Chapter 8
NERVOUS SYSTEMS

Bui Tan Anh – College of Natural Sciences

1. Organization of the Nervous System

- Objective
  - *List the divisions of the nervous system, and describe the characteristics of each.*

Organization of the Nervous System

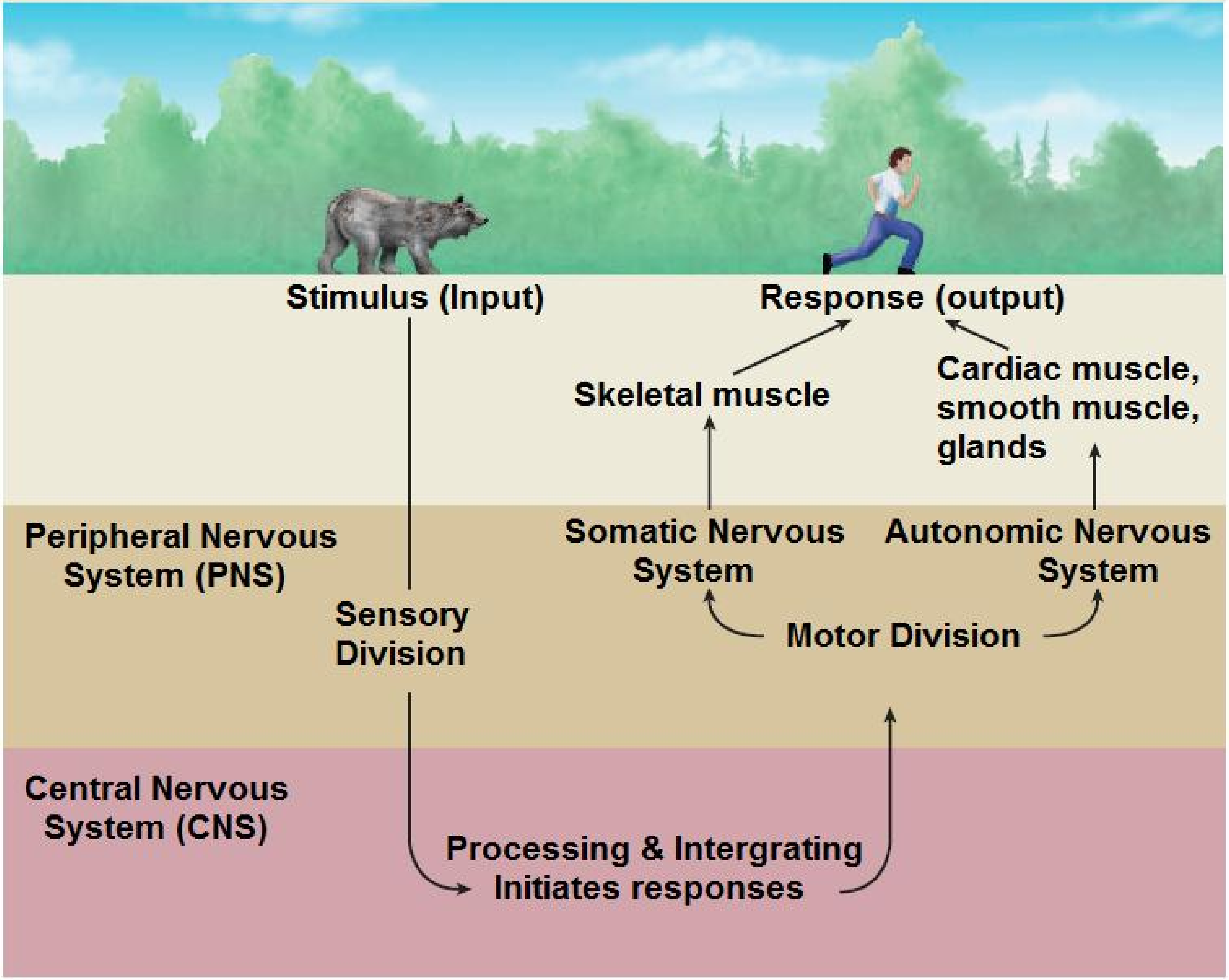
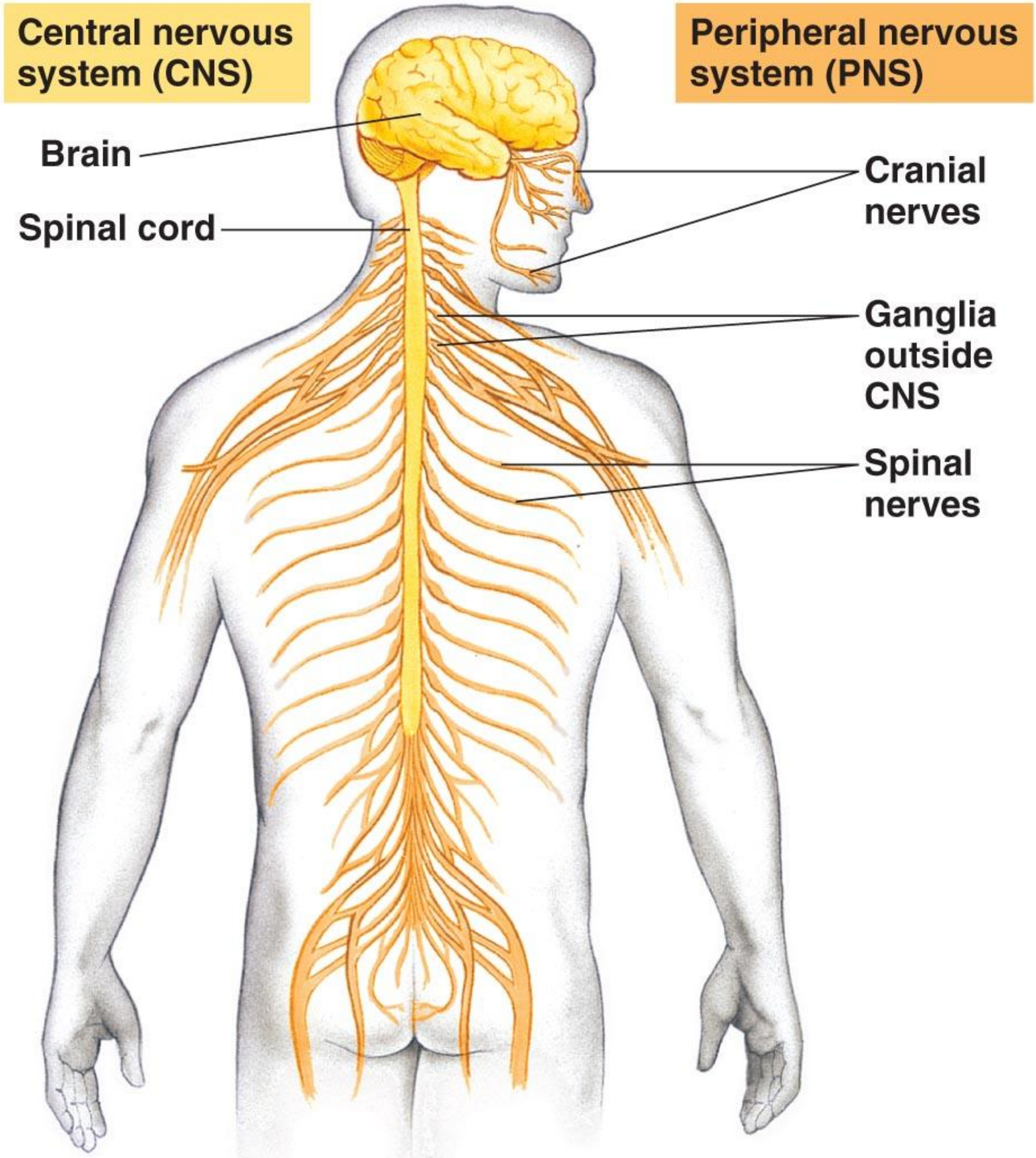
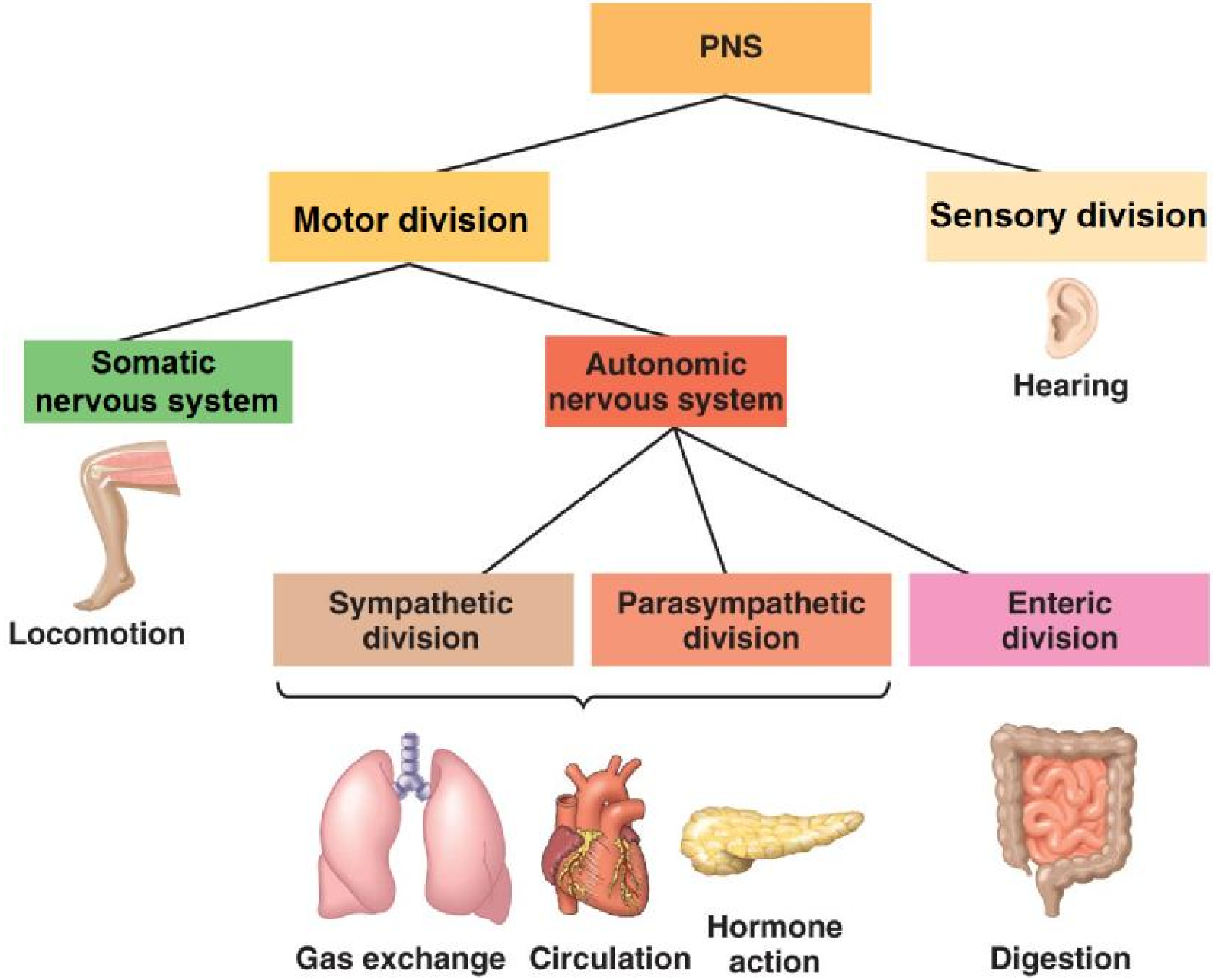


Table 1

A. Nerve	1. a collection of neuron cell bodies
B. Brain	2. an extensive network of axons
C. Spinal Cord	3. a bundle of axons
D. Ganglion	4. is located within the skull
E. Plexus	5. the endings of nerve cells or specialized cells
F. Sensory receptors	6. is located within the vertebral canal
G. Cranial nerves	7. Cranial nerves
H. Spinal nerves	8. Spinal nerves
	9. Central nervous system
	10. Peripheral nervous system


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


PNS
Motor division
Sensory division
Somatic nervous system
Autonomic nervous system
Hearing
Locomotion
Sympathetic division
Parasympathetic division
Enteric division
Gas exchange
Circulation
Hormone action
Digestion

Mastering Concepts

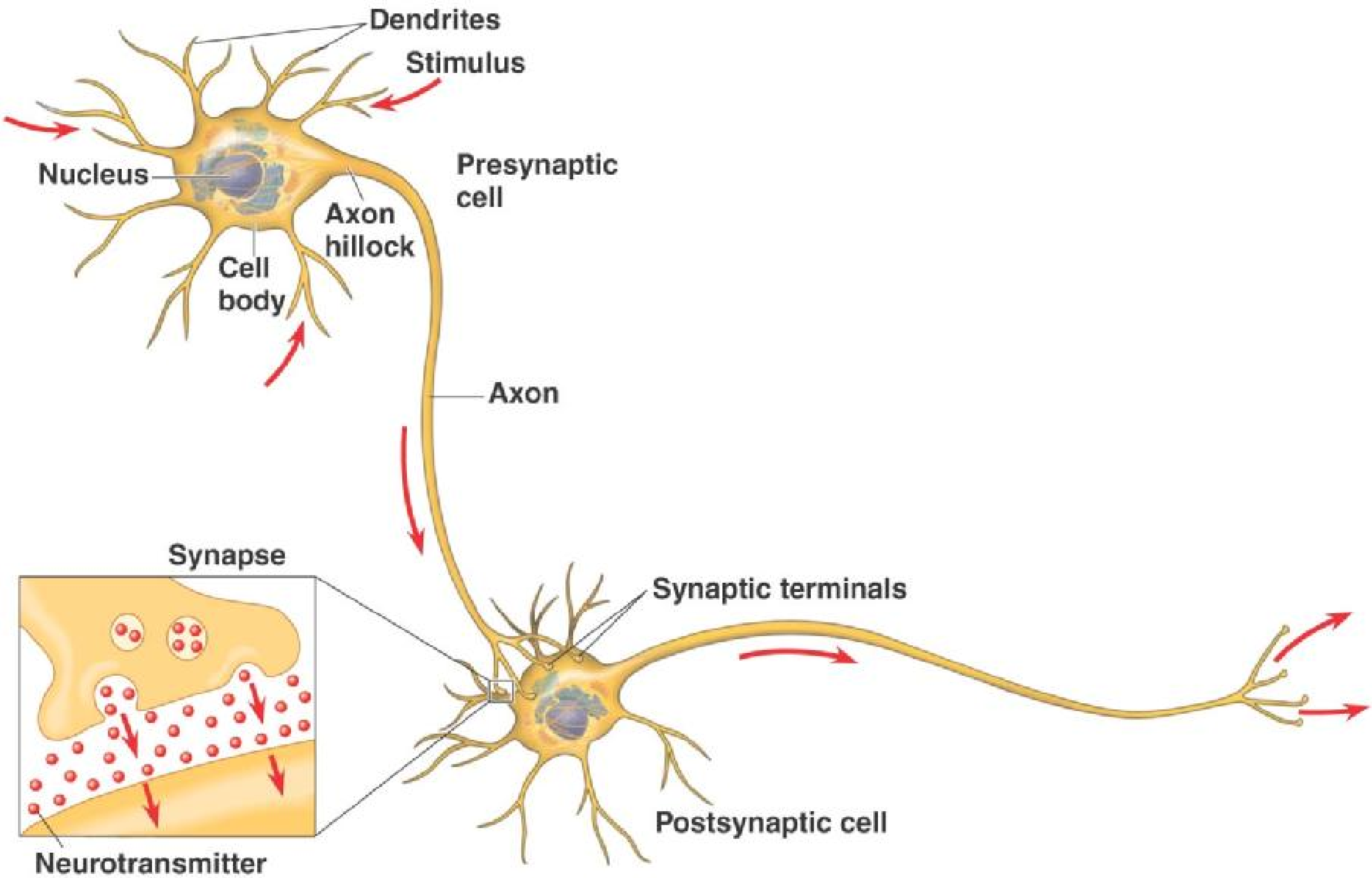
1) Define the CNS and the PNS.
2) What is a sensory receptor, nerve, ganglion, and plexus?
3) Based on the direction they transmit action potentials, what are the two subcategories of the PNS?
4) Based on the structures they supply, what are the two subcategories of the motor division?

2. Cells of the Nervous System

- Objectives:
  - *Describe the structure of neurons and the different types of neurons.*
  - *Describe the different types of neuroglia cells.*

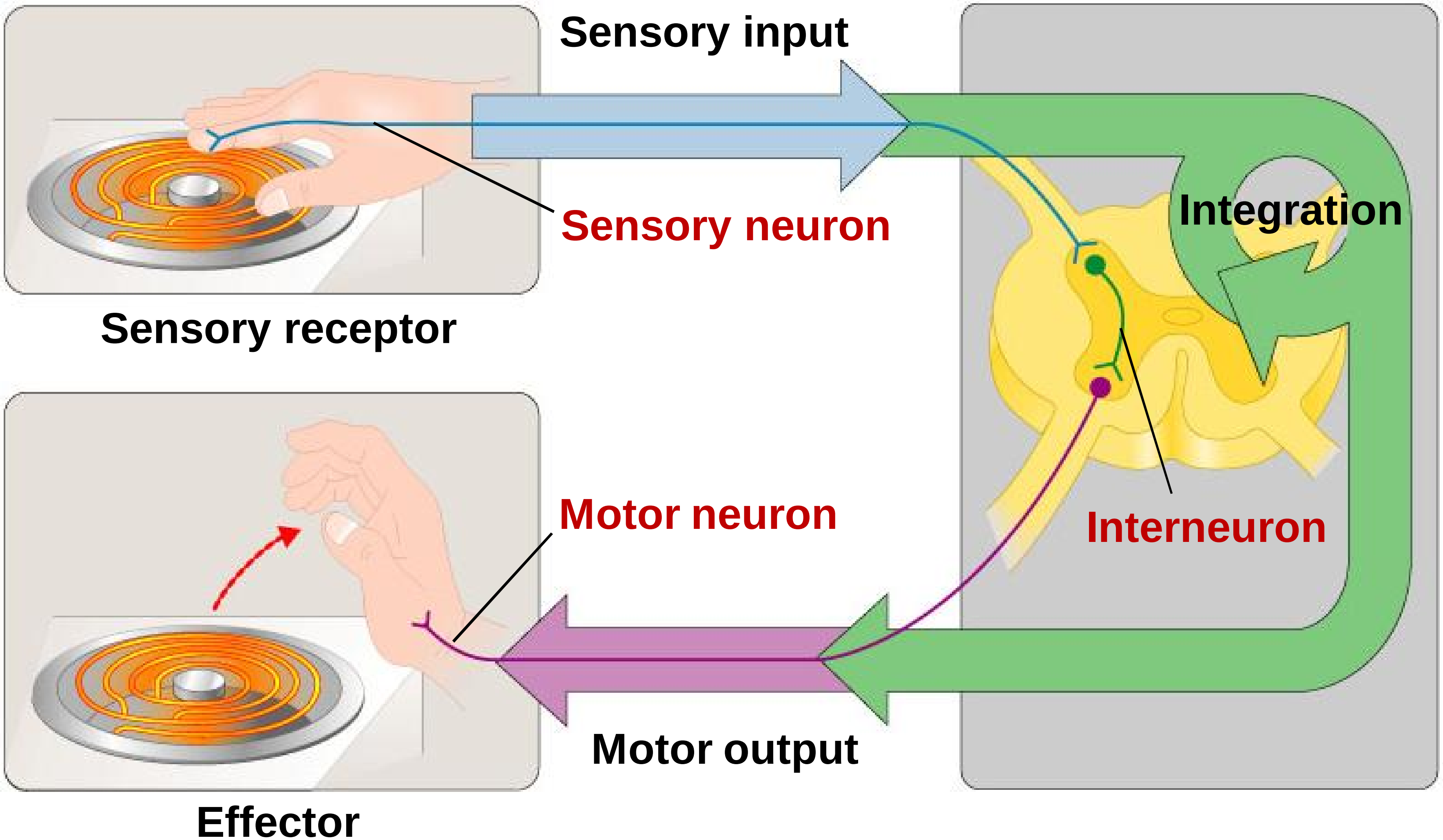
Neuron Structure

- Most of a neuron's organelles
  - Are located in the cell body
- Most neurons have dendrites
  - Highly branched extensions that receive signals from other neurons and convey the information toward the cell body
- The axon is typically a much longer extension
  - That transmits signals to other neuron or an effector
  - That may be covered with a myelin sheath


Dendrites
Stimulus
Nucleus
Presynaptic cell
Axon hillock
Cell body
Axon
Synapse
Synaptic terminals
Postsynaptic cell
Neurotransmitter

Neurons Functions

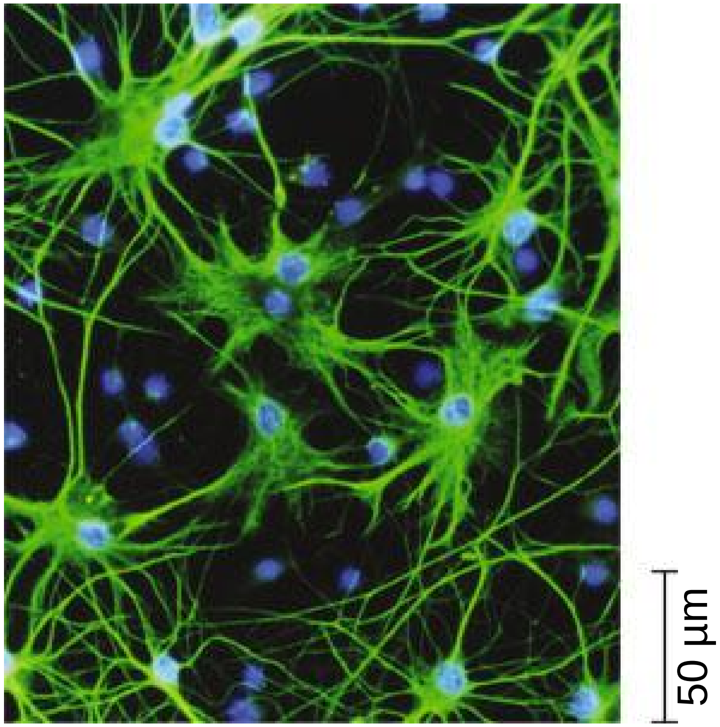
- A neuron may have one of three general functions:
- Sensory (afferent) neurons
  - Brings information about the internal or external environment toward the central nervous system.
- Interneurons
  - connects one neuron to another within the CNS to integrate information from many sources and coordinate responses
- Motor (efferent) neurons
  - conducts its message outward, from the CNS toward muscle or gland cells.


Sensory input
Sensory neuron
Integration
Sensory receptor
Motor neuron
Interneuron
Motor output
Effector

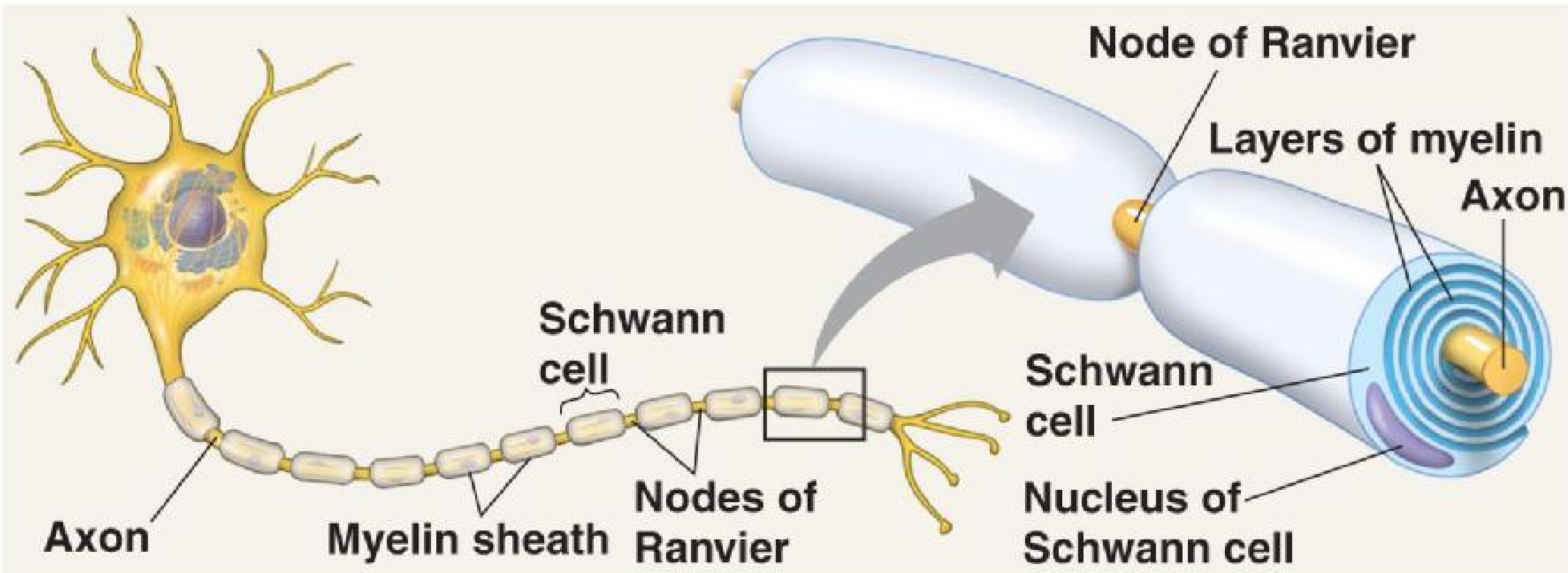
Neuroglial cells

- There are more glial cells than neurons in the human brain.
- Neuroglial cells come in several forms and have a diversity of functions:
  - supplying neurons with nutrients
  - consuming foreign particles and cell debris
  - helping maintain the proper ionic environment around neurons.
  - insulating axons

- In the CNS, astrocytes
  - Provide structural support for neurons and regulate the extracellular concentrations of ions and neurotransmitters

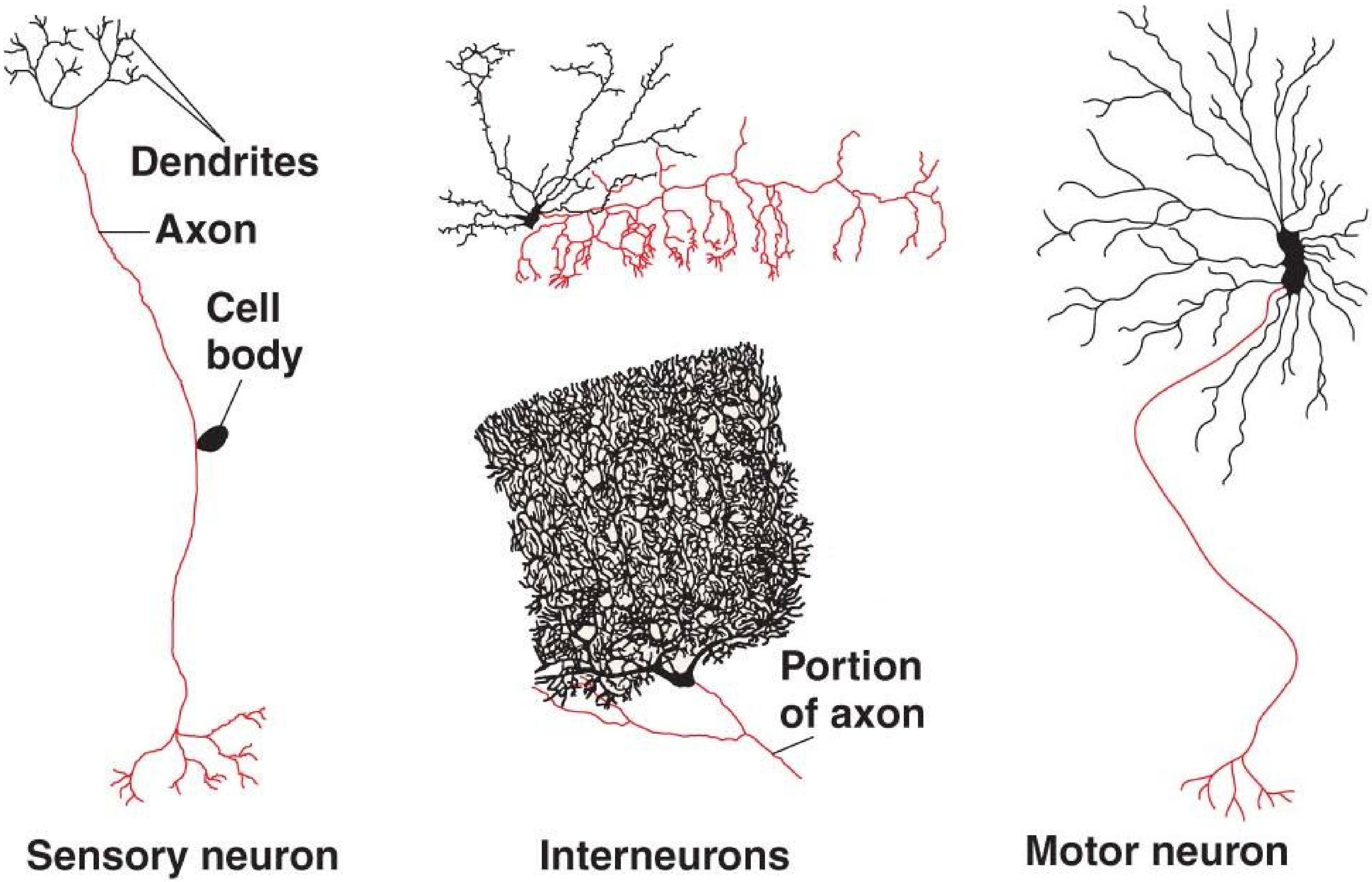


- Oligodendrocytes (in the CNS) and Schwann cells (in the PNS)
  - Are glia that form the myelin sheaths around the axons of many vertebrate neurons



Structural Diversity of Neurons

- Neurons have a wide variety of shapes
  – That reflect their input and output interactions


Dendrites
Axon
Cell
body
Sensory neuron
Portion
of axon
Interneurons
Motor neuron

Mastering Concepts

1) What are the two general cell types of a nervous system?
2) What are the parts of a neuron?
3) What are the three general functions of neurons?

3. Electric Signals

- Objectives:
  - *State the concentration differences that exist between intracellular fluid and extracellular fluid, and explain how they occur.*
  - *Describe how the resting membrane potential is established and how it can be changed.*
  - *Explain the production of action potentials and their propagation along axons.*

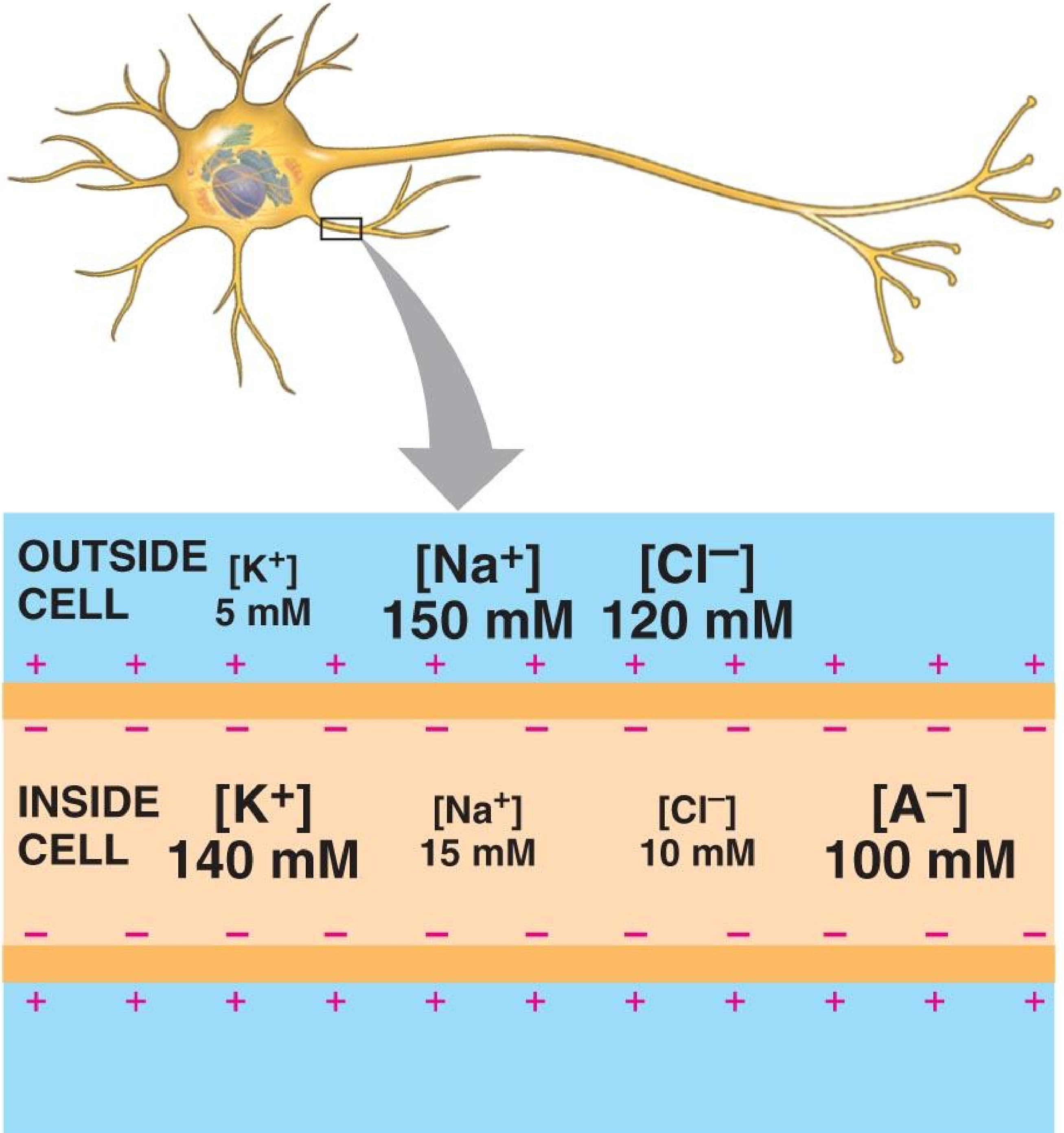
Resting Potetial

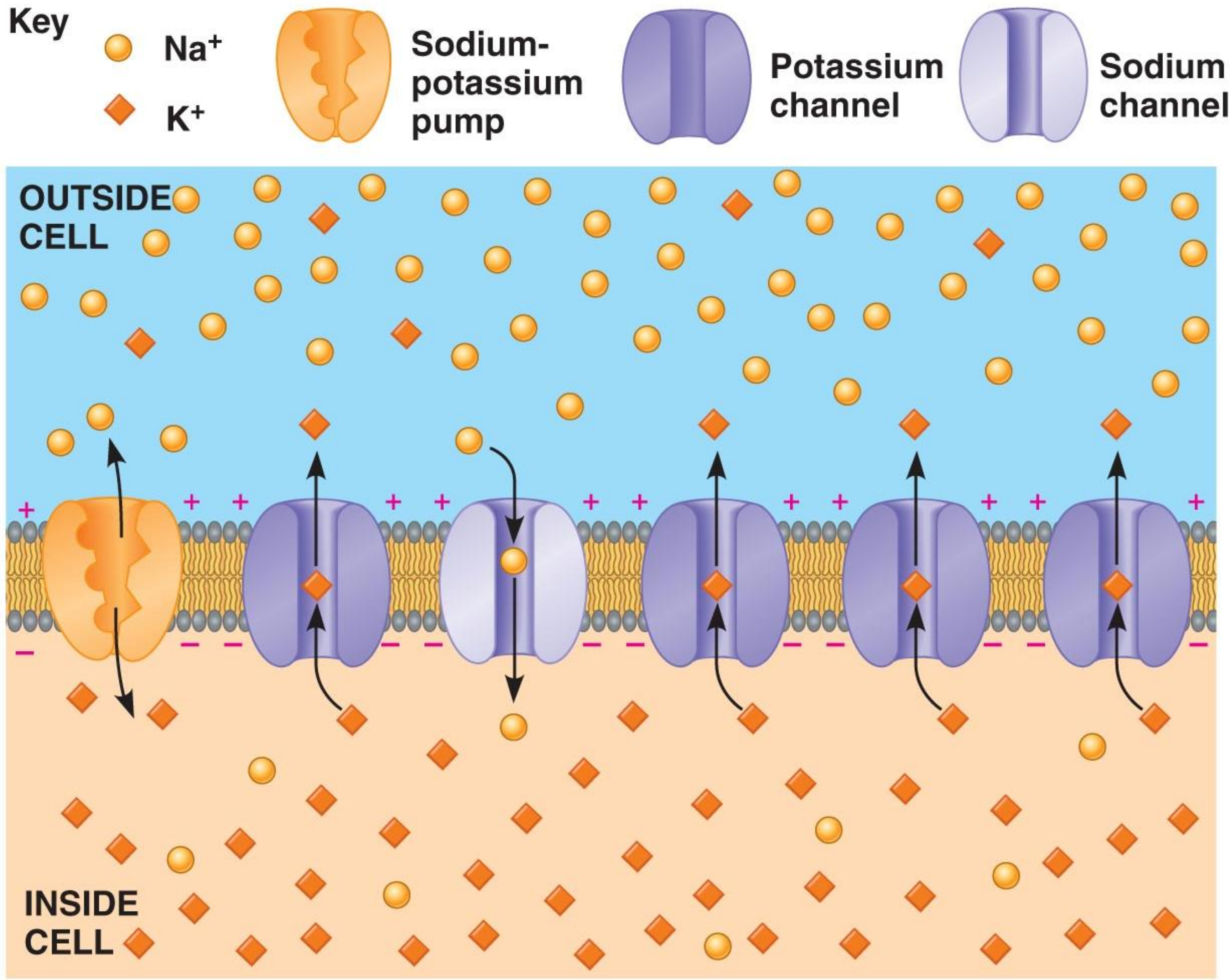
- Across its plasma membrane, every cell has a voltage called a membrane potential.
- The resting potential is the membrane potential of a neuron that is not transmitting signals.
- The membrane potential is typically around –70 mV

Formation of the Resting Potential

Three mechanisms establish and maintain the resting potential.

1) The sodium-potassium pump concentrates K^+ inside the cell and Na^+ outside.
2) Large, negatively charged proteins (and other negative ions) are trapped inside the cell because the cell membrane is not permeable to them.
3) The membrane in the resting state is 40 times more permeable to K^+ than to Na^+.


OUTSIDE CELL
[K+] 5 mM
[Na+] 150 mM
[Cl−] 120 mM
INSIDE CELL
[K+] 140 mM
[Na+] 15 mM
[Cl−] 10 mM
[A−] 100 mM


Key
Na+
K+
Sodium-potassium pump
Potassium channel
Sodium channel
OUTSIDE CELL
INSIDE CELL

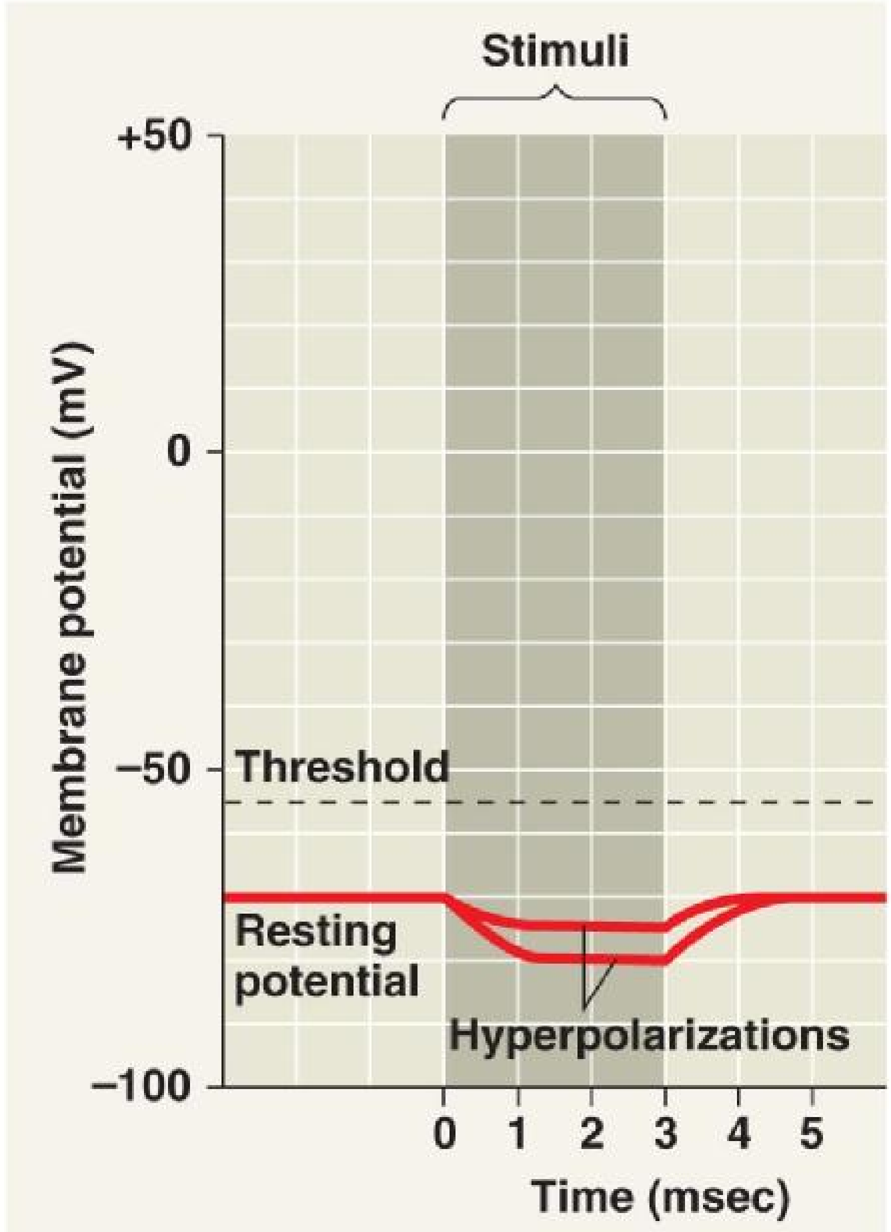
Action Potentials

- An action potential
  - Is the nerve impulse, or signal, that carries information along an axon.

- An action potential
  - Is the nerve impulse, or signal, that carries information along an axon

Action Potentials

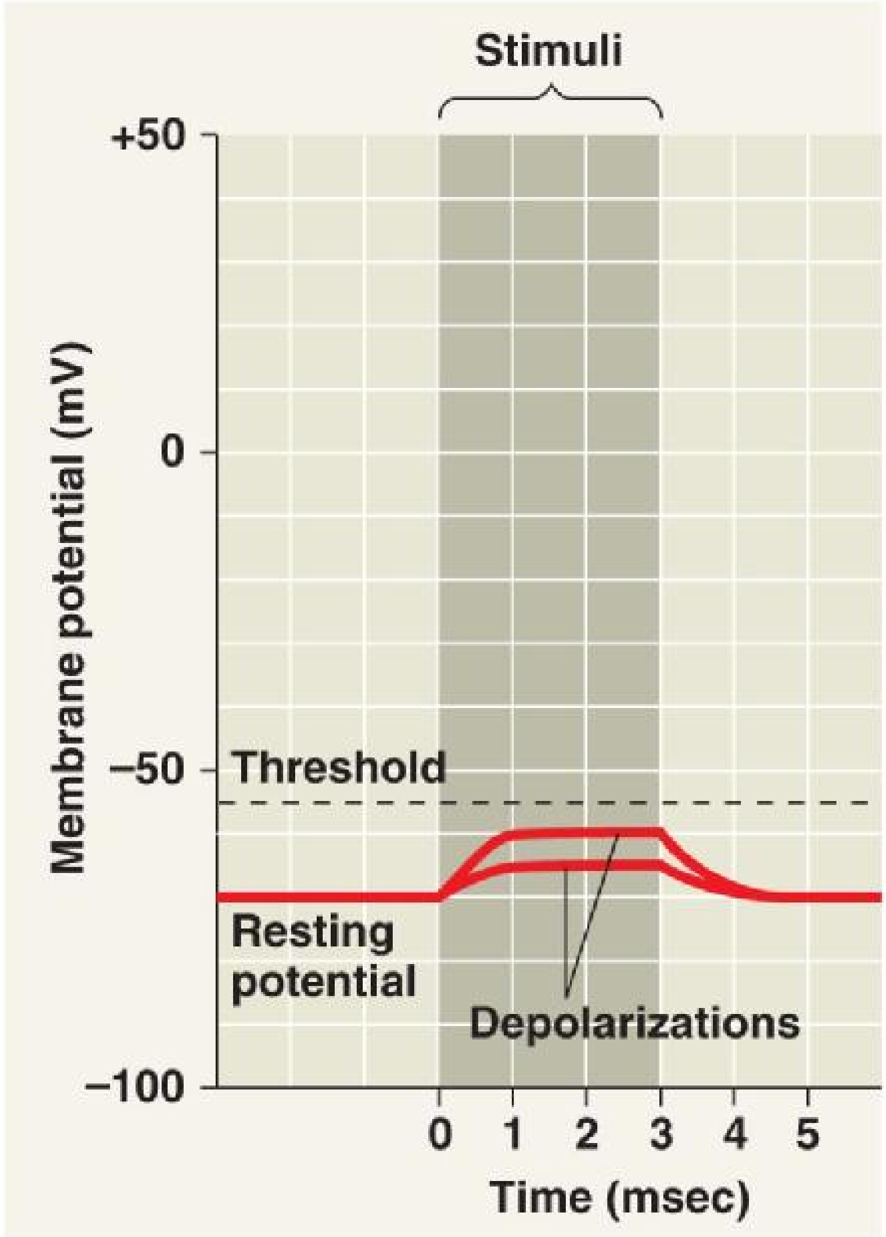
- Some stimuli trigger a hyperpolarization
  - An increase in the magnitude of the membrane potential



(a) Graded hyperpolarizations

Action Potentials

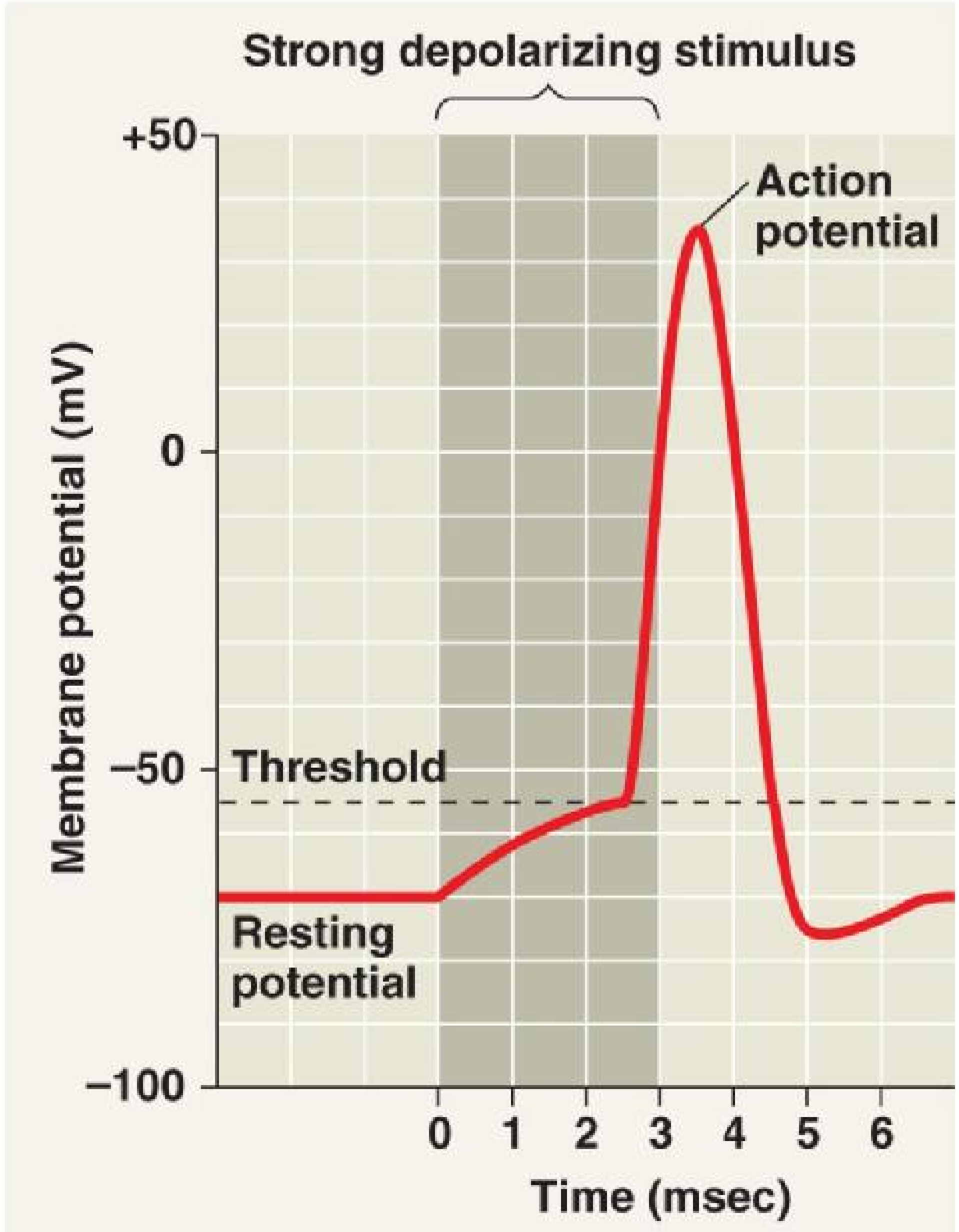
- Other stimuli trigger a depolarization
  - A reduction in the magnitude of the membrane potential



(b) Graded depolarizations

Production of Action Potentials

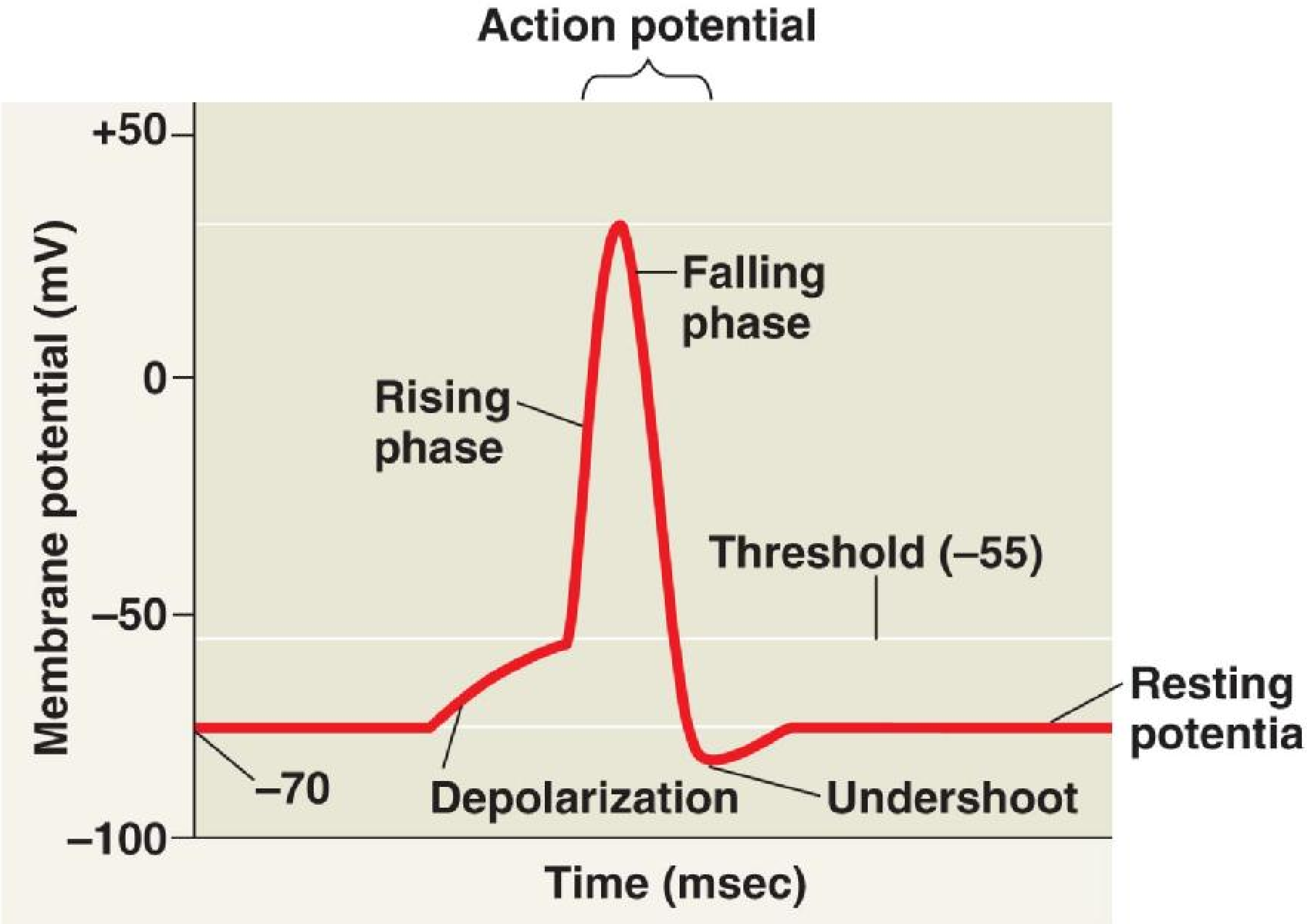
- In most neurons, depolarizations
  - Are graded only up to a certain membrane voltage, called the threshold
- A stimulus strong enough to produce a depolarization that reaches the threshold
  - Triggers a different type of response, called an action potential



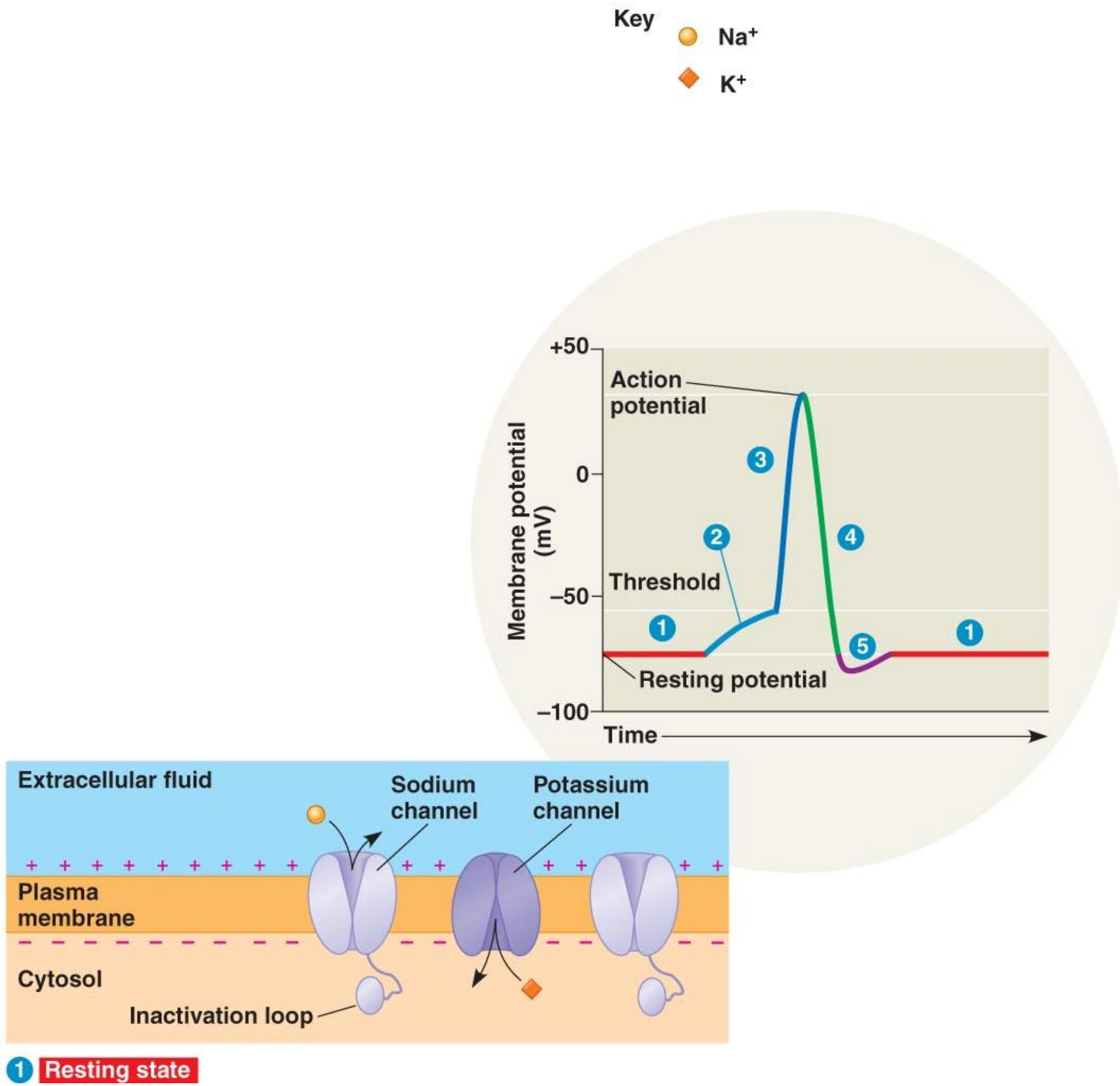
(c) Action potential

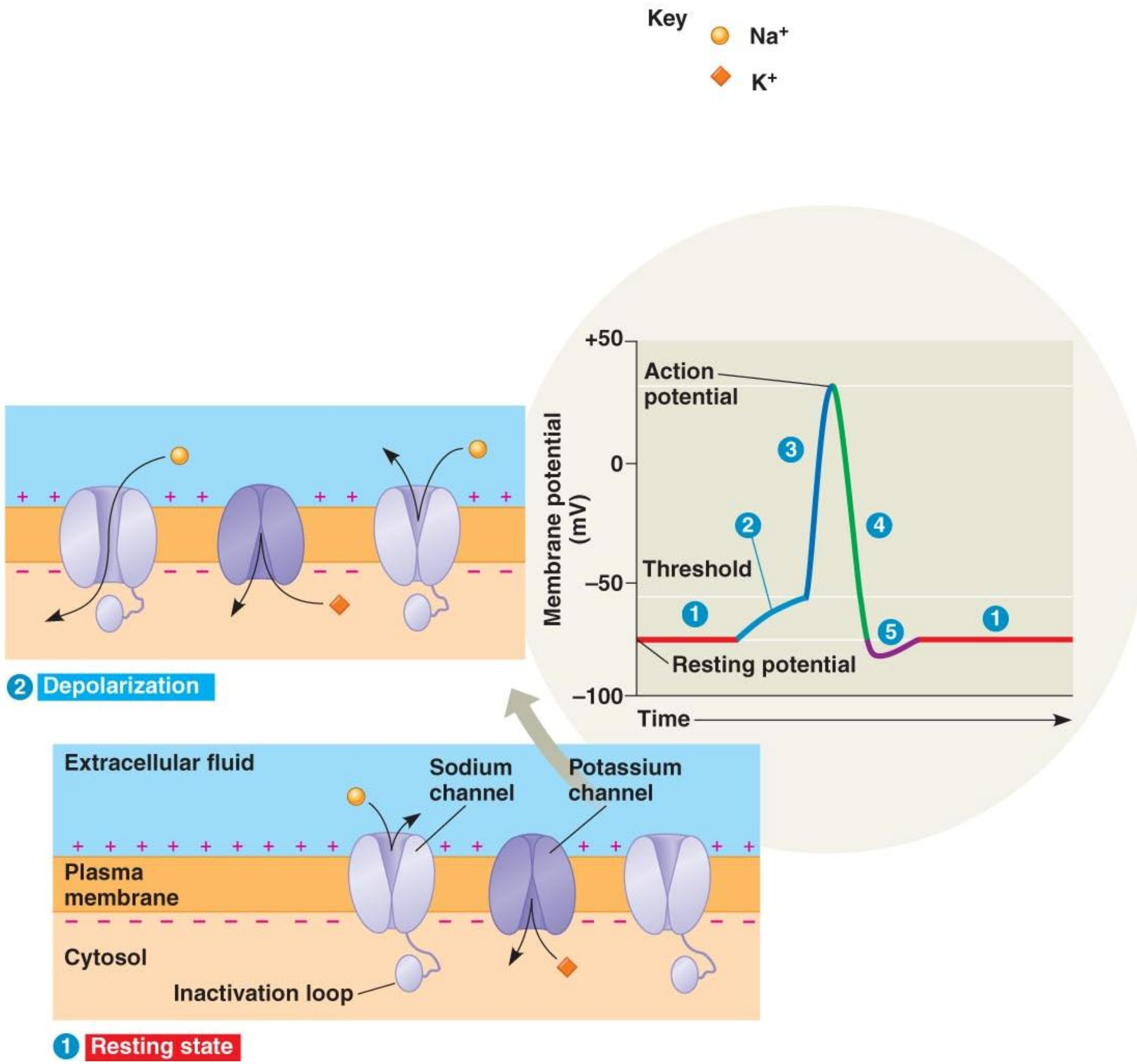
- Both voltage-gated Na^+ channels and voltage-gated K^+ channels
  - Are involved in the production of an action potential
- When a stimulus depolarizes the membrane
  - Na^+ channels open, allowing Na^+ to diffuse into the cell

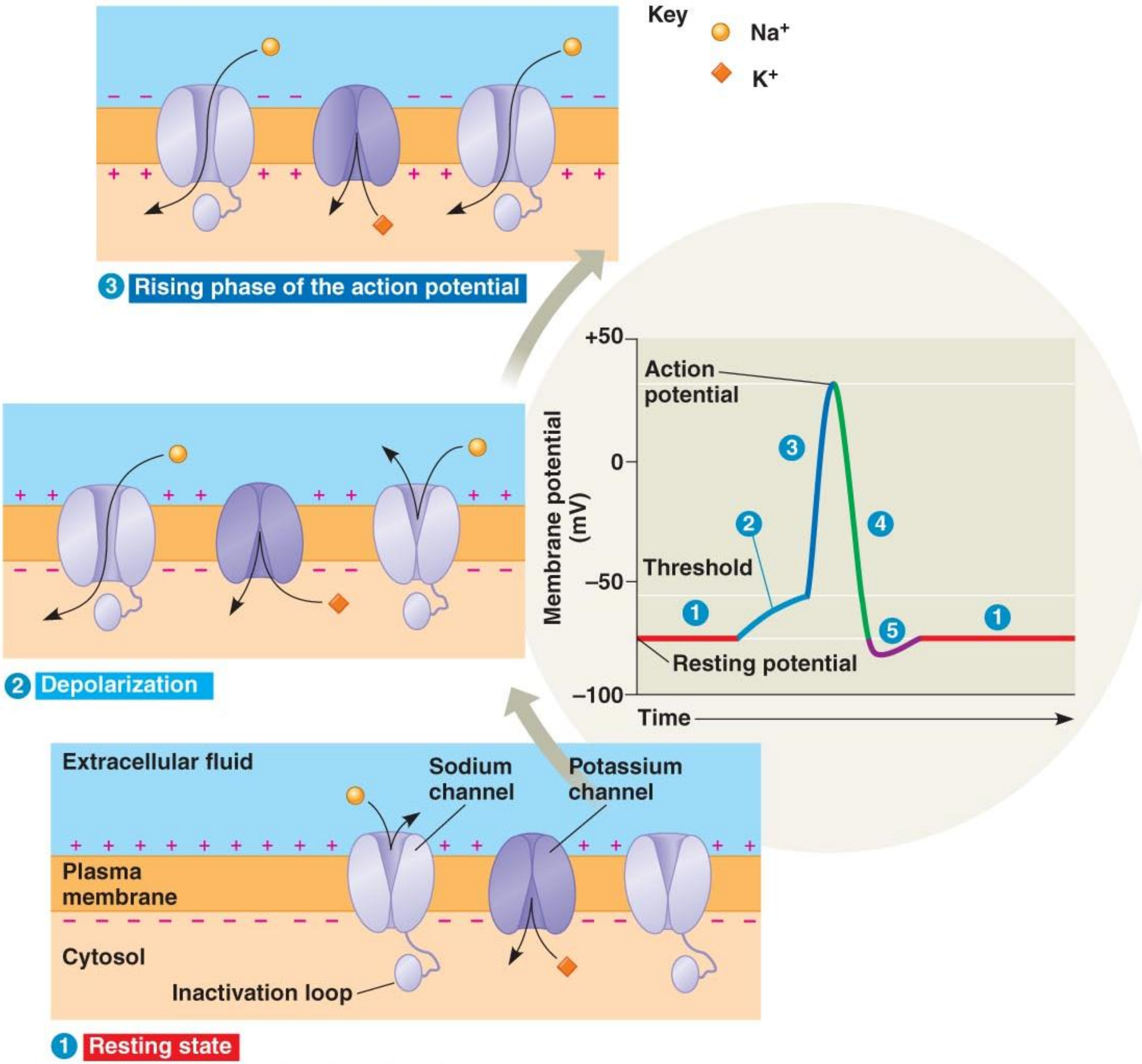
- As the action potential subsides
  - K^+ channels open, and K^+ flows out of the cell
- A refractory period follows the action potential
  - During which a second action potential cannot be initiated



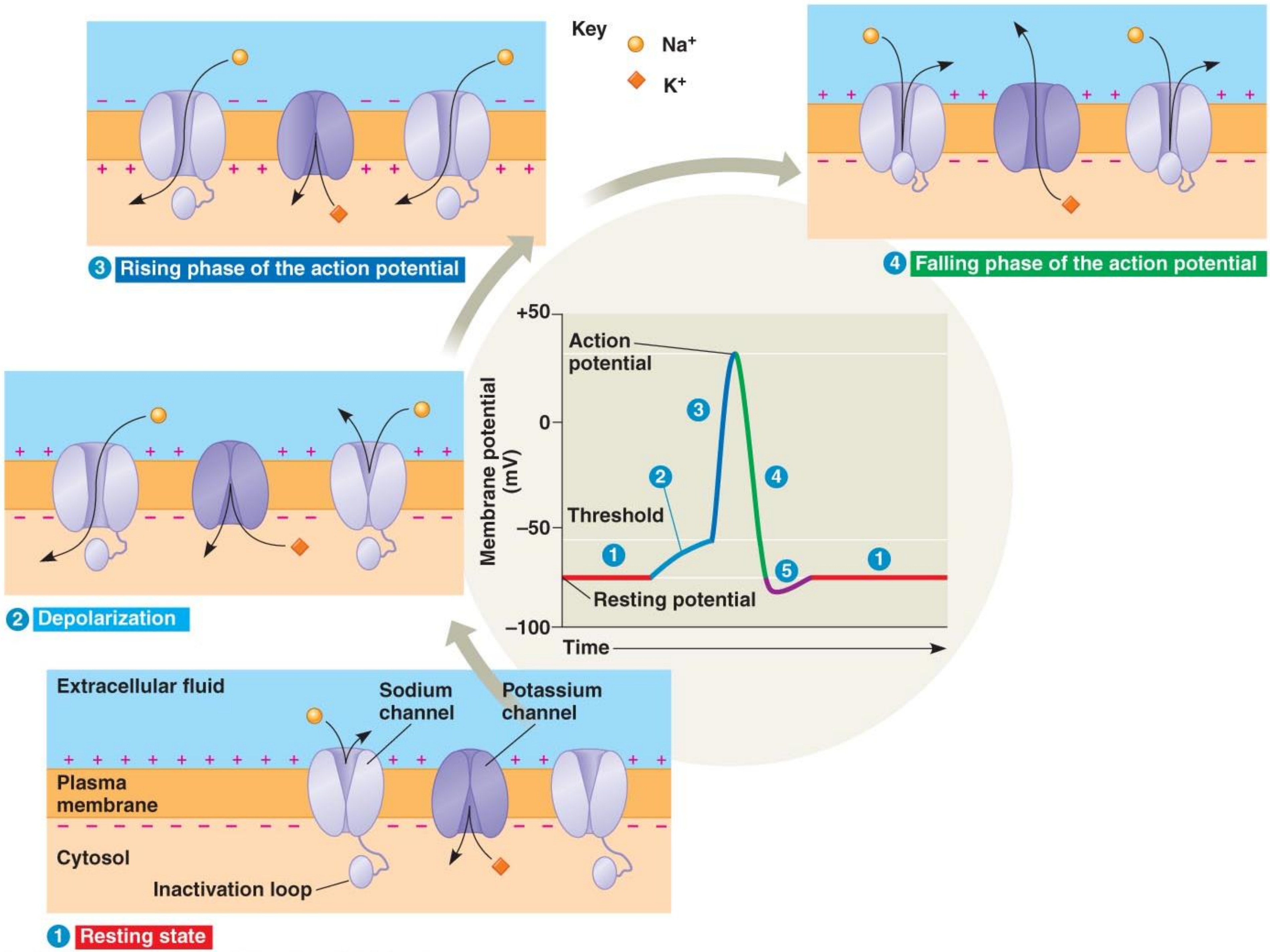
Action potential
+50
0
−50
−100
Membrane potential (mV)
Falling phase
Rising phase
Threshold (−55)
Resting potential
−70
Depolarization
Undershoot
Time (msec)


Key
Na^+
K^+
+50
0
–50
–100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
1
2
3
4
5
1
Extracellular fluid
Sodium channel
Potassium channel
Plasma membrane
Cytosol
Inactivation loop
1 Resting state

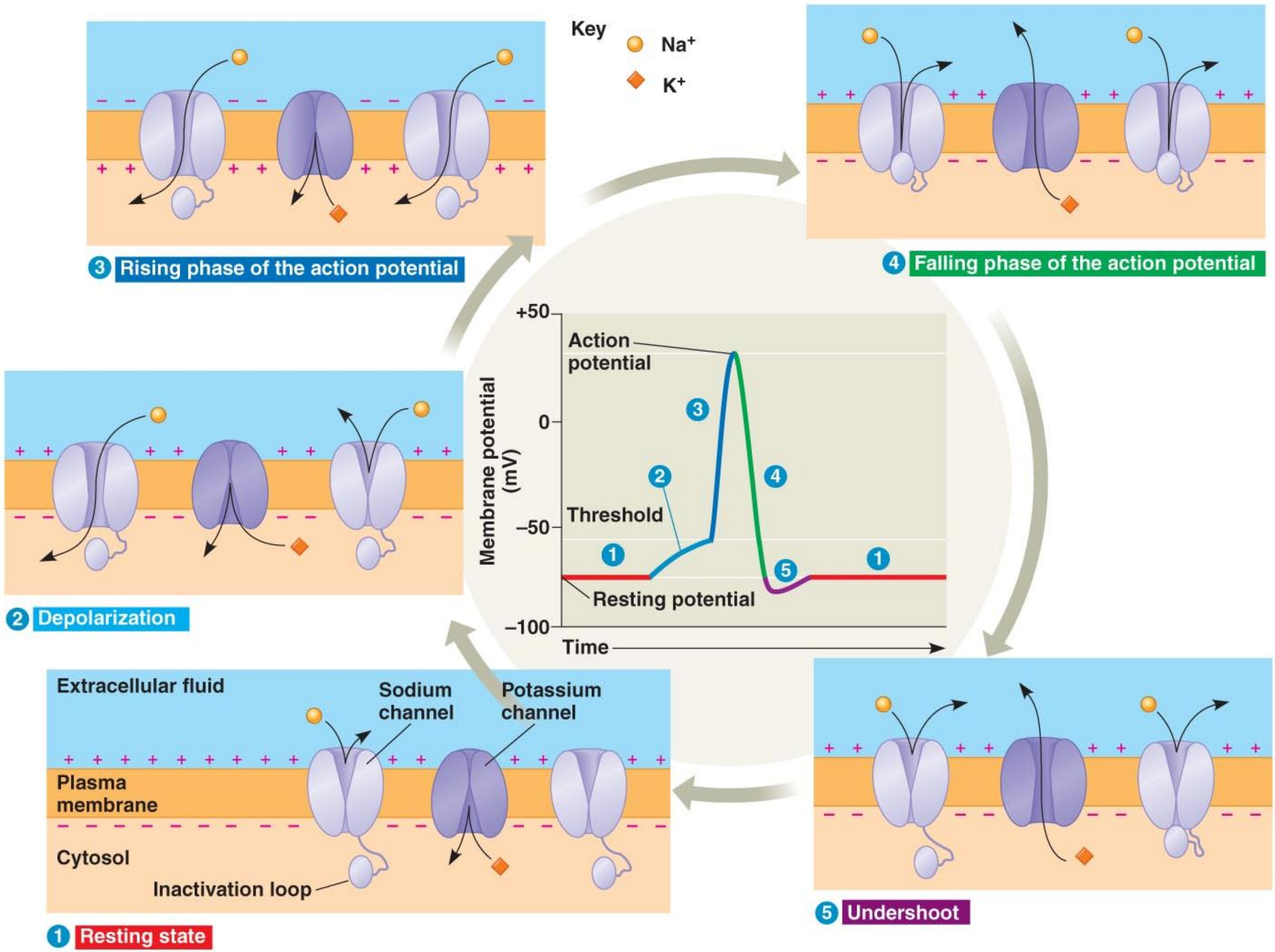

Key
Na+
K+
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
1
2
3
4
5
1
Extracellular fluid
Sodium channel
Potassium channel
Plasma membrane
Cytosol
Inactivation loop
2 Depolarization
1 Resting state



Key
Na+
K+
3 Rising phase of the action potential
2 Depolarization
Extracellular fluid
Sodium channel
Potassium channel
Plasma membrane
Cytosol
Inactivation loop
1 Resting state
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time



Key
Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
2 Depolarization
1 Resting state
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
Extracellular fluid
Sodium channel
Potassium channel
Plasma membrane
Cytosol
Inactivation loop

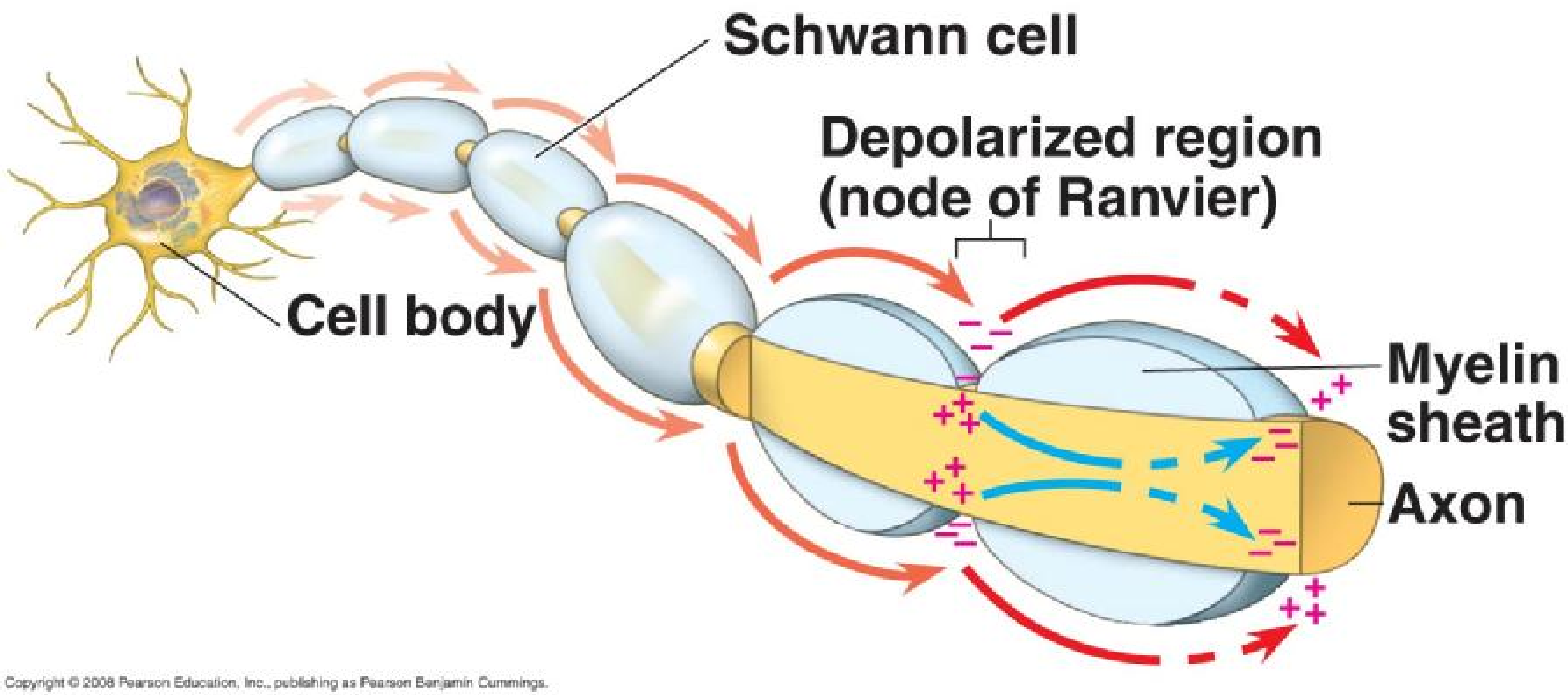

Key
Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
+50
Action potential
3
0
2
4
Membrane potential (mV)
Threshold
−50
1
5
1
Resting potential
−100
Time
2 Depolarization
Extracellular fluid
Sodium channel
Potassium channel
Plasma membrane
Cytosol
Inactivation loop
1 Resting state
5 Undershoot

Conduction of Action Potentials

Conduction Speed

- The speed of an action potential
  - Increases with the diameter of an axon
- In vertebrates, axons are myelinated
  - Also causing the speed of an action potential to increase

- Action potentials in myelinated axons
  - Jump between the nodes of Ranvier in a process called saltatory conduction



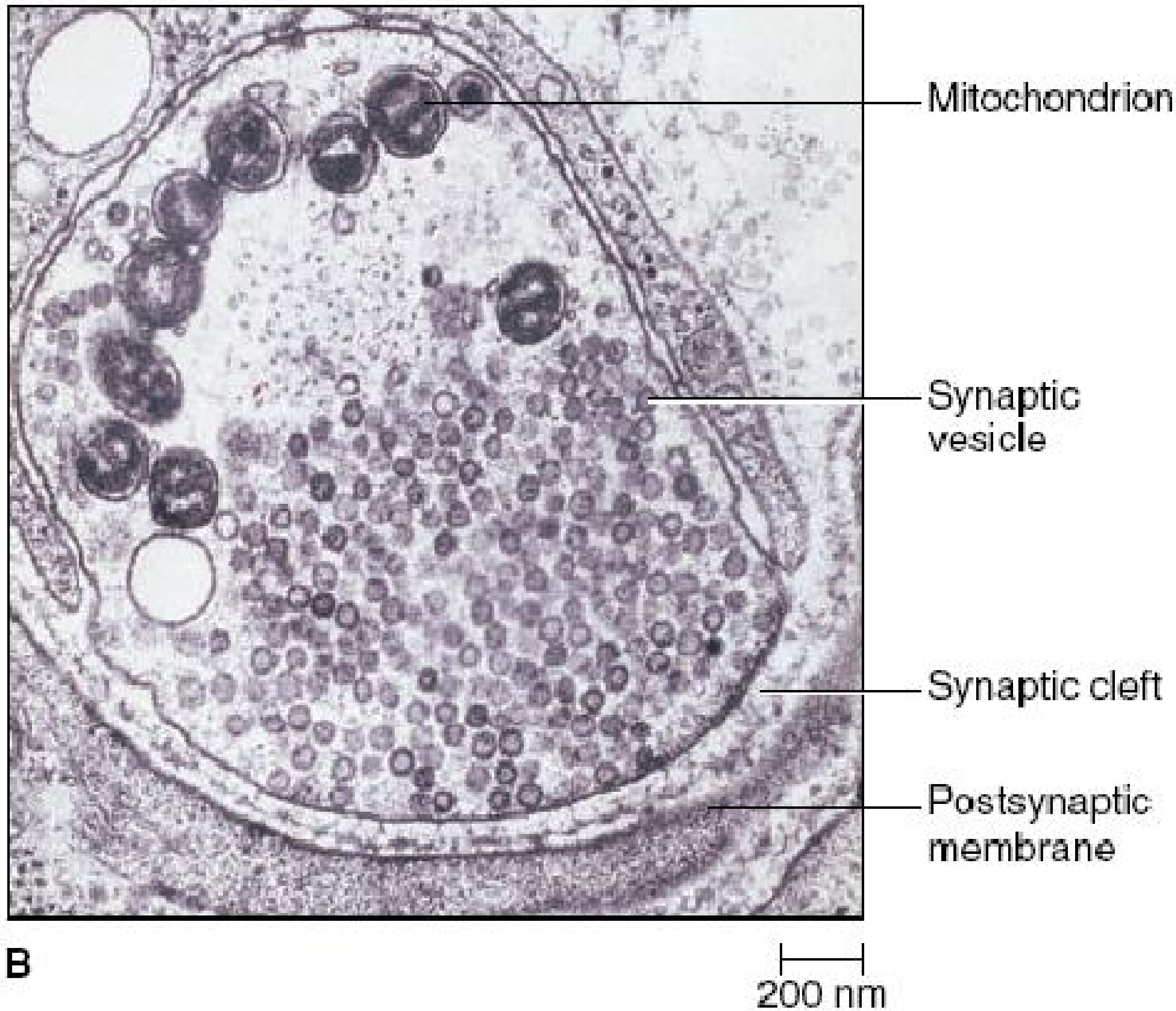
Mastering Concepts

1) What three mechanisms establish and maintain the resting potential?
2) How do changing cell membrane ion permeabilities generate and transmit a neural impulse?
3) In the disease multiple sclerosis, myelin sheaths gradually harden and deteriorate. How would this affect nervous system function?

Synapses

- Neurons communicate with other cells at synapses
- In an electrical synapse
  - Electrical current flows directly from one cell to another via a gap junction
- The vast majority of synapses
  - Are chemical synapses
- In a chemical synapse, a presynaptic neuron
  - Releases chemical neurotransmitters, which are stored in the synaptic terminal

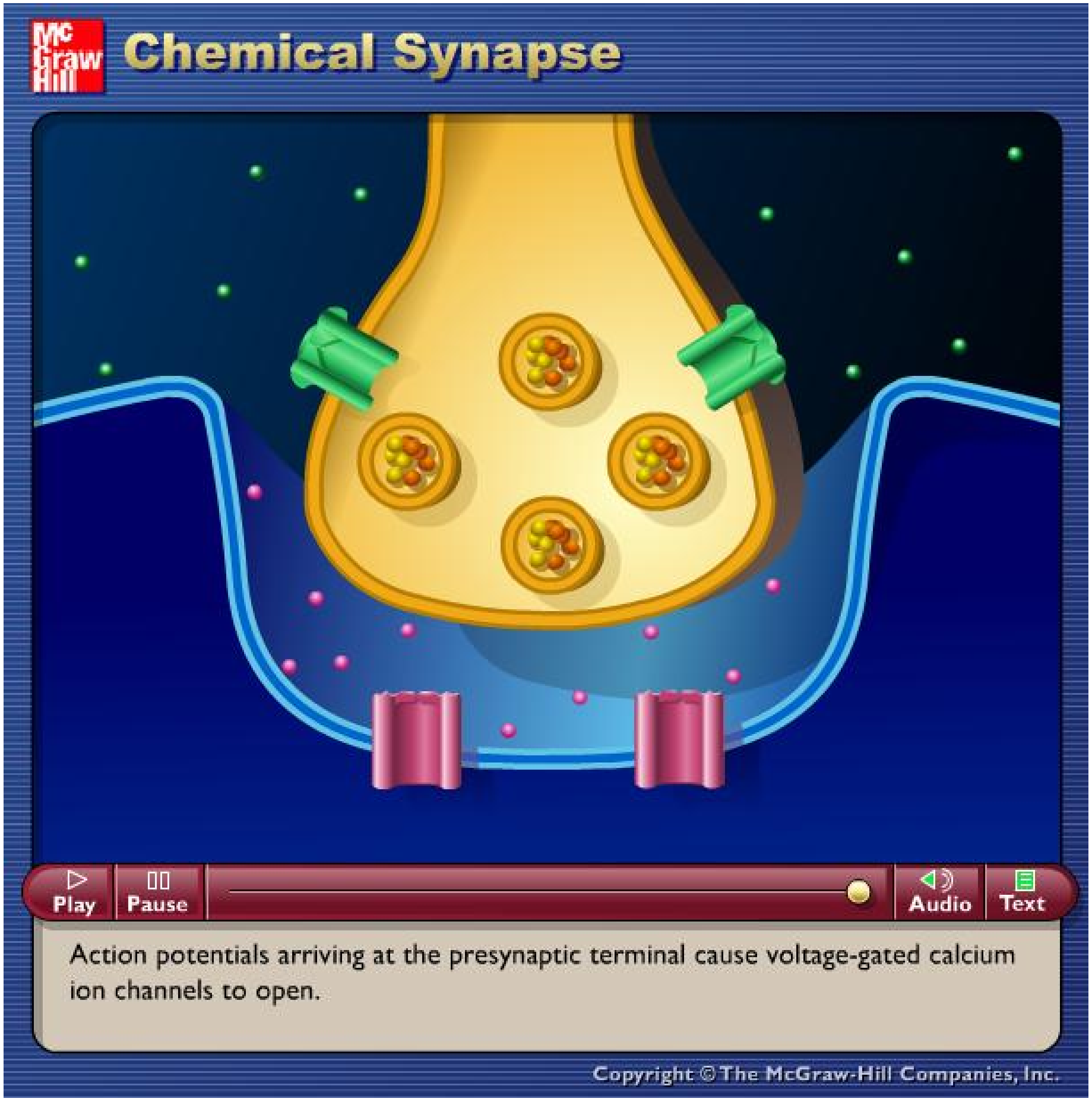
Postsynapti
neuron

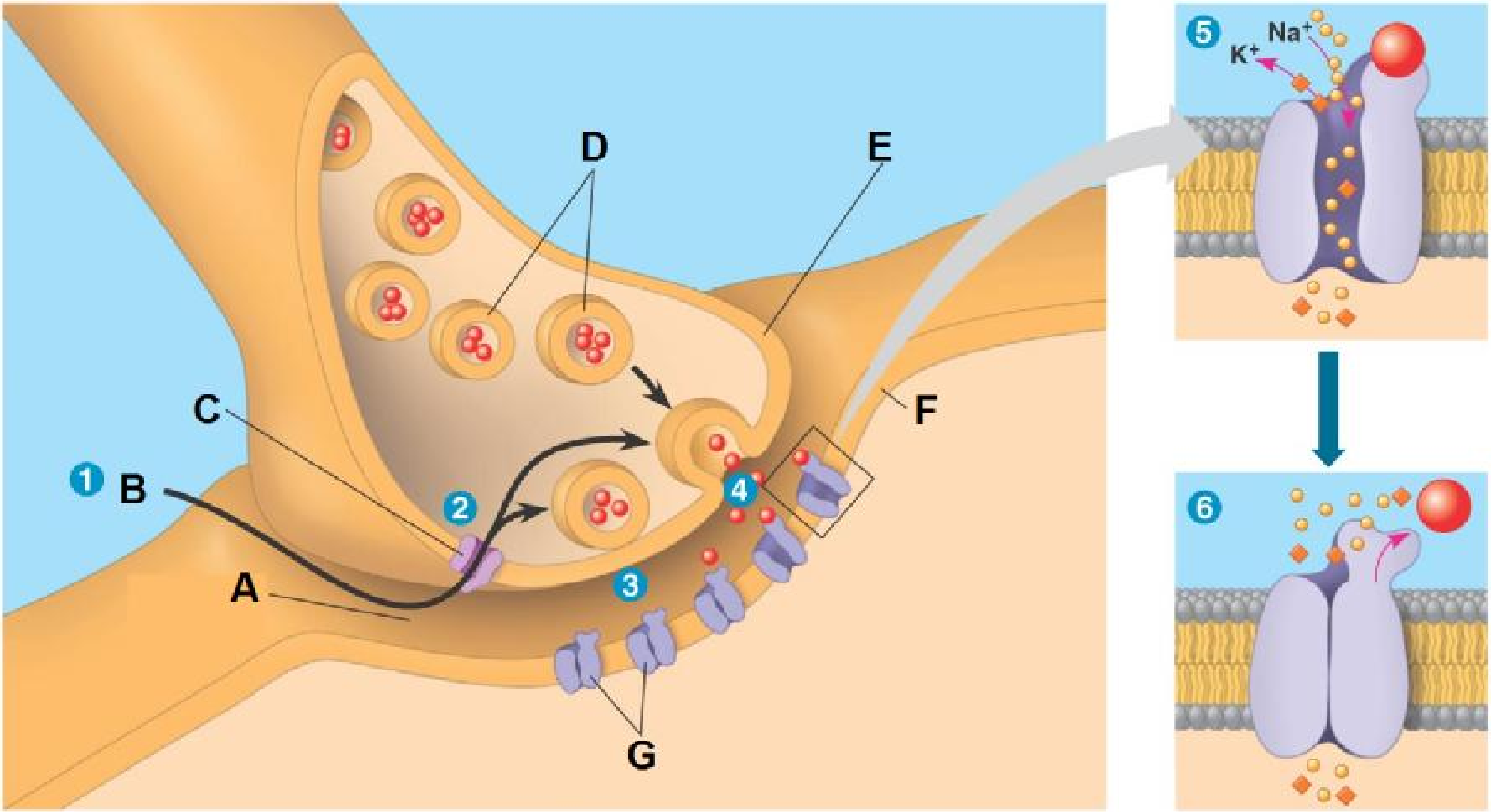


B

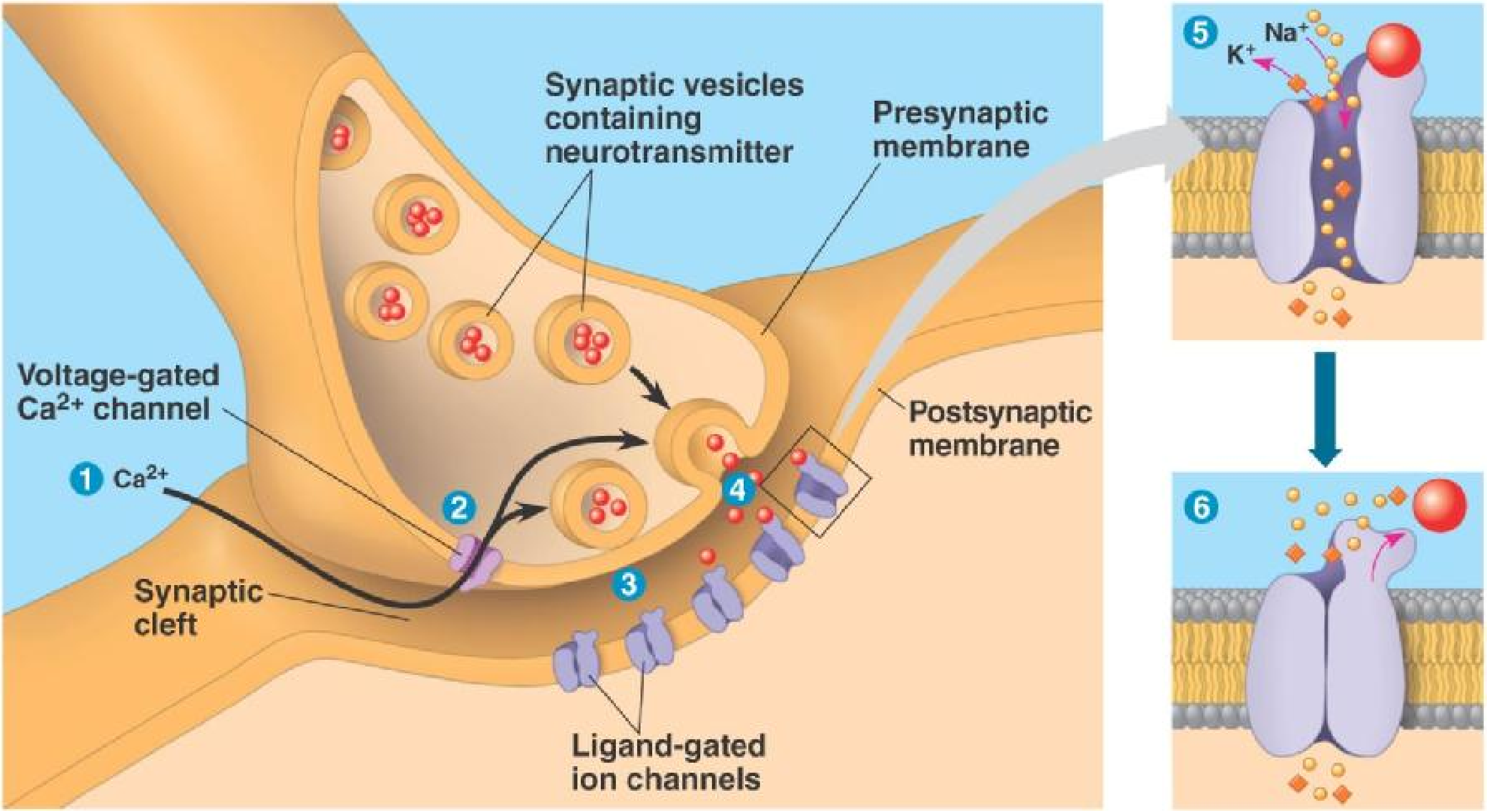
ynaptic
erminals
f pre-
ynaptic
eurons

Synaptic Transmission





1
B
2
C
A
3
D
E
4
F
G
5
Na^+
K^+
6



Synaptic vesicles containing neurotransmitter
Presynaptic membrane
Voltage-gated Ca^{2+} channel
1 Ca^{2+}
2
3
4
Postsynaptic membrane
Synaptic cleft
Ligand-gated ion channels
5
Na^{+}
K^{+}
6

Mastering Concepts

1) How do neurotransmitters send action potentials from a neuron to another neuron, a muscle, or a gland cell?
2) What happens to a neurotransmitter after it is released?
3) Organophosphate pesticides work by inhibiting acetylcholinesterase, the enzyme that breaks down the neurotransmitter acetylcholine. Explain how these toxins would affect post synaptic potentials produced by acetylcholine.

Testing your knowledge

1. What happens when a neuron's membrane depolarizes?

   A. There is a net diffusion of Na+ out of the cel1.

   B. The equilibrium potential for K+ becomes more positive.

   C. The neuron's membrane voltage becomes more positive.

   D. The neuron becomes less likely to generate an action potential.

   E. The inside of the cell becomes more negative relative to the outside.

2. Why are action potentials usually conducted in only one direction along an axon?

A. The nodes of Ranvier can conduct potentials in only one direction.

B. The brief refractory period prevents reopening of voltagegated Na+ channels.

C. The axon hillock has a higher membrane potential than the terminals of the axon.

D. Ions can flow along the axon in only one direction.

E. Voltage·gated channels for both Na+ and K+ open in only one direction.

3. A common feature of action potentials is that they

A. cause the membrane to hyperpolarize and then depolarize.

B. can undergo temporal and spatial summation.

C. are triggered by a depolarization that reaches the threshold.

D. move at the same speed along all axons.

E. result from the diffusion of Na-t and K-t through ligandgated channels.

4. Which ofthe following is a *direct* result of depolarizing the presynaptic membrane of an axon terminal?

A. Voltage-gated calcium channels in the membrane open.

B. Synaptic vesicles fuse with the membrane.

C. The postsynaptic cell produces an action potentia1.

D. Ligand·gated channels open, allowing neurotransmitters to enter the synaptic cleft.

E. An post synaptic potential is generated in the postsynaptic cel1.

5. Where are neurotransmitter receptors located?

A. on the nuclear membrane

B. at nodes of Ranvier

C. on the postsynaptic membrane

D. on the membranes of synaptic vesicles

E. in the myelin sheath

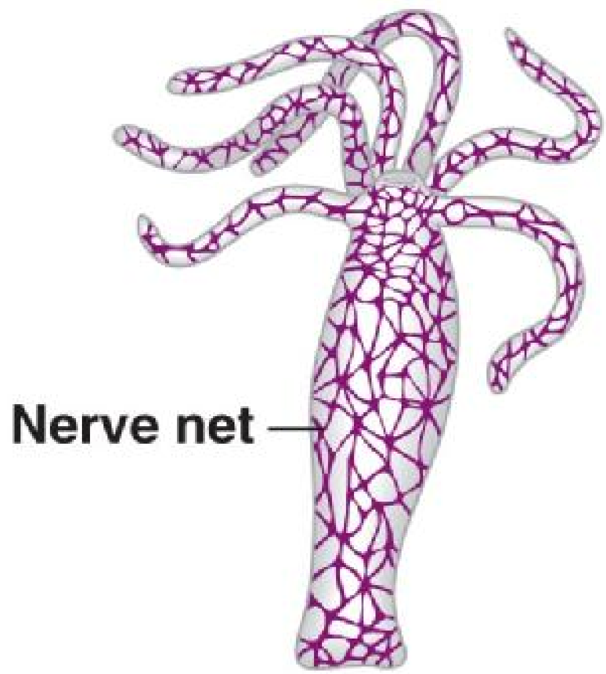
Evolutionary Trends in Nervous Systems

- Nervous systems in different animal phyla reflect adaptations to particular environments.
- In invertebrates, these systems increase in complexity, from simple net and ladder organizations, to the anterior concentration of neurons to form a rudimentary brain.
- The vertebrate nervous system consists of a centralized brain and spinal cord and peripheral nerves.

- Cephalization
  - Is the concentration of the nervous system at the head
- Centralization
  - Is the presence of a central nervous system (CNS) distinct from a peripheral nervous system (PNS)

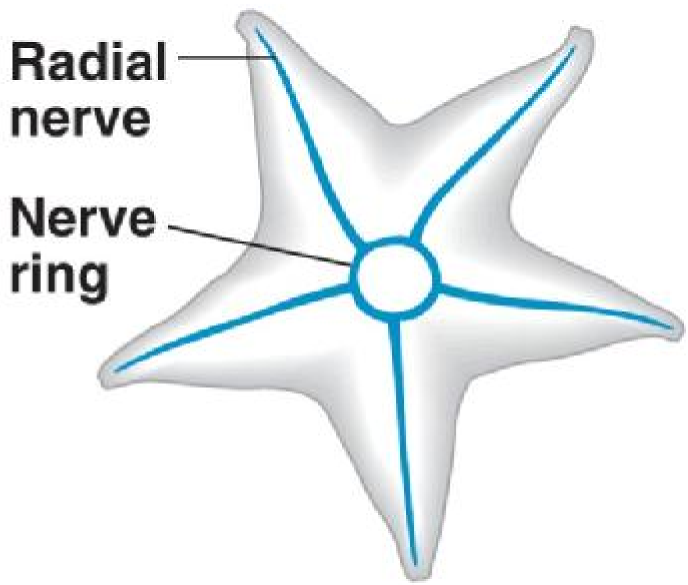
Organization of Nervous Systems

- The simplest animals with nervous systems, the cnidarians
  - Have neurons arranged in nerve nets



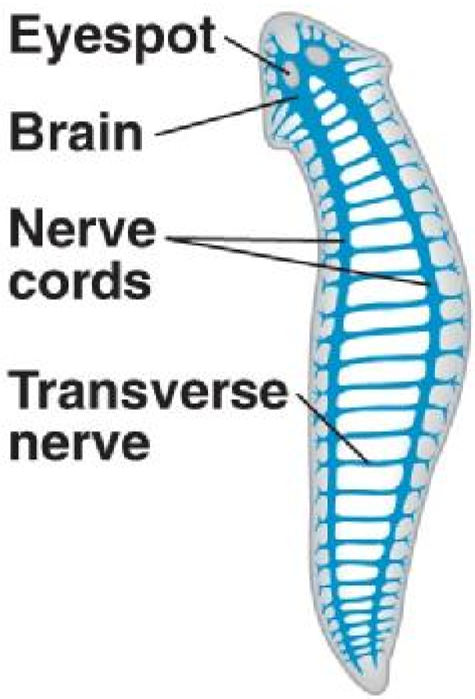
(a) Hydra (cnidarian)

- Sea stars have a nerve net in each arm
  - Connected by radial nerves to a central nerve ring



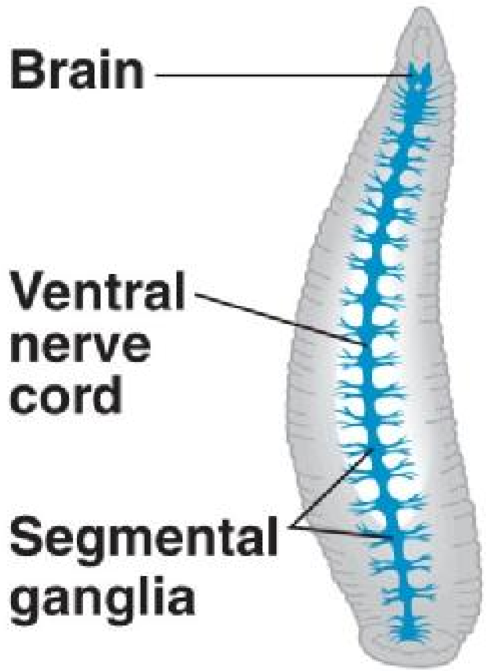
(b) Sea star (echinoderm)

- In relatively simple cephalized animals, such as flatworms
  - a small brain and longitudinal nerve cords constitute the simplest central nervous system (CNS)

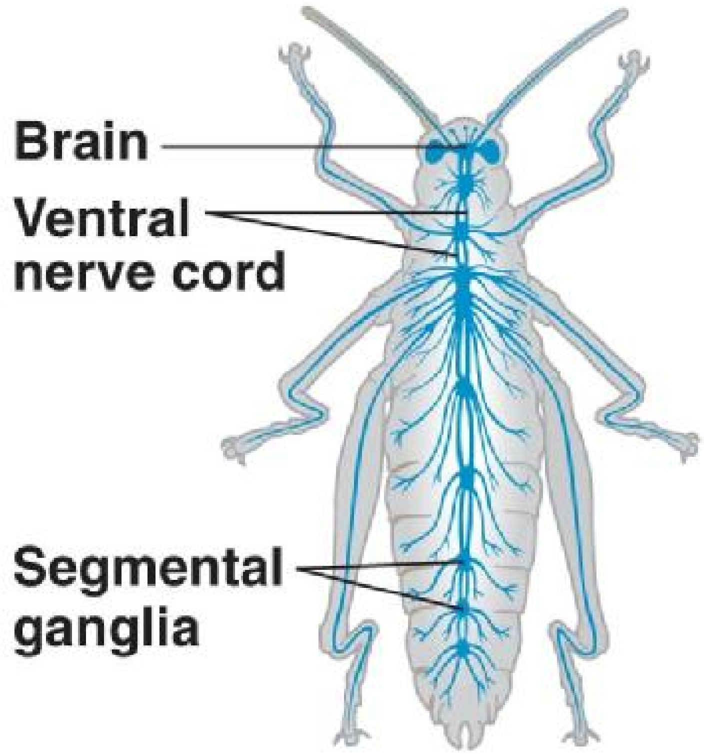


(c) Planarian (flatworm)

- Annelids and arthropods
  - Have segmentally arranged clusters of neurons called ganglia
- These ganglia connect to the CNS
  - And make up a peripheral nervous system (PNS)

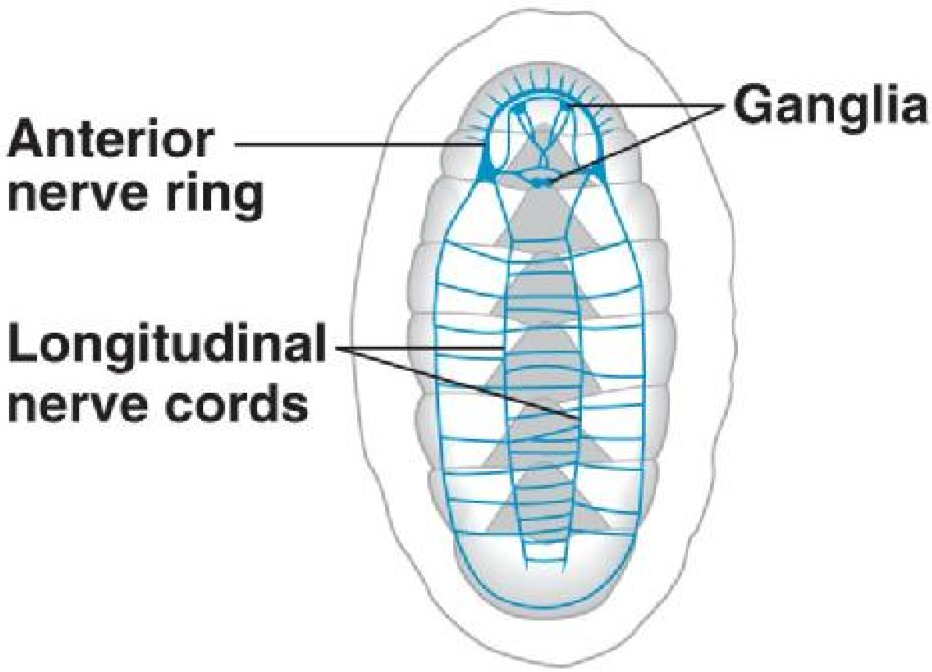


(d) Leech (annelid)

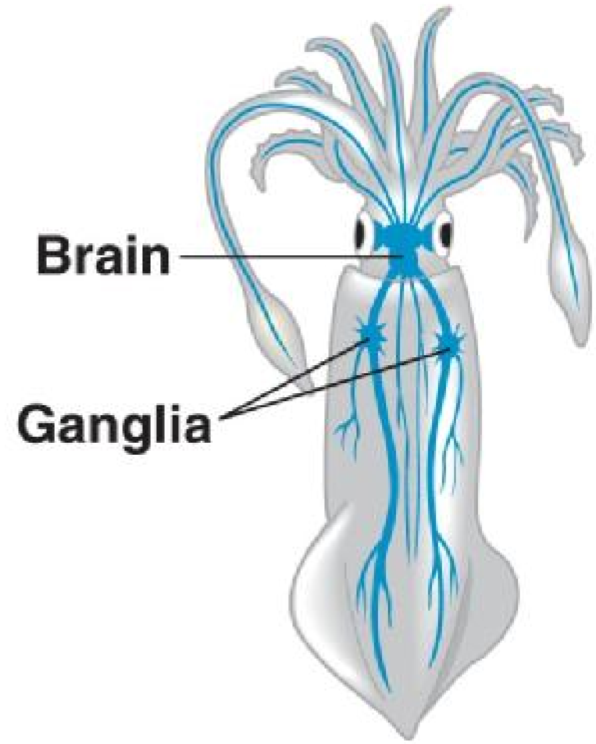


(e) Insect (arthropod)

- Nervous systems in molluscs
  - Correlate with the animals’ lifestyles
- Sessile molluscs have simple systems
  - While more complex molluscs have more sophisticated systems

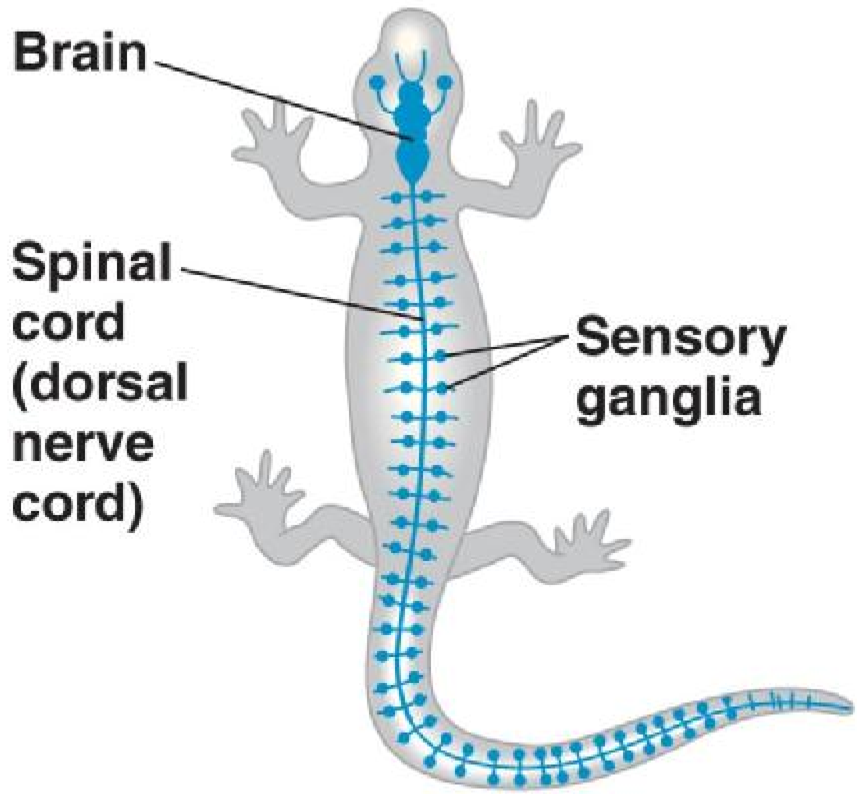


(f) Chiton (mollusc)

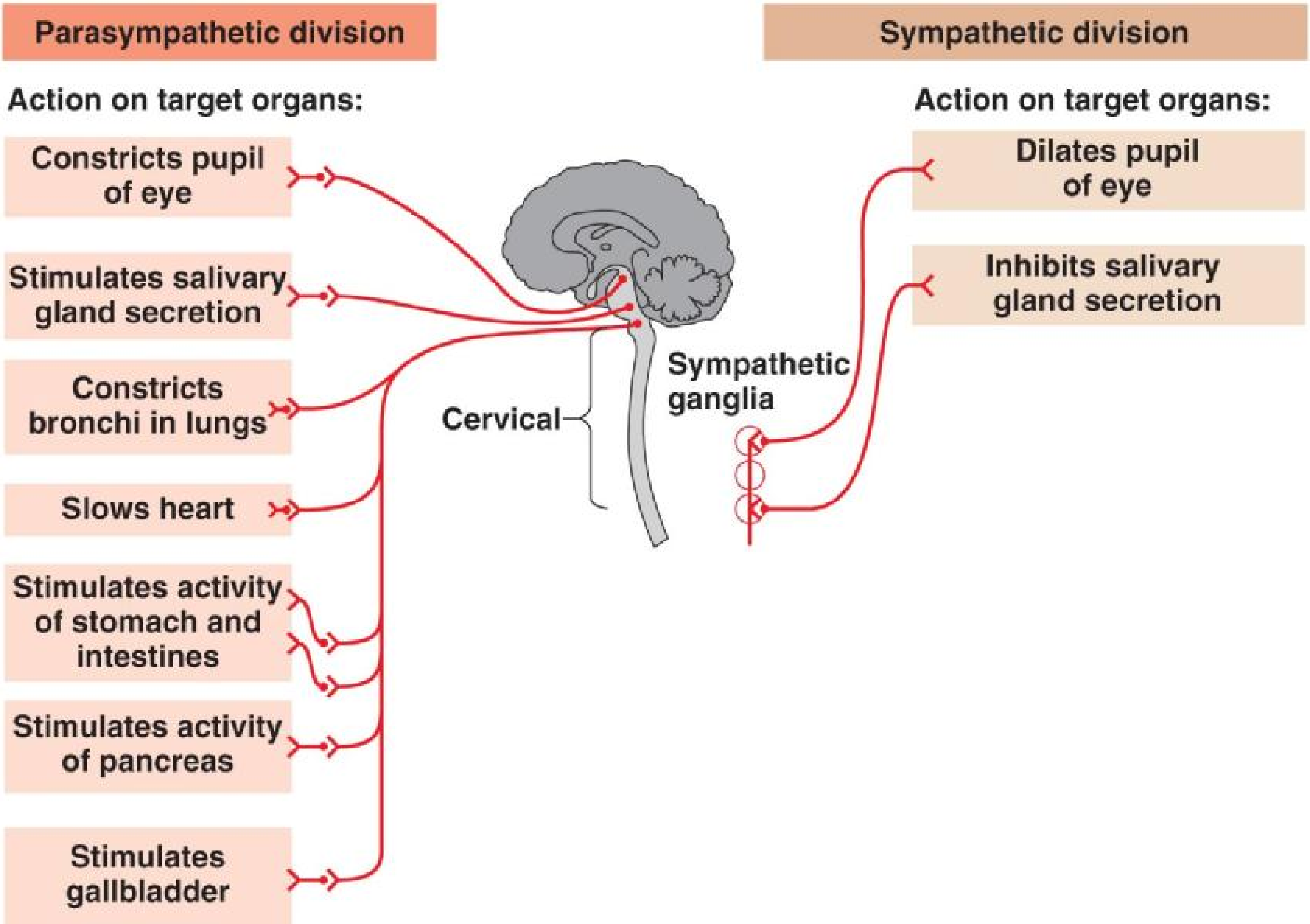


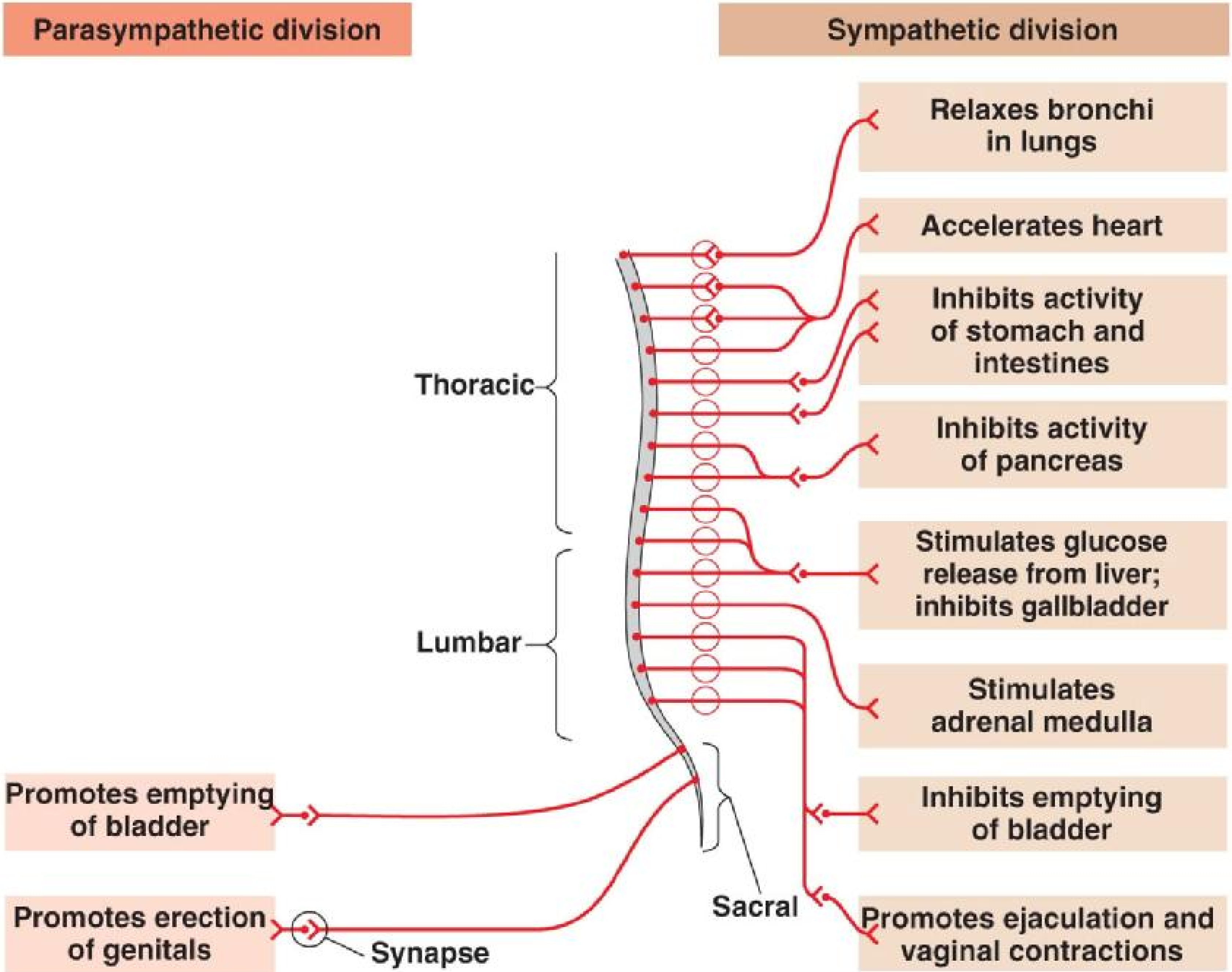
(g) Squid (mollusc)

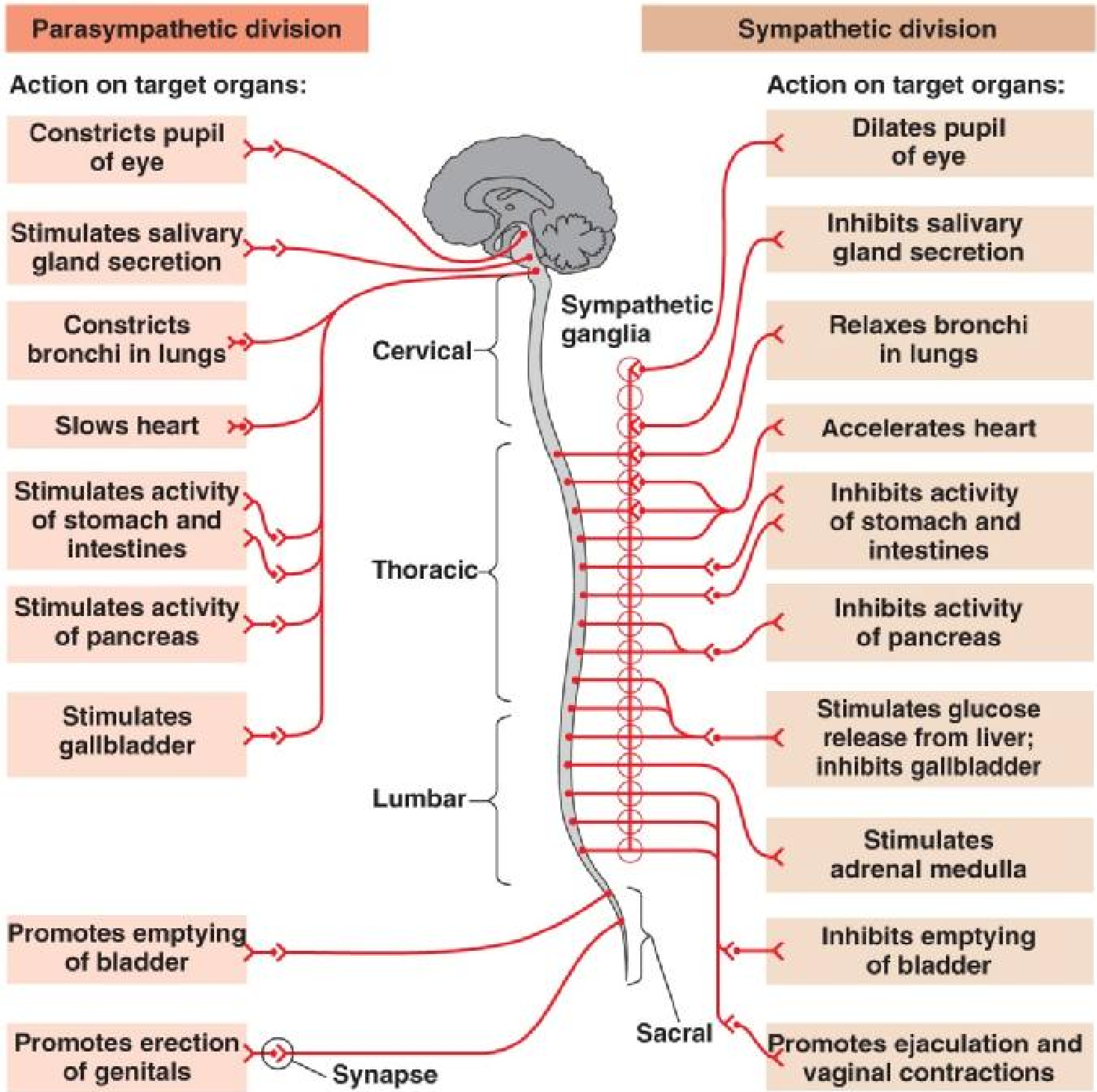
- In vertebrates
  - The central nervous system consists of a brain and dorsal spinal cord
  - The PNS connects to the CNS



(h) Salamander (vertebrate)


Parasympathetic 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
Cervical
Sympathetic ganglia
Sympathetic division
Action on target organs:
Dilates pupil of eye
Inhibits salivary gland secretion


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


Parasympathetic 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
Sympathetic division
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

The Human Brain

- The brain is divided into three regions
  - The forebrain, the midbrain, and the hindbrain

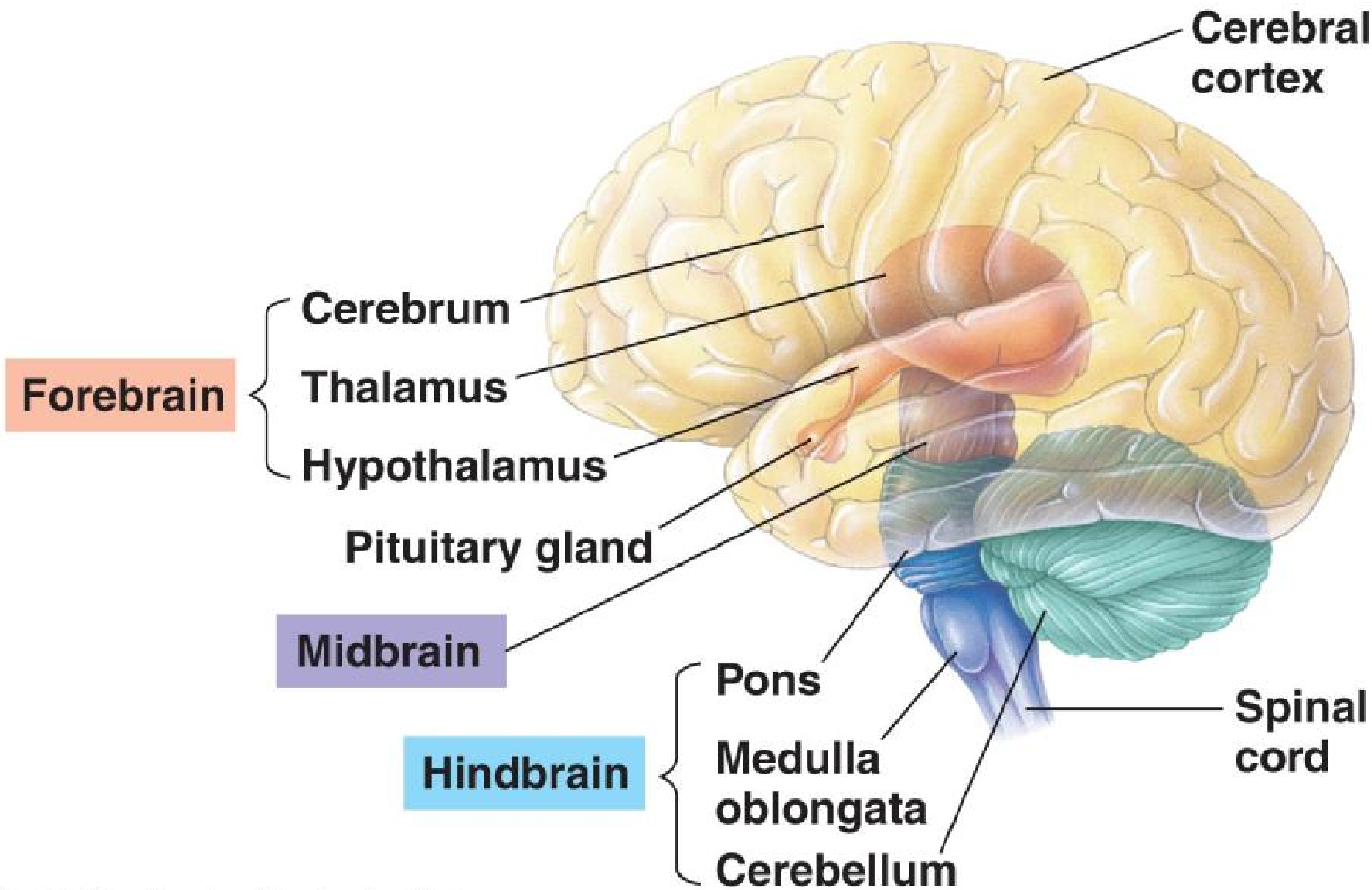

Cerebral cortex
Forebrain
Cerebrum
Thalamus
Hypothalamus
Pituitary gland
Midbrain
Hindbrain
Pons
Medulla oblongata
Cerebellum
Spinal cord

Table 27.1	Structures of the Brain
Brain Structure	**Major Function**
Thalamus	Input center for sensory data going to the cerebrum; output center for motor responses leaving the cerebrum; data sorting
Hypothalamus	Homeostatic control center; controls pituitary gland; biological clock
Cerebrum	Sophisticated integration; memory, learning, speech; emotions; formulates complex behavioral responses
Brain stem	Conducts data to and from other brain centers; homeostatic control; coordinates body movement
Medulla oblongata	Controls breathing, circulation, swallowing, digestion
Pons	Controls breathing
Midbrain	Receives and integrates auditory data; major visual center in nonmammalian vertebrates; coordinates visual reflexes in mammals; sends sensory data to higher brain centers
Cerebellum	Coordinates body movement; learns and remembers motor responses

Table 27.1

- The forebrain
  - Contains the most sophisticated integrating centers in the brain—the thalamus, the hypothalamus, and the cerebrum

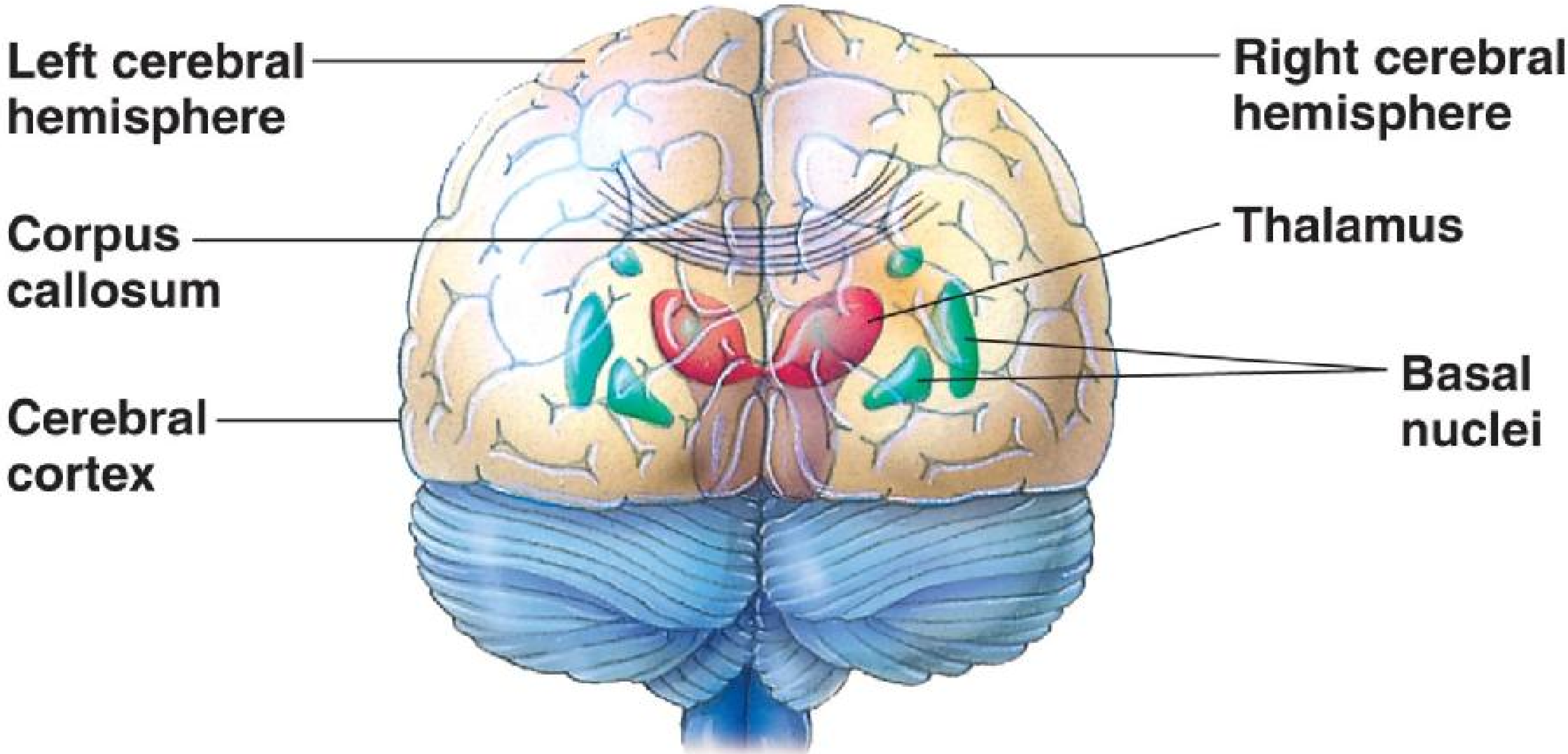
- The thalamus
  - Contains most of the cell bodies that relay information to the cerebral cortex
- The hypothalamus
  - Controls many regulatory functions

- The midbrain and parts of the hindbrain make up the brain stem, which serves as a sensory filter, selecting which information reaches higher brain centers

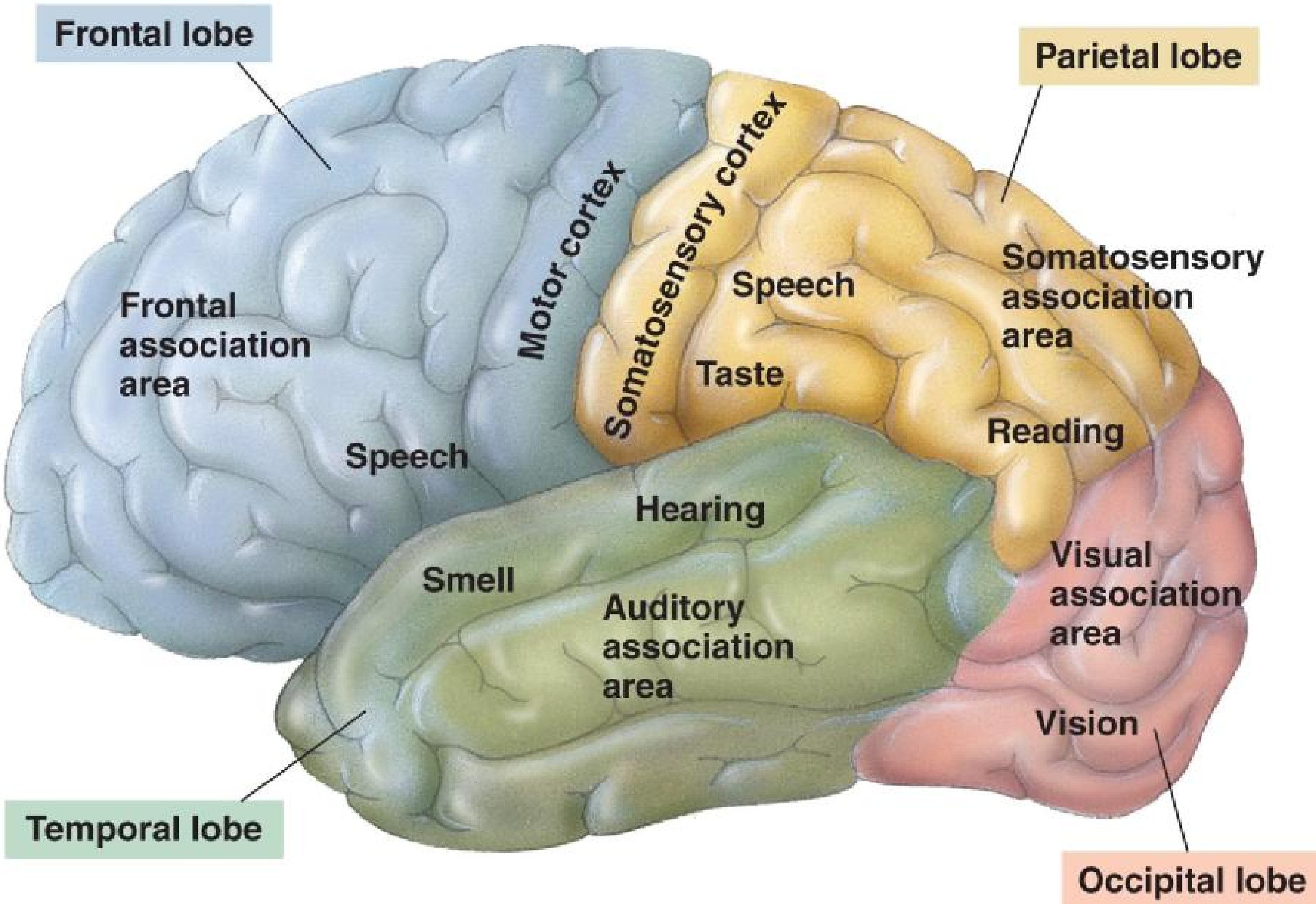
- The cerebellum, another part of the hindbrain
  - Is a planning center for body movements

The Cerebral Cortex

- The cerebrum
  - Is the largest and most sophisticated part of our brain
  - Consists of right and left cerebral hemispheres


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

- The cerebral cortex
  - Is a highly folded layer of gray matter forming the surface of the cerebrum
  - Helps produce our most distinctive human traits
- The right and left cerebral hemispheres
  - Are specialized for different mental tasks
  - Have four lobes


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