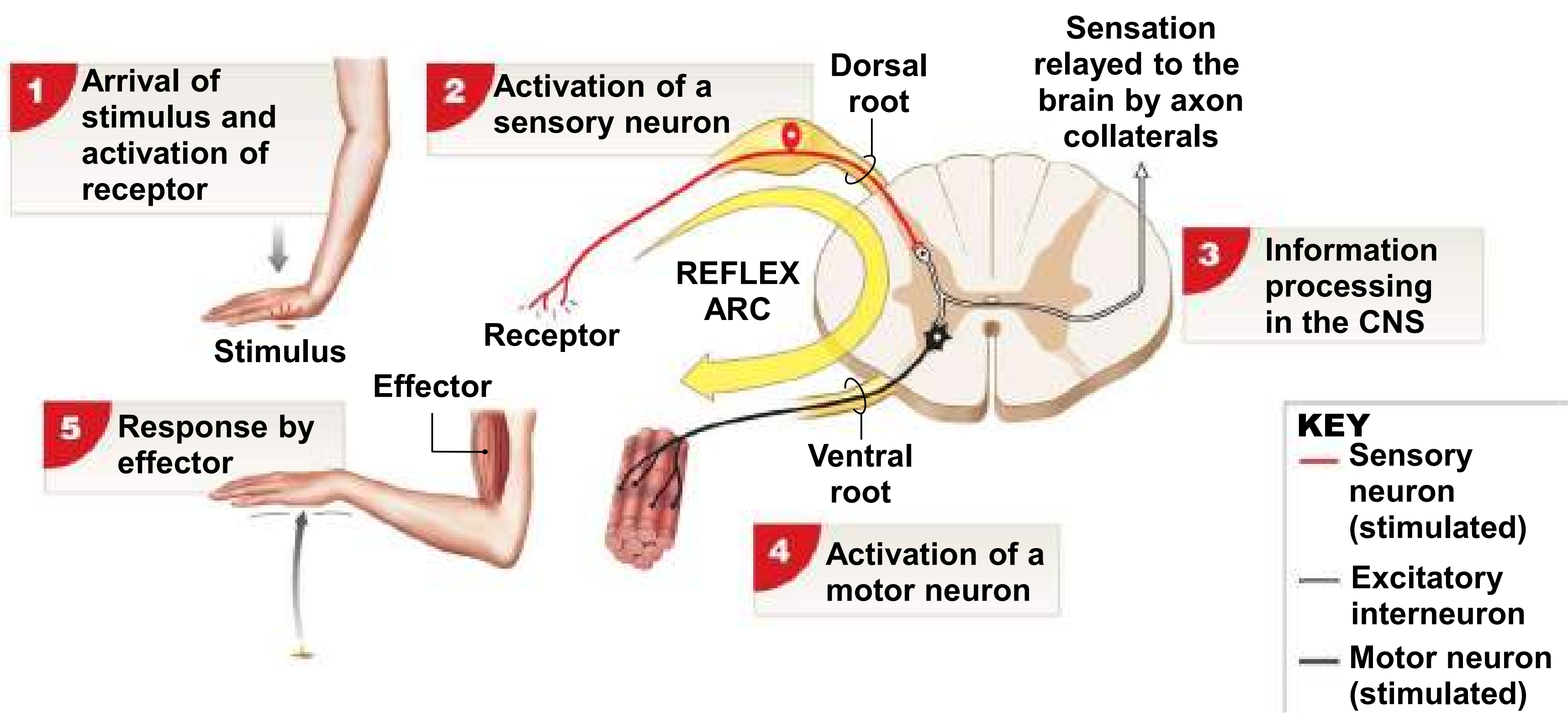
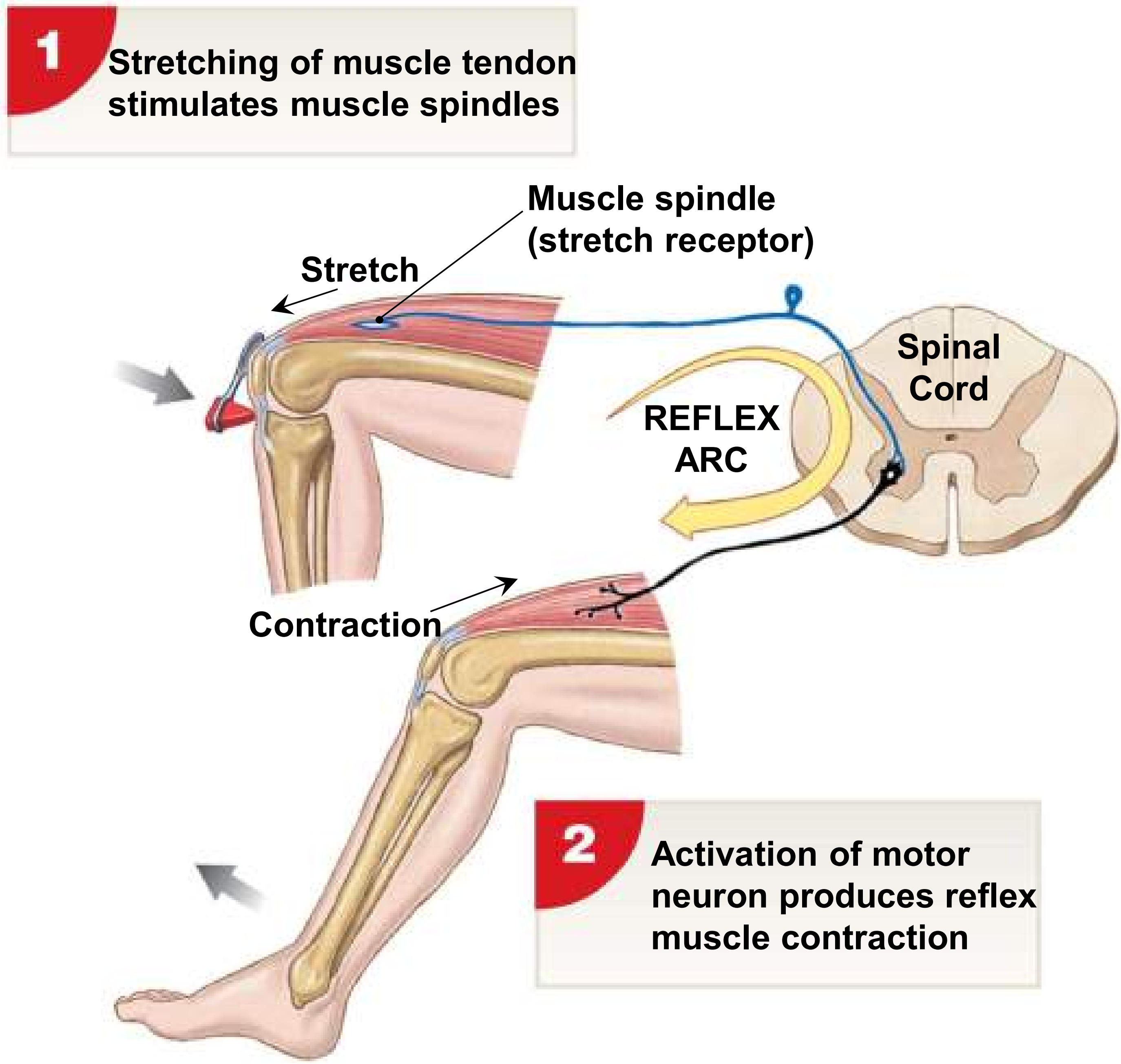


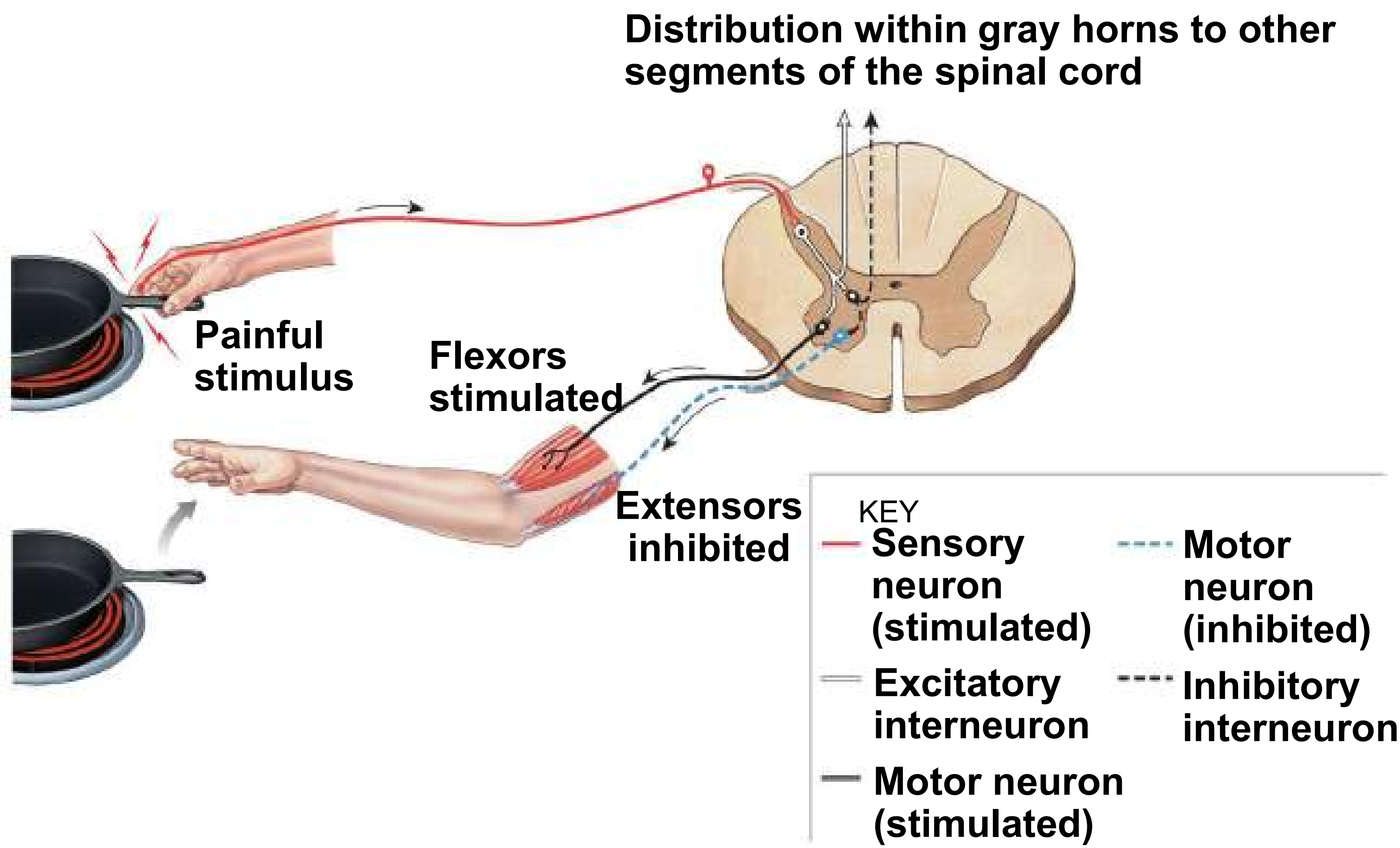
Figure 8-29 A Stretch Reflex.



Complex Reflexes (8-9)

- **Polysynaptic reflexes**
  - With at least one interneuron
  - Are slower than monosynaptic reflexes, but can activate more than one effector
- **Withdrawal reflexes**
  - Like the **flexor reflex,** move a body part away from the stimulation
  - Like touching a hot stove
- **Reciprocal inhibition**
  - Blocks the flexor's antagonist
  - To ensure that flexion is in no way interfered with

Figure 8-30 The Flexor Reflex, a Type of Withdrawal Reflex.



Input to Modify Reflexes (8-9)

- Reflexes are automatic, but higher brain centers can influence or modify them
- The **Babinski sign**
  - Triggered by stroking an infant's sole, resulting in a fanning of the toes
  - As descending inhibitory synapses develop, an adult will respond by curling the toes instead, called the **plantar reflex**

Table 8-4 Sensory and Motor Pathways

Table 8-4 Sensory and Motor Pathways	
Pathway	**Function**
SENSORY	
Posterior column pathway	Delivers highly localized sensations of fine touch, pressure, vibration, and proprioception to the primary sensory cortex
Spinothalamic pathway	Delivers poorly localized sensations of touch, pressure, pain, and temperature to the primary sensory cortex
Spinocerebellar pathway	Delivers proprioceptive information concerning the positions of muscles, bones, and joints to the cerebellar cortex
MOTOR	
Corticospinal pathway	Provides conscious control of skeletal muscles throughout the body
Medial and lateral pathways	Provides subconscious regulation of skeletal muscle tone, controls reflexive skeletal muscle responses to equilibrium sensations and to sudden or strong visual and auditory stimuli

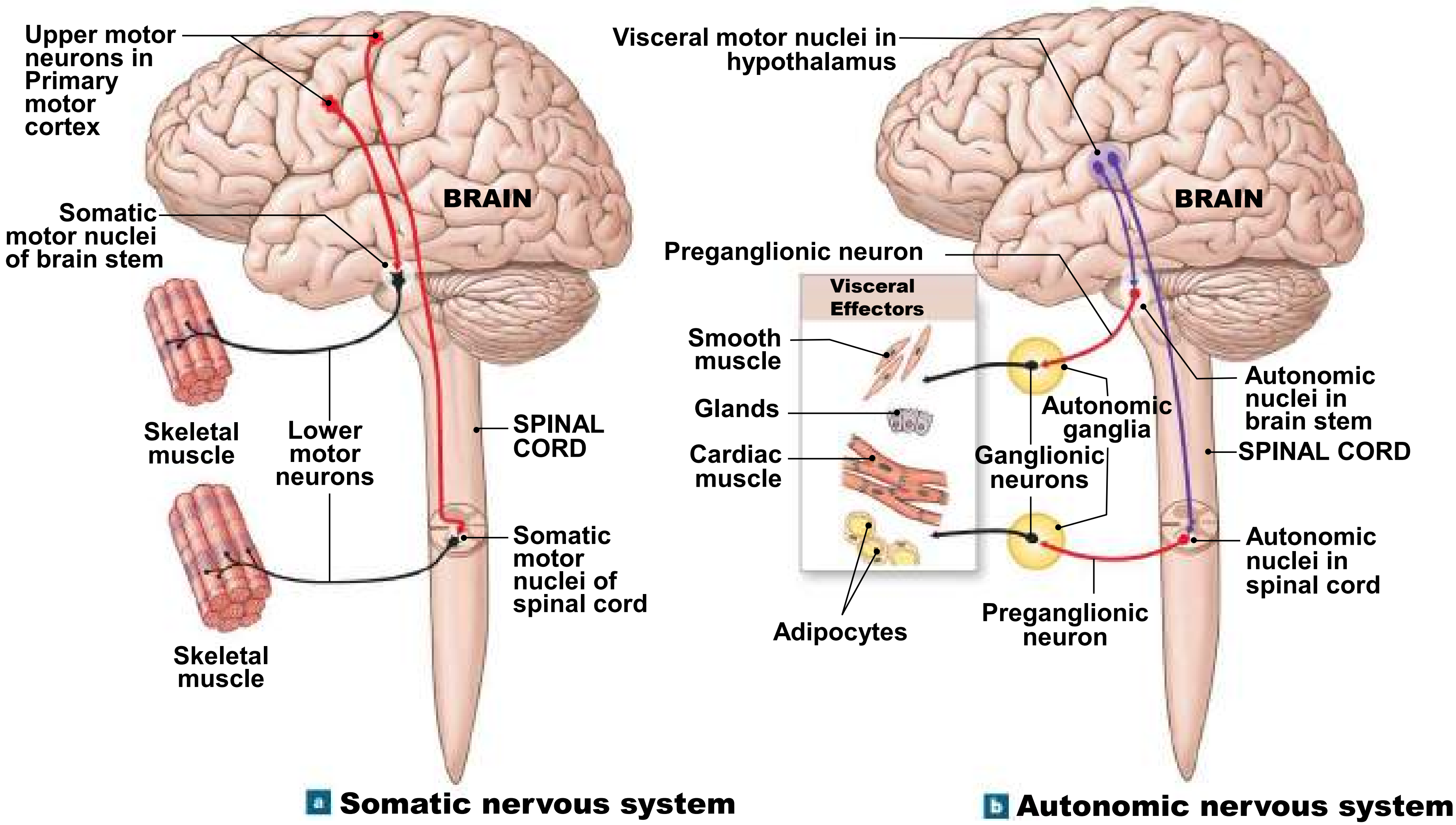
The Autonomic Nervous System (8-11)

- Unconscious adjustment of homeostatically essential visceral responses
  - **Sympathetic division**
  - **Parasympathetic division**
- The somatic NS and ANS are anatomically different
  - SNS: one neuron to skeletal muscle
  - ANS: two neurons to cardiac and smooth muscle, glands, and fat cells

Two Neuron Pathways of the ANS (8-11)

- **Preganglionic neuron**
  - Has cell body in spinal cord, synapses at the **ganglion** with the **postganglionic neuron**
- In **sympathetic division**
  - Preganglionic fibers are short
  - Postganglionic fibers are long
- In **parasympathetic division**
  - Preganglionic fibers are long
  - Postganglionic fibers are "short"

Figure 8-33 The Organization of the Somatic and Autonomic Nervous Systems.



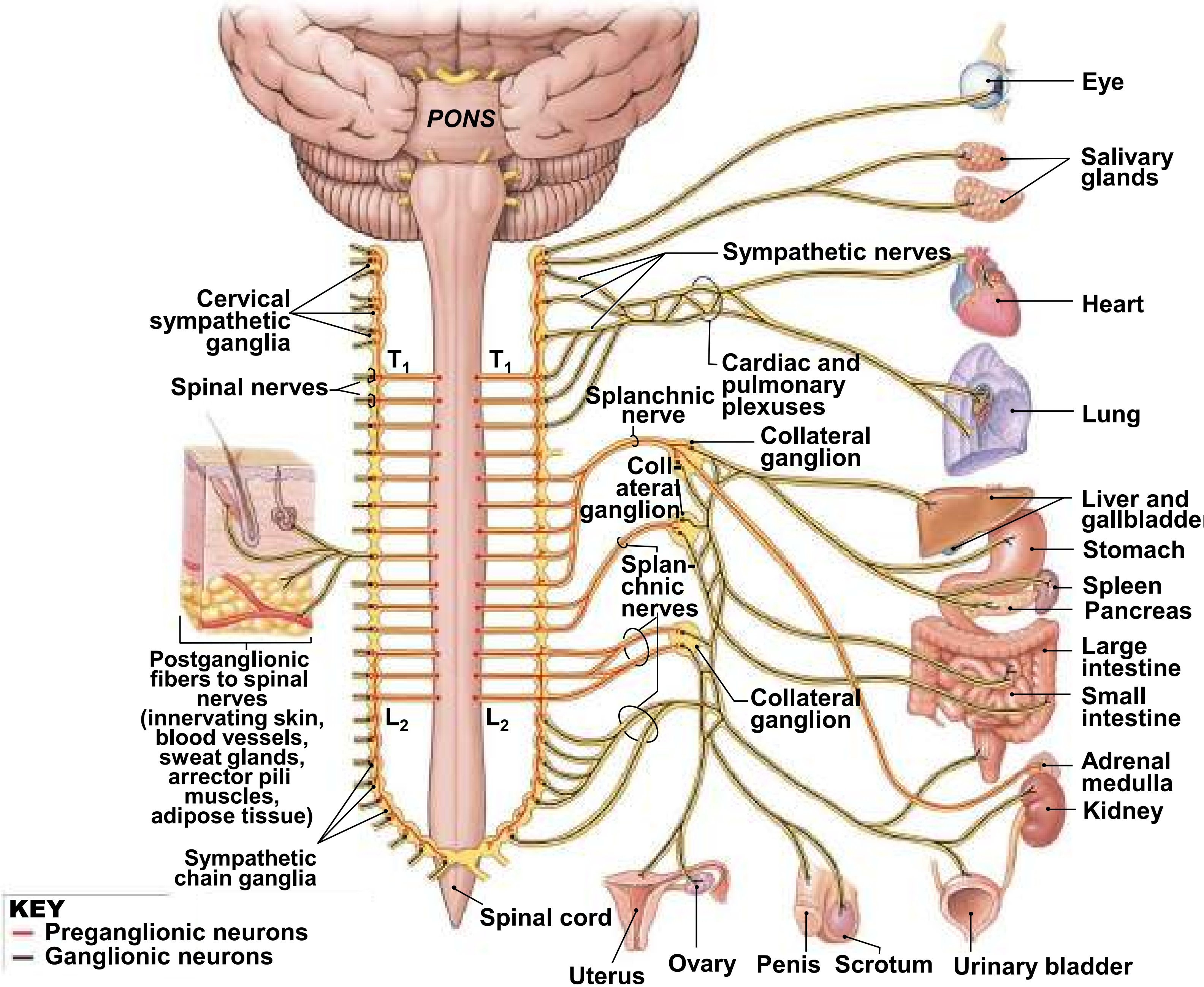
The Sympathetic Division (8-11)

- **Sympathetic chain**
  - Arises from spinal segments T_1–L_2
  - The preganglionic fibers enter the sympathetic chain ganglia just outside the spinal column
  - **Collateral ganglia** are unpaired ganglia that receive **splanchnic nerves** from the lower thoracic and upper lumbar segments
  - Postganglionic neurons innervate abdominopelvic cavity

The Sympathetic Division (8-11)

- The **adrenal medullae**
  - Are innervated by preganglionic fibers
  - Are modified neural tissue that secrete E and NE into capillaries, functioning like an endocrine gland
  - The effect is nearly identical to that of the sympathetic postganglionic stimulation of adrenergic synapses

Figure 8-34 The Sympathetic Division.



The Sympathetic Division (8-11)

- Also called the "fight-or-flight" division
- Effects
  - Increase in alertness, metabolic rate, sweating, heart rate, blood flow to skeletal muscle
  - Dilates the respiratory bronchioles and the pupils
  - Blood flow to the digestive organs is decreased
  - E and NE from the adrenal medullae support and prolong the effect

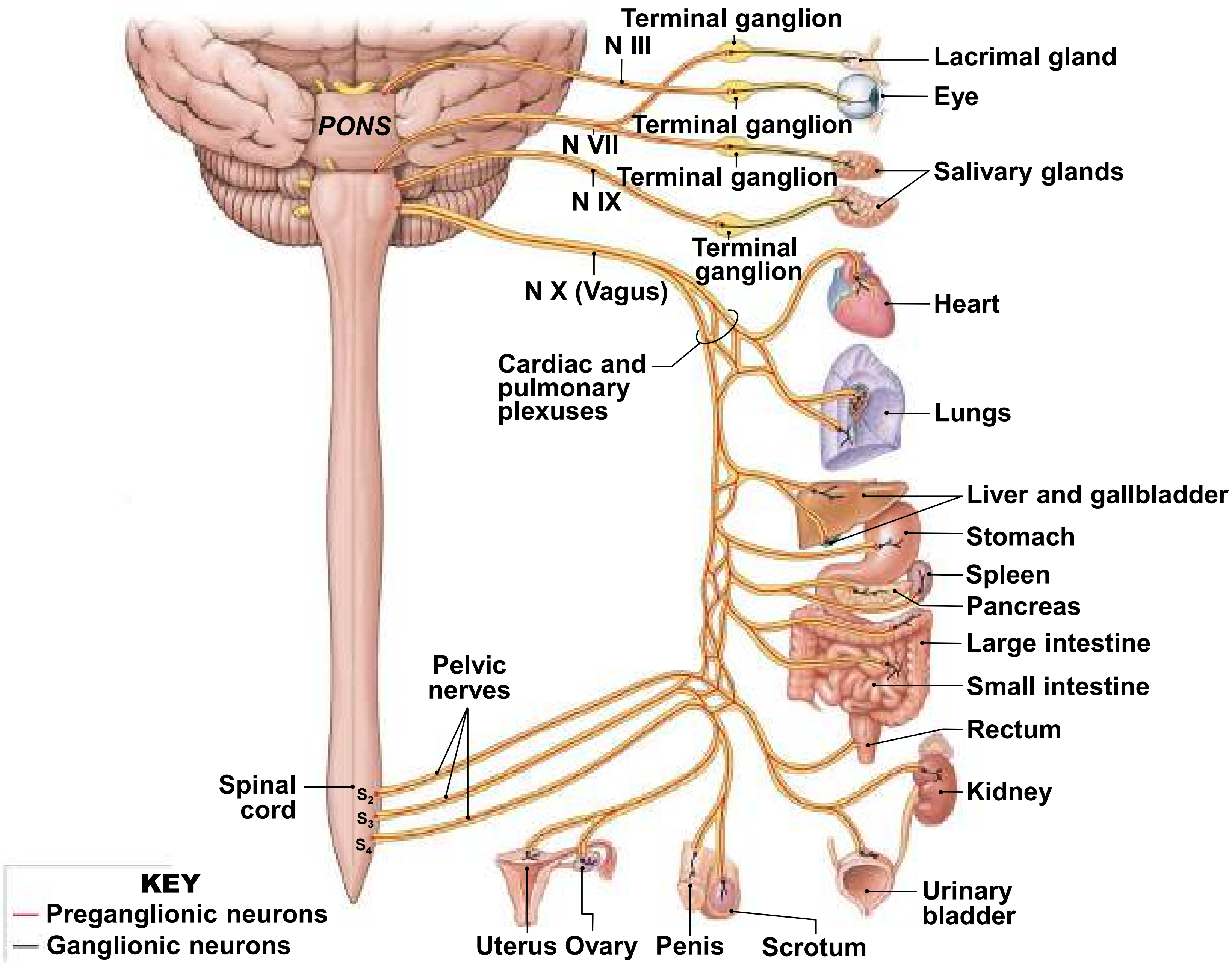
The Parasympathetic Division (8-11)

- Preganglionic neurons arise from the brain stem and sacral spinal cord
- Include cranial nerves III, VII, IX, and X, the vagus, a major parasympathetic nerve
- Ganglia very close to or within the target organ
- Preganglionic fibers of the sacral areas form the **pelvic nerves**

The Parasympathetic Division (8-11)

- Less divergence than in the sympathetic division, so effects are more localized
- Also called "rest-and digest" division
- Effects
  - Constriction of the pupils, increase in digestive secretions, increase in digestive tract smooth muscle activity
  - Stimulates urination and defecation
  - Constricts bronchioles, decreases heart rate

Figure 8-35 The Parasympathetic Division.



Dual Innervation (8-11)

- Refers to both divisions affecting the same organs
- Mostly have antagonistic effects
- Some organs are innervated by only one division

Table 8-5 The Effects of the Sympathetic and Parasympathetic Divisions of the ANS on Various Body Structures (1 of 2)

Table 8-5 The Effects of the Sympathetic and Parasympathetic Divisions of the ANS on Various Body Structures

Structure	Sympathetic Effects	Parasympathetic Effects
EYE		
	Dilation of pupil	Constriction of pupil
	Focusing for near vision	Focusing for distance vision
Tear Glands	Secretion	None (not innervated)
SKIN		
Sweat glands	Increases secretion	None (not innervated)
Arrector pili muscles	Contraction, erection of hairs	None (not innervated)
CARDIOVASCULAR SYSTEM		
Blood vessels	Vasoconstriction and vasodilation	None (not innervated)
Heart	Increases heart rate, force of contraction, and blood pressure	Decreases heart rate, force of contraction, and blood pressure
ADRENAL GLANDS		
	Secretion of epinephrine and norepinephrine by adrenal medullae	None (not innervated)
RESPIRATORY SYSTEM		
Airways	Increases diameter	Decreases diameter
Respiratory rate	Increases rate	Decreases rate

Table 8-5 The Effects of the Sympathetic and Parasympathetic Divisions of the ANS on Various Body Structures (2 of 2)

Table 8-5 The Effects of the Sympathetic and Parasympathetic Divisions of the ANS on Various Body Structures *(continued)*

Structure	Sympathetic Effects	Parasympathetic Effects
DIGESTIVE SYSTEM		
General level of activity	Decreases activity	Increases activity
Liver	Glycogen breakdown, glucose synthesis and release	Glycogen synthesis
SKELETAL MUSCLES		
	Increases force of contraction, glycogen breakdown	None (not innervated)
ADIPOSE TISSUE		
	Lipid breakdown, fatty acid release	None (not innervated)
URINARY SYSTEM		
Kidneys	Decreases urine production	Increases urine production
Urinary bladder	Constricts sphincter, relaxes urinary bladder	Tenses urinary bladder, relaxes sphincter to eliminate urine
REPRODUCTIVE SYSTEM		
	Increased glandular secretions; ejaculation in males	Erection of penis (males) or clitoris (females)

Aging and the Nervous System (8-12)

- Common changes
  - Reduction in brain size and weight and reduction in number of neurons
  - Reduction in blood flow to the brain
  - Change in synaptic organization of the brain
  - Increase in intracellular deposits and extracellular plaques
  - **Senility** can be a result of all these changes


Thank
You!!!