Chapter 49

Nervous Systems

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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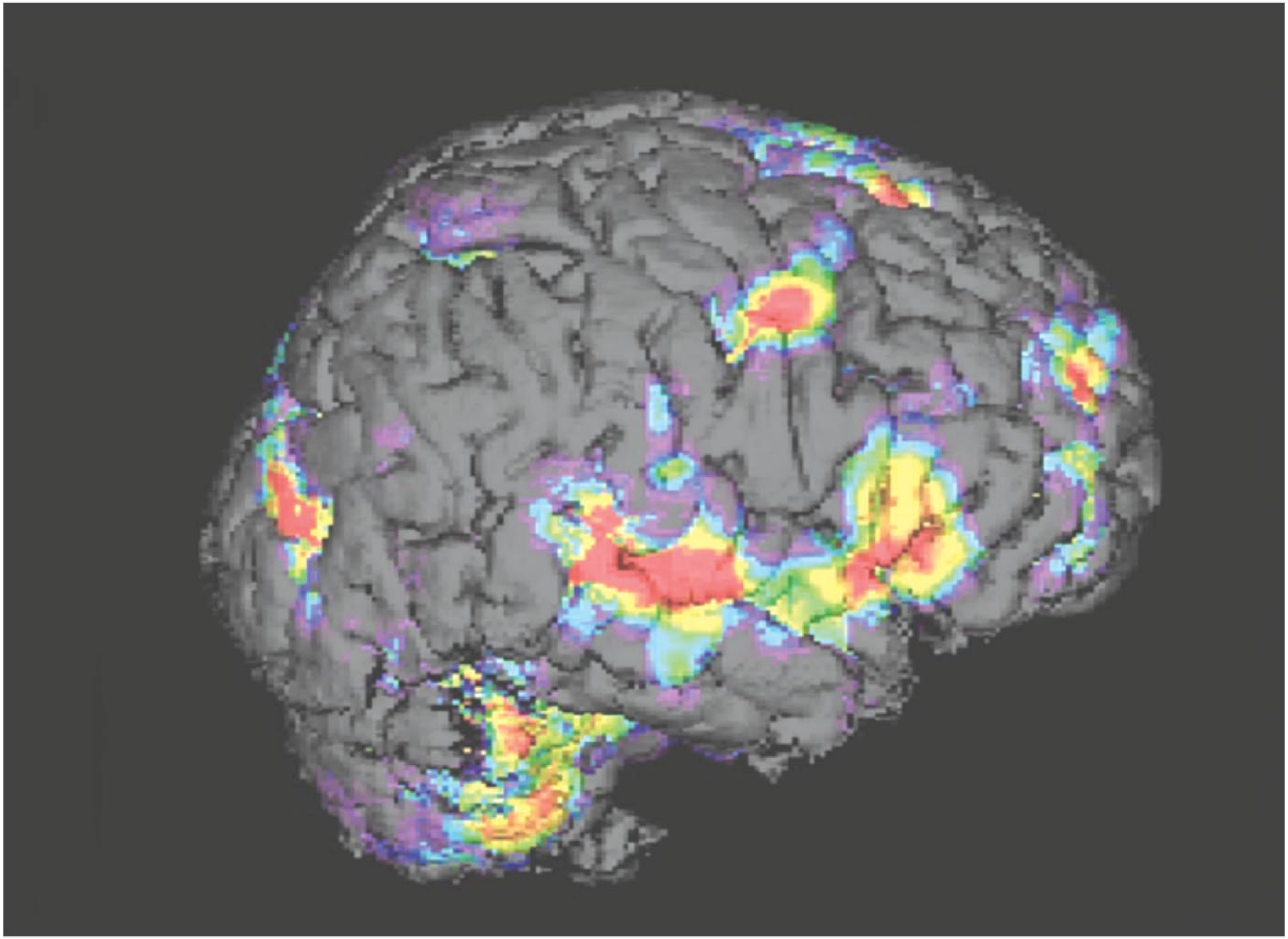
Overview: Command and Control Center

- The circuits in the brain are more complex than the most powerful computers
- Functional magnetic resonance imaging (MRI) can be used to construct a 3-D map of brain activity
- The vertebrate brain is organized into regions with different functions

Fig. 49-1



- Each single-celled organism can respond to stimuli in its environment
- Animals are multicellular and most groups respond to stimuli using systems of neurons

Concept 49.1: Nervous systems consist of circuits of neurons and supporting cells

- The simplest animals with nervous systems, the cnidarians, have neurons arranged in nerve nets
- A **nerve net** is a series of interconnected nerve cells
- More complex animals have nerves

- **Nerves** are bundles that consist of the axons of multiple nerve cells
- Sea stars have a nerve net in each arm connected by radial nerves to a central nerve ring

Fig. 49-2

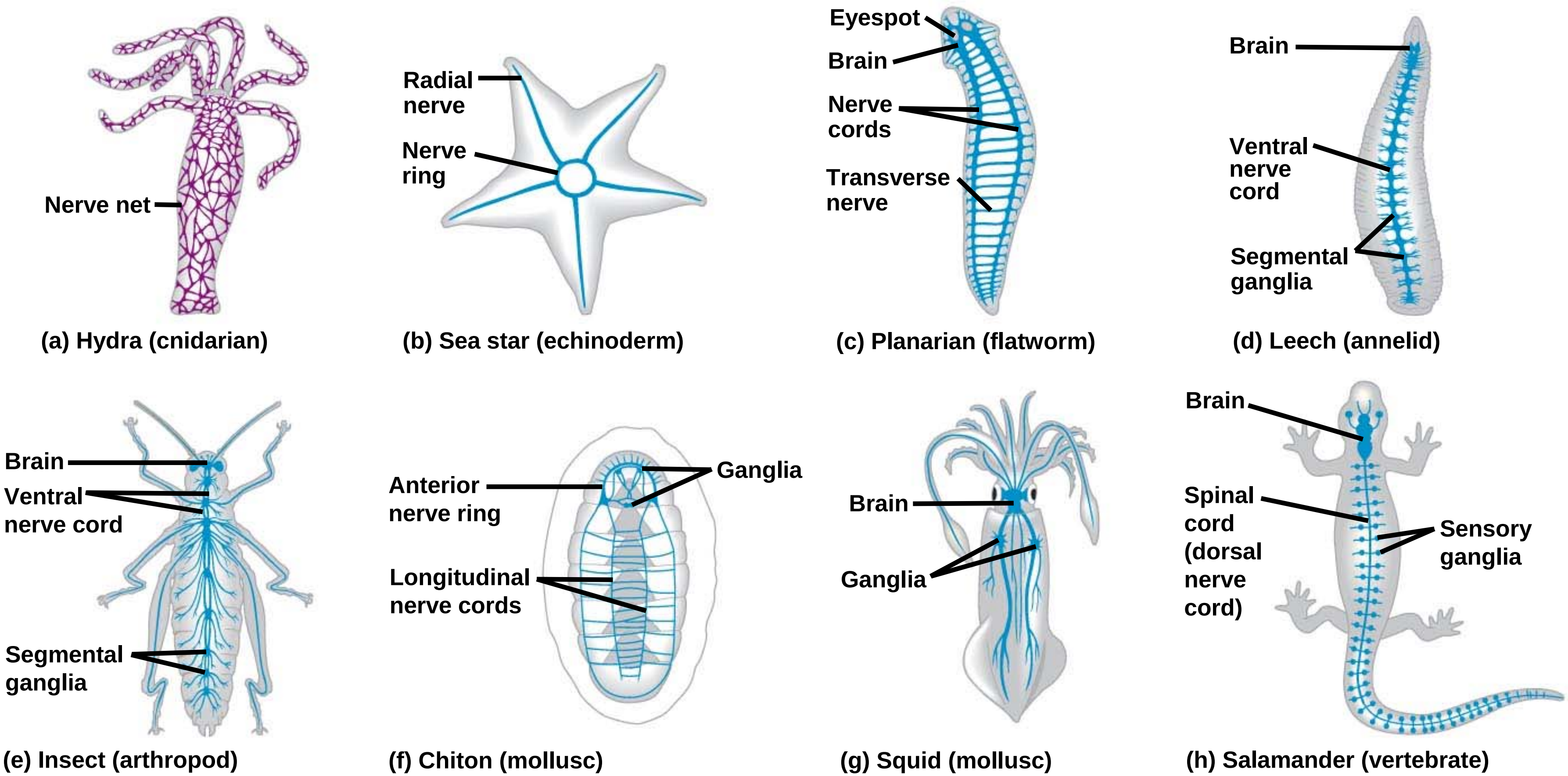
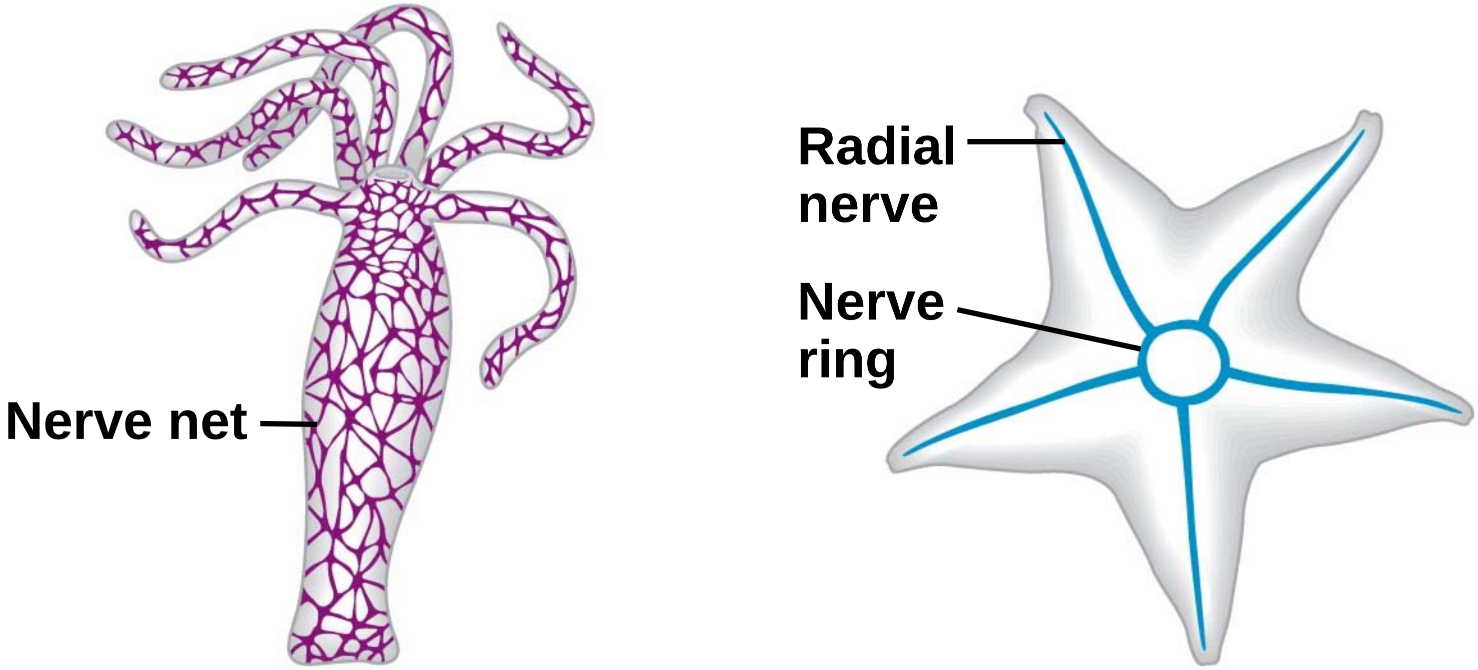

Nerve net
(a) Hydra (cnidarian)
Radial nerve
Nerve ring
(b) Sea star (echinoderm)
Eyespot
Brain
Nerve cords
Transverse nerve
(c) Planarian (flatworm)
Brain
Ventral nerve cord
Segmental ganglia
(d) Leech (annelid)
Brain
Ventral nerve cord
Segmental ganglia
(e) Insect (arthropod)
Anterior nerve ring
Ganglia
Longitudinal nerve cords
(f) Chiton (mollusc)
Brain
Ganglia
(g) Squid (mollusc)
Brain
Spinal cord (dorsal nerve cord)
Sensory ganglia
(h) Salamander (vertebrate)

Fig. 49-2a

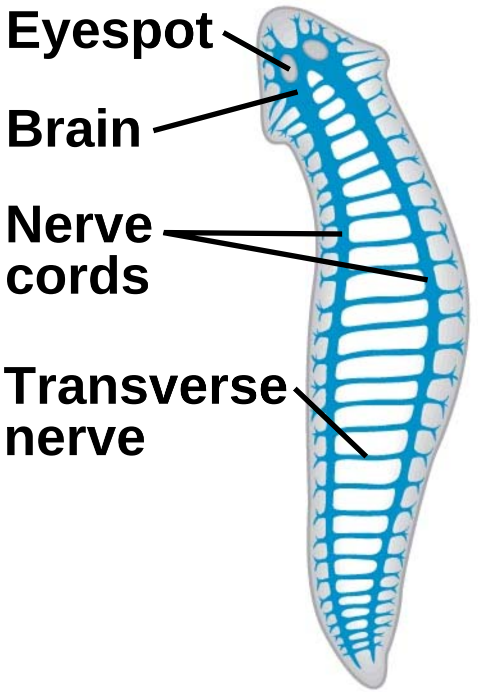


(a) Hydra (cnidarian)

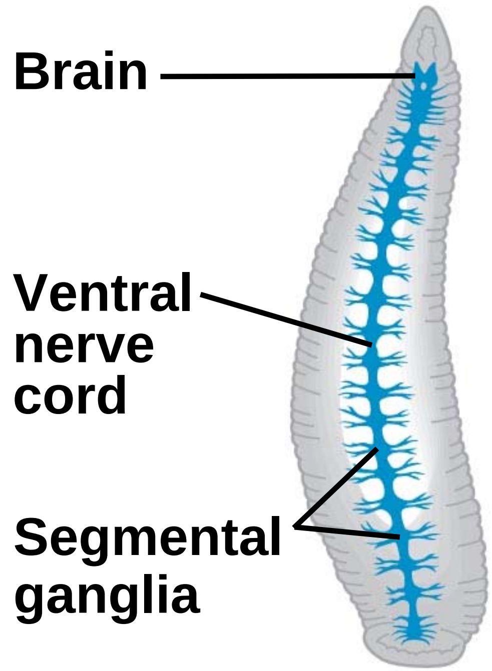
(b) Sea star (echinoderm)

- Bilaterally symmetrical animals exhibit cephalization
- Cephalization is the clustering of sensory organs at the front end of the body
- Relatively simple cephalized animals, such as flatworms, have a *central nervous system* (*CNS*)
- The CNS consists of a brain and longitudinal nerve cords

Fig. 49-2b



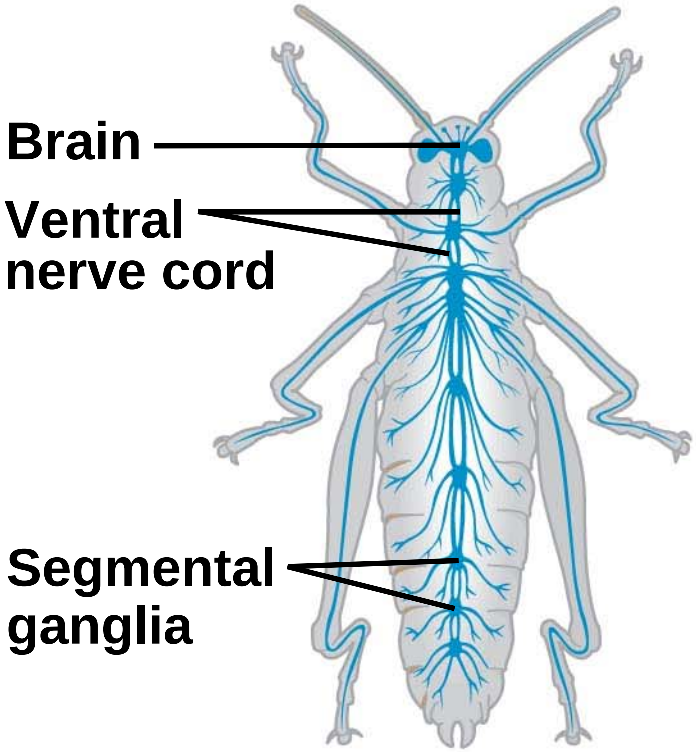
(c) Planarian (flatworm)



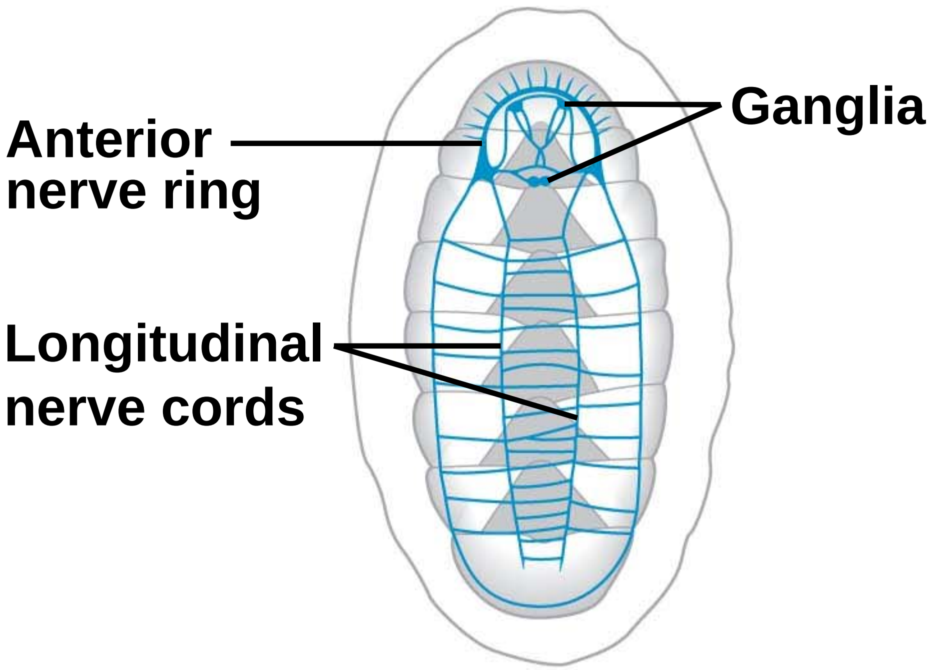
(d) Leech (annelid)

- Annelids and arthropods have segmentally arranged clusters of neurons called ganglia

Fig. 49-2c



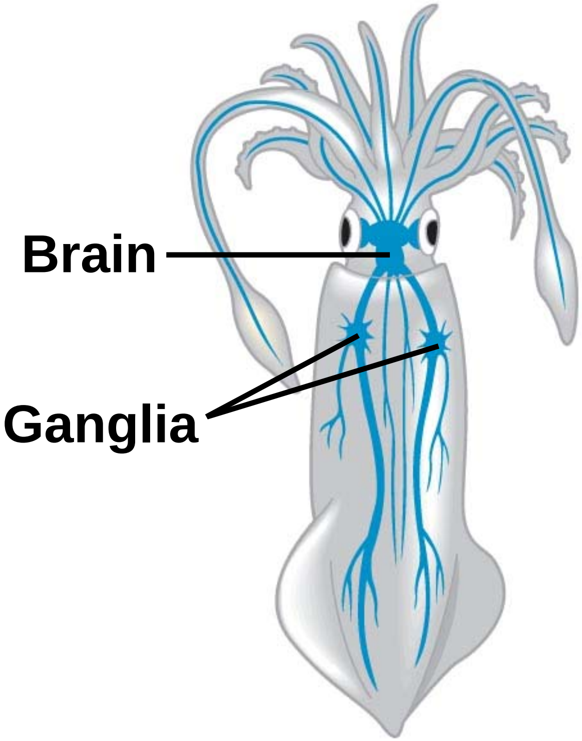
(e) Insect (arthropod)



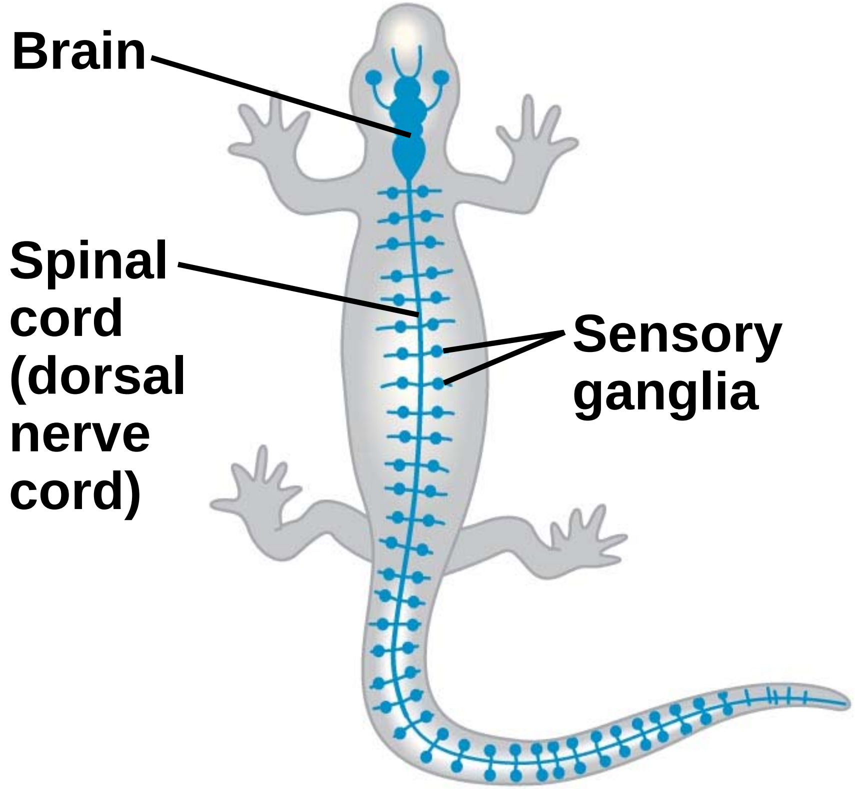
(f) Chiton (mollusc)

- Nervous system organization usually correlates with lifestyle
- Sessile molluscs (e.g., clams and chitons) have simple systems, whereas more complex molluscs (e.g., octopuses and squids) have more sophisticated systems

Fig. 49-2d



(g) Squid (mollusc)



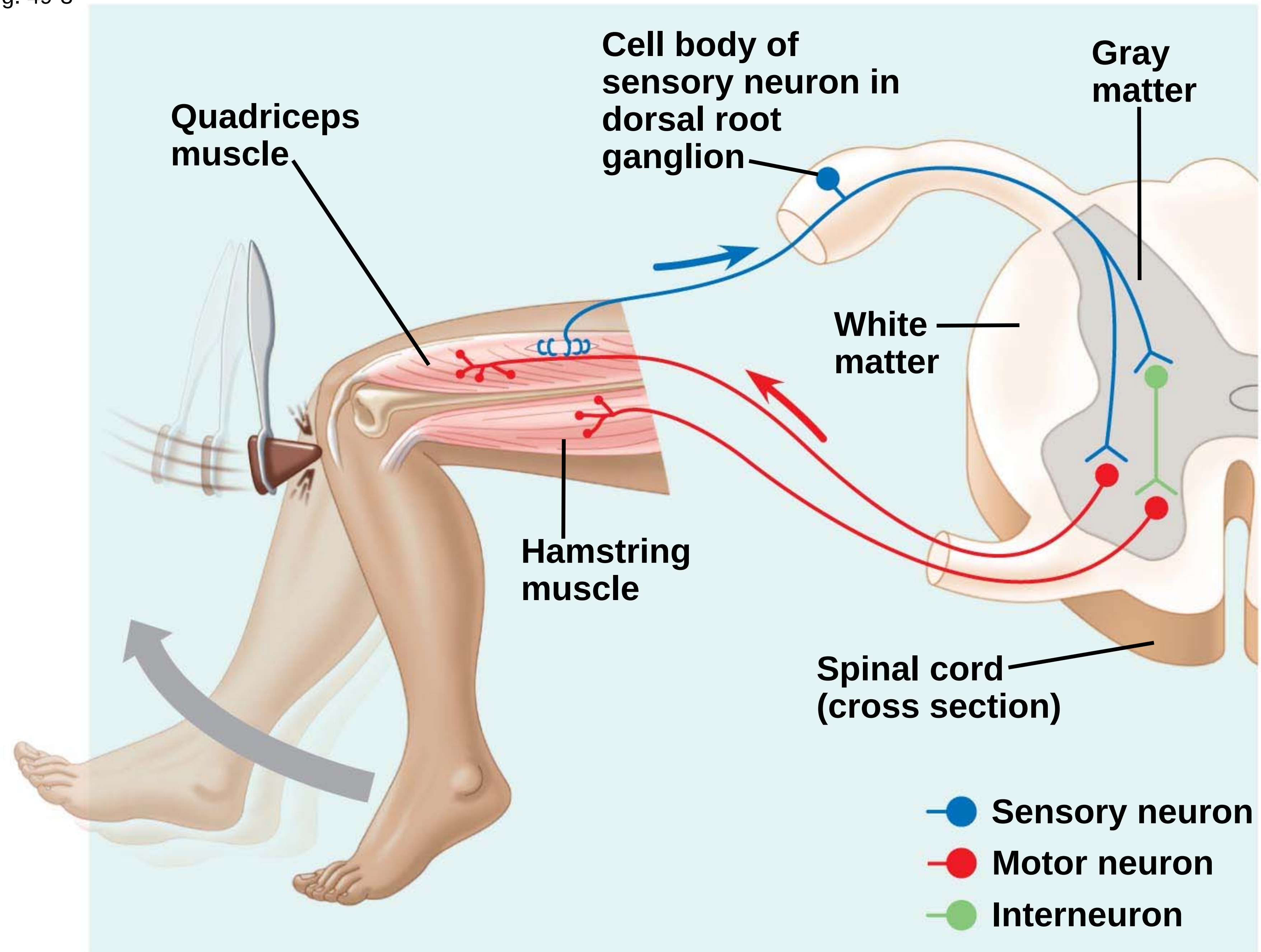
(h) Salamander (vertebrate)

- In vertebrates
  - The CNS is composed of the brain and spinal cord
  - The *peripheral nervous system* (*PNS*) is composed of nerves and ganglia

Organization of the Vertebrate Nervous System

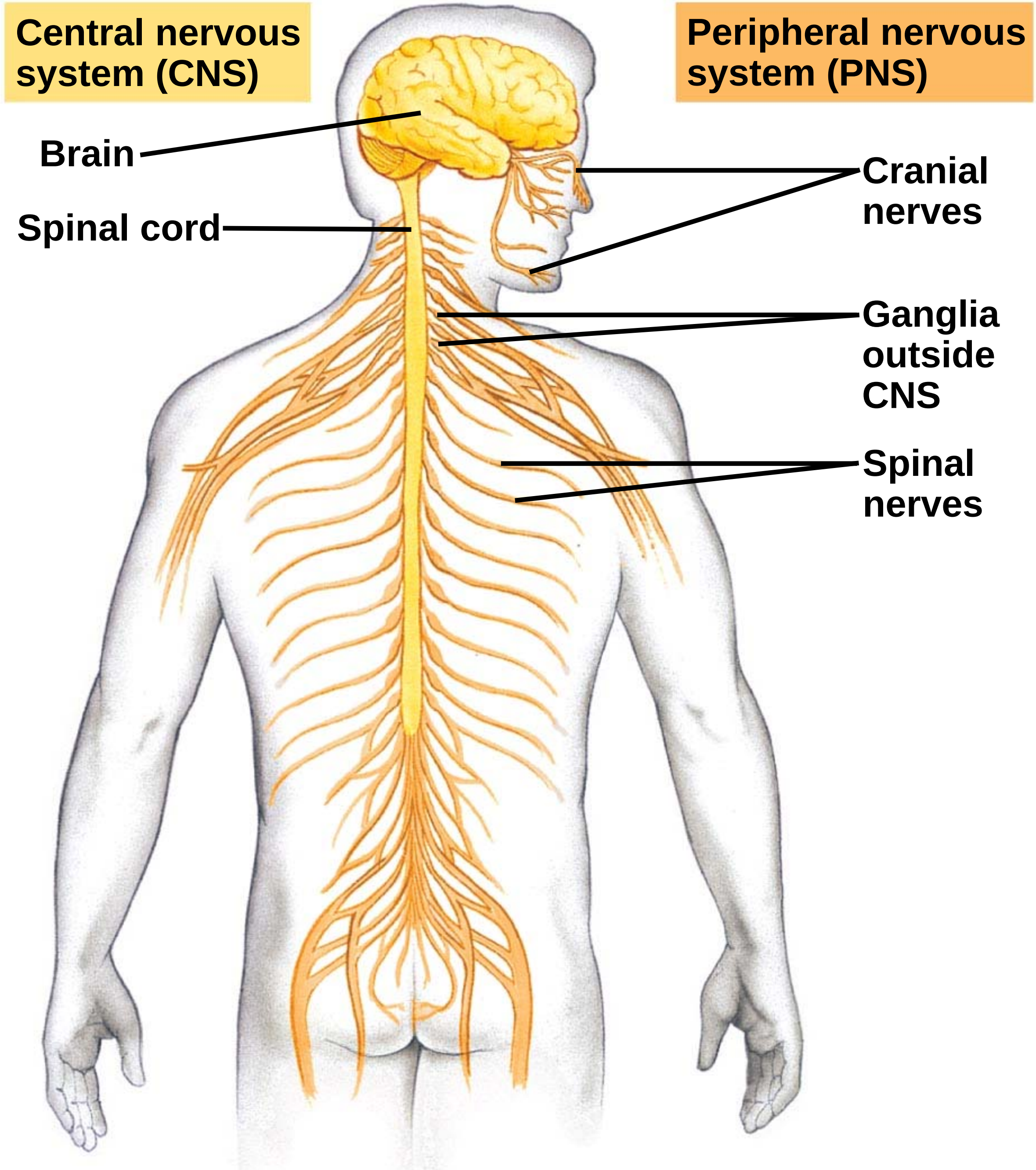
- The spinal cord conveys information from the brain to the PNS
- The spinal cord also produces reflexes independently of the brain
- A **reflex** is the body’s automatic response to a stimulus
  - For example, a doctor uses a mallet to trigger a knee-jerk reflex

Fig. 49-3


Cell body of sensory neuron in dorsal root ganglion
Gray matter
Quadriceps muscle
White matter
Hamstring muscle
Spinal cord (cross section)
Sensory neuron
Motor neuron
Interneuron

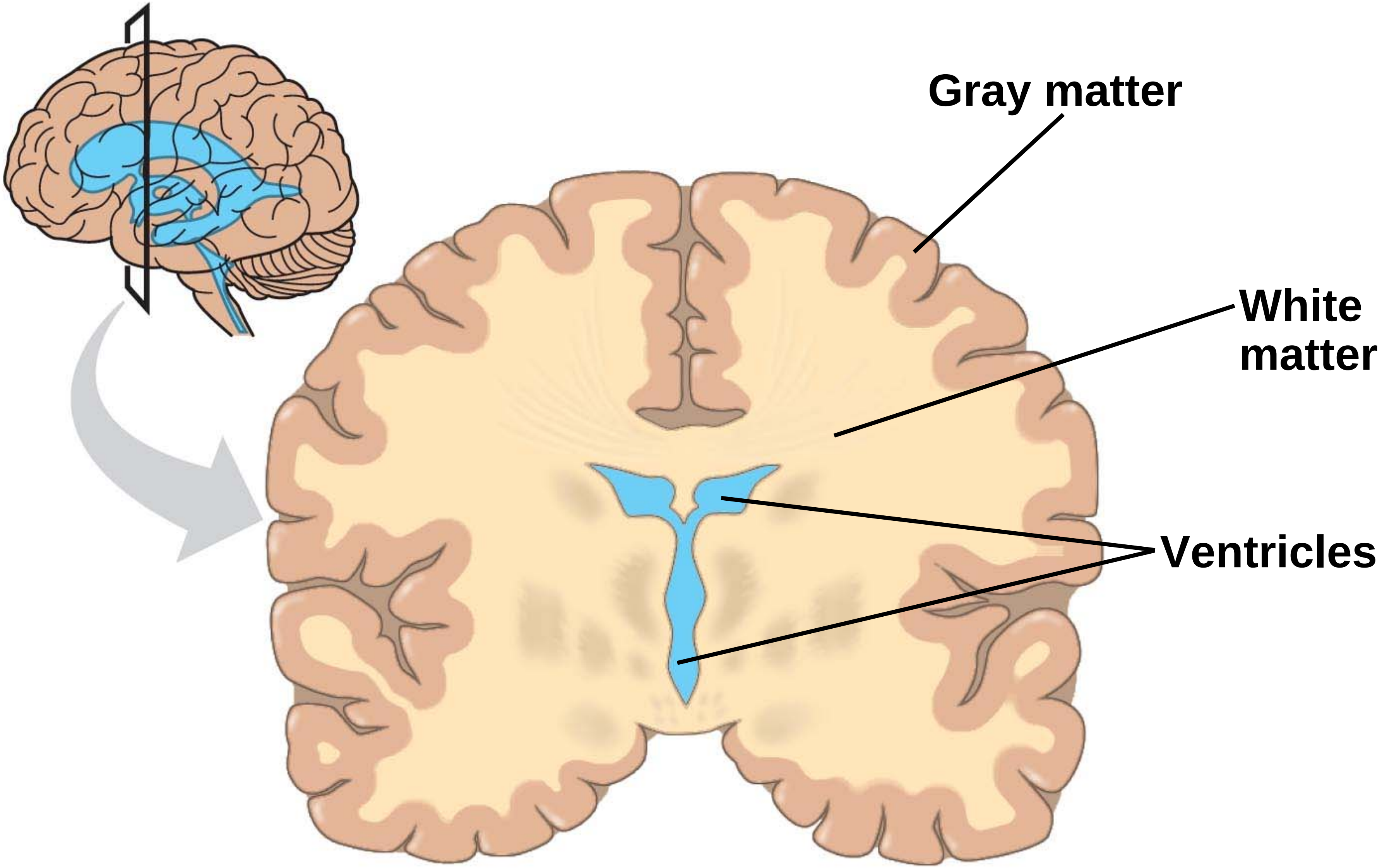
- Invertebrates usually have a ventral nerve cord while vertebrates have a dorsal spinal cord
- The spinal cord and brain develop from the embryonic nerve cord

Fig. 49-4



Central nervous system (CNS)
Peripheral nervous system (PNS)
Brain
Spinal cord
Cranial nerves
Ganglia outside CNS
Spinal nerves

Fig. 49-5



- The **central canal** of the spinal cord and the **ventricles** of the brain are hollow and filled with **cerebrospinal fluid**
- The cerebrospinal fluid is filtered from blood and functions to cushion the brain and spinal cord

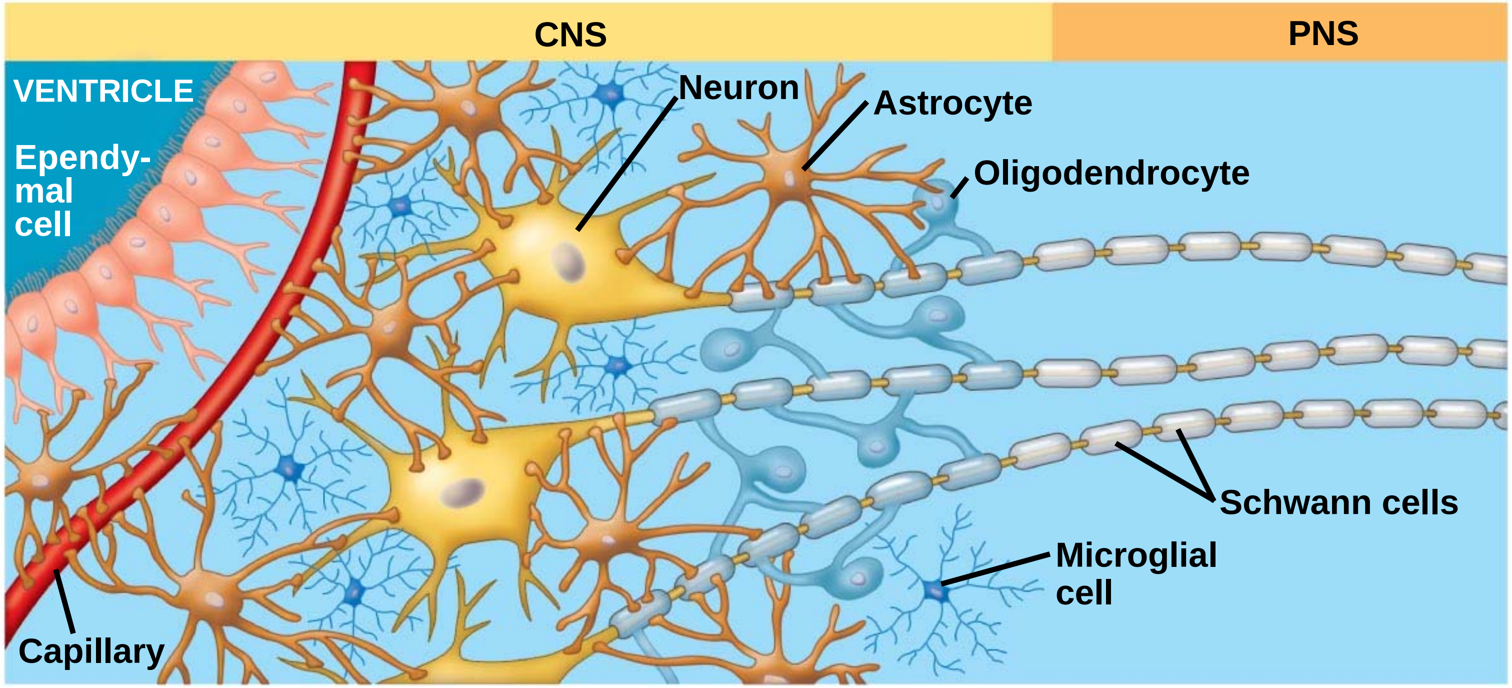
- The brain and spinal cord contain
  - **Gray matter**, which consists of neuron cell bodies, dendrites, and unmyelinated axons
  - **White matter**, which consists of bundles of myelinated axons

Glia in the CNS

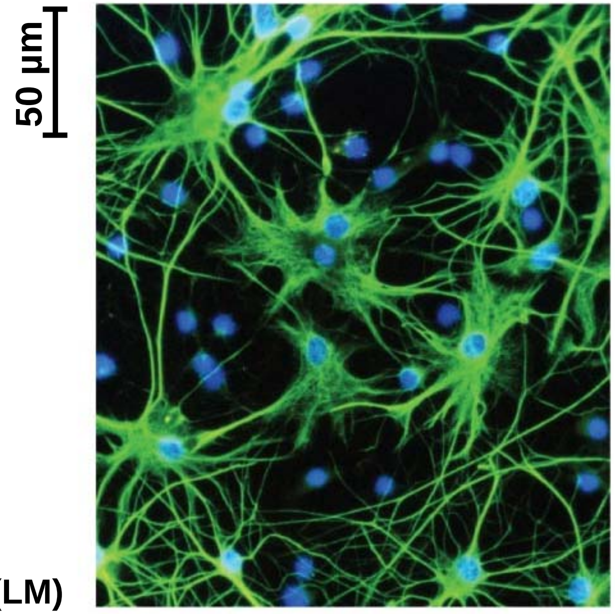
- Glia have numerous functions
  - Ependymal cells promote circulation of cerebrospinal fluid
  - Microglia protect the nervous system from microorganisms
  - Oligodendrocytes and Schwann cells form the myelin sheaths around axons

- Glia have numerous functions
  - **Astrocytes** provide structural support for neurons, regulate extracellular ions and neurotransmitters, and induce the formation of a **blood-brain barrier** that regulates the chemical environment of the CNS
  - **Radial glia** play a role in the embryonic development of the nervous system

Fig. 49-6

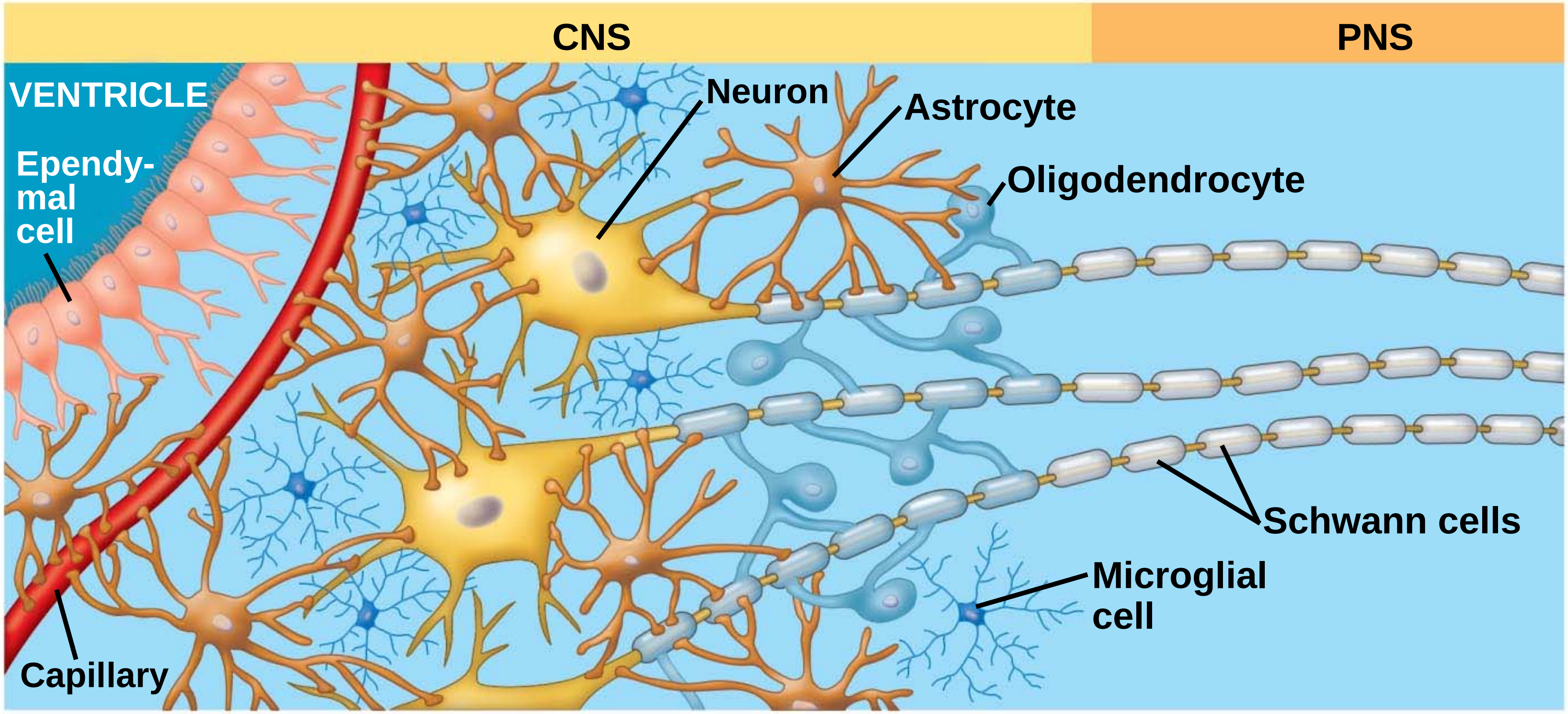


(a) Glia in vertebrates



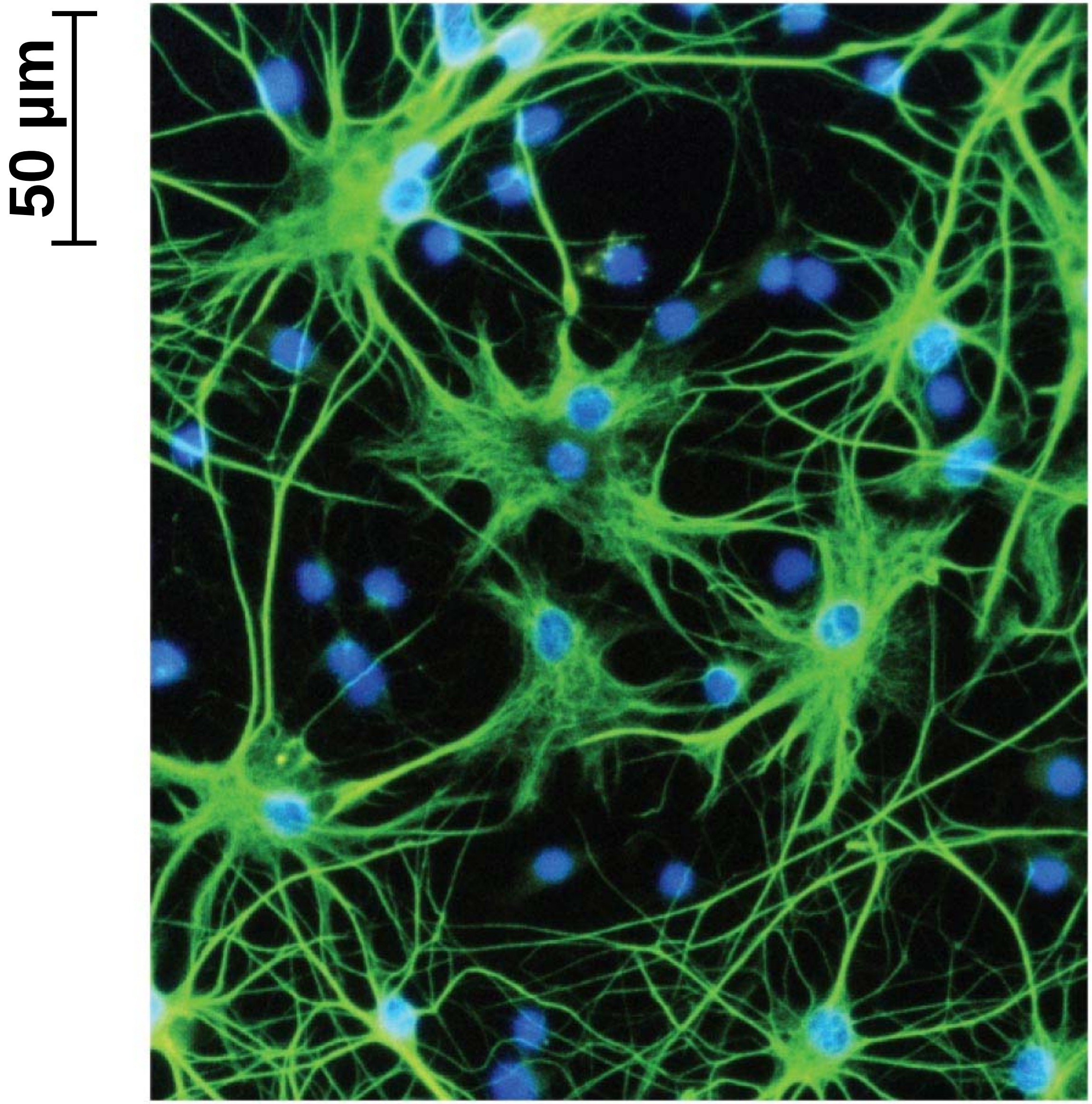
(b) Astrocytes (LM)

Fig. 49-6a



(a) Glia in vertebrates

Fig. 49-6b



(b) Astrocytes (LM)

The Peripheral Nervous System

- The PNS transmits information to and from the CNS and regulates movement and the internal environment
- In the PNS, *afferent* neurons transmit information to the CNS and *efferent* neurons transmit information away from the CNS
- **Cranial nerves** originate in the brain and mostly terminate in organs of the head and upper body
- **Spinal nerves** originate in the spinal cord and extend to parts of the body below the head

Fig. 49-7-1

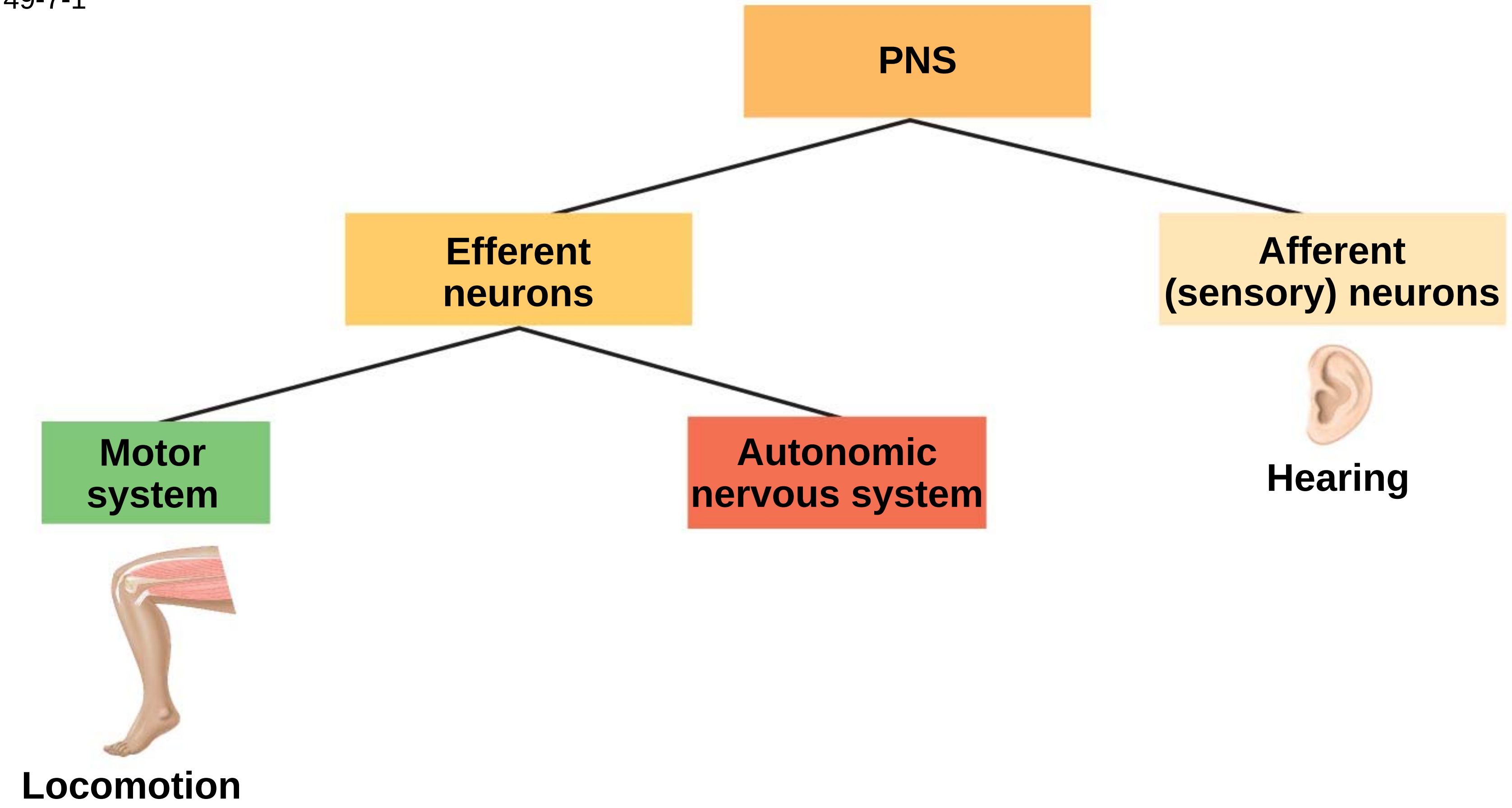
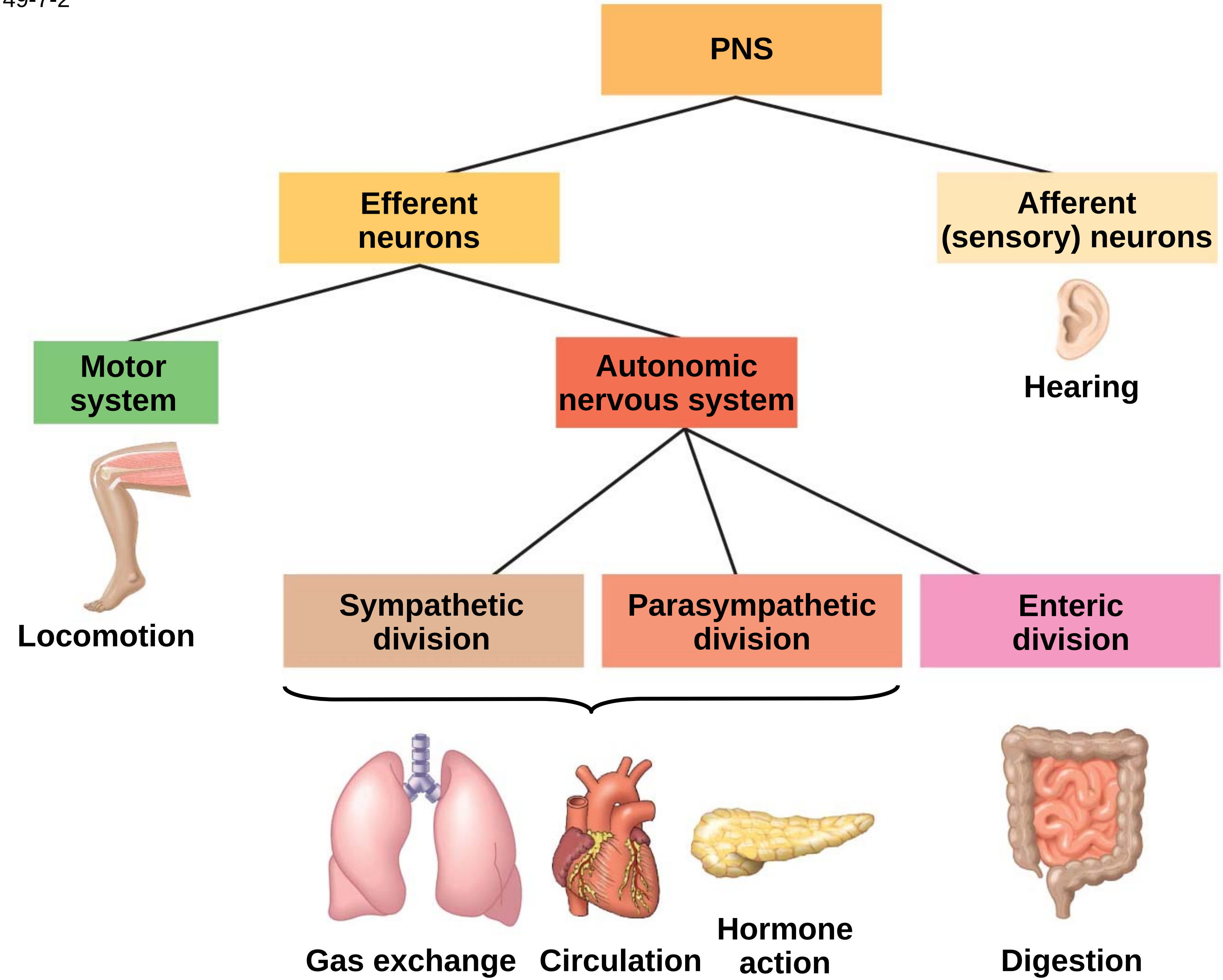

PNS
Efferent neurons
Afferent (sensory) neurons
Motor system
Autonomic nervous system
Hearing
Locomotion

Fig. 49-7-2

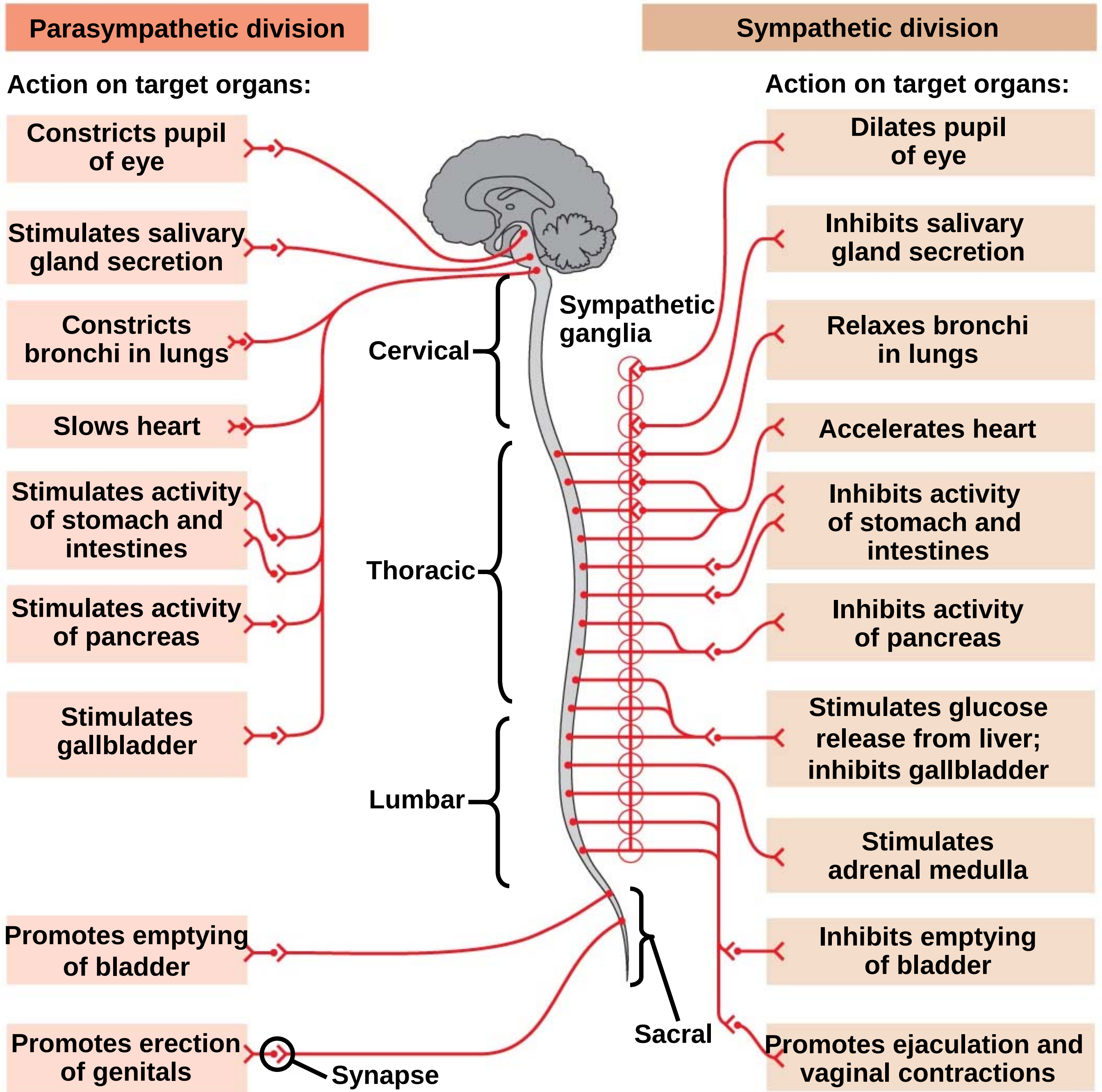

PNS
Efferent neurons
Afferent (sensory) neurons
Hearing
Motor system
Autonomic nervous system
Locomotion
Sympathetic division
Parasympathetic division
Enteric division
Gas exchange
Circulation
Hormone action
Digestion

- The PNS has two functional components: the motor system and the autonomic nervous system
- The **motor system** carries signals to skeletal muscles and is voluntary
- The **autonomic nervous system** regulates the internal environment in an involuntary manner

- The autonomic nervous system has sympathetic, parasympathetic, and enteric divisions
- The sympathetic and parasympathetic divisions have antagonistic effects on target organs

- The **sympathetic division** correlates with the “fight-or-flight” response
- The **parasympathetic division** promotes a return to “rest and digest”
- The **enteric division** controls activity of the digestive tract, pancreas, and gallbladder

Fig. 49-8



Parasympathetic division
Sympathetic division
Action on target organs:
Constricts pupil of eye
Stimulates salivary gland secretion
Constricts bronchi in lungs
Slows heart
Stimulates activity of stomach and intestines
Stimulates activity of pancreas
Stimulates gallbladder
Promotes emptying of bladder
Promotes erection of genitals
Synapse
Cervical
Thoracic
Lumbar
Sacral
Sympathetic ganglia
Action on target organs:
Dilates pupil of eye
Inhibits salivary gland secretion
Relaxes bronchi in lungs
Accelerates heart
Inhibits activity of stomach and intestines
Inhibits activity of pancreas
Stimulates glucose release from liver; inhibits gallbladder
Stimulates adrenal medulla
Inhibits emptying of bladder
Promotes ejaculation and vaginal contractions

Fig. 49-8a

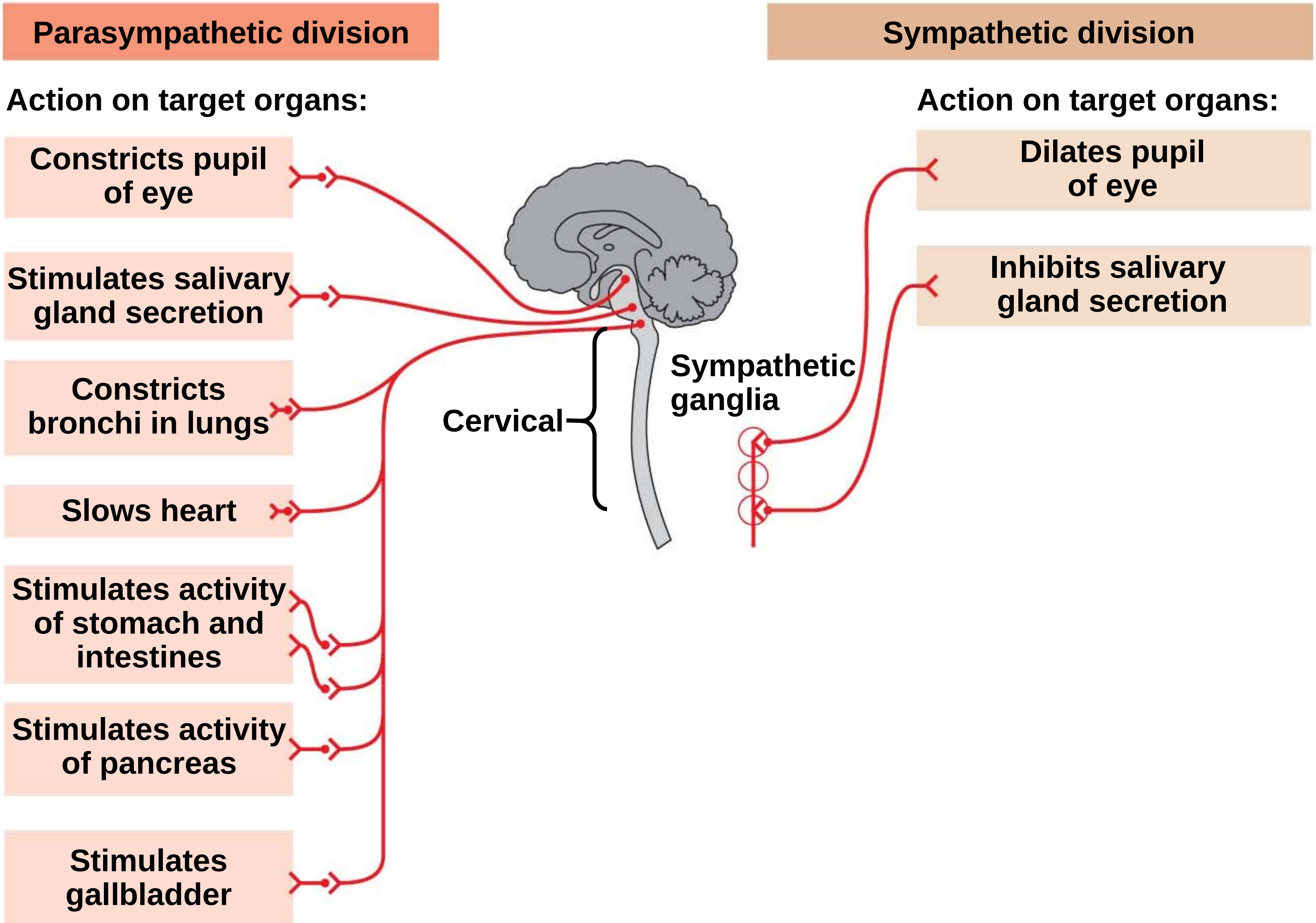
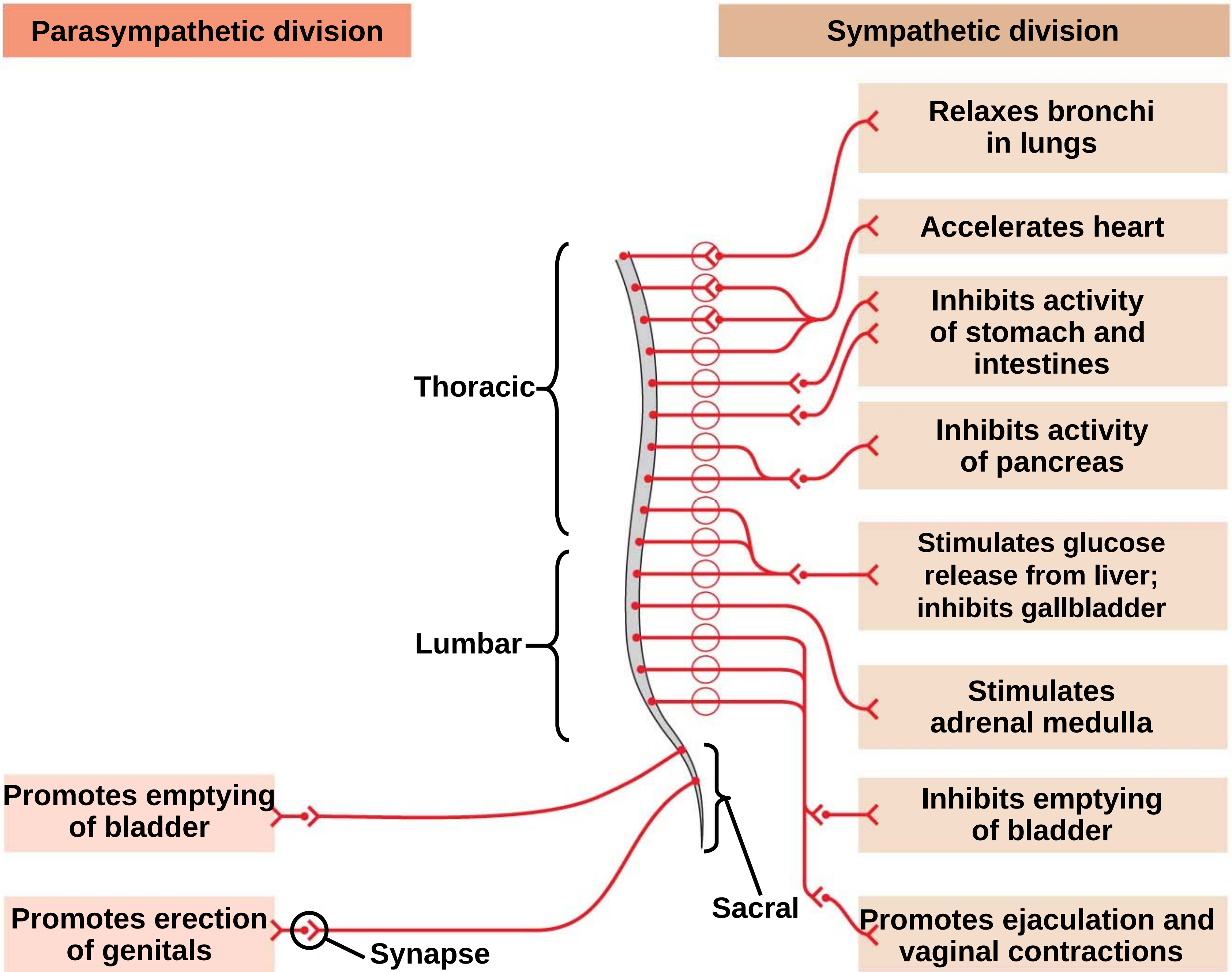

Parasympathetic division
Sympathetic division
Action on target organs:
Action on target organs:
Constricts pupil of eye
Stimulates salivary gland secretion
Constricts bronchi in lungs
Slows heart
Stimulates activity of stomach and intestines
Stimulates activity of pancreas
Stimulates gallbladder
Cervical
Sympathetic ganglia
Dilates pupil of eye
Inhibits salivary gland secretion

Fig. 49-8b



Parasympathetic division
Sympathetic division
Relaxes bronchi in lungs
Accelerates heart
Inhibits activity of stomach and intestines
Inhibits activity of pancreas
Stimulates glucose release from liver; inhibits gallbladder
Stimulates adrenal medulla
Inhibits emptying of bladder
Promotes ejaculation and vaginal contractions
Thoracic
Lumbar
Sacral
Promotes emptying of bladder
Promotes erection of genitals
Synapse

Table 49-1

Table 49.1 Properties of Parasympathetic and Sympathetic Neurons

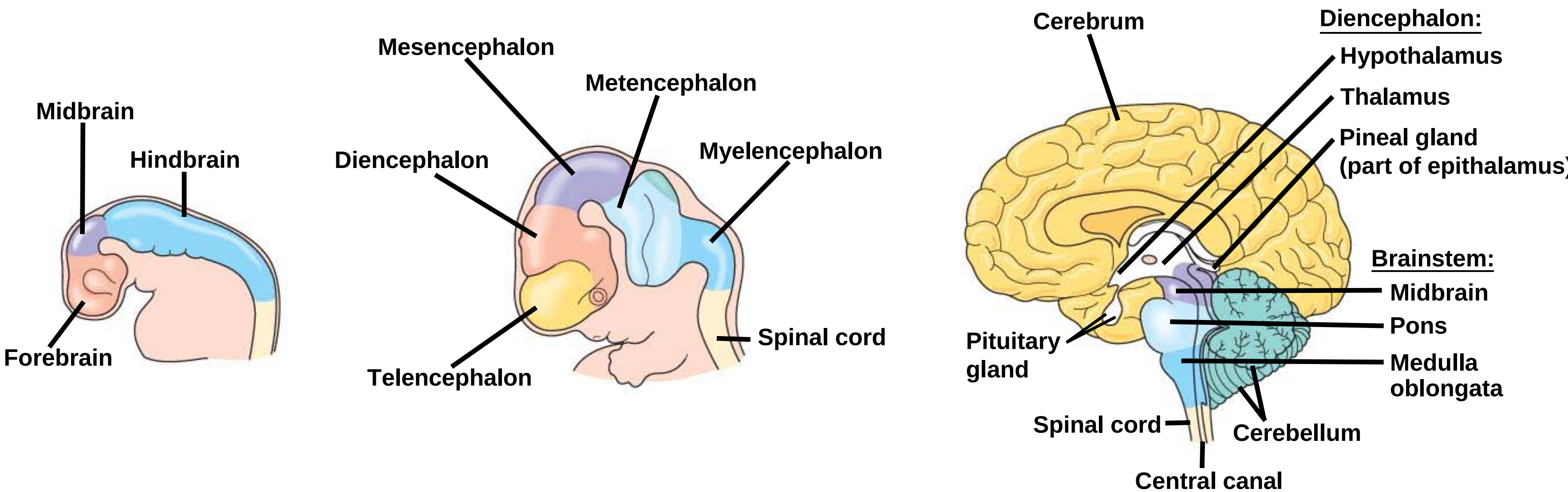
	Parasympathetic Division	Sympathetic Division
Preganglionic Neurons		
Location	Brainstem, sacral segments of spinal cord	Thoracic and lumbar segments of spinal cord
Neurotransmitter released	Acetylcholine	Acetylcholine
Postganglionic Neurons		
Location	Ganglia close to or within target organs	Ganglia close to target organs or chain of ganglia near spinal cord
Neurotransmitter released	Acetylcholine	Norepinephrine

Concept 49.2: The vertebrate brain is regionally specialized

- All vertebrate brains develop from three embryonic regions: **forebrain**, **midbrain**, and **hindbrain**
- By the fifth week of human embryonic development, five brain regions have formed from the three embryonic regions

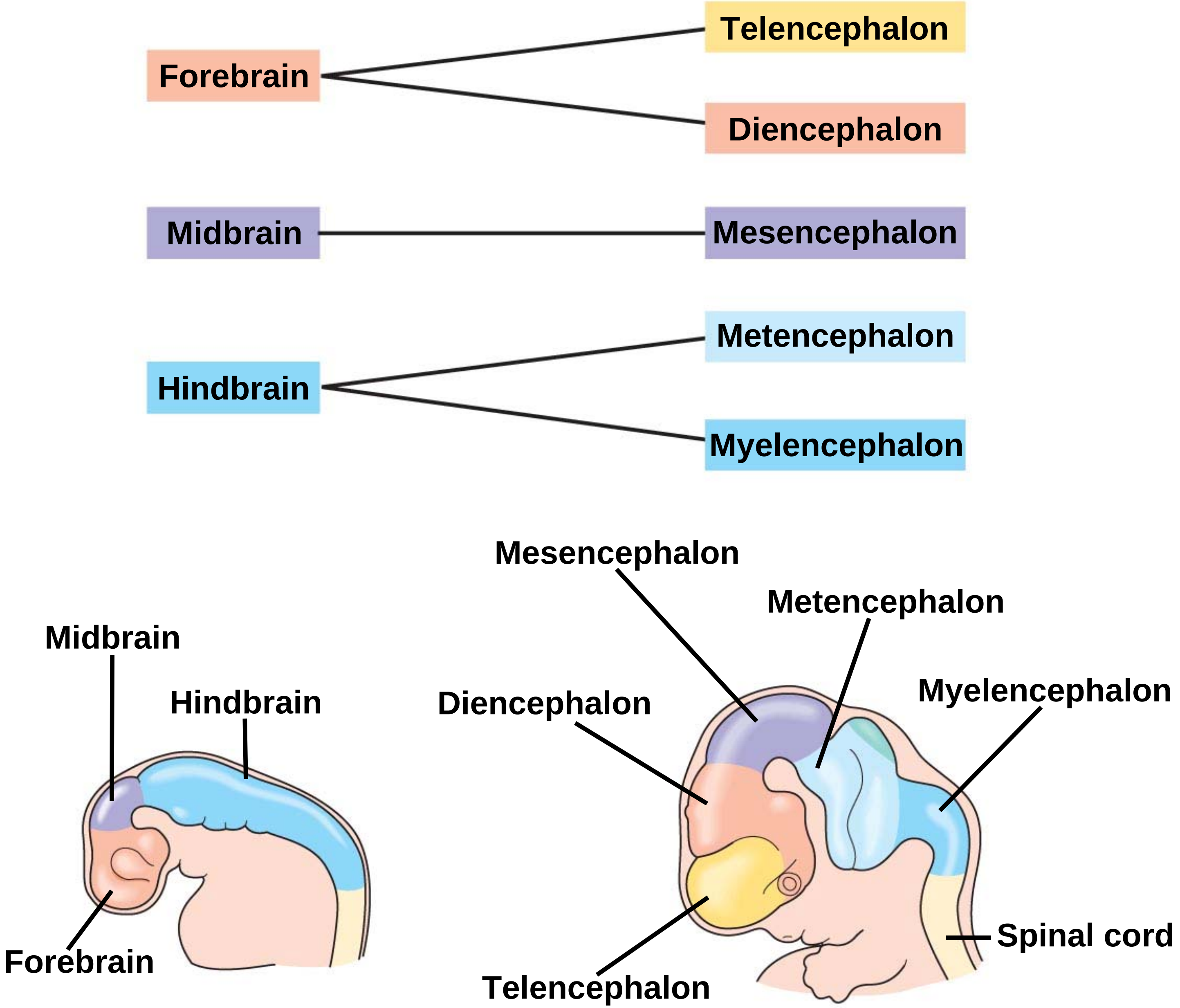
Fig. 49-9

Forebrain	Telencephalon	Cerebrum (includes cerebral cortex, white matter, basal nuclei)
	Diencephalon	Diencephalon (thalamus, hypothalamus, epithalamus)
Midbrain	Mesencephalon	Midbrain (part of brainstem)
Hindbrain	Metencephalon	Pons (part of brainstem), cerebellum
	Myelencephalon	Medulla oblongata (part of brainstem)



(a) Embryo at 1 month (b) Embryo at 5 weeks (c) Adult

Fig. 49-9ab



(a) Embryo at 1 month (b) Embryo at 5 weeks

Fig. 49-9c

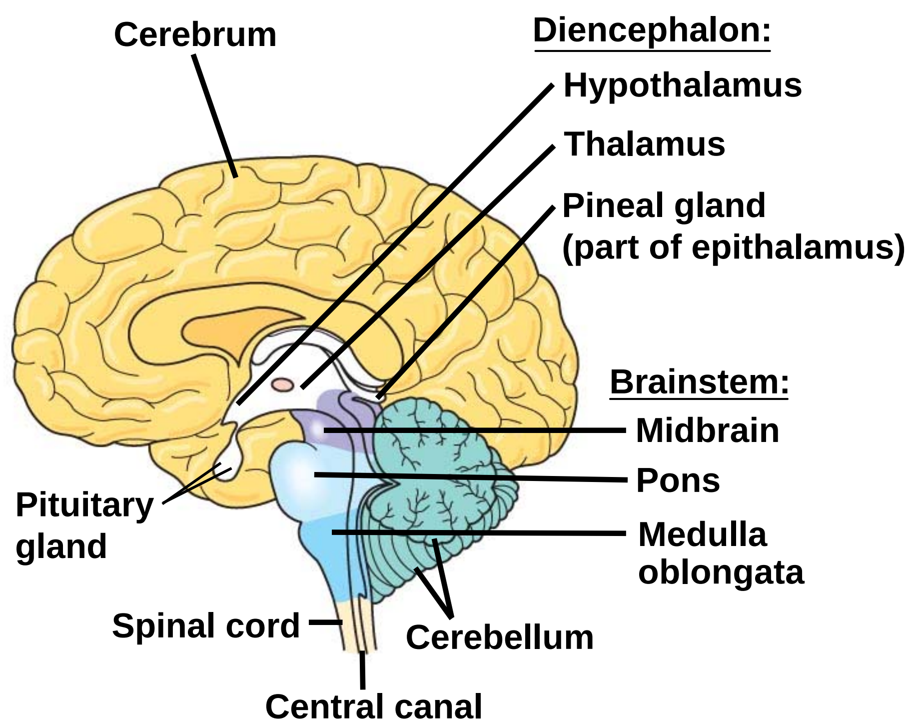
Cerebrum (includes cerebral cortex, white matter, basal nuclei)

Diencephalon (thalamus, hypothalamus, epithalamus)

Midbrain (part of brainstem)

Pons (part of brainstem), cerebellum

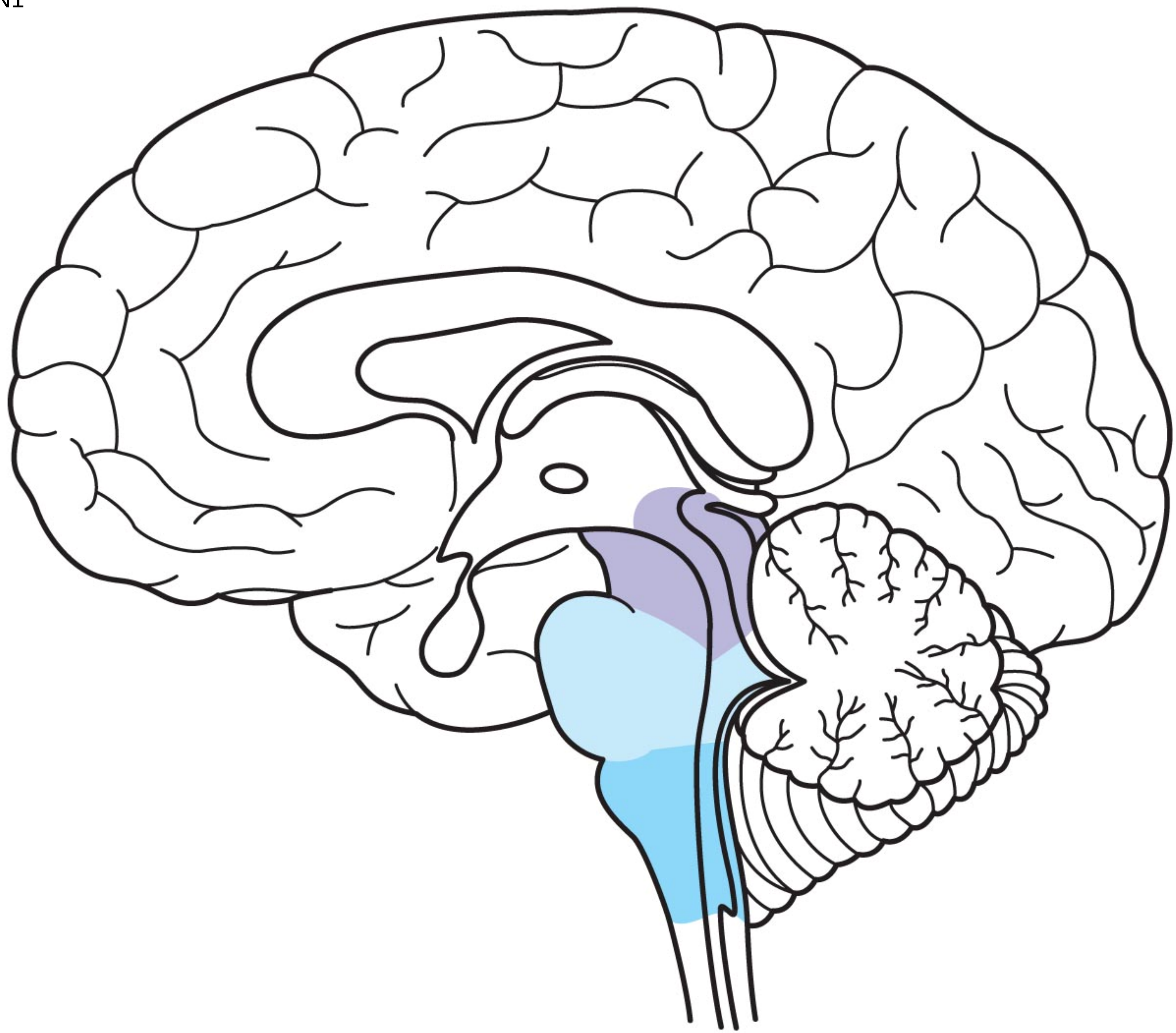
Medulla oblongata (part of brainstem)



(c) Adult

- As a human brain develops further, the most profound change occurs in the forebrain, which gives rise to the **cerebrum**
- The outer portion of the cerebrum called the **cerebral cortex** surrounds much of the brain

Fig. 49-UN1



The Brainstem

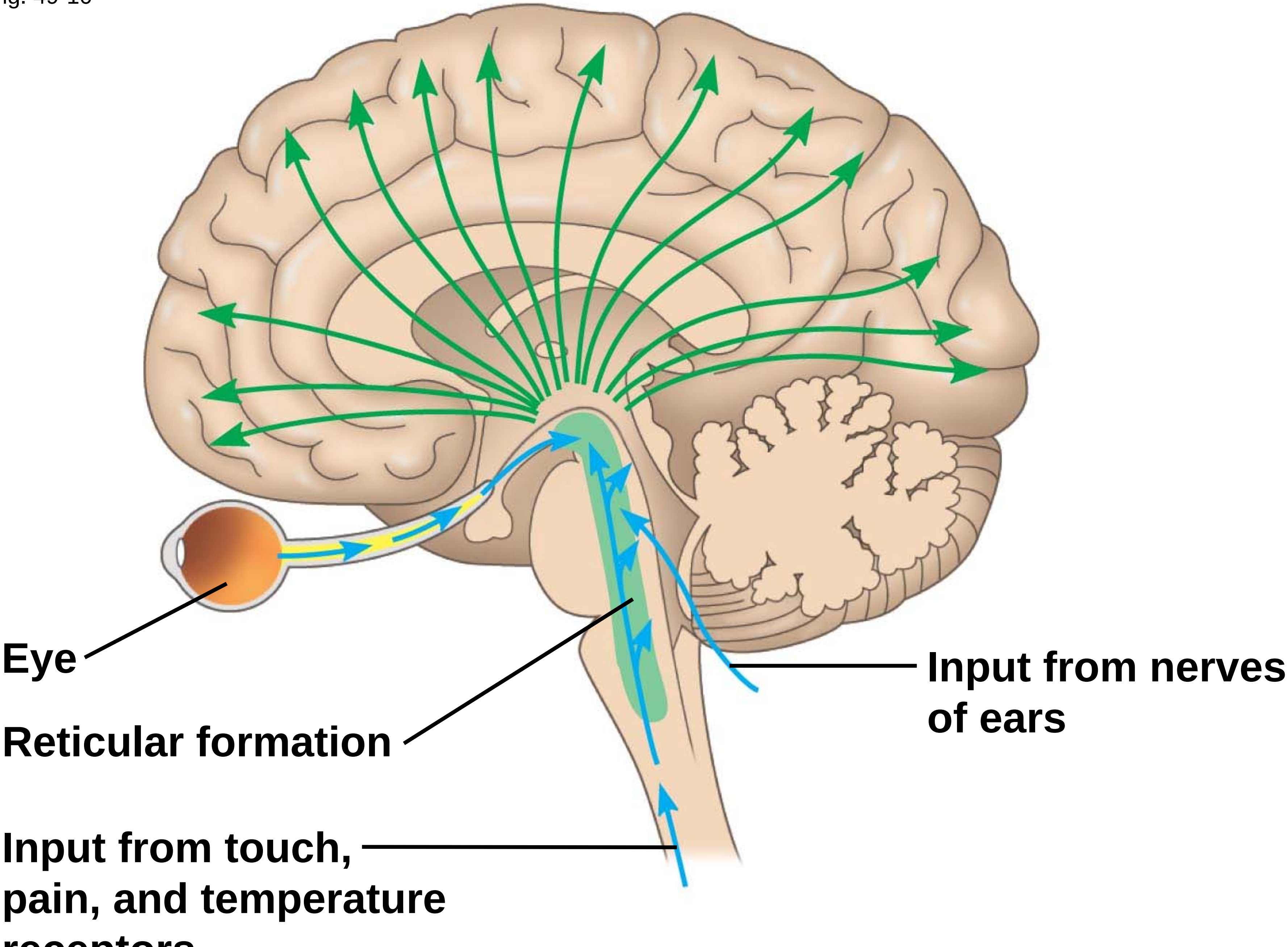
- The **brainstem** coordinates and conducts information between brain centers
- The brainstem has three parts: the midbrain, the **pons**, and the **medulla oblongata**

- The midbrain contains centers for receipt and integration of sensory information
- The pons regulates breathing centers in the medulla
- The medulla oblongata contains centers that control several functions including breathing, cardiovascular activity, swallowing, vomiting, and digestion

Arousal and Sleep

- The brainstem and cerebrum control arousal and sleep
- The core of the brainstem has a diffuse network of neurons called the **reticular formation**
- This regulates the amount and type of information that reaches the cerebral cortex and affects alertness
- The hormone melatonin is released by the pineal gland and plays a role in bird and mammal sleep cycles

Fig. 49-10


Eye
Reticular formation
Input from touch, pain, and temperature receptors
Input from nerves of ears

- Sleep is essential and may play a role in the consolidation of learning and memory
- Dolphins sleep with one brain hemisphere at a time and are therefore able to swim while "asleep"

Fig. 49-11

Key

 **Low-frequency waves characteristic of sleep**

 **High-frequency waves characteristic of wakefulness**

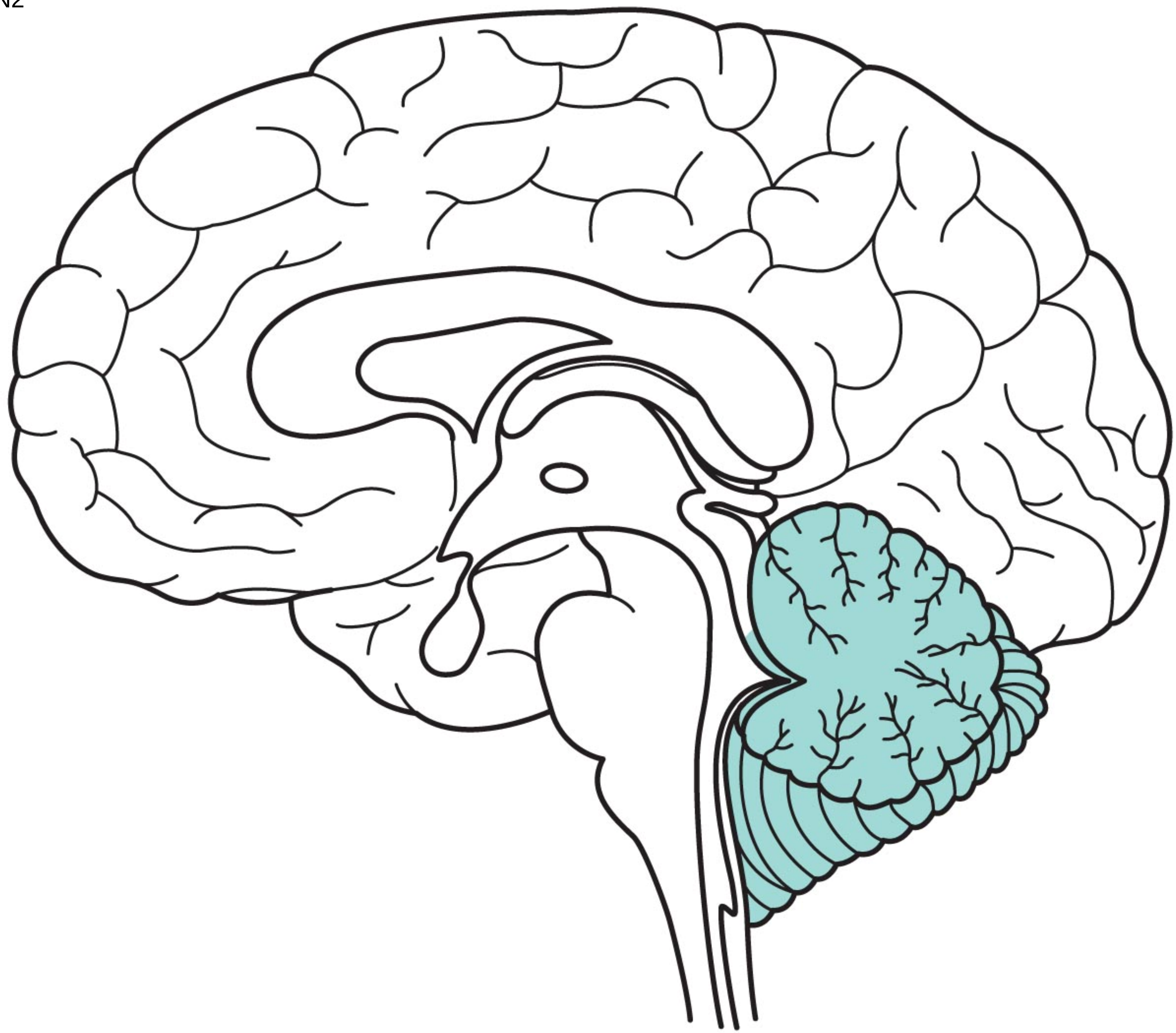
Location	Time: 0 hours	Time: 1 hour
Left hemisphere		
Right hemisphere		

The Cerebellum

- The **cerebellum** is important for coordination and error checking during motor, perceptual, and cognitive functions

- It is also involved in learning and remembering motor skills

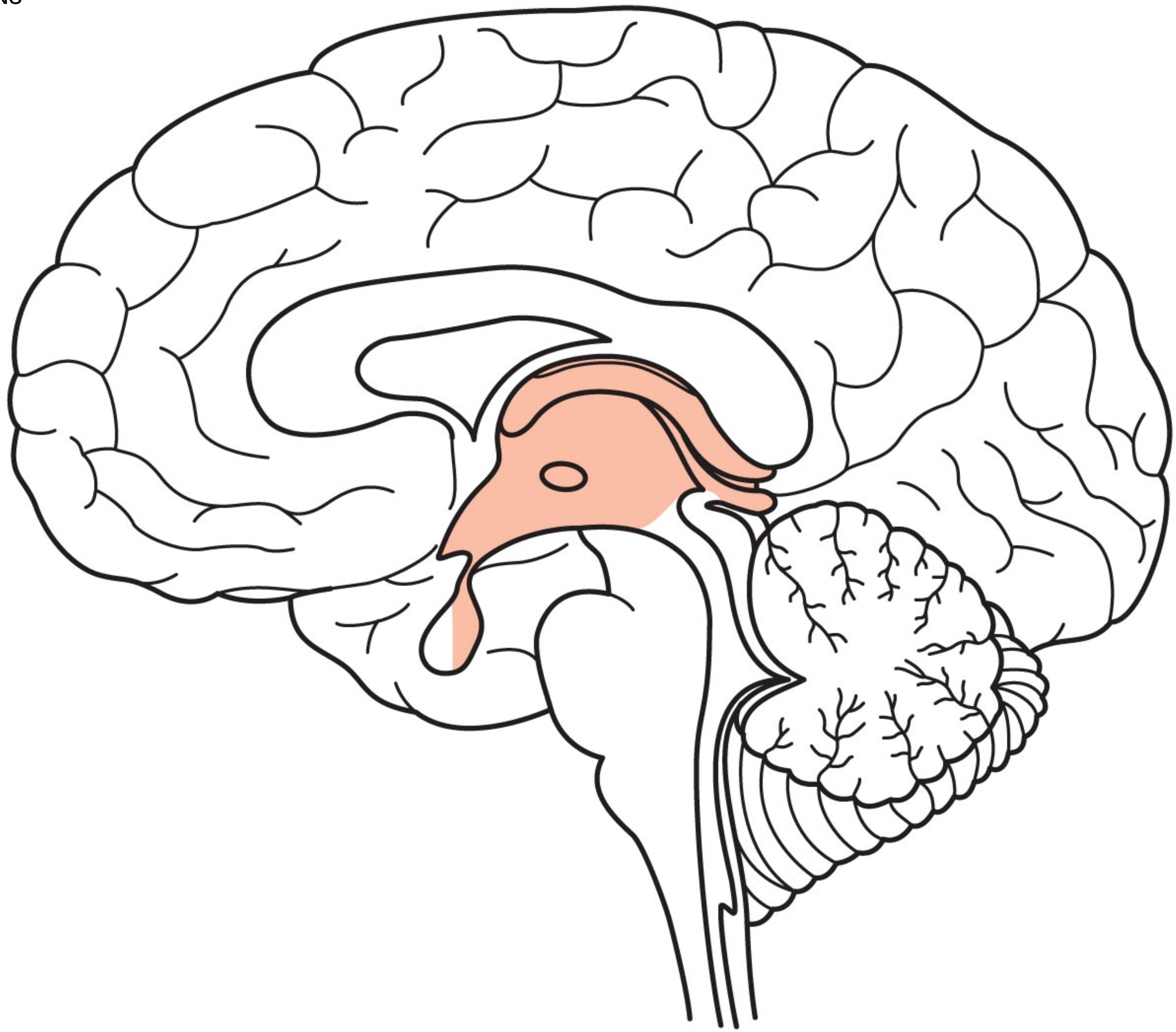
Fig. 49-UN2



The Diencephalon

- The diencephalon develops into three regions: the epithalamus, thalamus, and hypothalamus
- The *epithalamus* includes the pineal gland and generates cerebrospinal fluid from blood
- The **thalamus** is the main input center for sensory information to the cerebrum and the main output center for motor information leaving the cerebrum
- The **hypothalamus** regulates homeostasis and basic survival behaviors such as feeding, fighting, fleeing, and reproducing

Fig. 49-UN3

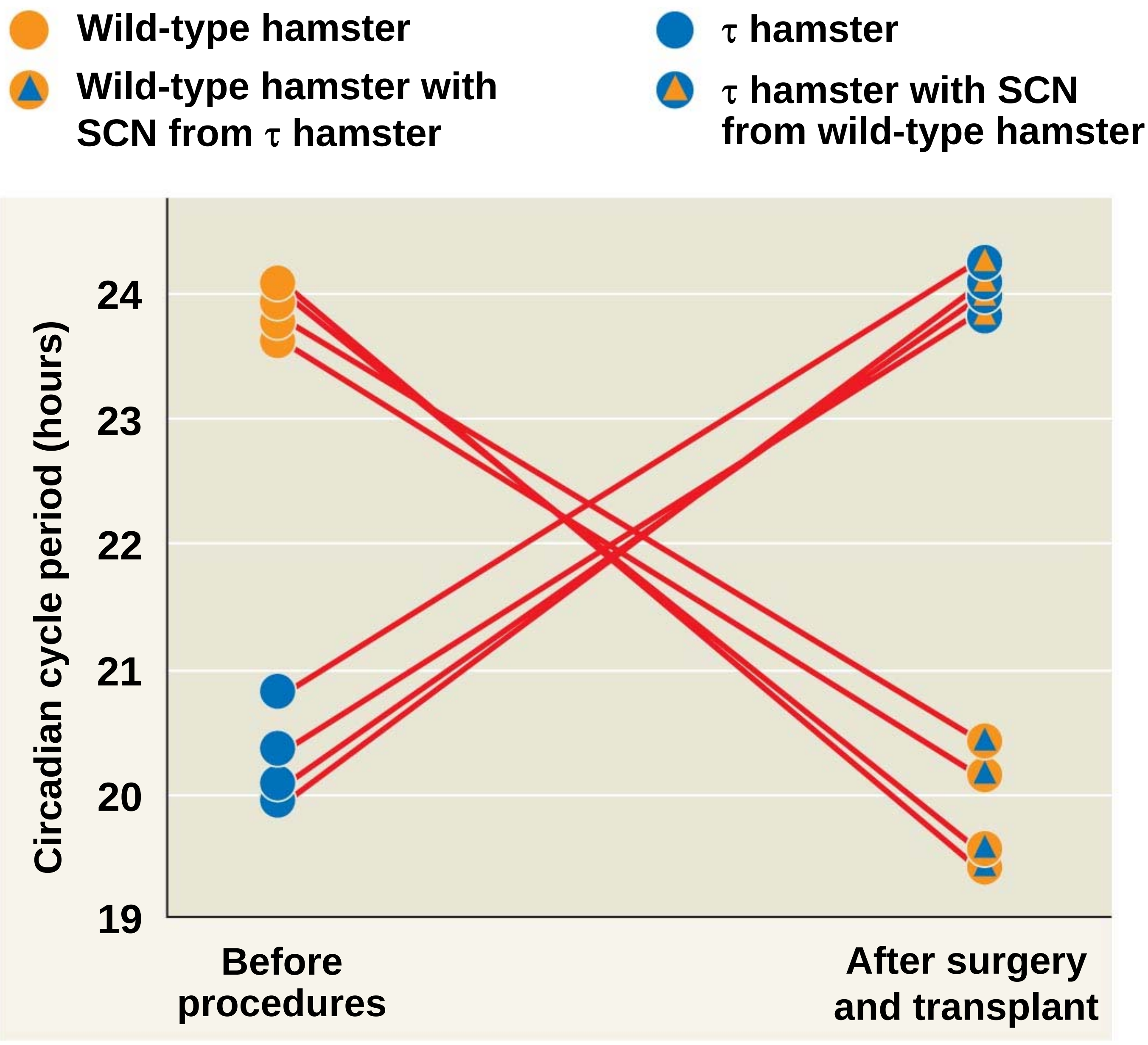


Biological Clock Regulation by the Hypothalamus

- The hypothalamus also regulates circadian rhythms such as the sleep/wake cycle
- Mammals usually have a pair of **suprachiasmatic nuclei** (**SCN**) in the hypothalamus that function as a **biological clock**
- Biological clocks usually require external cues to remain synchronized with environmental cycles

Fig. 49-12

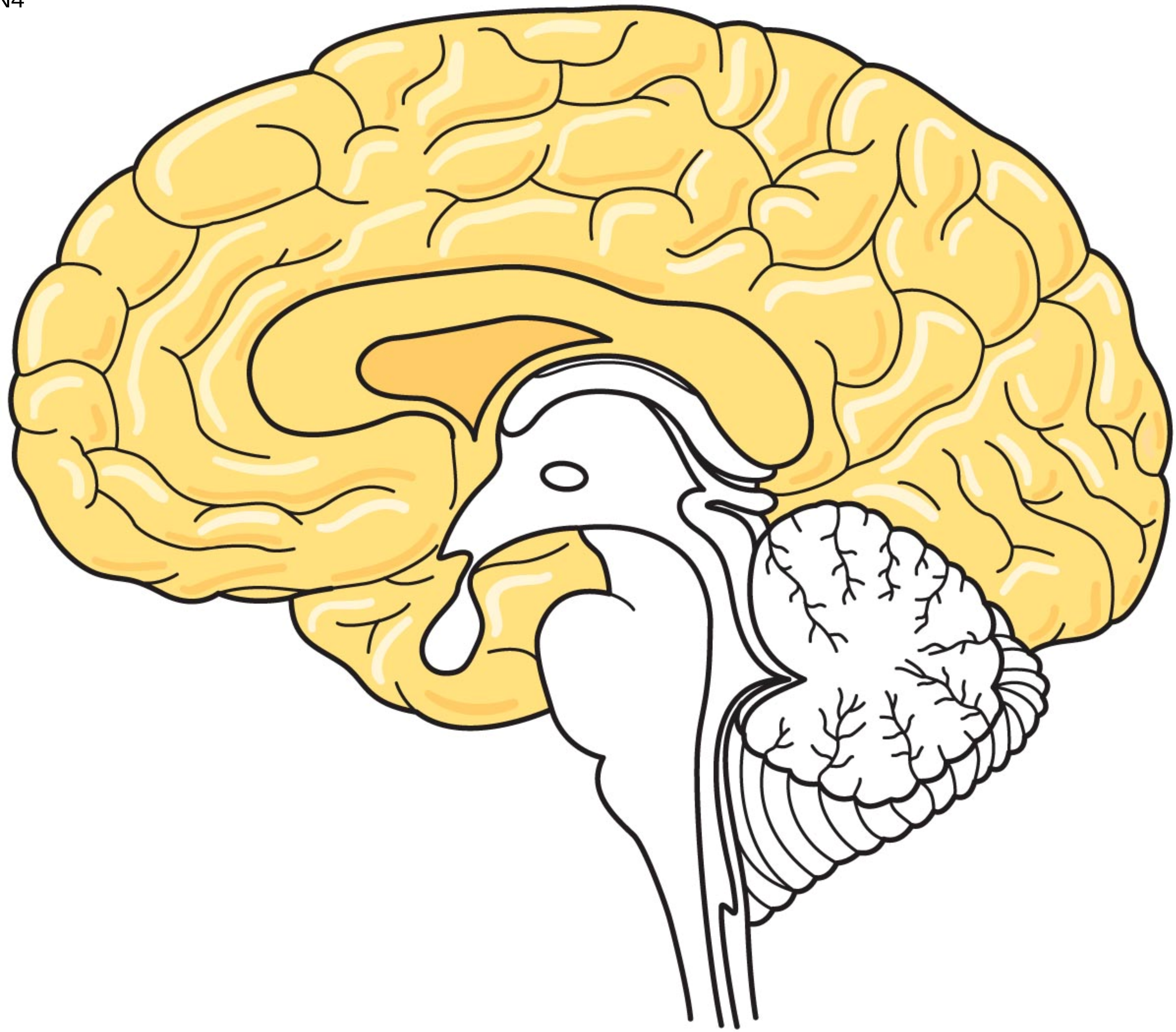
RESULTS



The Cerebrum

- The cerebrum develops from the embryonic telencephalon

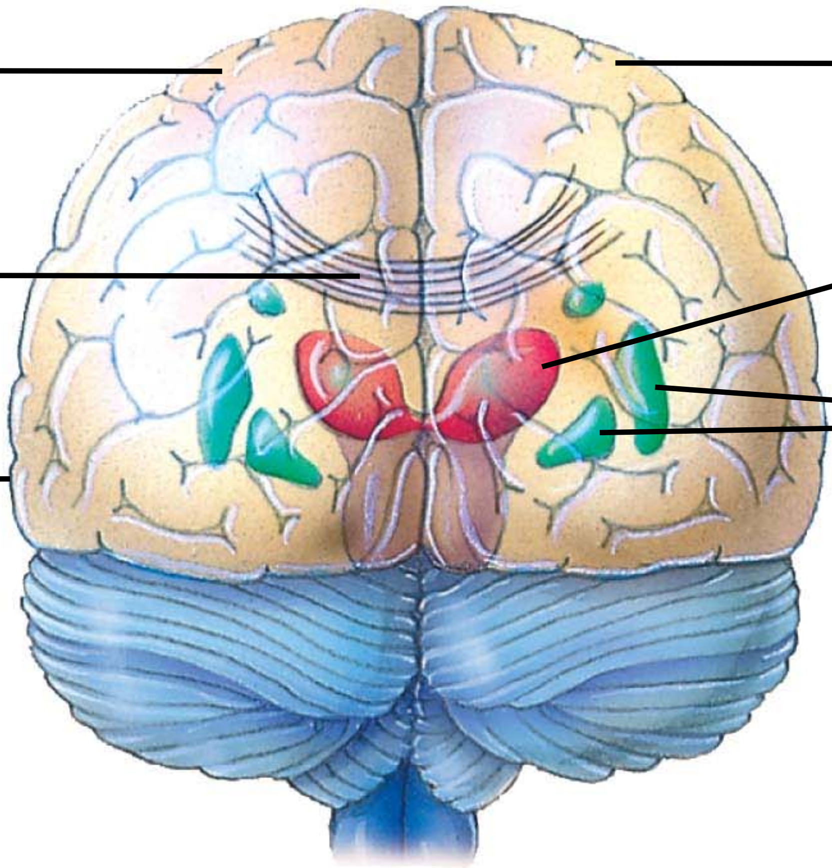
Fig. 49-UN4



- The cerebrum has right and left **cerebral hemispheres**
- Each cerebral hemisphere consists of a cerebral cortex (gray matter) overlying white matter and basal nuclei
- In humans, the cerebral cortex is the largest and most complex part of the brain
- The basal nuclei are important centers for planning and learning movement sequences

- A thick band of axons called the **corpus callosum** provides communication between the right and left cerebral cortices
- The right half of the cerebral cortex controls the left side of the body, and vice versa

Fig. 49-13

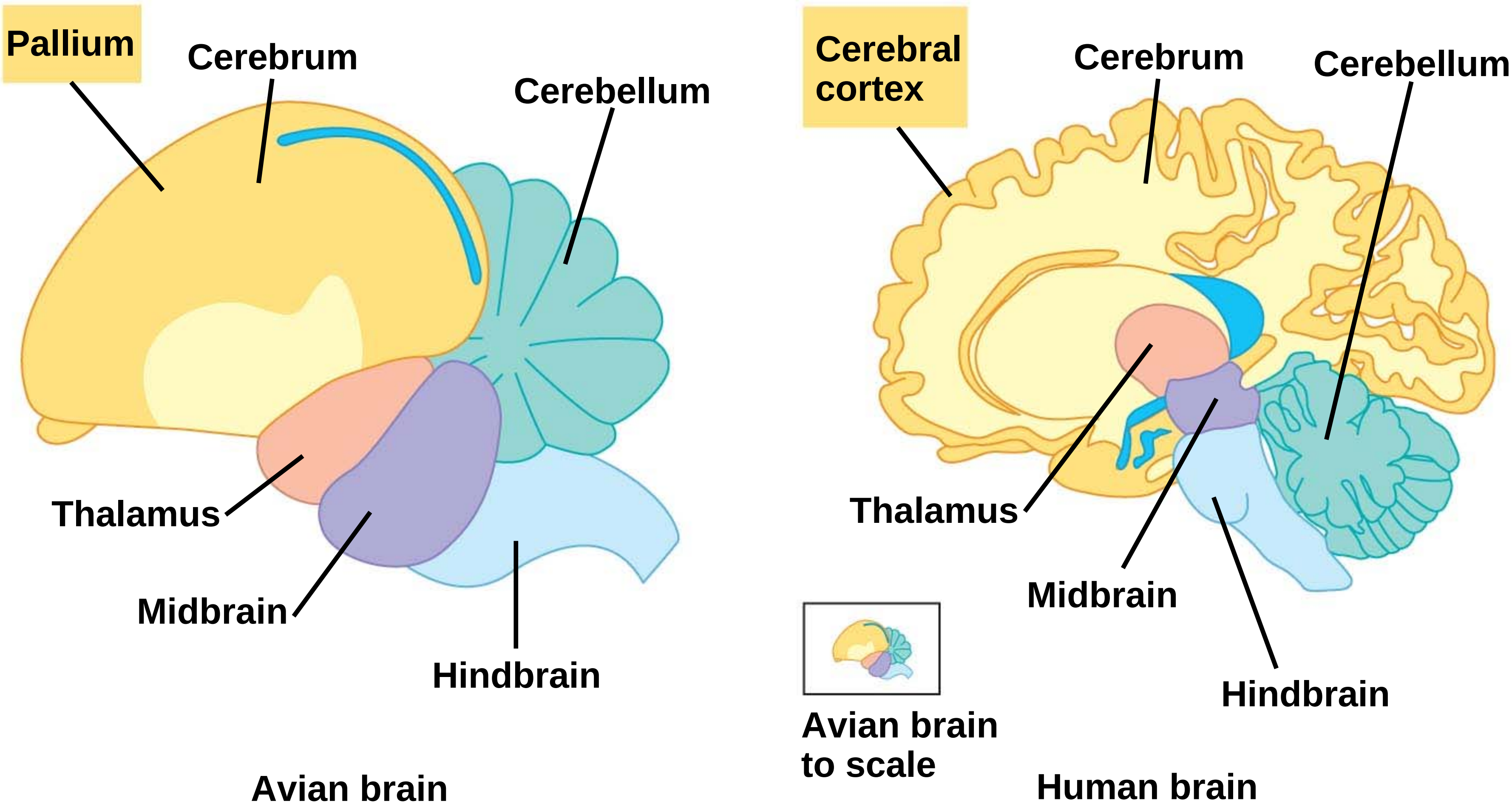


Left cerebral hemisphere
Right cerebral hemisphere
Corpus callosum
Thalamus
Basal nuclei
Cerebral cortex

Evolution of Cognition in Vertebrates

- The outermost layer of the cerebral cortex has a different arrangement in birds and mammals
- In mammals, the cerebral cortex has a convoluted surface called the *neocortex*, which was previously thought to be required for cognition
- Cognition is the perception and reasoning that form knowledge
- However, it has recently been shown that birds also demonstrate cognition even though they lack a neocortex

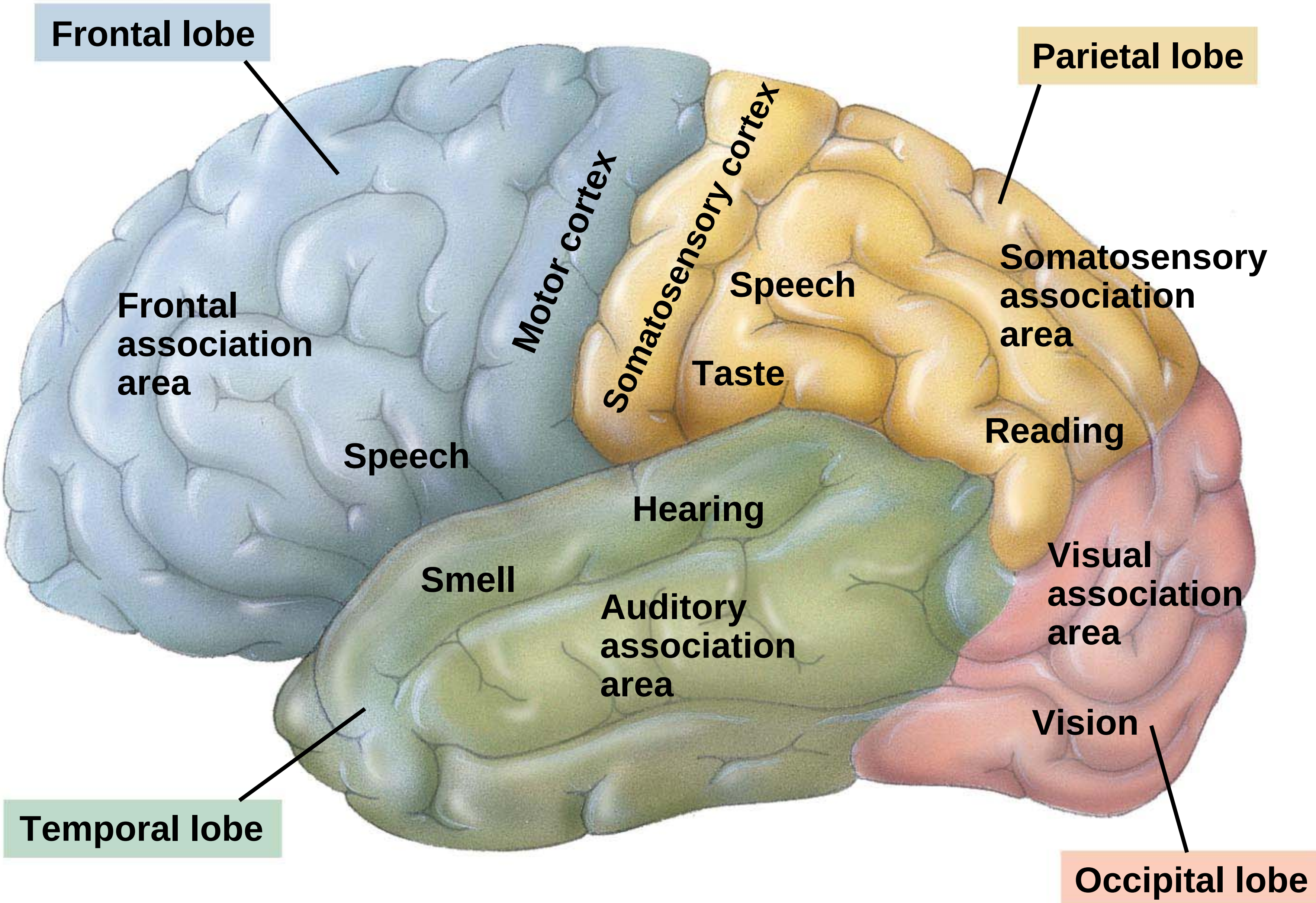
Fig. 49-14


Pallium
Cerebrum
Cerebellum
Thalamus
Midbrain
Hindbrain
Avian brain
Cerebral cortex
Cerebrum
Cerebellum
Thalamus
Midbrain
Hindbrain
Avian brain to scale
Human brain

Concept 49.3: The cerebral cortex controls voluntary movement and cognitive functions

- Each side of the cerebral cortex has four lobes: frontal, temporal, occipital, and parietal
- Each lobe contains primary sensory areas and association areas where information is integrated

Fig. 49-15



Frontal lobe
Parietal lobe
Motor cortex
Somatosensory cortex
Speech
Somatosensory association area
Frontal association area
Taste
Reading
Speech
Hearing
Smell
Auditory association area
Visual association area
Vision
Temporal lobe
Occipital lobe

Information Processing in the Cerebral Cortex

- The cerebral cortex receives input from sensory organs and *somatosensory* receptors
- Specific types of sensory input enter the primary sensory areas of the brain lobes
- Adjacent areas process features in the sensory input and integrate information from different sensory areas
- In the somatosensory and motor cortices, neurons are distributed according to the body part that generates sensory input or receives motor input

Fig. 49-16

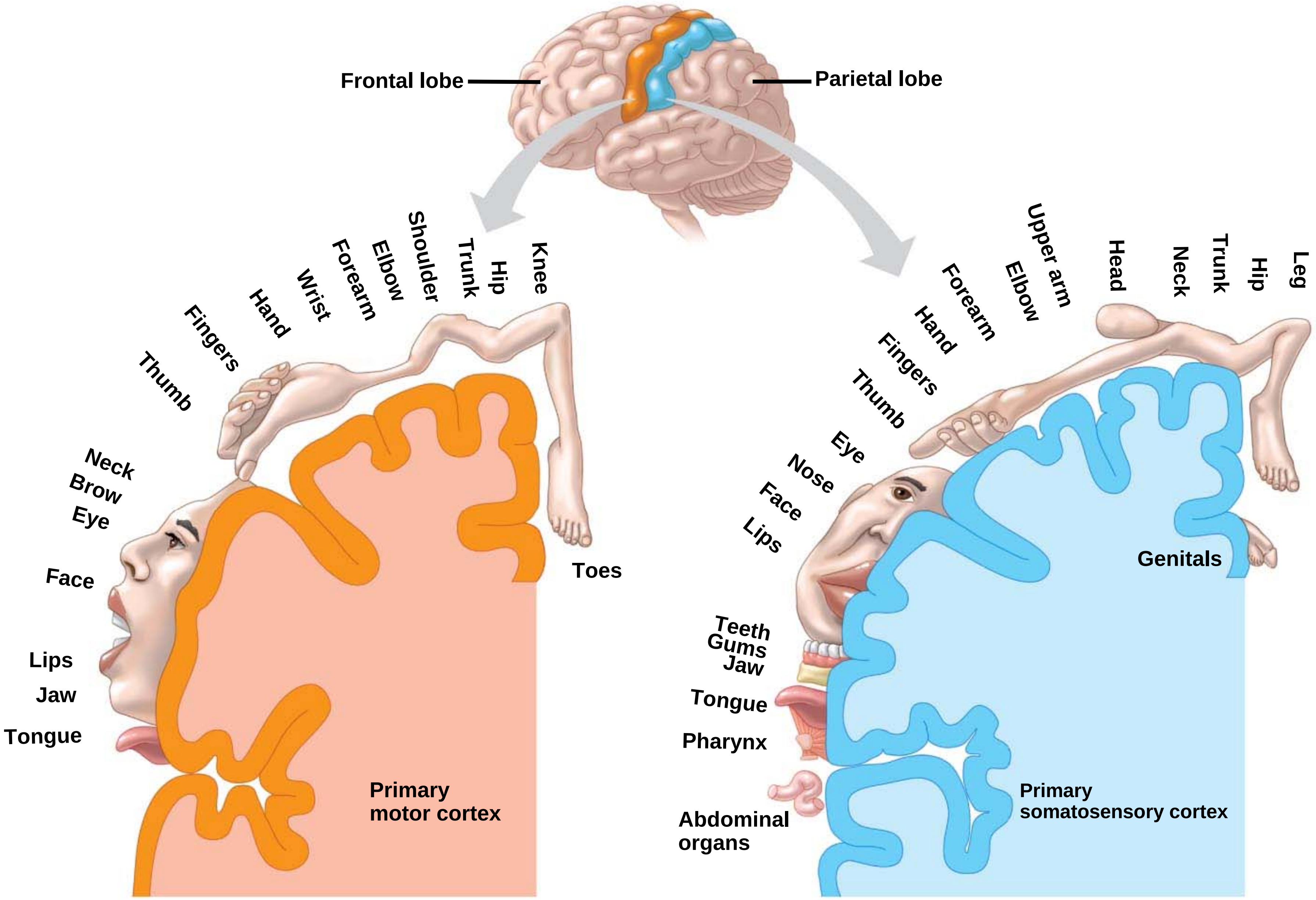

Frontal lobe
Parietal lobe
Shoulder
Elbow
Forearm
Wrist
Hand
Fingers
Thumb
Trunk
Hip
Knee
Neck
Brow
Eye
Face
Lips
Jaw
Tongue
Toes
Primary
motor cortex
Upper arm
Head
Neck
Trunk
Hip
Leg
Elbow
Forearm
Hand
Fingers
Thumb
Eye
Nose
Face
Lips
Genitals
Teeth
Gums
Jaw
Tongue
Pharynx
Abdominal
organs
Primary
somatosensory cortex

Fig. 49-16a

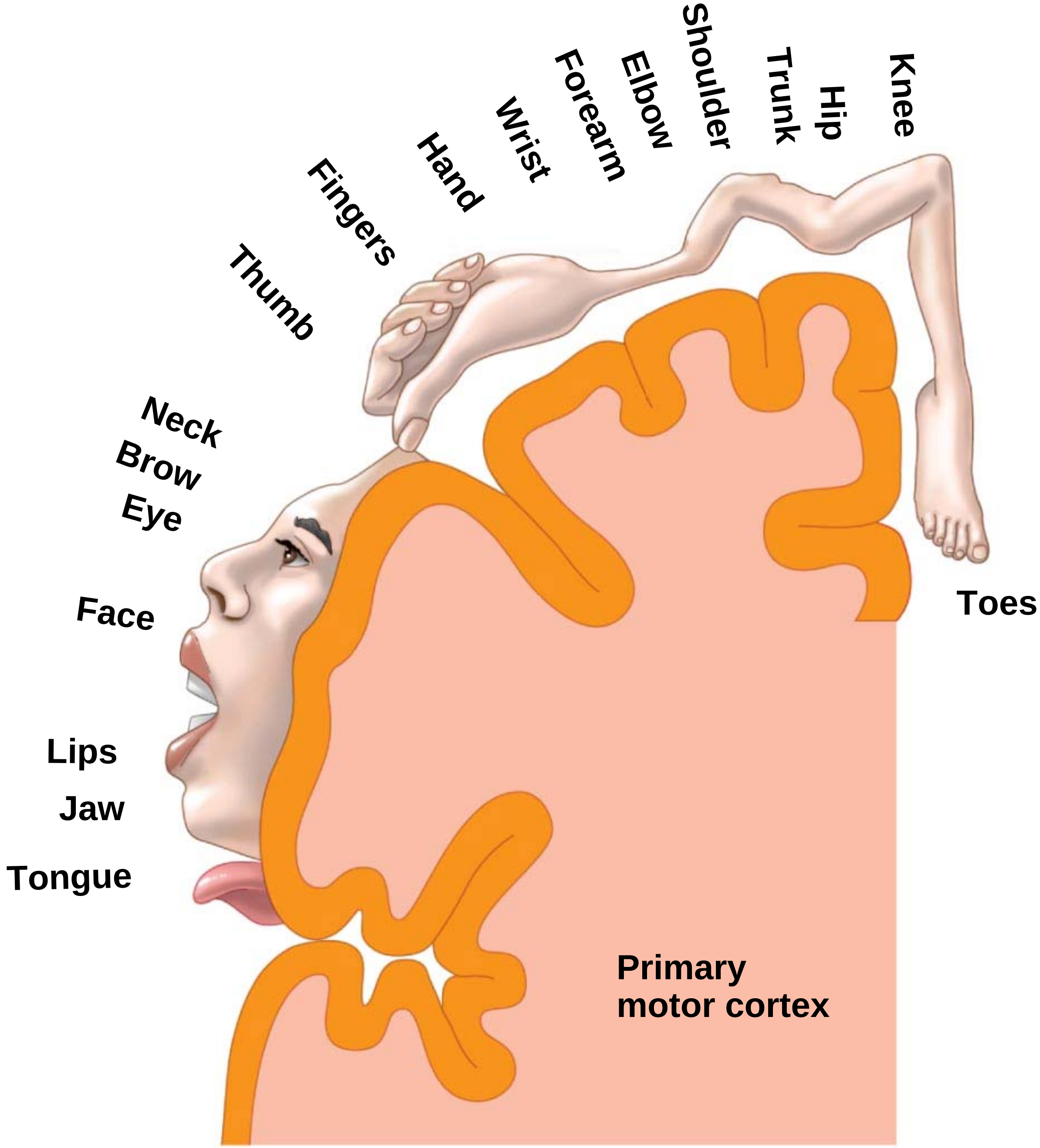
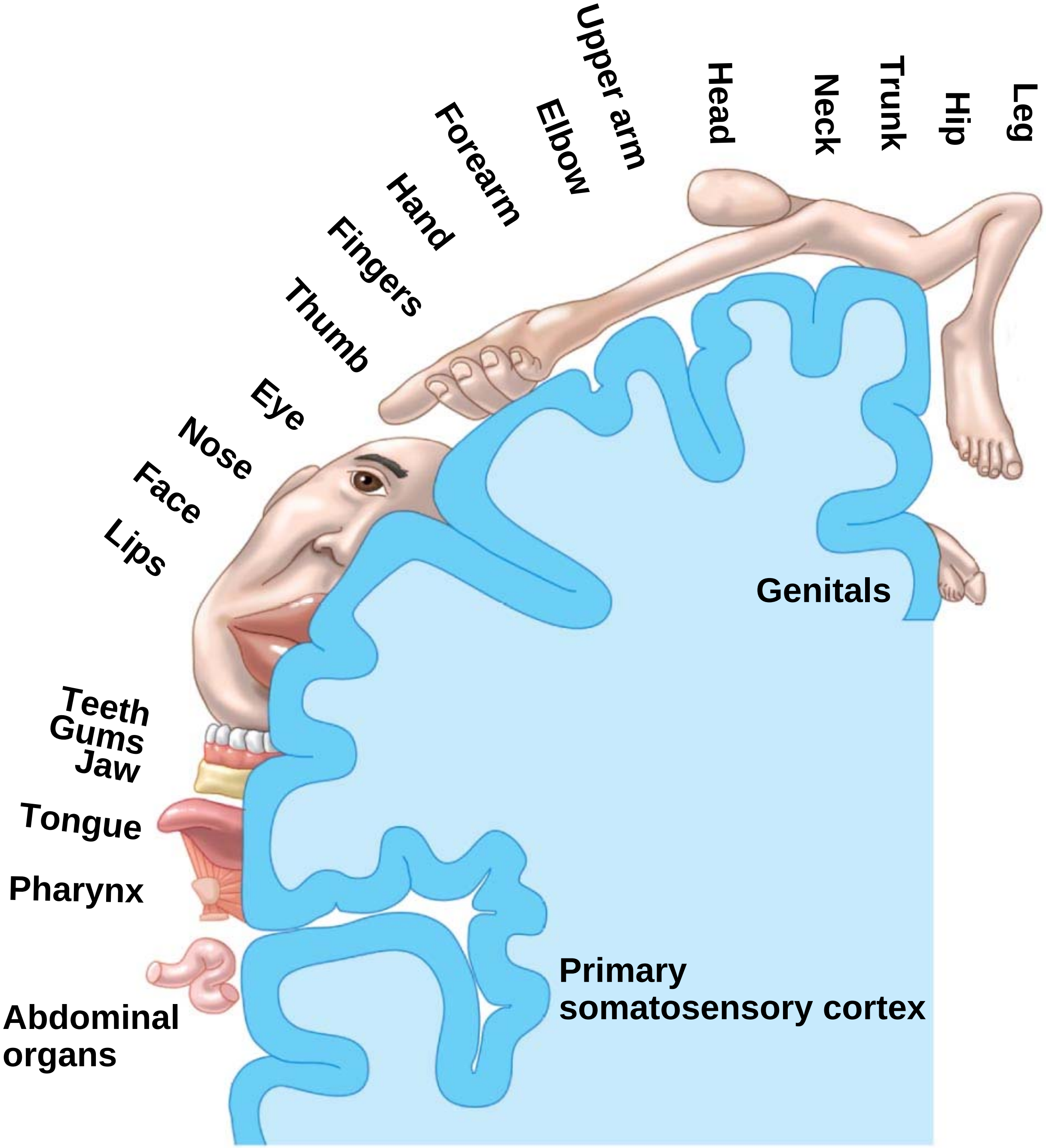

Knee
Hip
Trunk
Shoulder
Elbow
Forearm
Wrist
Hand
Fingers
Thumb
Neck
Brow
Eye
Face
Lips
Jaw
Tongue
Toes
Primary
motor cortex

Fig. 49-16b

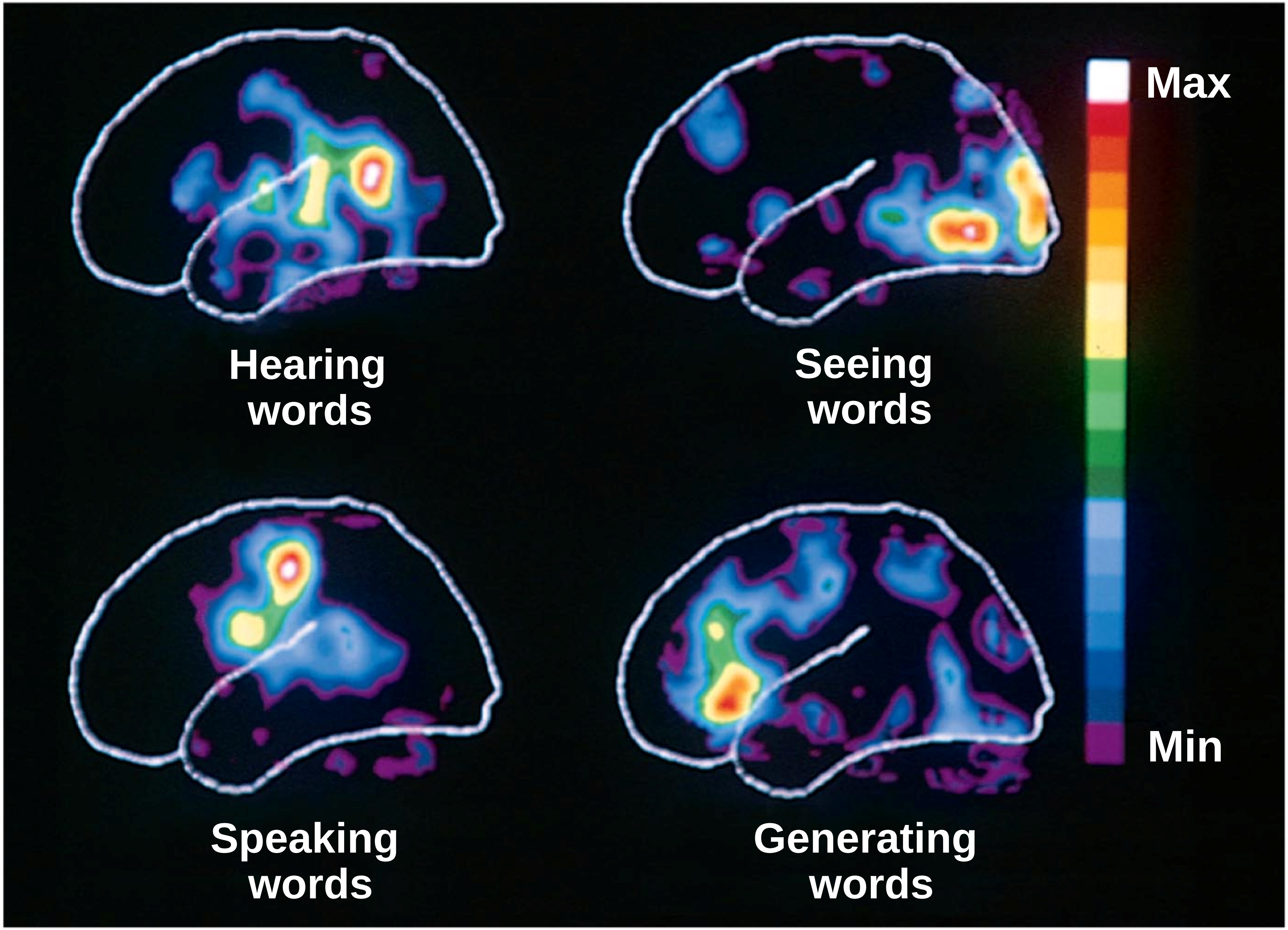


Upper arm
Head
Neck
Trunk
Hip
Leg
Elbow
Forearm
Hand
Fingers
Thumb
Eye
Nose
Face
Lips
Genitals
Teeth
Gums
Jaw
Tongue
Pharynx
Abdominal organs
Primary somatosensory cortex

Language and Speech

- Studies of brain activity have mapped areas responsible for language and speech
- Broca’s area in the frontal lobe is active when speech is generated
- Wernicke’s area in the temporal lobe is active when speech is heard

Fig. 49-17



Max
Min
Hearing words
Seeing words
Speaking words
Generating words

Lateralization of Cortical Function

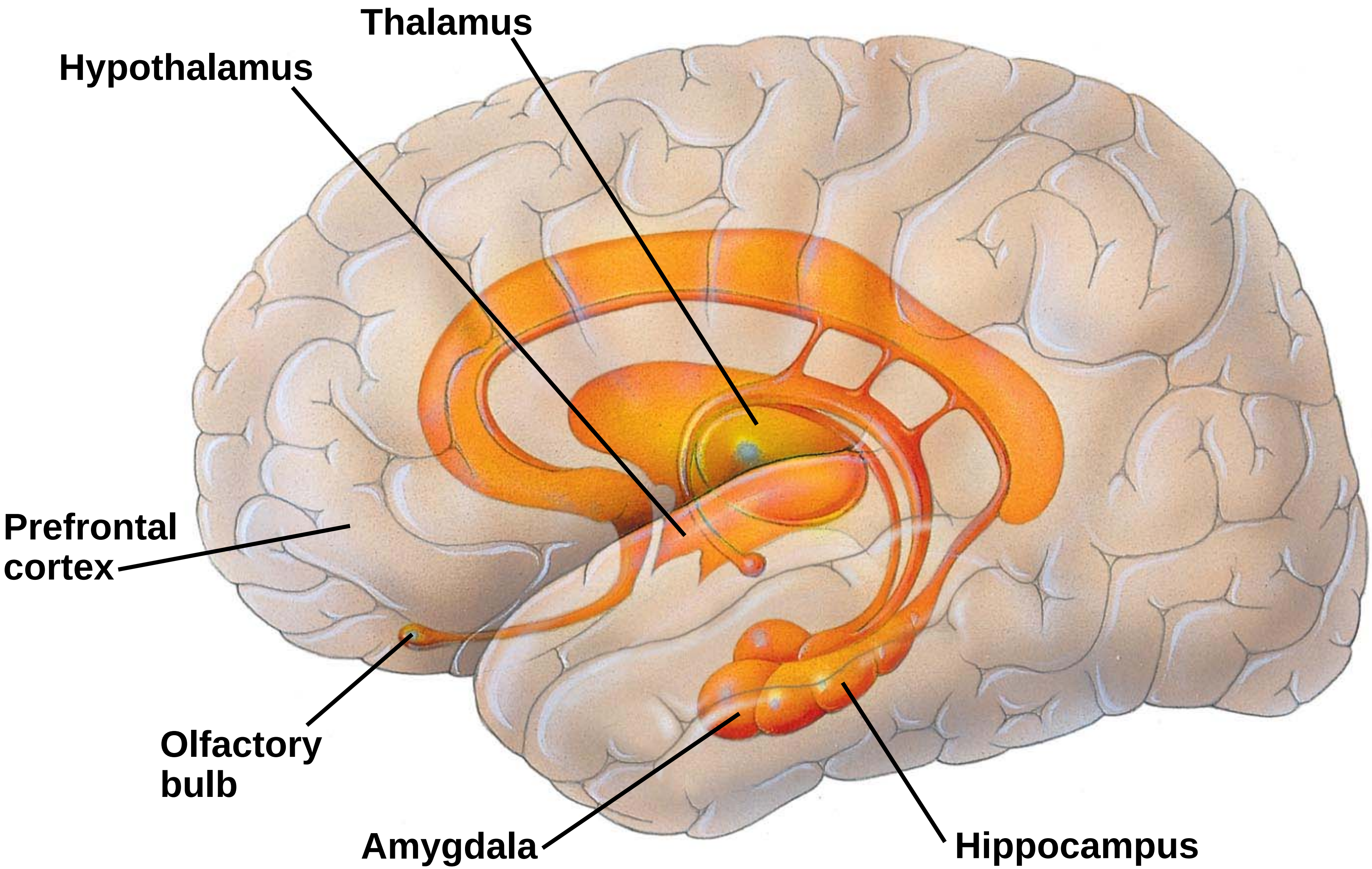
- The corpus callosum transmits information between the two cerebral hemispheres
- The left hemisphere is more adept at language, math, logic, and processing of serial sequences
- The right hemisphere is stronger at pattern recognition, nonverbal thinking, and emotional processing

- The differences in hemisphere function are called **lateralization**
- Lateralization is linked to handedness

Emotions

- Emotions are generated and experienced by the limbic system and other parts of the brain including the sensory areas
- The *limbic system* is a ring of structures around the brainstem that includes the amygdala, hippocampus, and parts of the thalamus
- The **amygdala** is located in the temporal lobe and helps store an emotional experience as an emotional memory

Fig. 49-18


Thalamus
Hypothalamus
Prefrontal cortex
Olfactory bulb
Amygdala
Hippocampus

Consciousness

- Modern brain-imaging techniques suggest that consciousness is an emergent property of the brain based on activity in many areas of the cortex

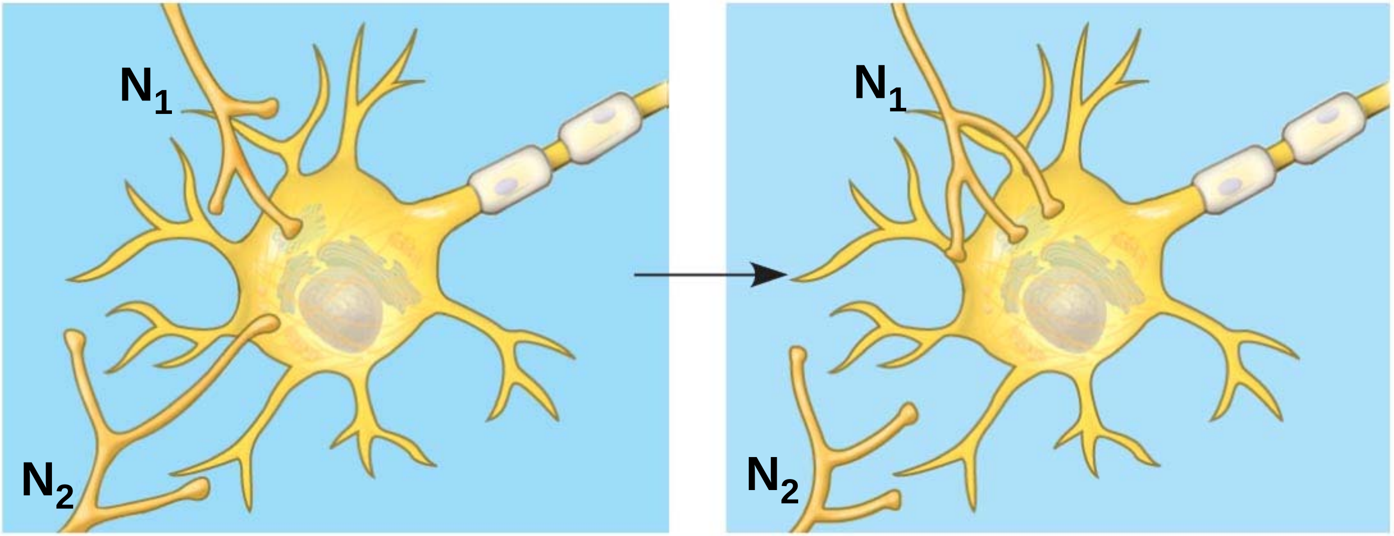
Concept 49.4 Changes in synaptic connections underlie memory and learning

- Two processes dominate embryonic development of the nervous system
  - Neurons compete for growth-supporting factors in order to survive
  - Only half the synapses that form during embryo development survive into adulthood

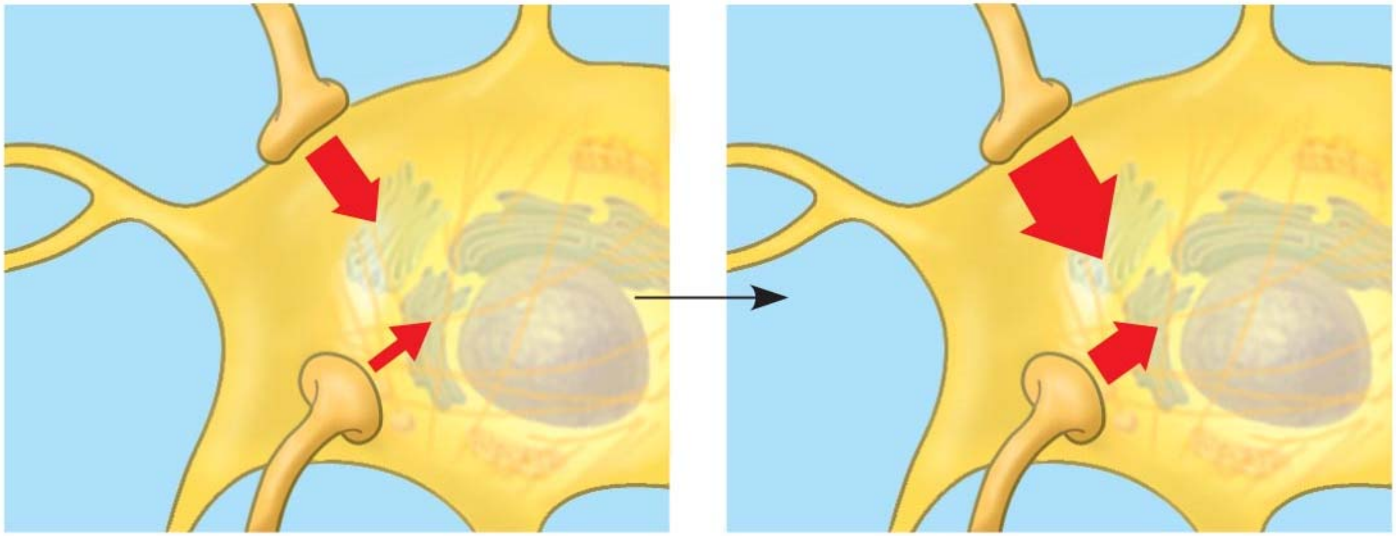
Neural Plasticity

- **Neural plasticity** describes the ability of the nervous system to be modified after birth
- Changes can strengthen or weaken signaling at a synapse

Fig. 49-19



(a) Synapses are strengthened or weakened in response to activity.



(b) If two synapses are often active at the same time, the strength of the postsynaptic response may increase at both synapses.

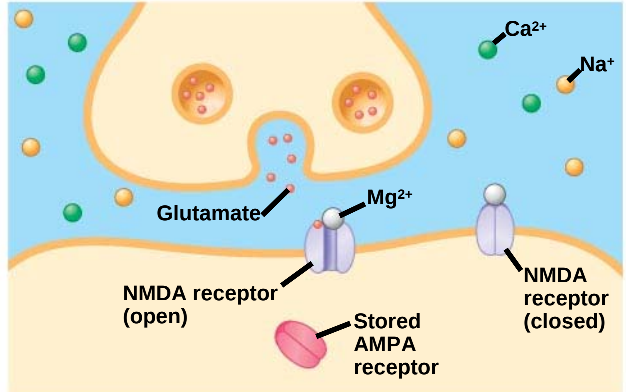
Memory and Learning

- Learning can occur when neurons make new connections or when the strength of existing neural connections changes
- **Short-term memory** is accessed via the hippocampus
- The hippocampus also plays a role in forming **long-term memory**, which is stored in the cerebral cortex

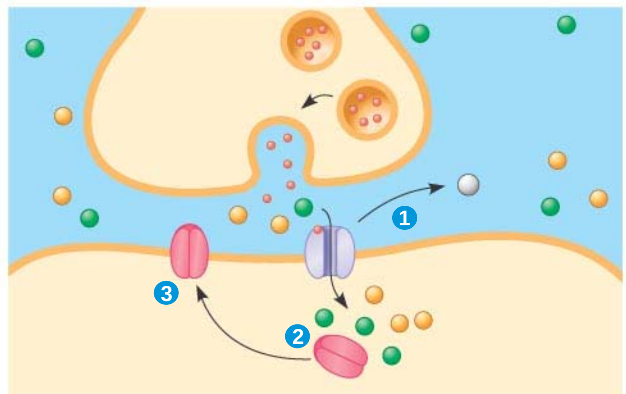
Long-Term Potentiation

- In the vertebrate brain, a form of learning called **long-term potentiation** (**LTP**) involves an increase in the strength of synaptic transmission
- LTP involves glutamate receptors
- If the presynaptic and postsynaptic neurons are stimulated at the same time, the set of receptors present on the postsynaptic membranes changes

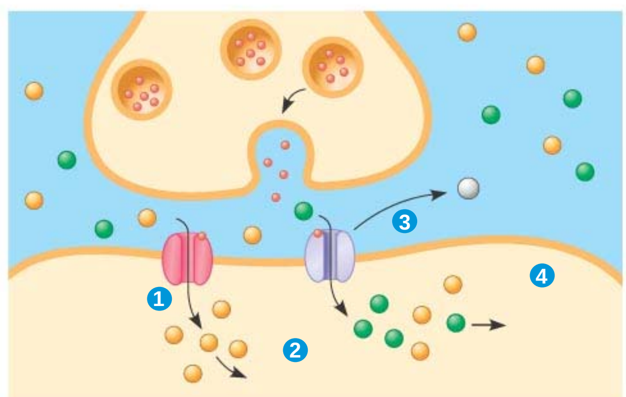
Fig. 49-20



(a) Synapse prior to long-term potentiation (LTP)

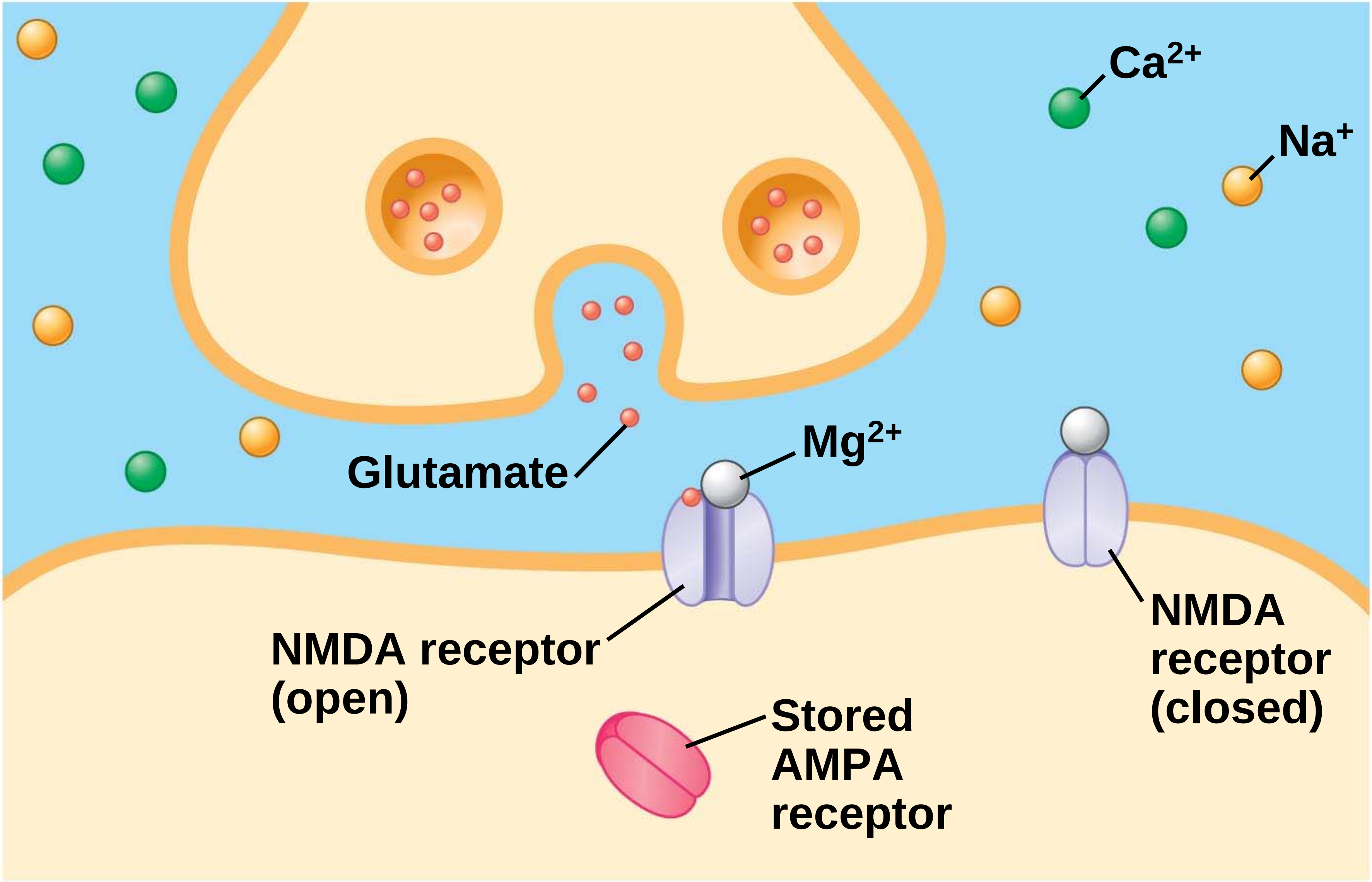


(b) Establishing LTP



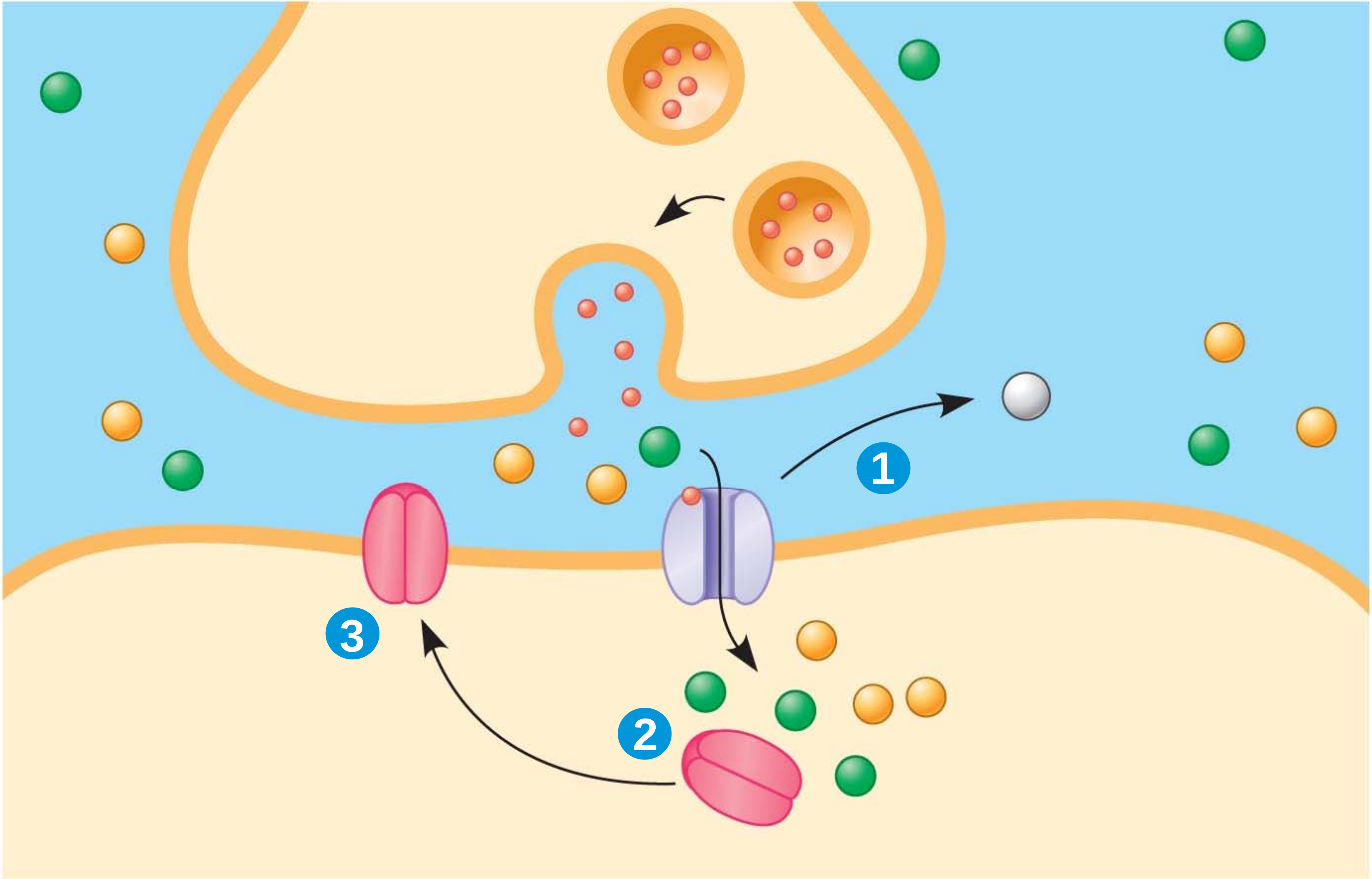
(c) Synapse exhibiting LTP

Fig. 49-20a



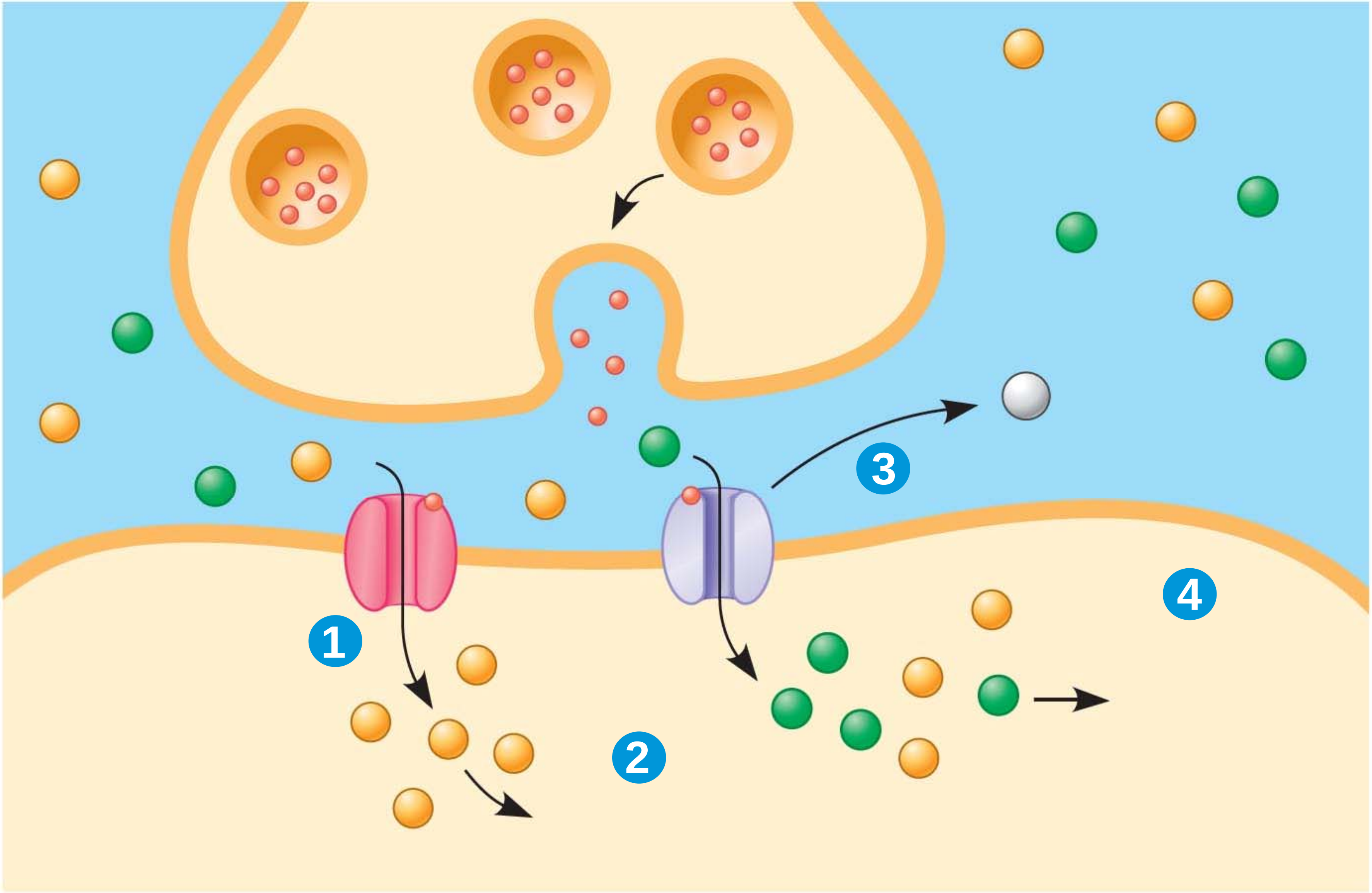
(a) Synapse prior to long-term potentiation (LTP)

Fig. 49-20b



(b) Establishing LTP

Fig. 49-20c



(c) Synapse exhibiting LTP

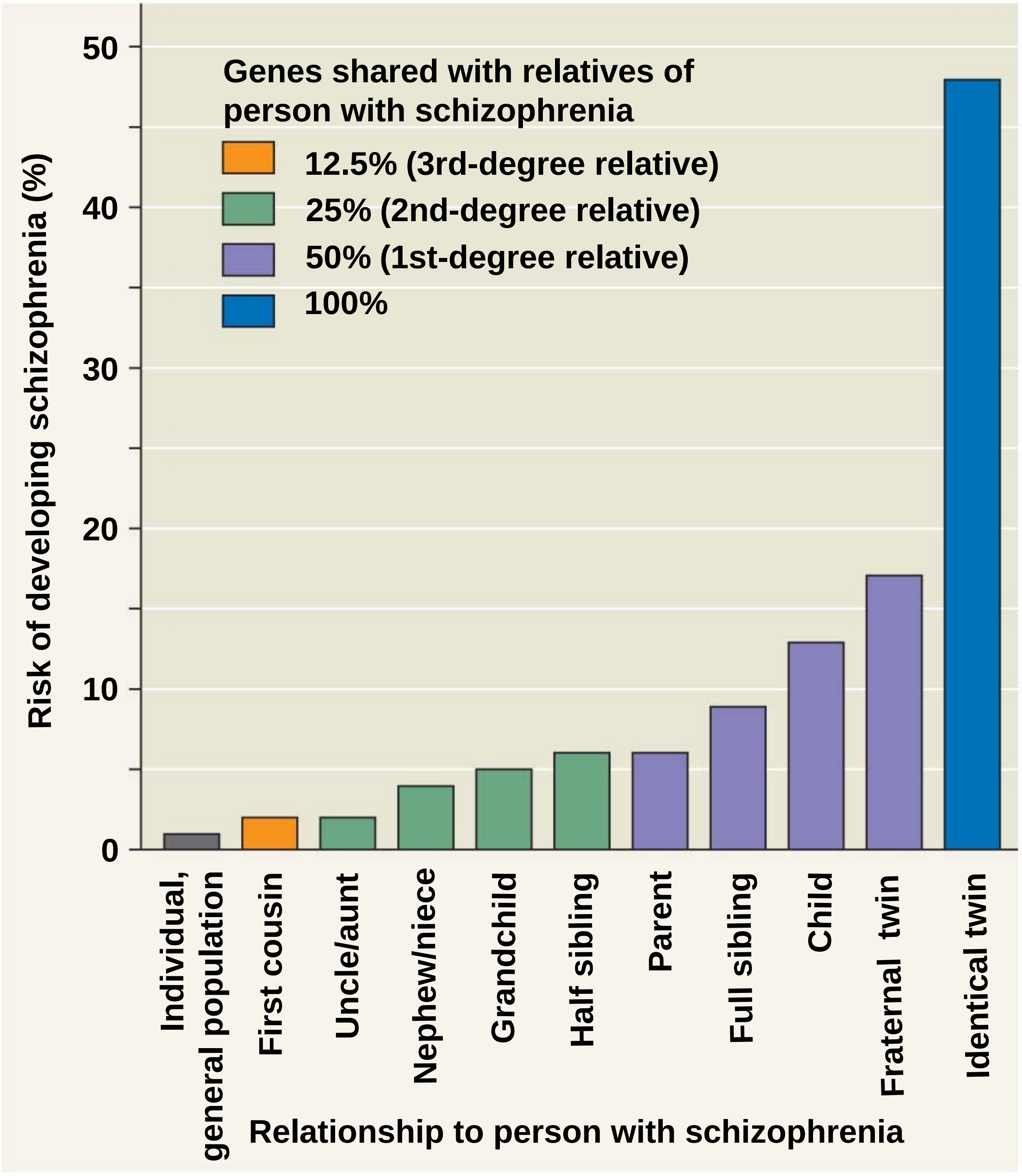
Concept 49.5: Nervous system disorders can be explained in molecular terms

- Disorders of the nervous system include schizophrenia, depression, Alzheimer’s disease, and Parkinson’s disease
- Genetic and environmental factors contribute to diseases of the nervous system

Schizophrenia

- About 1% of the world's population suffers from **schizophrenia**
- Schizophrenia is characterized by hallucinations, delusions, blunted emotions, and other symptoms
- Available treatments focus on brain pathways that use dopamine as a neurotransmitter

Fig. 49-21



Genes shared with relatives of person with schizophrenia
12.5% (3rd-degree relative)
25% (2nd-degree relative)
50% (1st-degree relative)
100%
Risk of developing schizophrenia (%)
50
40
30
20
10
0
Individual, general population
First cousin
Uncle/aunt
Nephew/niece
Grandchild
Half sibling
Parent
Full sibling
Child
Fraternal twin
Identical twin
Relationship to person with schizophrenia

Depression

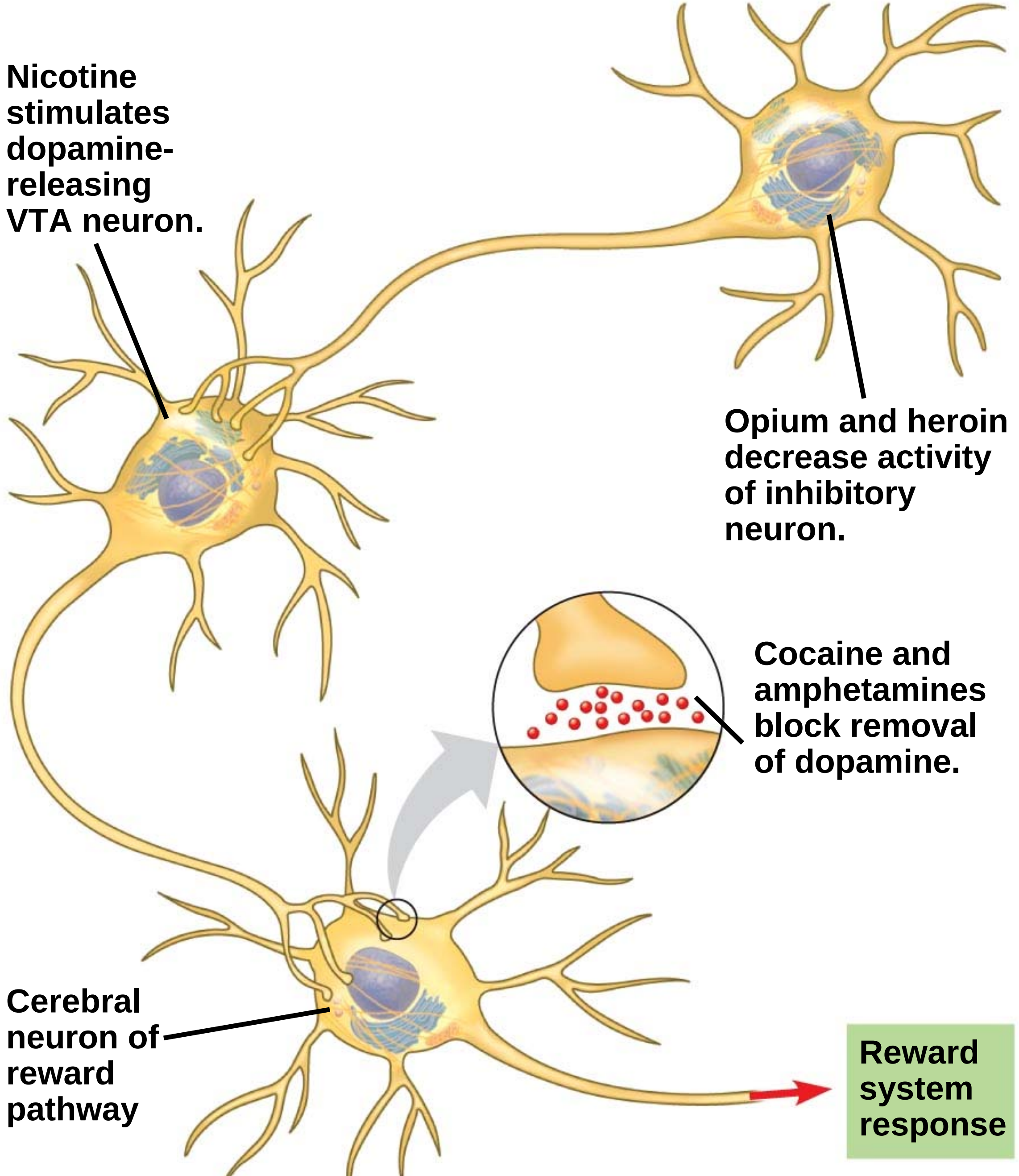
- Two broad forms of depressive illness are known: major depressive disorder and bipolar disorder
- In **major depressive disorder**, patients have a persistent lack of interest or pleasure in most activities
- **Bipolar disorder** is characterized by manic (high-mood) and depressive (low-mood) phases
- Treatments for these types of depression include drugs such as Prozac and lithium

Drug Addiction and the Brain Reward System

- The brain's reward system rewards motivation with pleasure
- Some drugs are addictive because they increase activity of the brain's reward system
- These drugs include cocaine, amphetamine, heroin, alcohol, and tobacco
- Drug addiction is characterized by compulsive consumption and an inability to control intake

- Addictive drugs enhance the activity of the dopamine pathway
- Drug addiction leads to long-lasting changes in the reward circuitry that cause craving for the drug

Fig. 49-22

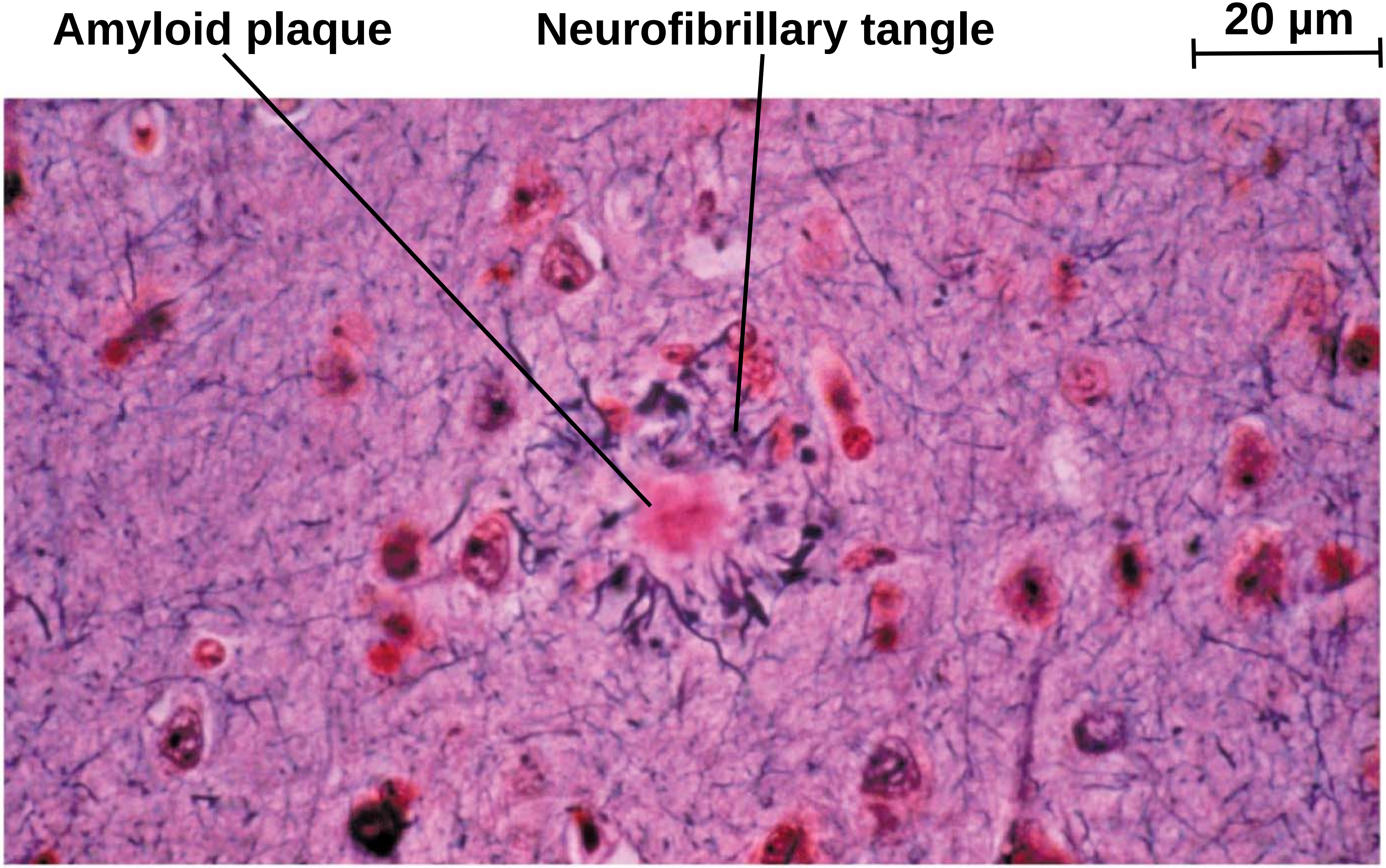


Nicotine stimulates dopamine-releasing VTA neuron.
Opium and heroin decrease activity of inhibitory neuron.
Cocaine and amphetamines block removal of dopamine.
Cerebral neuron of reward pathway
Reward system response

Alzheimer’s Disease

- **Alzheimer’s disease** is a mental deterioration characterized by confusion, memory loss, and other symptoms
- Alzheimer’s disease is caused by the formation of neurofibrillary tangles and amyloid plaques in the brain
- A successful treatment in humans may hinge on early detection of amyloid plaques
- There is no cure for this disease though some drugs are effective at relieving symptoms

Fig. 49-23



Parkinson's Disease

- **Parkinson's disease** is a motor disorder caused by death of dopamine-secreting neurons in the midbrain
- It is characterized by difficulty in initiating movements, muscle tremors, slowness of movement, and rigidity
- There is no cure, although drugs and various other approaches are used to manage symptoms

Stem Cell–Based Therapy

- Unlike the PNS, the CNS cannot fully repair itself
- However, it was recently discovered that the adult human brain contains stem cells that can differentiate into mature neurons
- Induction of stem cell differentiation and transplantation of cultured stem cells are potential methods for replacing neurons lost to trauma or disease

Fig. 49-24

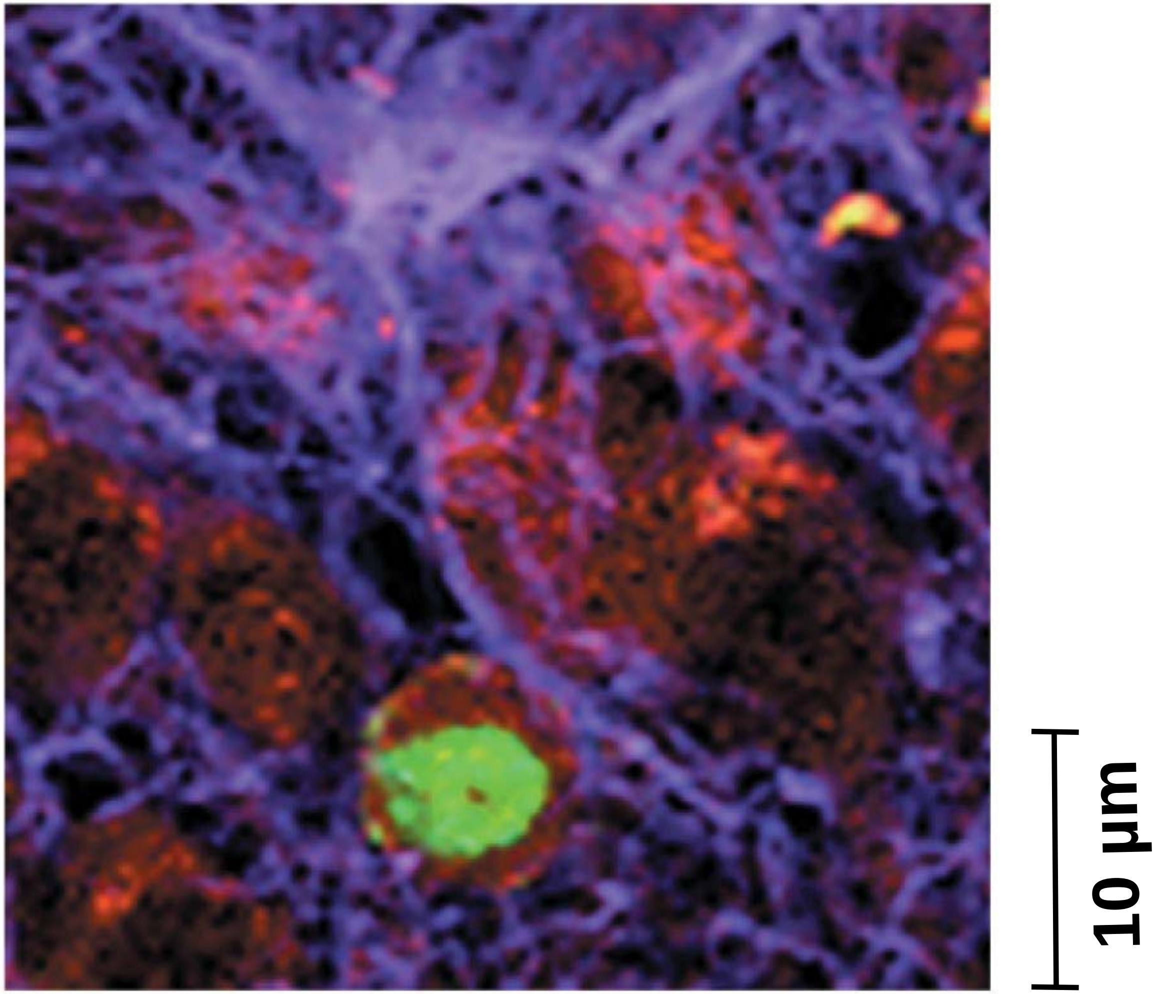
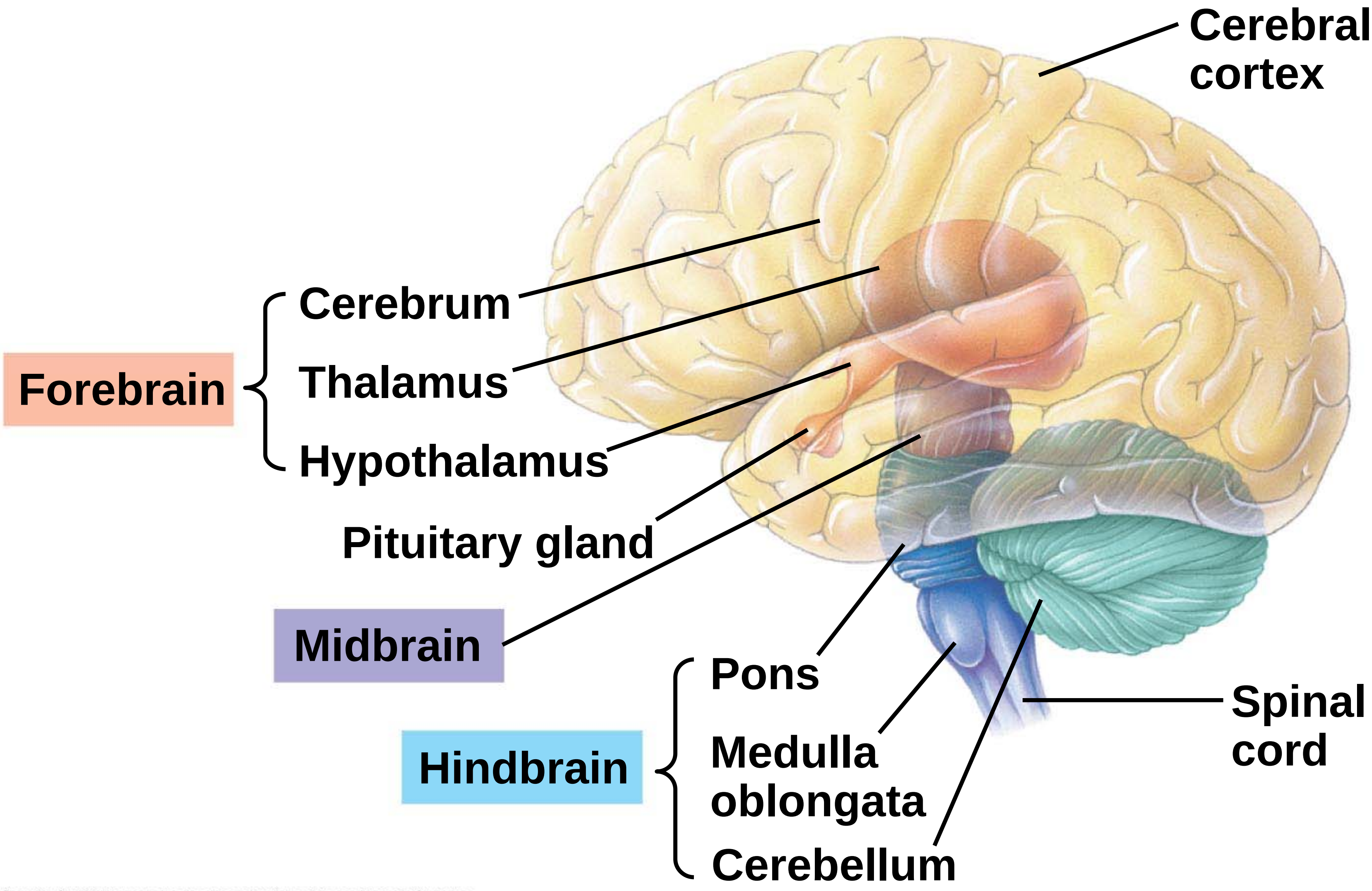
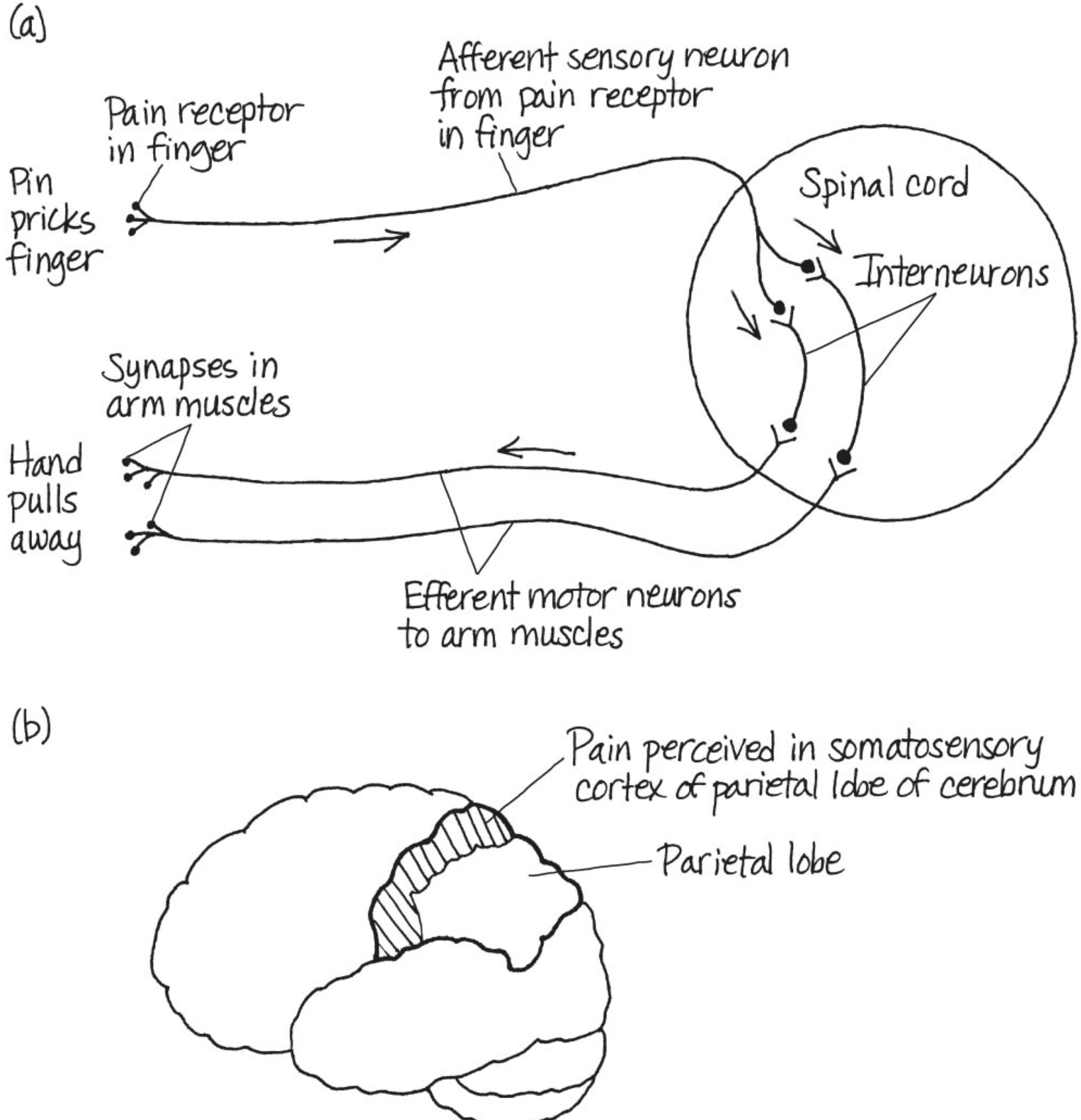


Fig. 49-UN5



Cerebral cortex
Forebrain
Cerebrum
Thalamus
Hypothalamus
Pituitary gland
Midbrain
Hindbrain
Pons
Medulla oblongata
Cerebellum
Spinal cord

Fig. 49-UN6


(a)
Afferent sensory neuron from pain receptor in finger
Pain receptor in finger
Pin pricks finger
Spinal cord
Interneurons
Synapses in arm muscles
Hand pulls away
Efferent motor neurons to arm muscles
(b)
Pain perceived in somatosensory cortex of parietal lobe of cerebrum
Parietal lobe

You should now be able to:

1. Compare and contrast the nervous systems of: hydra, sea star, planarian, nematode, clam, squid, and vertebrate
2. Distinguish between the following pairs of terms: central nervous system, peripheral nervous system; white matter, gray matter; bipolar disorder and major depression
3. List the types of glia and their functions
4. Compare the three divisions of the autonomic nervous system

5. Describe the structures and functions of the following brain regions: medulla oblongata, pons, midbrain, cerebellum, thalamus, epithalamus, hypothalamus, and cerebrum
6. Describe the specific functions of the brain regions associated with language, speech, emotions, memory, and learning
7. Explain the possible role of long-term potentiation in memory storage and learning

8. Describe the symptoms and causes of schizophrenia, Alzheimer’s disease, and Parkinson’s disease

9. Explain how drug addiction affects the brain reward system