NERVOUS SYSTEM

Chapter 48-49

Nervous System

- **Function:** coordinates and controls bodily functions with nerves and electrical impulses
- The system is composed of different types of nerve cells called neurons
  - One neuron may communicate with thousands of other neurons
  - Communication between neurons can be long-distance electrical signals or short-distance chemical signals

Nervous System

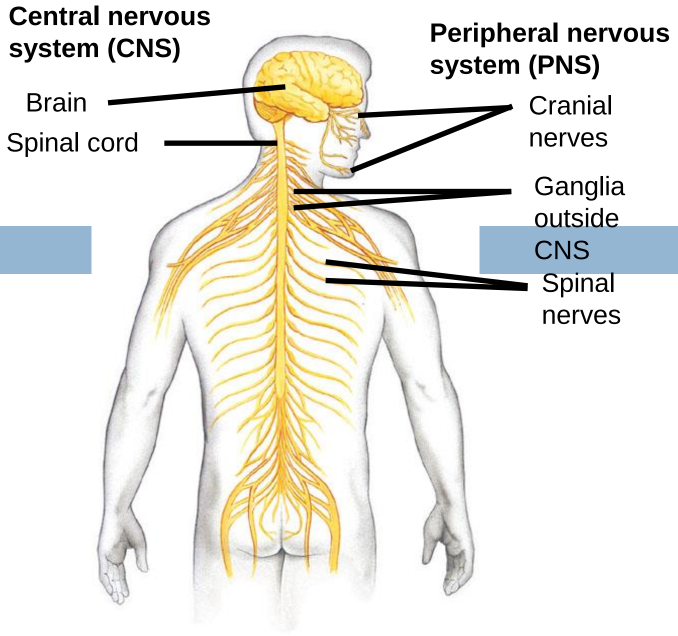


Figure 48.19

- In all vertebrates, the nervous system shows a high degree of cephalization and distinct CNS and PNS components
- The brain provides the integrative power that underlies the complex behavior of vertebrates
- The spinal cord integrates simple responses to certain kinds of stimuli and conveys information to and from the brain

Information Processing

- The nervous system processes information through detection, generation, transmission, and integration of signal information
  - Essentially: Sensory input, integration, and motor output

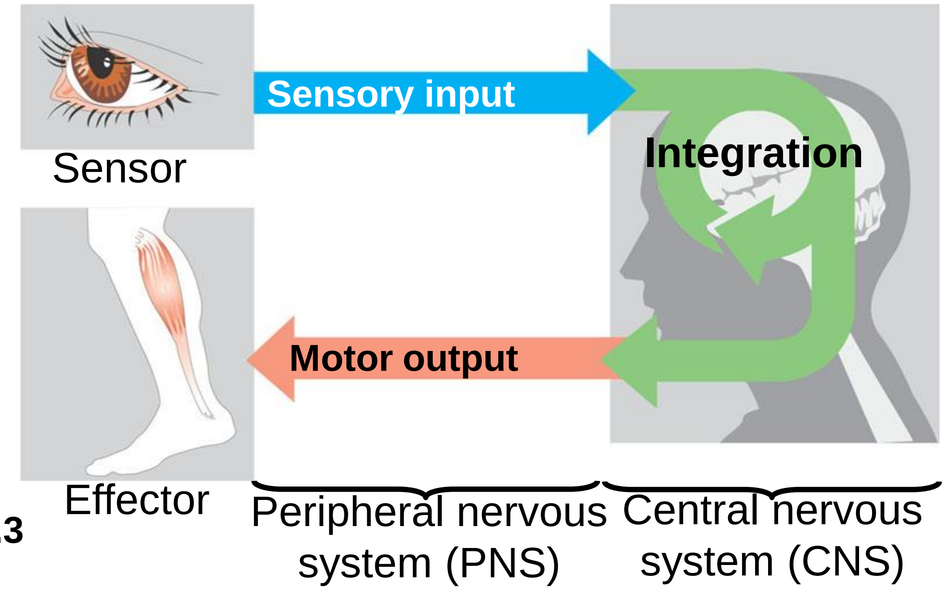


Figure 48.3

Divisions of the Nervous System

- 2 main divisions are the Central and Peripheral Nervous systems – CNS and PNS

- The CNS integrates and processes information from the body
- The PNS transmits information to and from the CNS

Peripheral Nervous System

- Divisions of PNS:
  - ***Sensory*** and ***Motor*** division
    - Sensory = sends signals to the CNS from receptors
    - Motor = send signals away from the CNS to the parts of the body
  - Motor division can be separated into the ***Somatic*** nervous system and the ***Autonomic*** nervous system – SNS and ANS
  - Autonomic nervous system divides into ***Parasympathetic*** and ***Sympathetic*** divisions

Peripheral Nervous System

- **Somatic nervous system**
  - Carries signals to skeletal muscles and is voluntarily controlled
- **Autonomic nervous system**
  - Involuntarily regulates the internal environment
  - Carries signals to cardiac muscle, smooth muscle, and glands

Peripheral Nervous System

- The ANS division have antagonistic effects on target organs
  - **Sympathetic division**: "fight-or-flight" response
  - **Parasympathetic division**: promotes a return to self-maintenance functions and resting and digesting

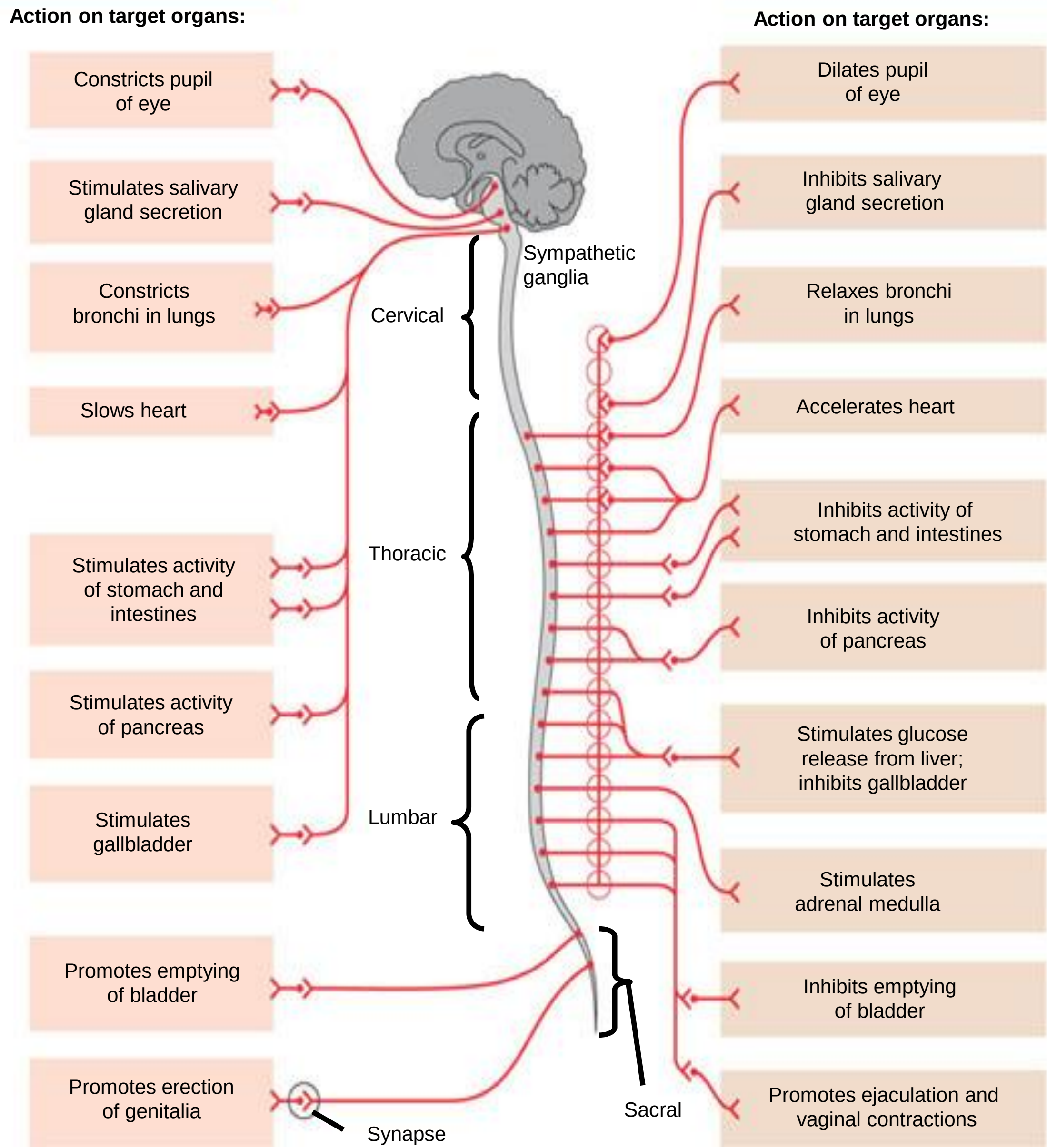
Parasympathetic division | **Sympathetic division**

Location of preganglionic neurons: brainstem and sacral segments of spinal cord

Neurotransmitter released by preganglionic neurons: acetylcholine

Location of postganglionic neurons: in ganglia close to or within target organs

Neurotransmitter released by postganglionic neurons: acetylcholine



Location of preganglionic neurons: thoracic and lumbar segments of spinal cord

Neurotransmitter released by preganglionic neurons: acetylcholine

Location of postganglionic neurons: some in ganglia close to target organs; others in a chain of ganglia near spinal cord

Neurotransmitter released by postganglionic neurons: norepinephrine

Figure 49.8

Types of Neurons

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

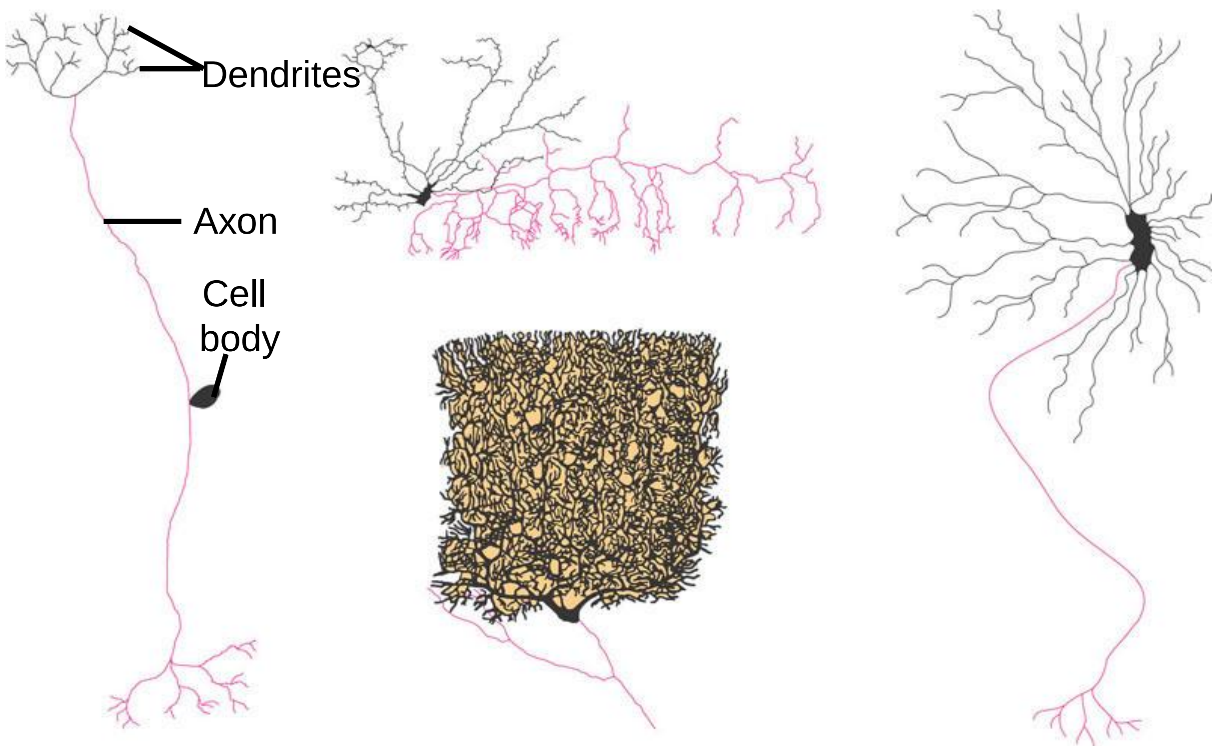


Figure 48.5

(a) Sensory neuron (b) Interneurons (c) Motor neuron

Types of Neurons

- **Sensory neurons** transmit information from sensory receptors to the CNS
  - Detects external stimuli and internal conditions
- **Interneurons** integrate the information in the CNS
  - This can be in the spinal cord or connect up to the brain
- **Motor neurons** transmit information away from the CNS
  - Neurons communicate with effector cells/organs (muscles and glands)

Stages of Information Processing

- Reflex arc – body's automatic response to a stimulus
  - This pathway includes:
    - Receptor
    - Sensory neuron
    - Interneuron
    - Motor neuron
    - Effector organ

Reflex Arc

- This is a much faster response compared to the typical stimulus-response transmission pathways
  - The reason is that reflex arcs do not involve the integration of the brain and have fewer neuron connections compared to other pathways
  - Reflex arcs also do not require conscious control and involuntarily occur which leads to some of our innate responses

Reflex Arc

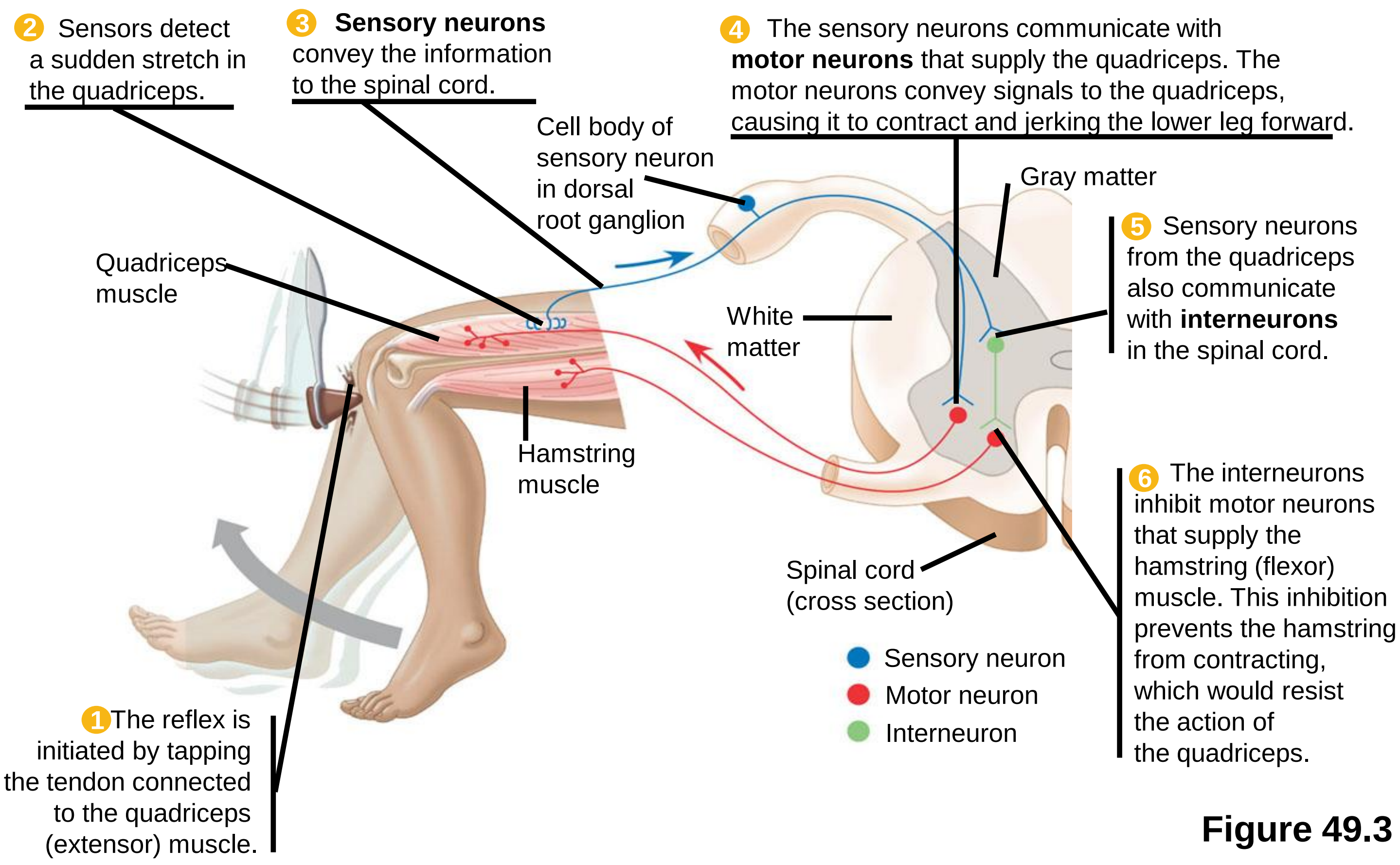


Figure 49.3

Neuron Structure

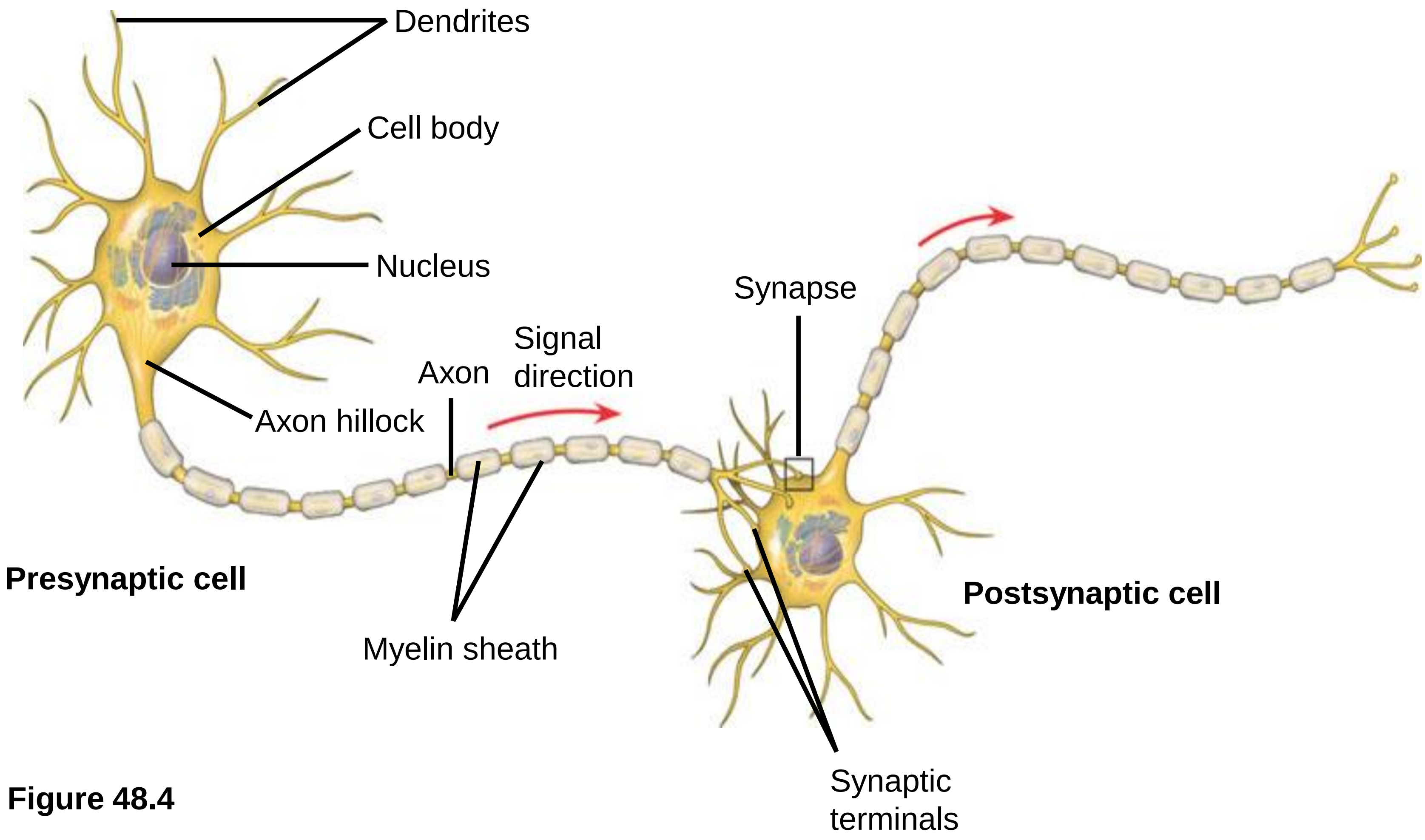


Figure 48.4

Neuron Structure

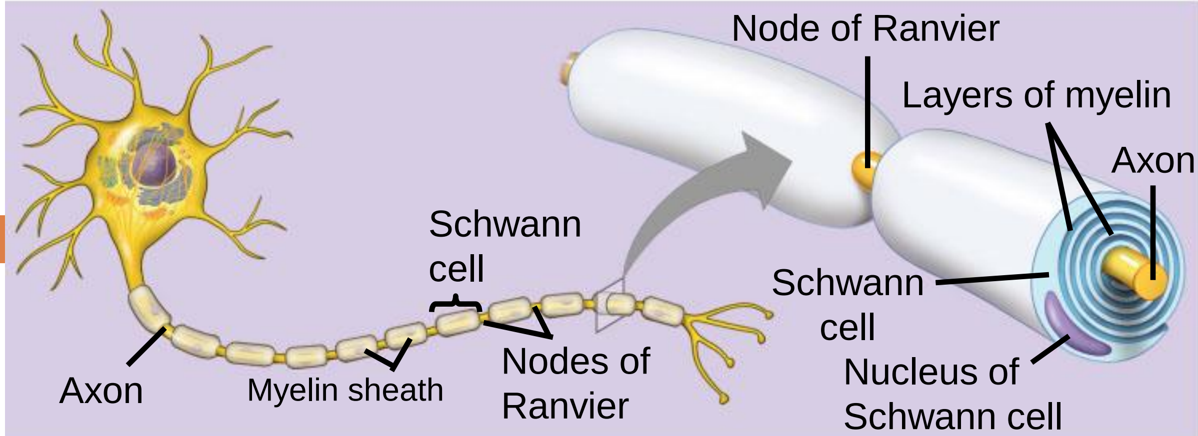
- Cell body = contains the organelles
- Dendrites = highly branched extensions that receive signals from other neurons
- Axon = cytoplasmic extension that transmits signals to other cells at synapses
  - May be covered with Schwann cells which is a fatty cell wrapped around the axon to form the myelin sheath

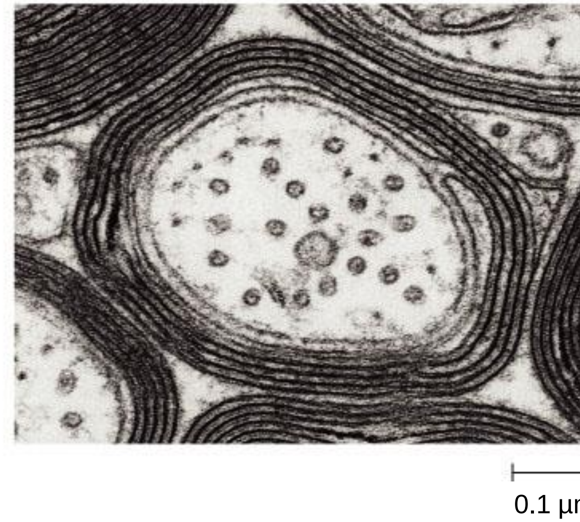
Neuron Structure

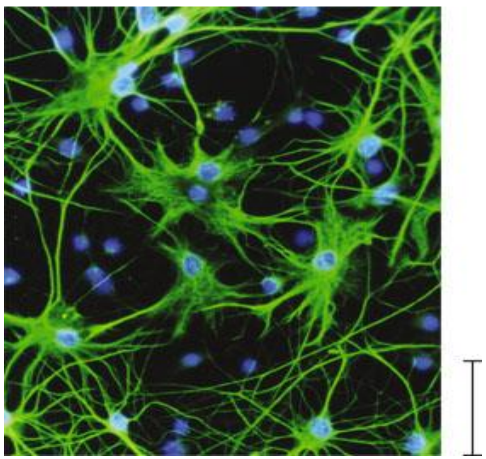
- Nodes of Ranvier = space between the Schwann cells on the axon
- Axon terminals = contains the vesicles of neurotransmitters (chemical messengers that act as ligands)

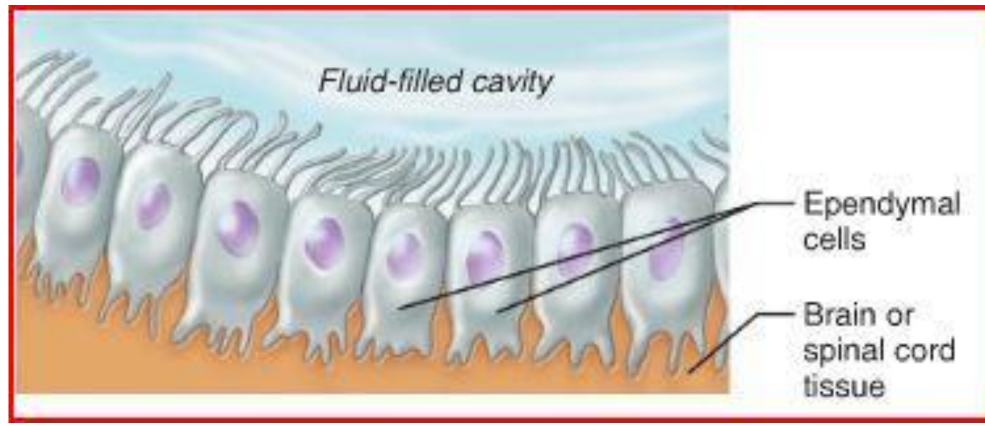
Supporting Cells (Glia)

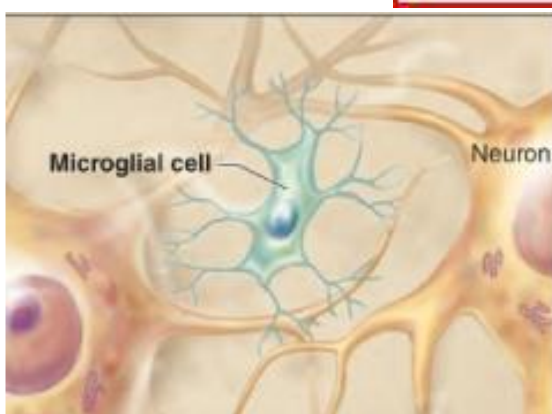
- Essential for the structural integrity of the nervous system and for the normal functioning of neurons
  - CNS
    - Astrocytes – supplies nutrients to neurons in the CNS
    - Oligodendrocytes – protection
    - Ependymal cells – lines ventricles and has cilia to move cerebrospinal fluid
    - Microglial cells – protection against microorganisms and clean up cellular debris
  - PNS
    - Schwann cells – protection


Node of Ranvier
Layers of myelin
Axon
Schwann cell
Schwann cell
Nucleus of Schwann cell
Nodes of Ranvier
Myelin sheath
Axon

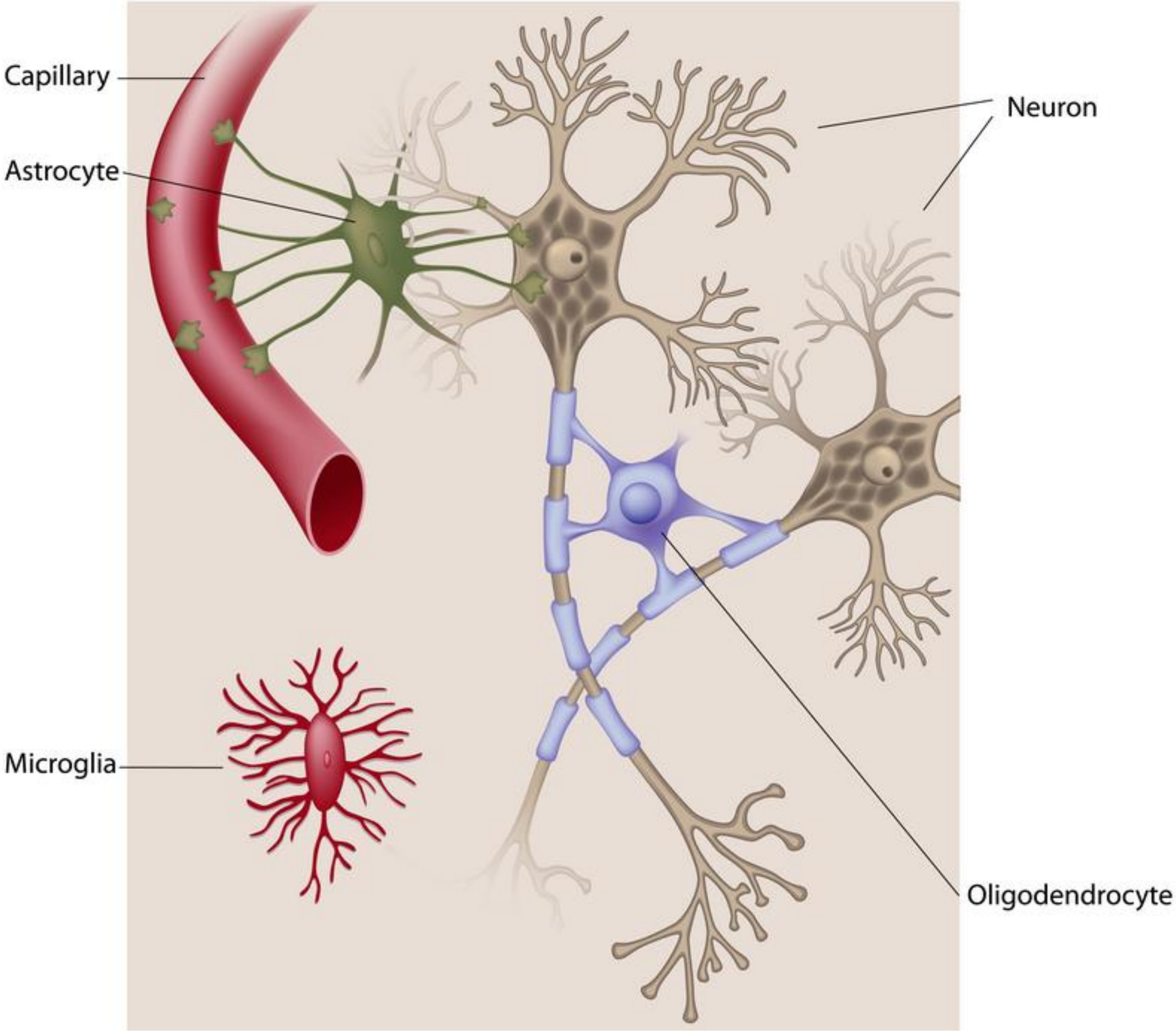

0.1 µm




Fluid-filled cavity
Ependymal cells
Brain or spinal cord tissue


Microglial cell
Neuron

Cells of the Central Nervous System



Nerve Physiology

4 Steps:

- Resting membrane potential
- Depolarization after threshold
- Action Potential
- Repolarization

Nerve Physiology

- Membranes of neurons are polarized due to an electrical potential difference called the resting membrane potential
  - The inside of the cell is negative relative to the outside and is measured using a voltmeter

- The resting membrane potential is when a neuron is not transmitting a signal
  - Resting membrane potential = - 70mV

Resting Membrane Potential

- In all neurons, the resting membrane potential depends on the ionic gradients that exist across the plasma membrane
  - Ion pumps and ion channels maintain the resting potential of a neuron

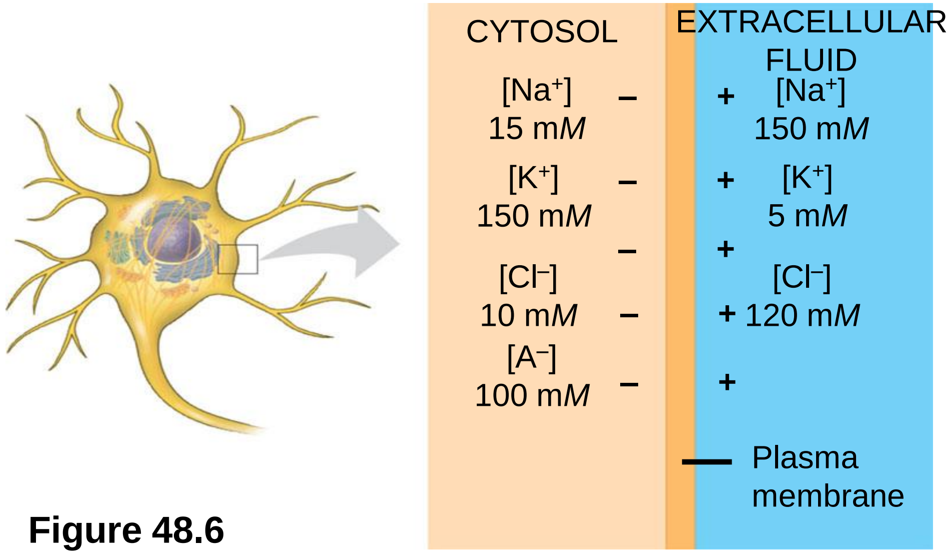


Figure 48.6

Resting Membrane Potential

- The concentration of Na^+ is higher in the extracellular fluid than in the cytosol while the opposite is true for K^+
- A neuron that is not transmitting signals contains many open K^+ channels and very few open Na^+ channels in its plasma membrane
- The diffusion of K^+ and Na^+ through these channels leads to a separation of charges across the membrane, producing the resting potential

Why is the charge -70 mV?

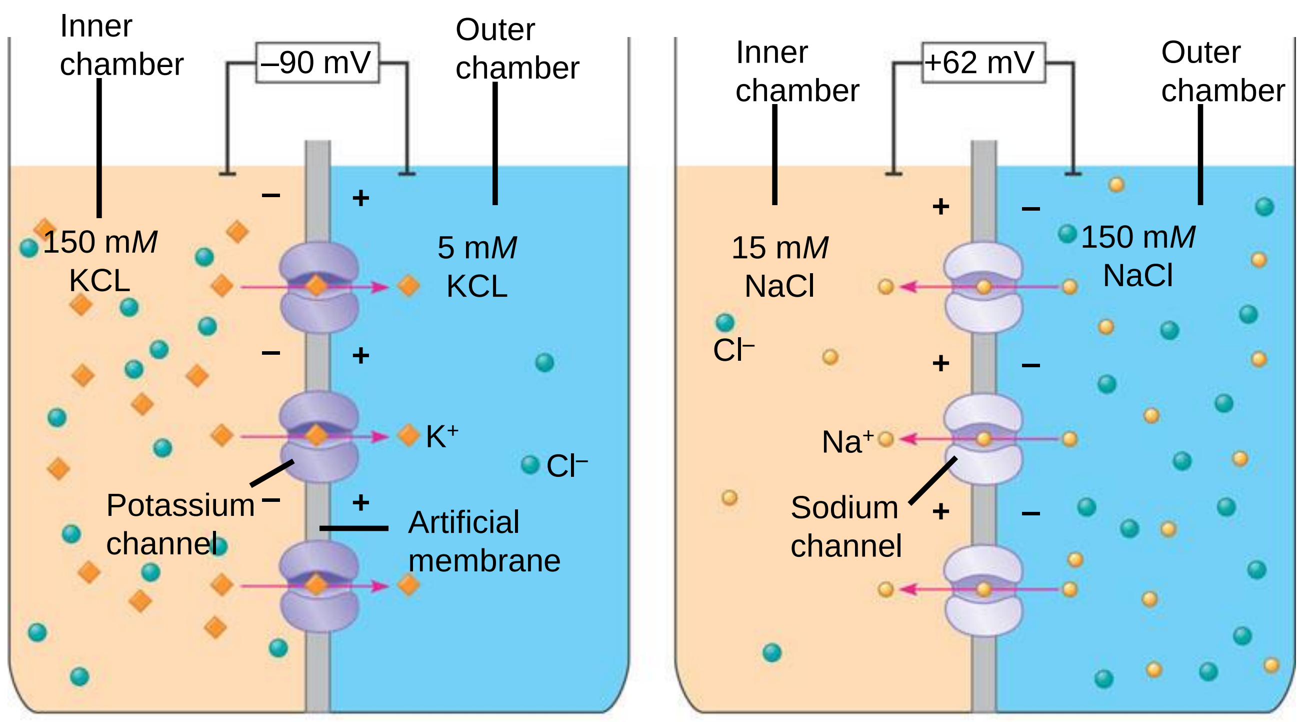


Figure 48.7 **(a) Membrane selectively permeable to K^+** **(b) Membrane selectively permeable to Na^+**

Why is the charge -70 mV?

- K^+ is moved into the cell and Na^+ is moved outside due to the action of the Na/K pump
- If K^+ is allowed to flow back to equilibrium, the membrane would be at -90mV
- Separately, if Na^+ is allowed to flow to equilibrium, the membrane would be at +62 mV

Why is the charge -70 mV?

- **Because there are more K^+ channels open compared to Na^+ channels AND there are negative proteins inside the cell, the charge difference settles to -70mV**
- Basically, a few positive things are leaking back into the cell which cancels out some of the -90mV difference from the K+ flow

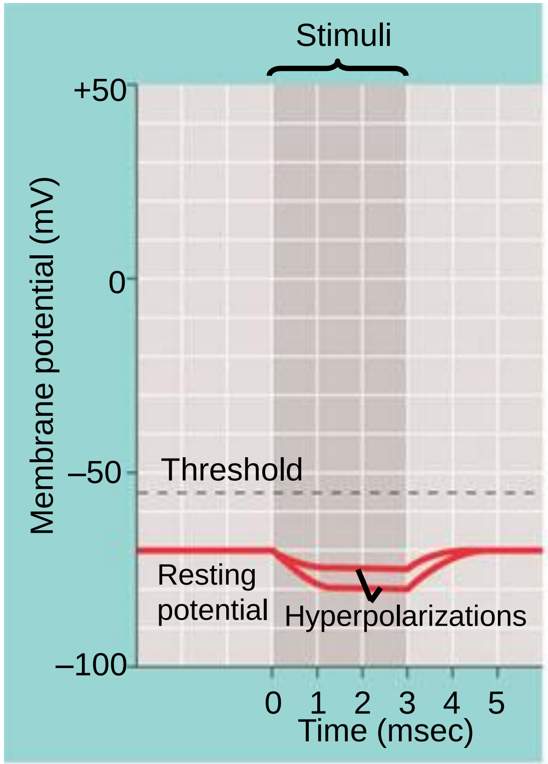
Action Potential Steps

- Gated ion channels open or close in response to the binding of a specific ligand or a voltage change
  - The response is a change in the membrane potential

- When ion channels are stimulated, two different responses can occur: hyperpolarization or depolarization
  - Both are called **graded potentials** because the magnitude of the change in membrane potential varies with the strength of the stimulus

Cell Responses

- Some stimuli trigger a hyperpolarization
  - An increase in the magnitude of the membrane potential (larger negative difference from outside to inside)

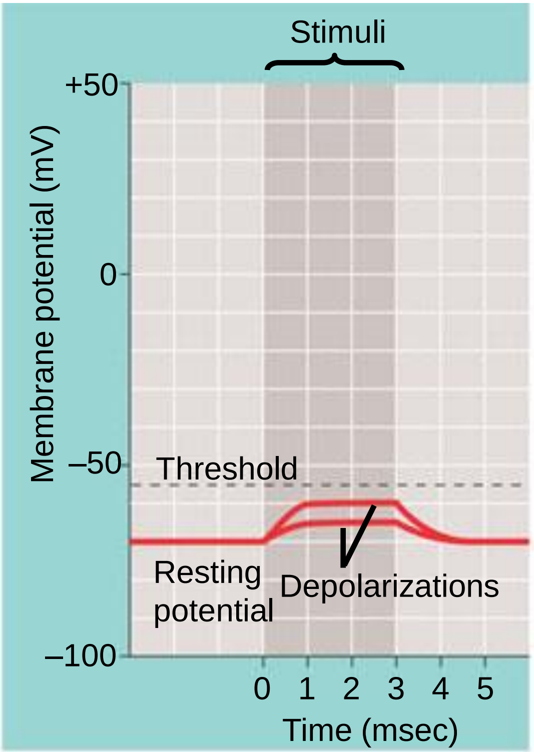


(a) Graded hyperpolarizations produced by two stimuli that increase membrane permeability to K^+. The larger stimulus produces a larger hyperpolarization.

Figure 48.9

Cell Responses

- Other stimuli trigger a depolarization
  - A reduction in the magnitude of the membrane potential (move towards a positive difference from outside to inside)

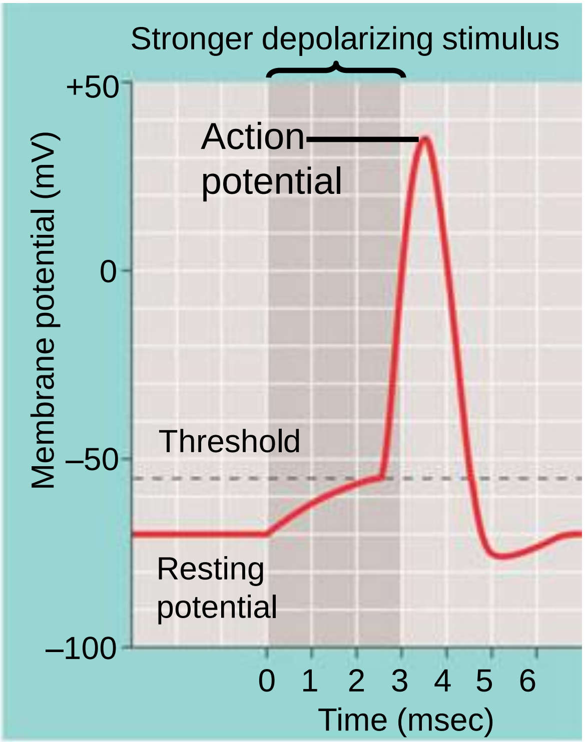


(b) Graded depolarizations produced by two stimuli that increase membrane permeability to Na+. The larger stimulus produces a larger depolarization.

Figure 48.9

Cell Responses

- A stimulus strong enough to produce a depolarization that reaches the threshold will trigger an action potential
- Threshold = membrane voltage amount needed to cause an action potential
  - - 55 mV



(c) Action potential triggered by a depolarization that reaches the threshold.

Figure 48.9

Action Potential Steps

- An action potential is a brief all-or-none depolarization of a neuron's plasma membrane that carries information along axons

- Both voltage-gated Na^+ channels and voltage-gated K^+ channels are involved in the production of an action potential
  - Voltage-gated channels rely of electrical signals rather than ligands

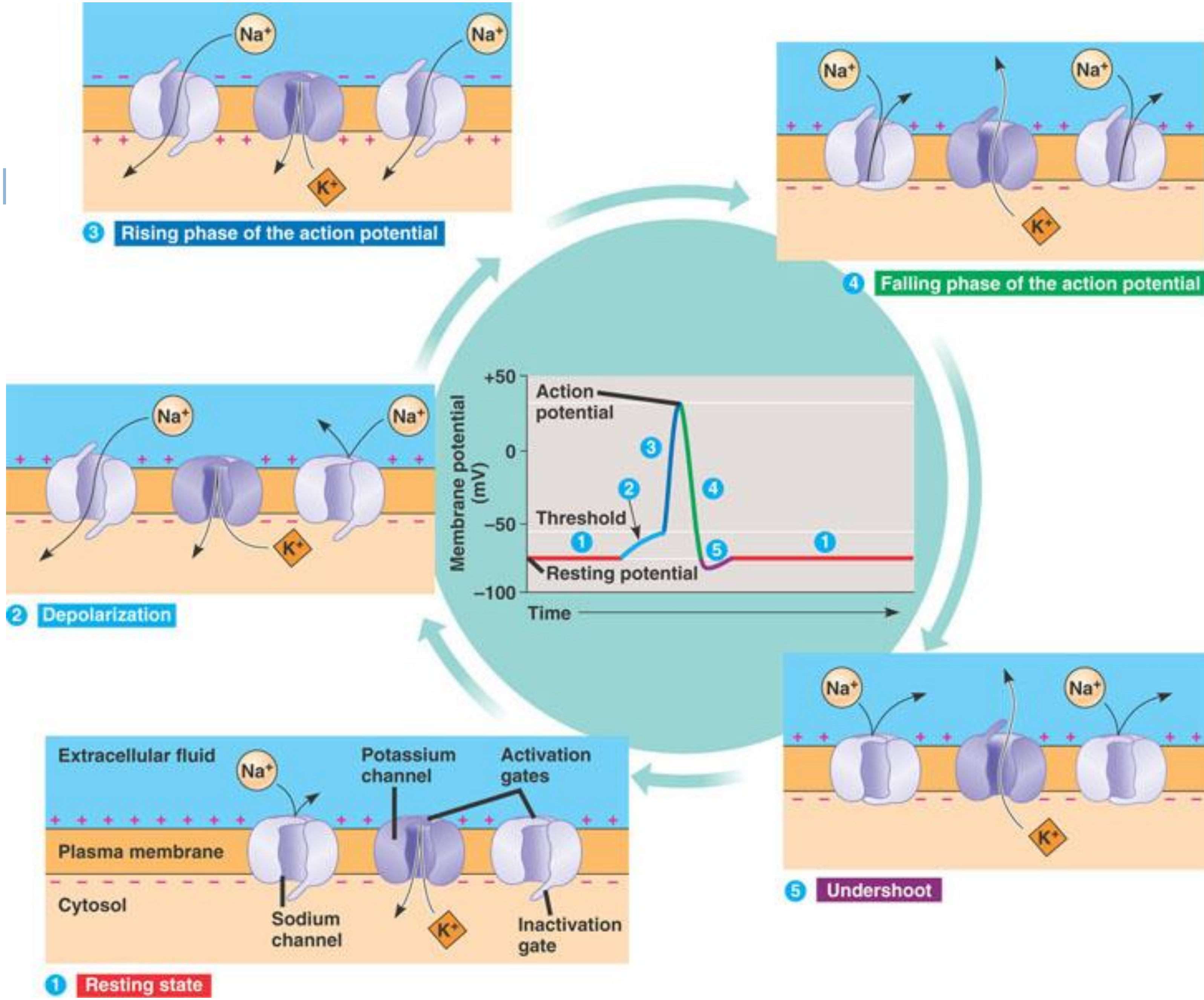
Action Potential Steps

- Depolarization
  - Membrane Na^+ channels open which allows Na^+ to diffuse into the cell
  - This causes the charge on the neuron membrane to change to positive inside and negative outside
- Action Potential
  - Propagation of the signal is continued depolarization down the axon

Action Potential Steps

- Repolarization
  - As the action potential subsides K^+ channels open, and K^+ flows out of the cell which changes the charge again on the membrane
  - Na/K pump restores the ion concentration differences with the use of ATP
    - This comes back to the resting membrane potential

- A refractory period follows the action potential during which a second action potential cannot be initiated



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

Conduction of Action Potentials

- An action potential can travel long distances by regenerating itself along the axon
- The opening of Na^+ channels triggers the opening of even more channels

- The speed of an action potential increases with the diameter of an axon

Conduction of Action Potentials

- Action potentials in myelinated axons jump between the nodes of Ranvier in a process called **saltatory conduction**
  - This allows the signal to travel faster down the axon

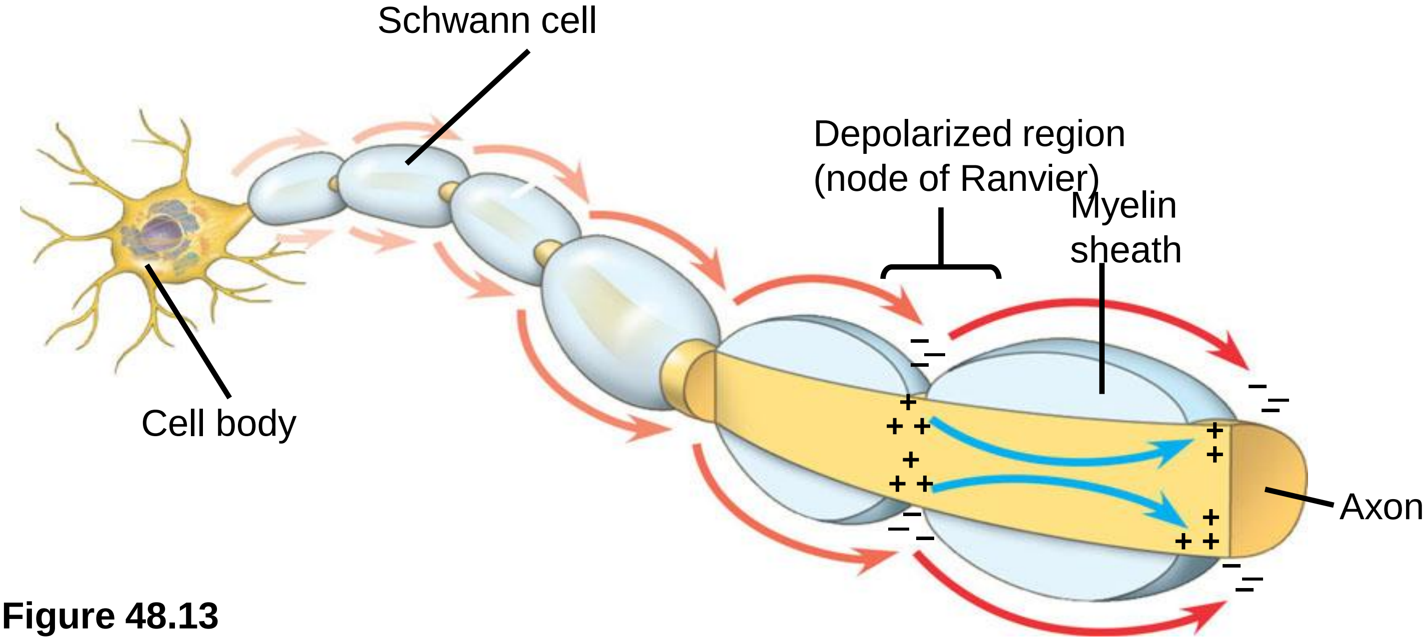


Figure 48.13

Synapse

- 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
  - The neurotransmitters will travel through the space between the cells called the synaptic cleft to bind to the post-synaptic neuron

Synapse

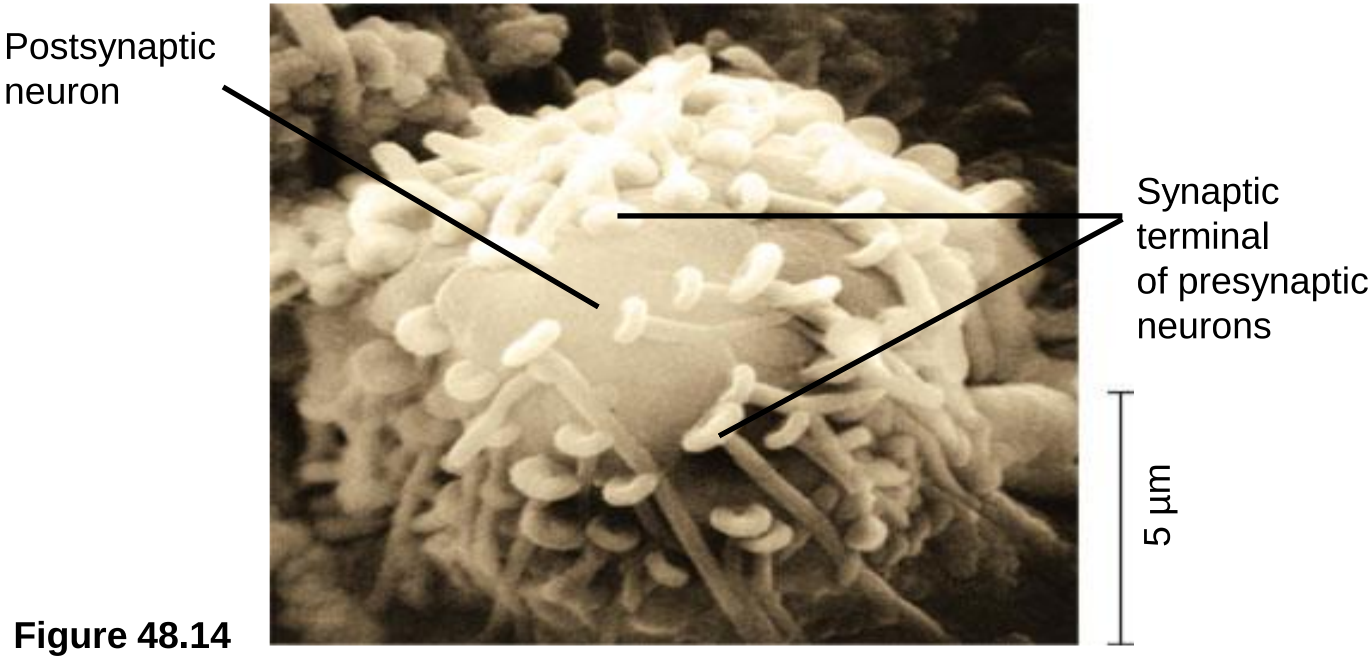


Figure 48.14

Synapse

- When an action potential reaches the terminal a voltage-gated Ca^{2+} channel opens to allow Ca^{2+} to flow into the axon terminal
- Ca^{2+} acts a second messenger and causes the vesicles holding the neurotransmitters to fuse with the plasma membrane
- The final result is the release of neurotransmitters into the synaptic cleft

Synapse

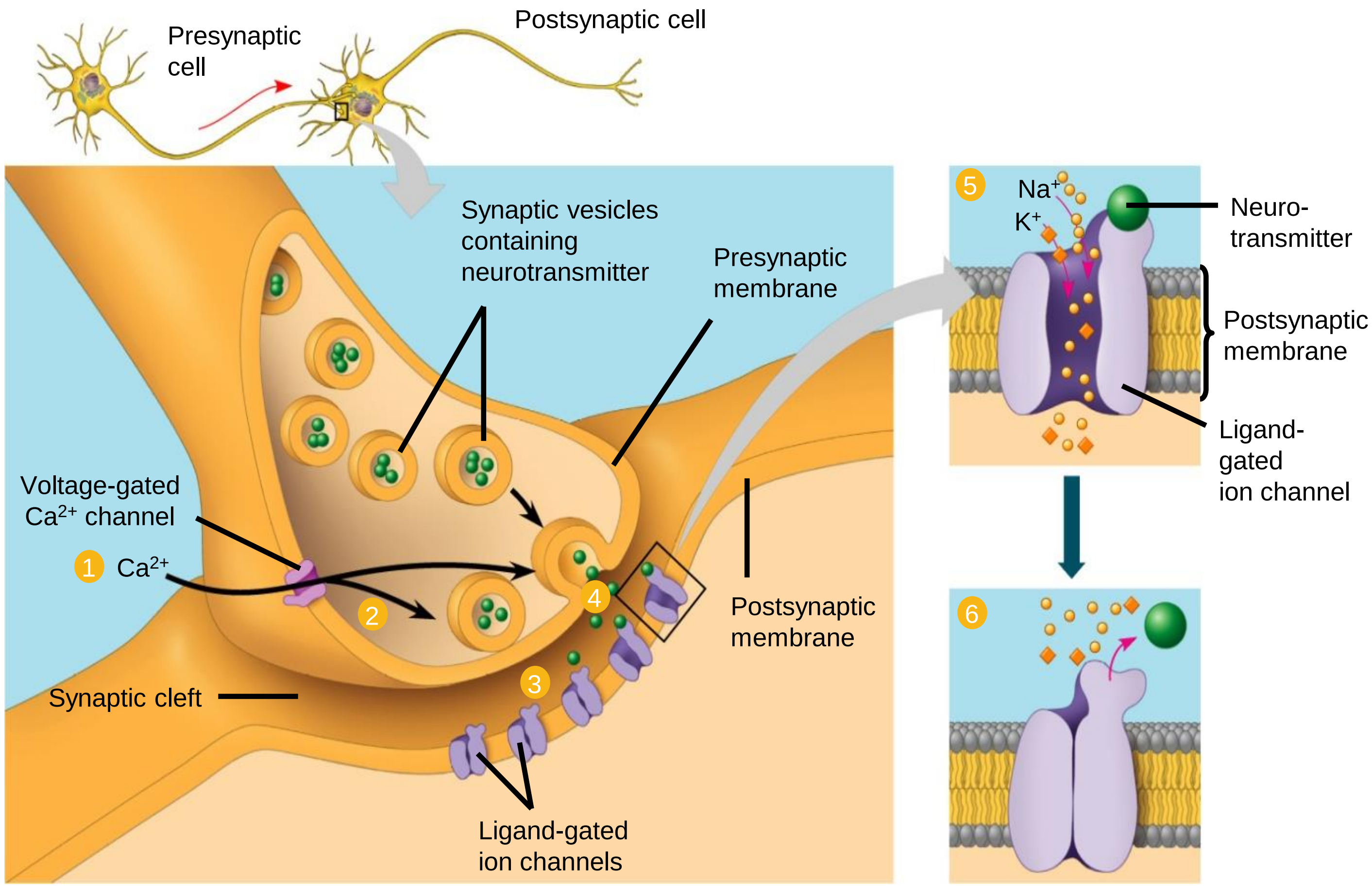


Figure 48.15

Direct Synaptic Transmission

- The process of direct synaptic transmission involves the binding of neurotransmitters to ligand-gated ion channels
- Neurotransmitter binding causes the ion channels to open, generating a postsynaptic potential
- Postsynaptic potentials fall into two categories:
  - Excitatory (stimulatory) or Inhibitory

Direct Synaptic Transmission

- After its release, the neurotransmitter diffuses out of the synaptic cleft
  - May be taken up by the pre-synaptic cell or degraded by enzymes

Neurotransmitters

- Chemical messengers that act on cells to create a response
- The same neurotransmitter can produce different effects in different types of cells
- Types:
  - Acetylcholine, biogenic amines, various amino acids and peptides, and certain gases

Neurotransmitters

- Acetylcholine is one of the most common neurotransmitters in both vertebrates and invertebrates
  - Can be inhibitory or excitatory
  - Used in muscle contraction
- Biogenic amines: include epinephrine, norepinephrine, dopamine, and serotonin
  - Are active in the CNS and PNS

Neurotransmitters

- Various amino acids and peptides are active in the brain
- Gases such as nitric oxide and carbon monoxide are local regulators in the PNS

Structure of the Brain

Cerebrum, cerebellum, brainstem, and diencephalon

Anatomy

- Gray matter – no myelin sheath
  - Located on outside in brain and inside in spinal cord

- White matter – has myelin sheath
  - Located on outside in spinal cord and inside in brain

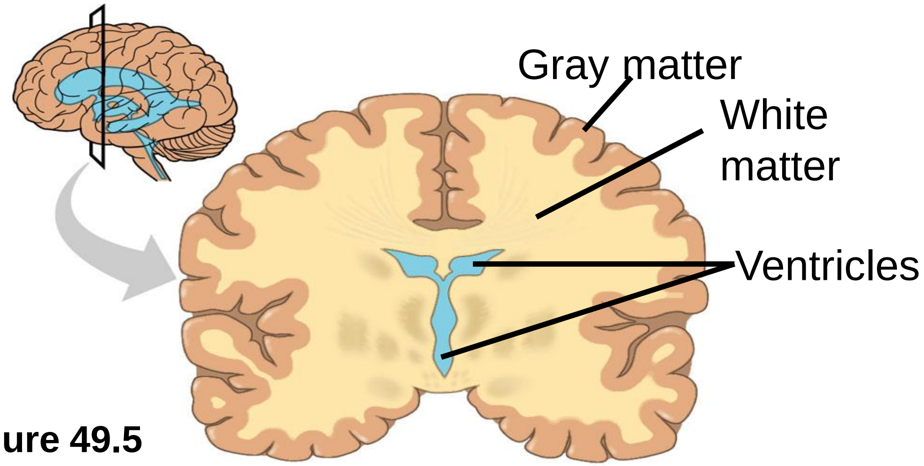
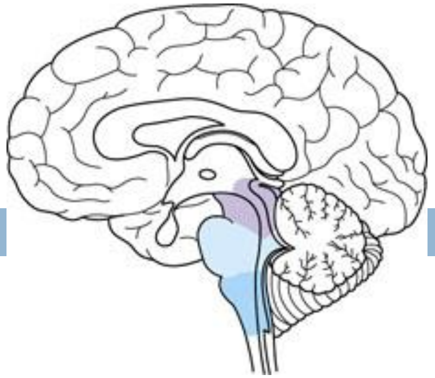


Figure 49.5

Brainstem



- The brainstem consists of three parts:
  - medulla oblongata, pons, and midbrain
- The medulla oblongata contains centers that control heart rate, blood pressure, breathing, swallowing, and vomiting
- The pons controls breathing
- The midbrain contains centers for passing ascending and descending signals

Arousal and Sleep

- A diffuse network of neurons called the reticular formation is present in the core of the brainstem
  - A part of the reticular formation, the reticular activating system (RAS) regulates sleep and arousal

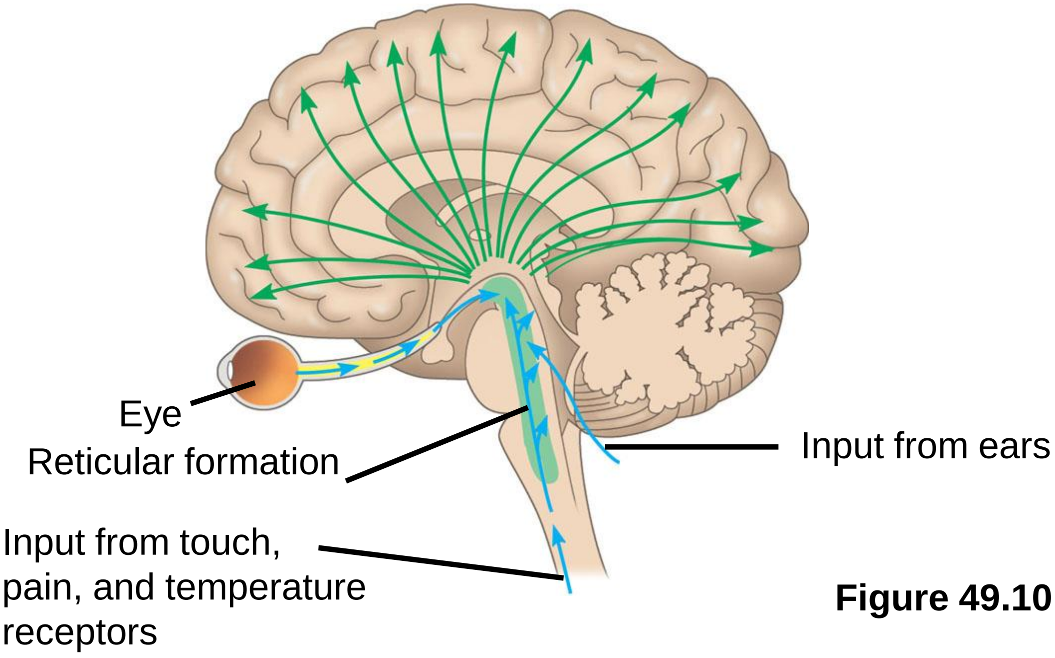
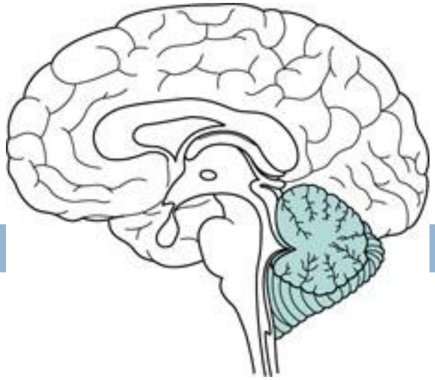


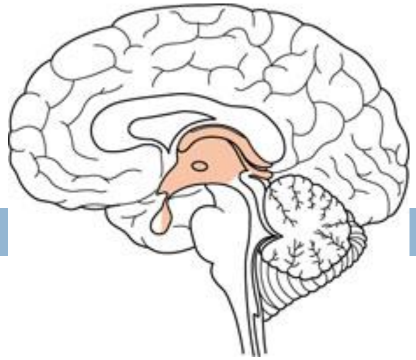
Figure 49.10

Cerebellum



- The cerebellum is important for coordination and balance
  - Also involved in learning and remembering motor skills

Diencephalon

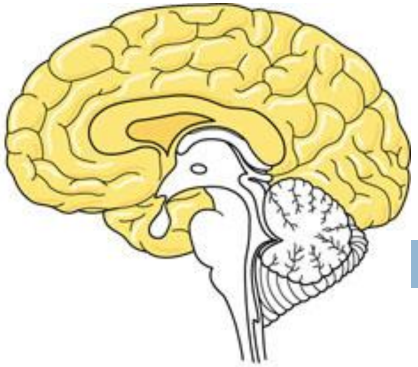


- The embryonic diencephalon develops into three adult brain regions:
  - epithalamus, thalamus, and hypothalamus
- The epithalamus includes the pineal gland (releases melatonin) and the choroid plexus (capillaries that produce cerebrospinal fluid)
- The thalamus sends sensory and motor information to the cerebrum

Diencephalon

- The hypothalamus regulates homeostasis
  - Basic survival behaviors such as feeding, fighting, fleeing, and reproducing
  - Part of the limbic center

Cerebrum



- The cerebrum contains right and left cerebral hemispheres
  - Each consist of cerebral cortex overlying white matter and basal nuclei (regions of gray matter inside brain) – centers for planning and learning movement sequences

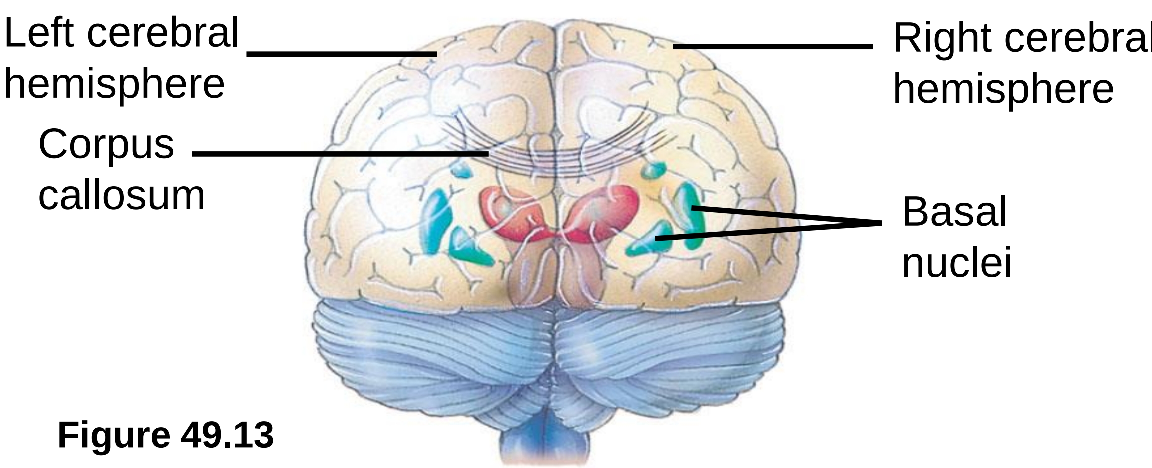


Figure 49.13

Cerebrum

- A thick band of axons, the corpus callosum provides communication between the right and left cerebral cortices

- In humans, the largest and most complex part of the brain is the cerebral cortex, where sensory information is analyzed, motor commands are issued, and language is generated

Cerebrum

- Each side of the cerebral cortex has four lobes
  - Frontal, parietal, temporal, and occipital

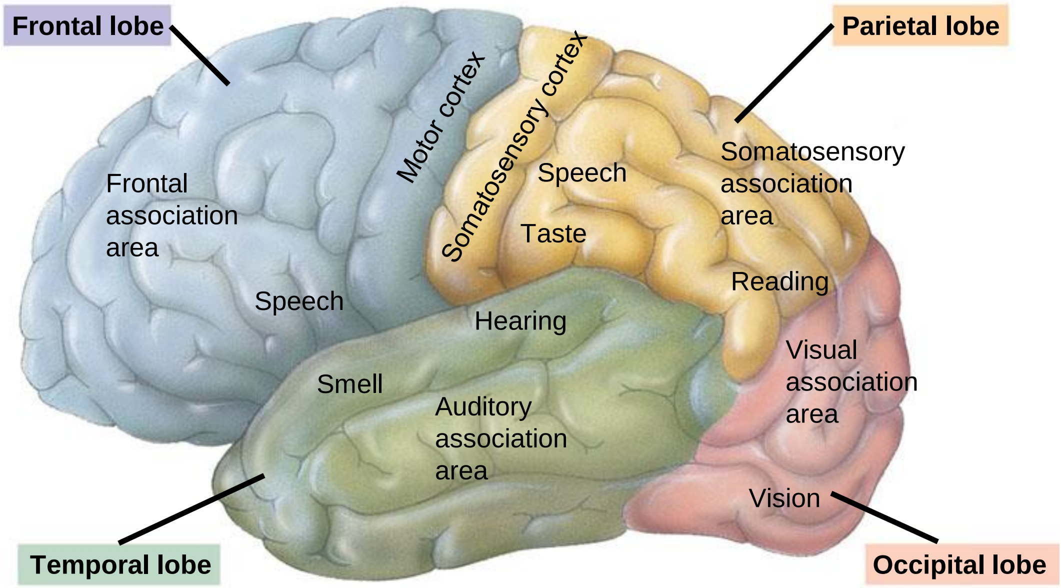


Figure 48.27

Cerebrum

- In the somatosensory cortex and motor cortex neurons are distributed according to the part of the body that generates sensory input or receives motor input

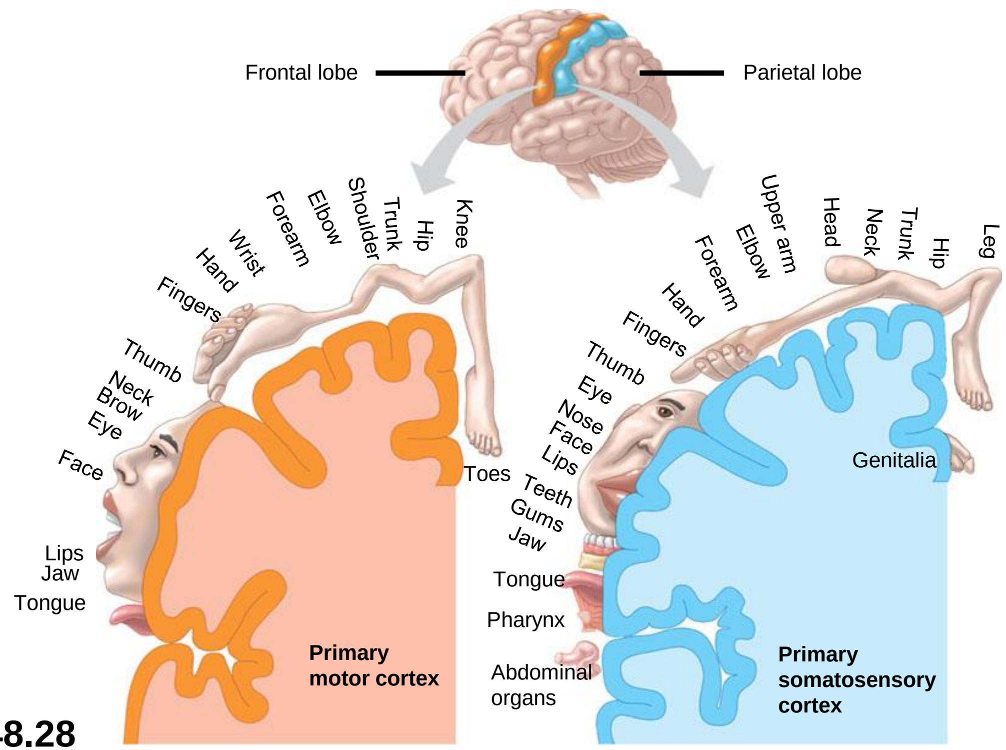


Figure 48.28

Emotions

- The limbic system is a ring of structures around the brainstem

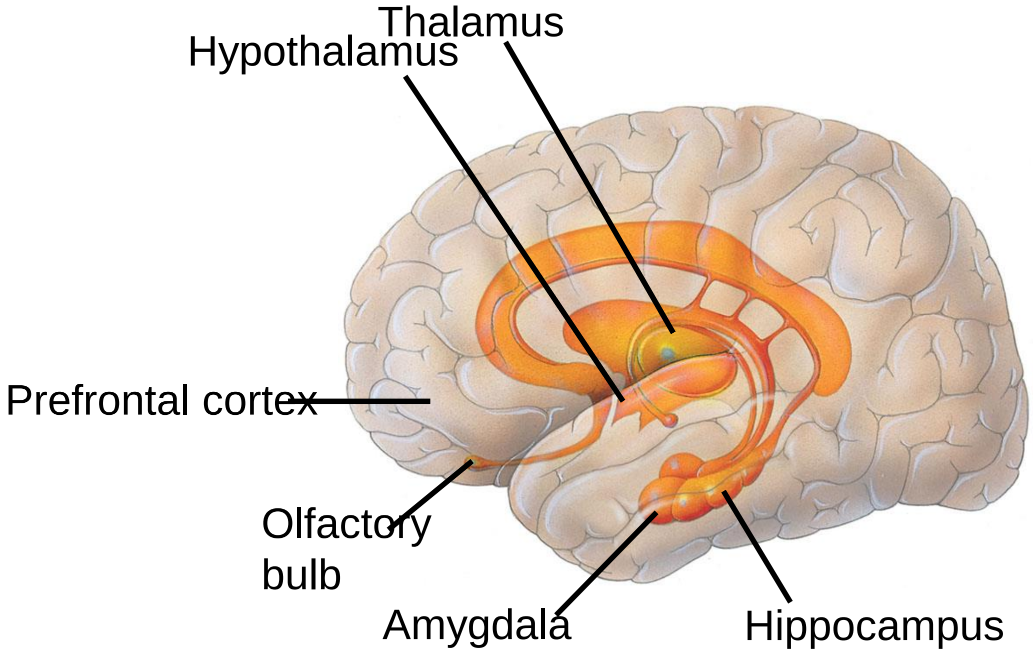


Figure 48.30

Emotions

- This limbic system includes three parts of the cerebral cortex: amygdala, hippocampus, and olfactory bulb
- These structures attach emotional "feelings" to survival-related functions
- Structures of the limbic system form in early development and provide a foundation for emotional memory, associating emotions with particular events or experiences

Memory and Learning

- The frontal lobes are a site of short-term memory
  - Interact with the hippocampus and amygdala to consolidate long-term memory
- Many sensory and motor association areas of the cerebral cortex are involved in storing and retrieving words and images

Neural Stem Cells

- The adult human brain contains stem cells that can differentiate into mature neurons
- The induction of stem cell differentiation and the transplantation of cultured stem cells are potential methods for replacing neurons lost to trauma or disease

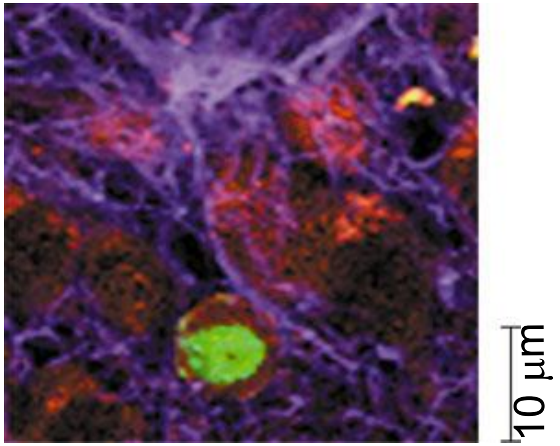


Figure 49.24