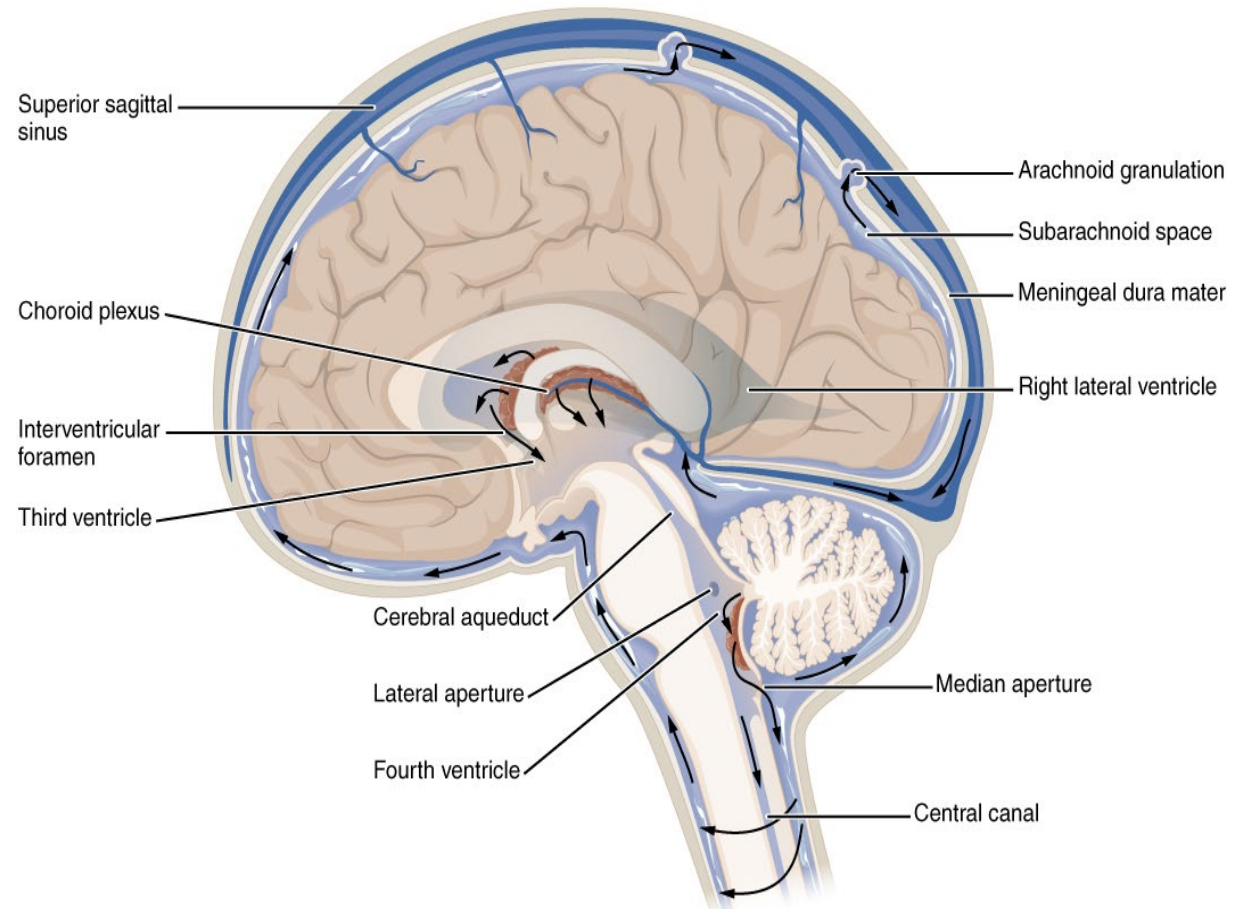


BIOLOGY 1103/1109

Human Anatomy and Physiology I

UNIT 9

Nervous system



Nervous system

Objectives 1-6

1. Describe the organization of the nervous system and explain the functions of its principal components.
2. Describe the structure of the following: neuron, glia, ganglion, nerve, gray matter, tract, white matter, sensory neuron, motor neuron.
3. Name, locate and describe the functions of the main areas of the human brain.
4. Describe the structure and explain the functions of the spinal cord.
5. Describe the components of a reflex arc and explain how a reflex arc works.
6. Describe the function of the autonomic nervous system (ANS) and compare the specific functions of the parasympathetic and sympathetic divisions of the ANS.

Anatomical division of the nervous system

- The central nervous system (CNS) is the brain and spinal cord
- The brain is within the cranial cavity of the skull, and the spinal cord is within the vertebral cavity
- The peripheral nervous system (PNS) is everything else

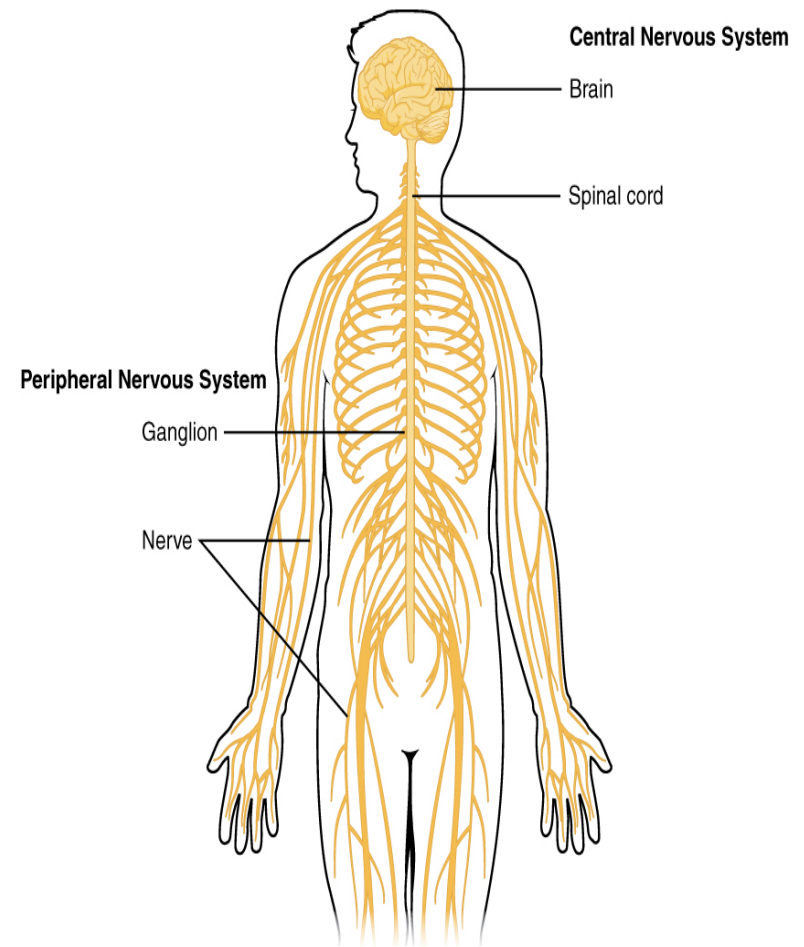


Figure 1

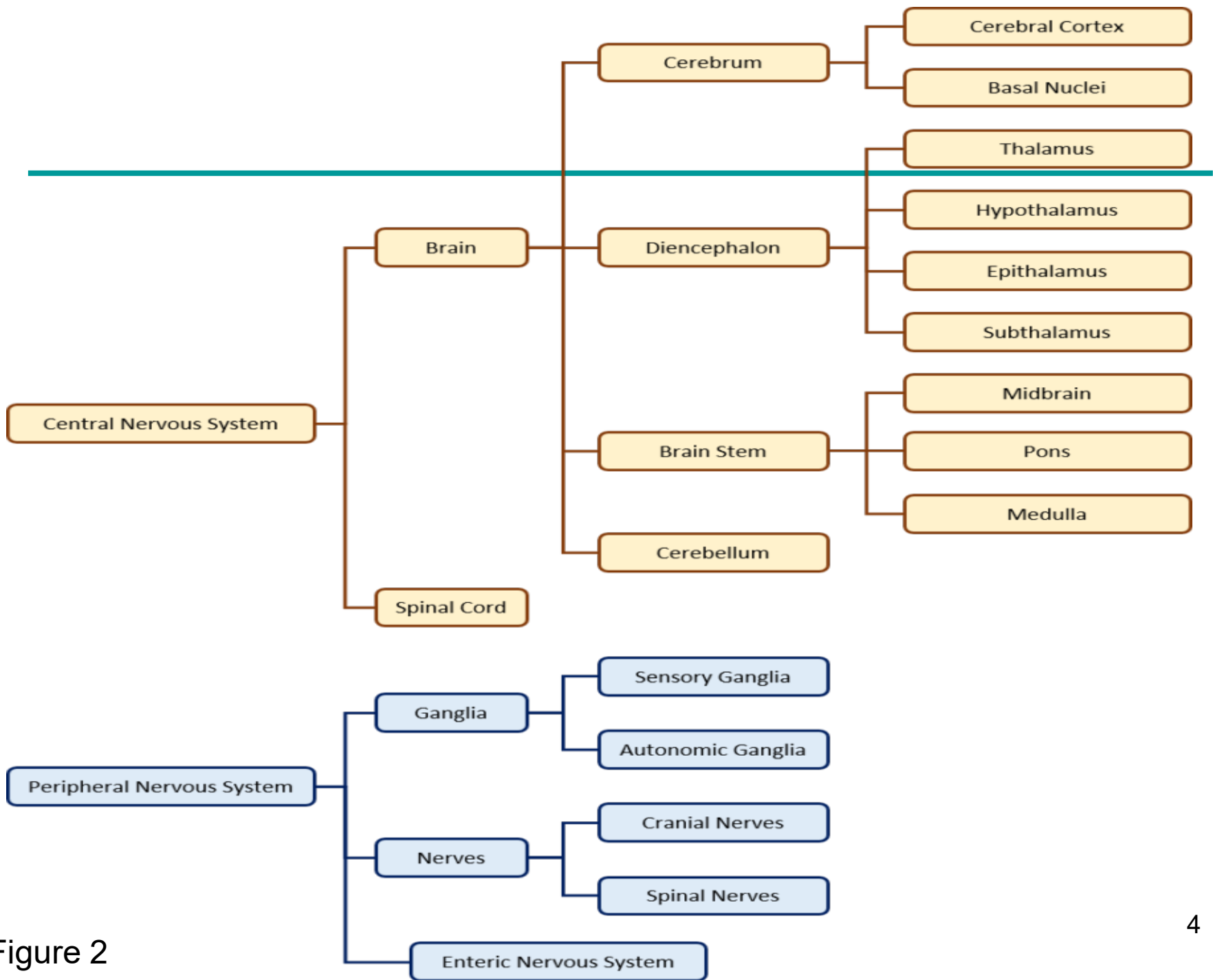
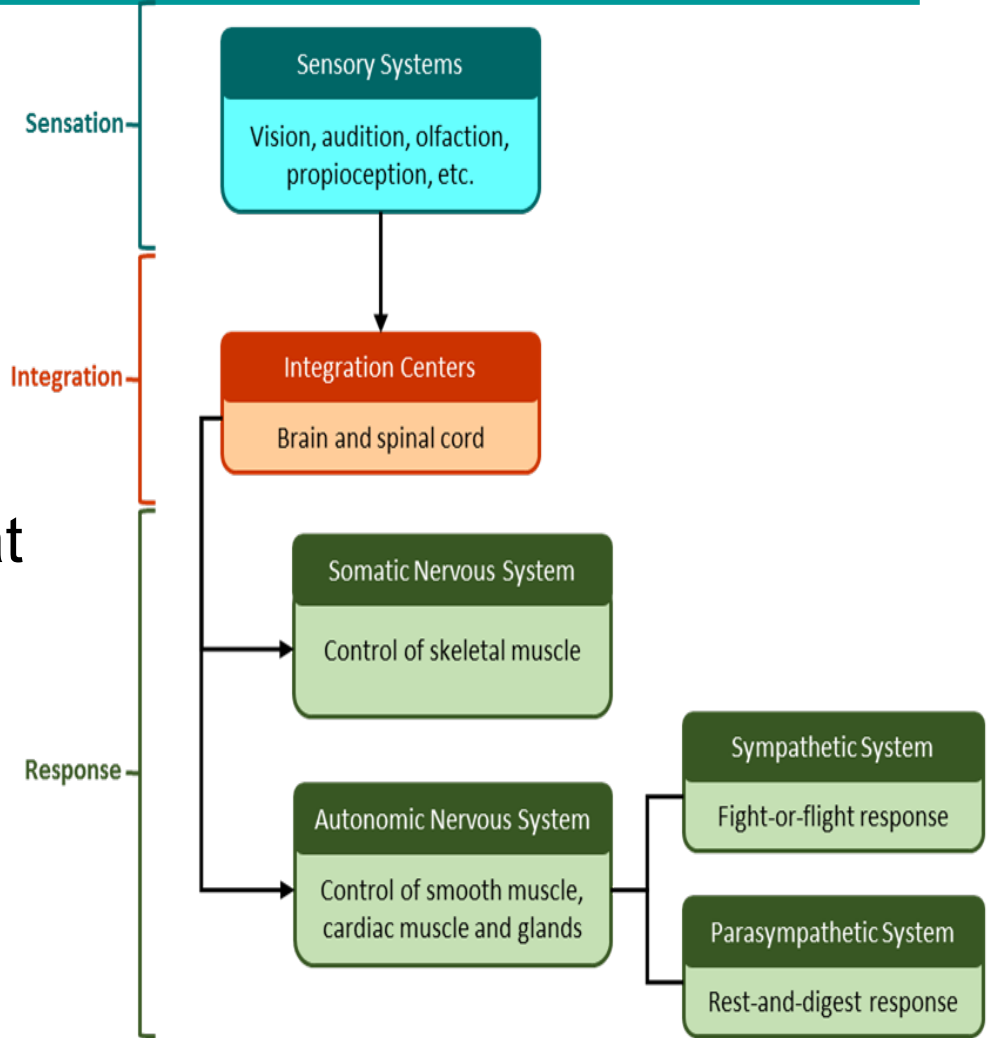


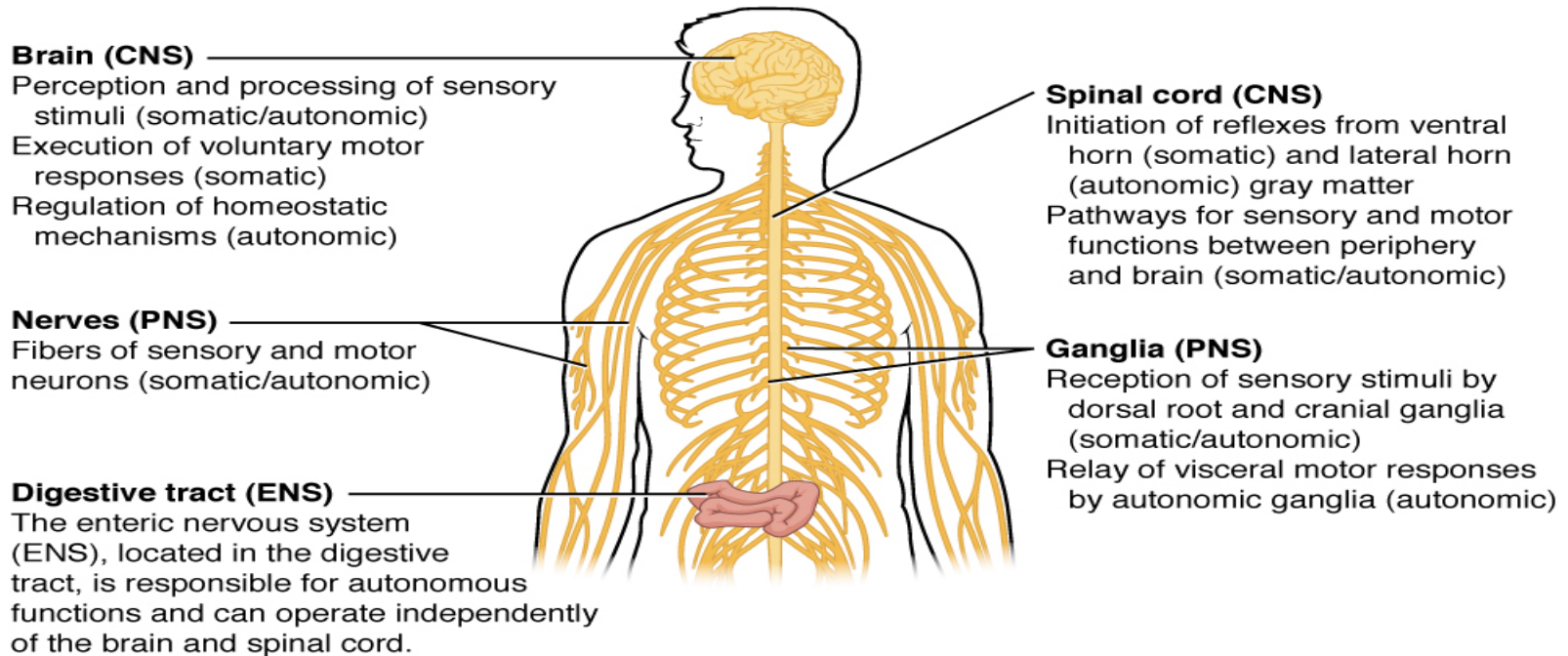
Figure 2

- Sensation, integration, and response
- Control of the body can be somatic or autonomic—divisions that are largely defined by the structures that are involved in the response



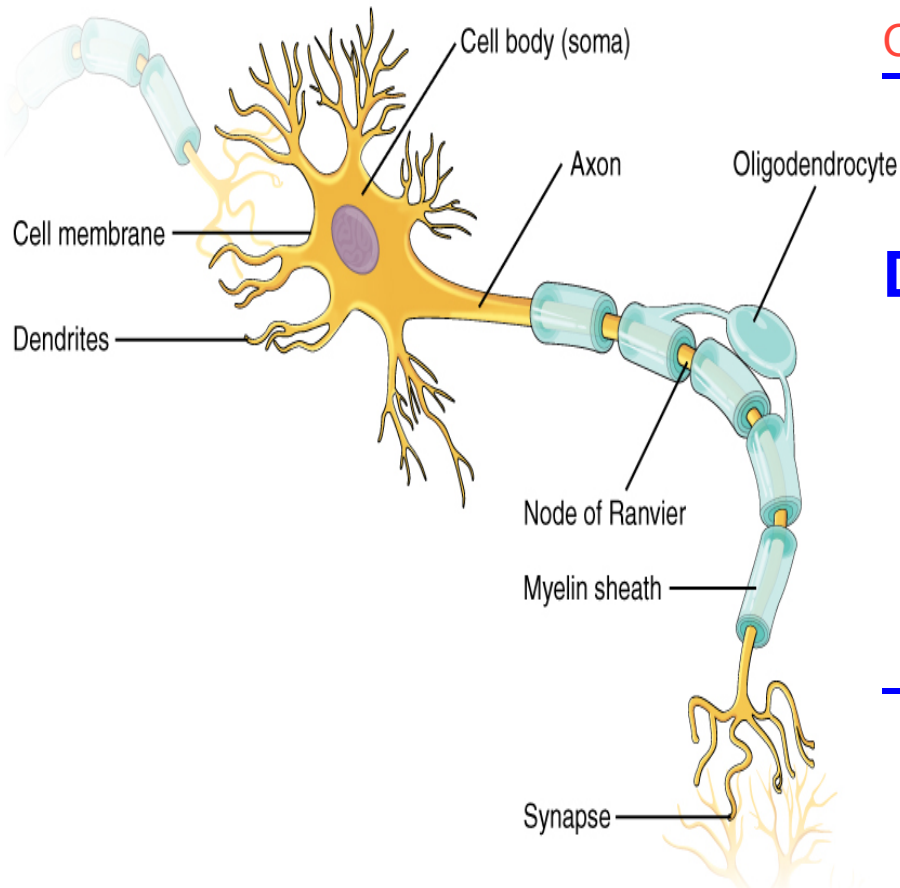
Somatic, autonomic

Figure 7



- **Somatic nervous system (SNS)** = conscious perception and voluntary motor responses
- **Autonomic nervous system (ANS)** = involuntary control of the body, usually for the sake of homeostasis

Neuron cell structure



Cell body (soma):

Holds the majority of the cellular organelles

Dendrite:

Cytoplasmic processes

Conducting impulses toward cell body

Usually short, branched fibers

Axon :

Conducts impulses away from cell body

Usually a single, long process

Organization of neurons

- Cell bodies are grouped together with cell bodies (and same goes for axons; with other axons)
- *Outside* the central nervous system,
 - groups of cell bodies are called **ganglia**
 - groups of axons are called nerves
- *Inside* the central nervous system:
 - groups of cell bodies are called gray matter , nucleus
 - collection of axons is called a **tract**
 - group of tracts is called **white matter** (due to the myelin sheaths covering the axons)

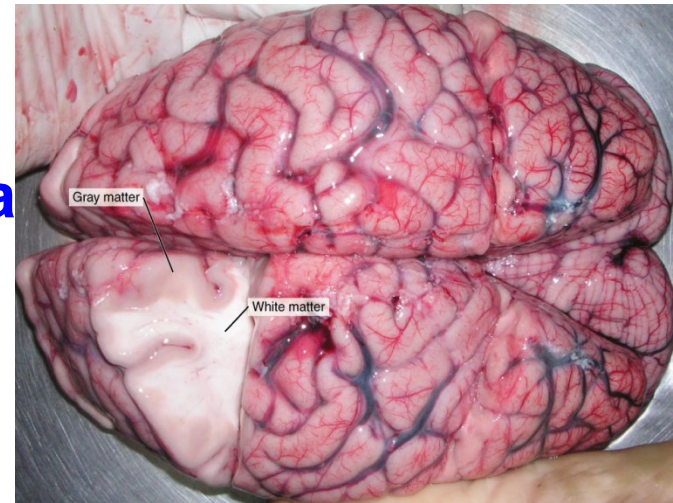
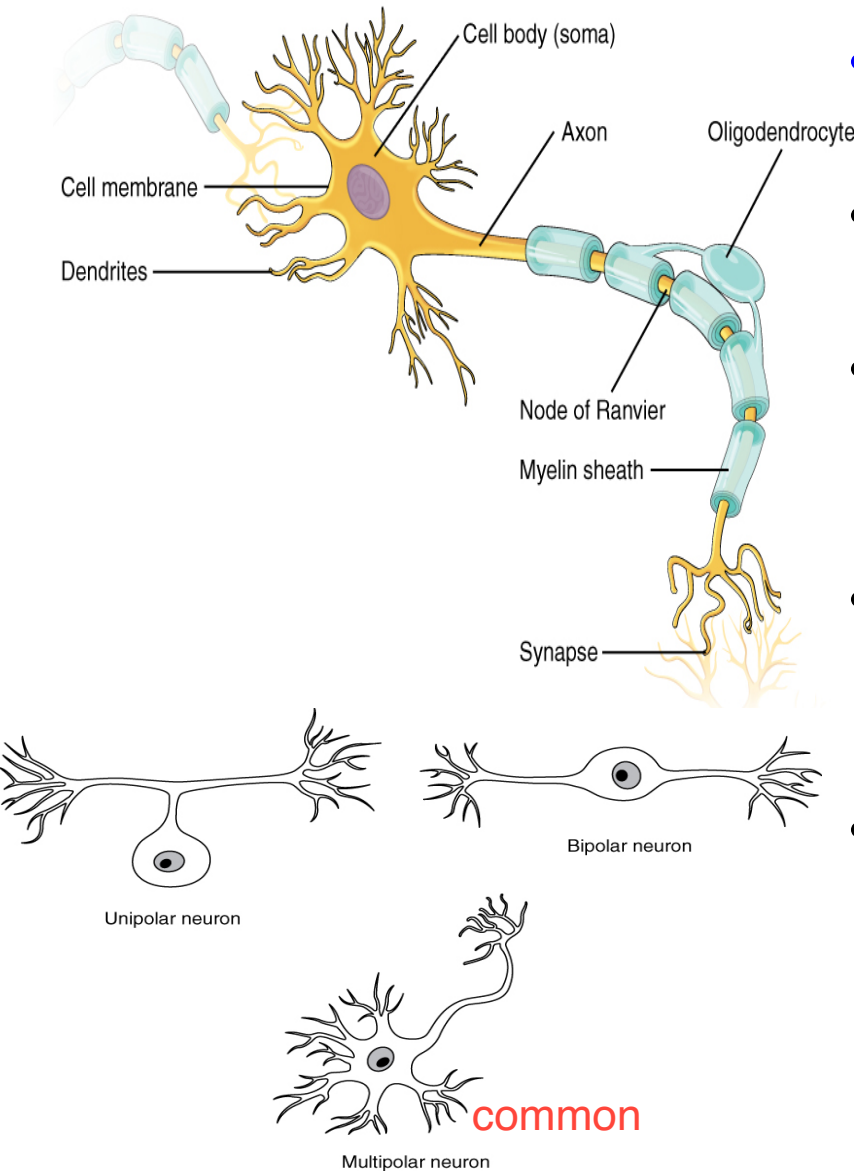


Figure 3

Neurons

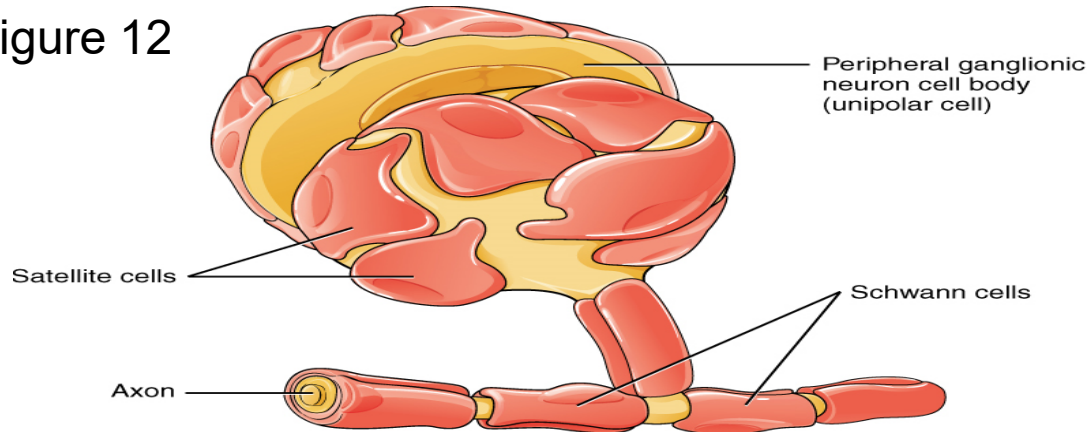
Figures 8 and 9



- Cell body (soma), Dendrite and Axons
- Has polarity: information flows from the dendrites to the axon
- Axon is wrapped in myelin (made from glial cells) with gaps called **Node of Ranvier**
- Ends with enlarged segment called synaptic end bulbs which connect to target cells
- Classified based upon the number of processes or where they are found

Myelin

Figure 12



- Provide by neuroglial cell oligodendrocytes in the CNS, and Schwann cells in the PNS.
- Myelin is a **lipid-rich sheath** that surrounds the axon
- The myelin sheath **increases speed** of nerve impulse conduction
- Neurons without a myelin sheath are referred to as unmyelinated neurons
- Loss or destruction of myelin sheath (demyelination) can lead to several disorders

Neuroglia (glial)

- The “glue” between neurons
- Supporting and insulating cells between neurons
- Segregates and insulates neurons
- Promote health and growth
- 5-10 times more numerous than neurons
- Several different types found in the body

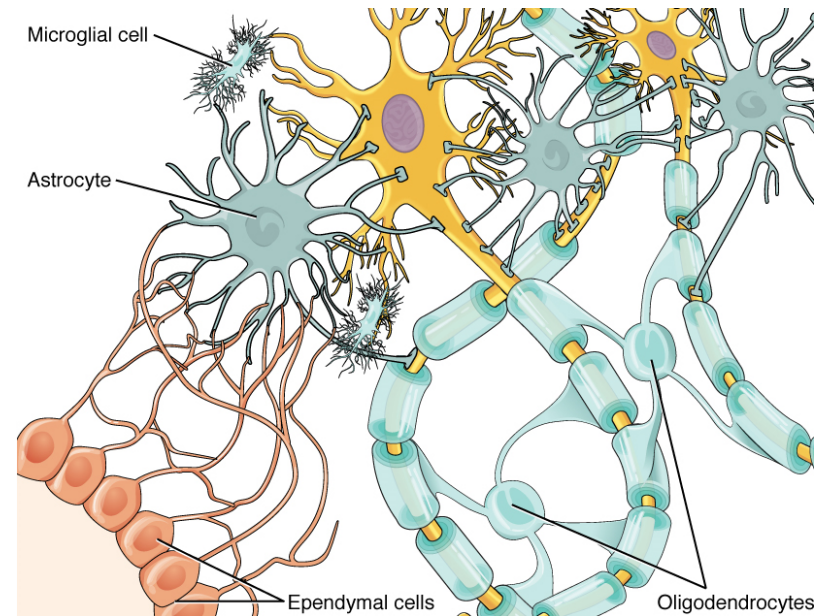
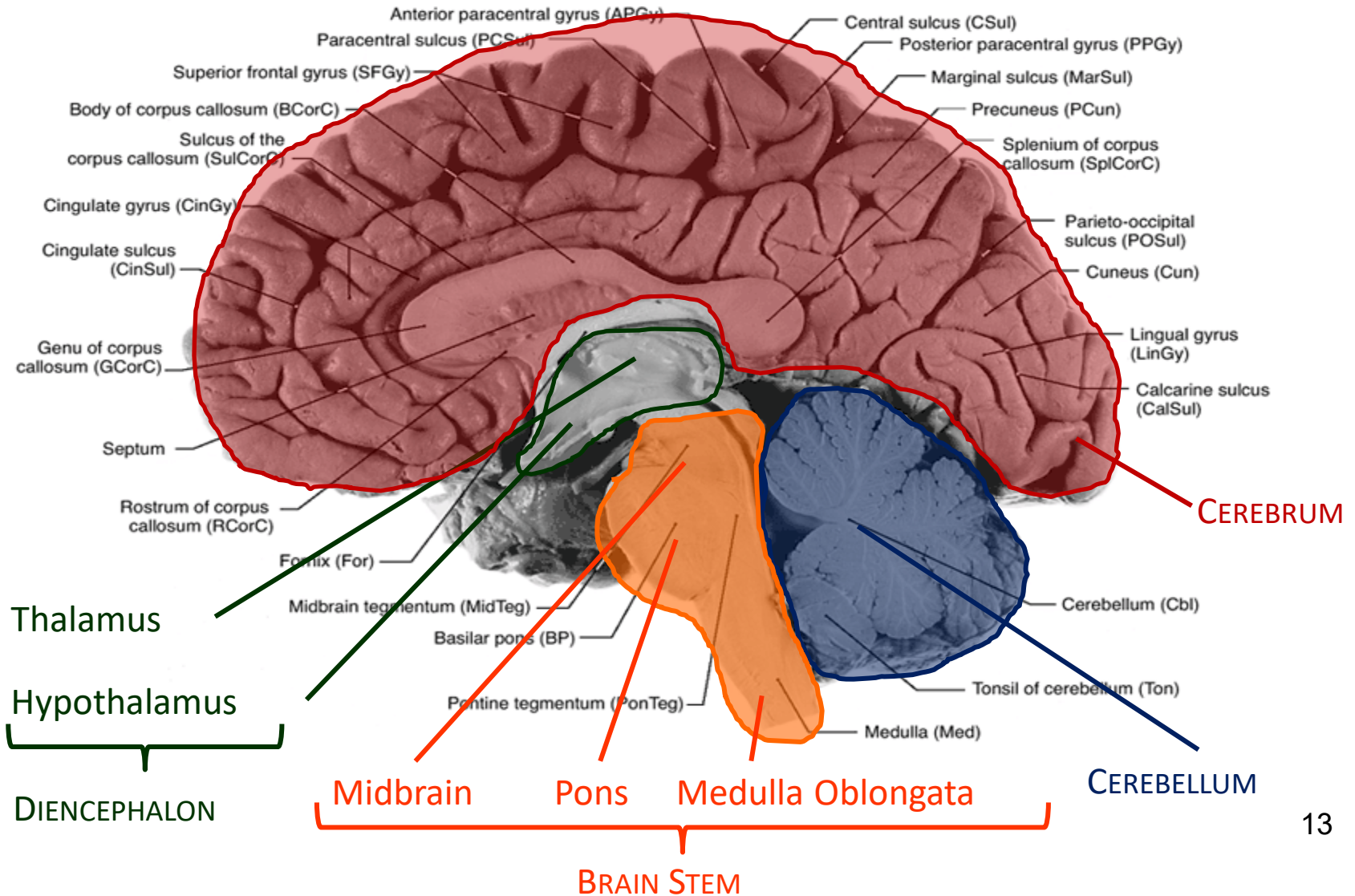


Figure 11



THE CENTRAL NERVOUS SYSTEM

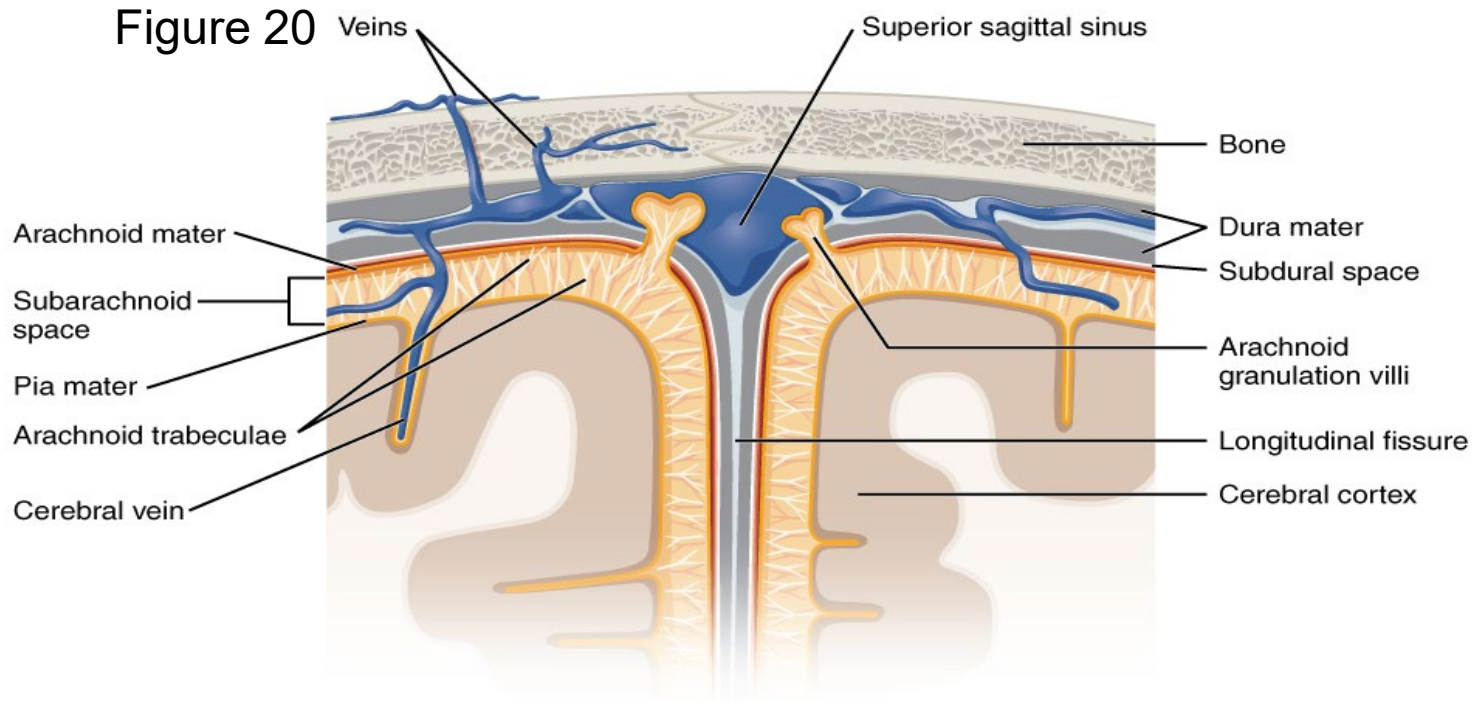
The Brain: 4 major regions



Meninges

- A set of connective tissue membranes that surround the central nervous system (brain and spinal cord)
- From **inside** to **outside**, the names of the three membranes are (*PAD!*):
 - **Pia mater** (thin fibrous membrane that follows the convolutions of gyri and sulci in the cerebral cortex and fits into other grooves and indentations)
 - **Arachnoid mater** (thin fibrous tissue that forms a loose sac around the CNS)
 - **Dura mater** (thick fibrous layer and a strong protective sheath over the entire brain and spinal cord)

Meninges function



- Cover and protect the CNS
- Protect blood vessels and enclose venous sinuses
- Contain cerebrospinal fluid (CSF)
 - Found between the arachnoid mater and pia mater
- Form partitions within the skull

Brain ventricles and cerebrospinal fluid circulation

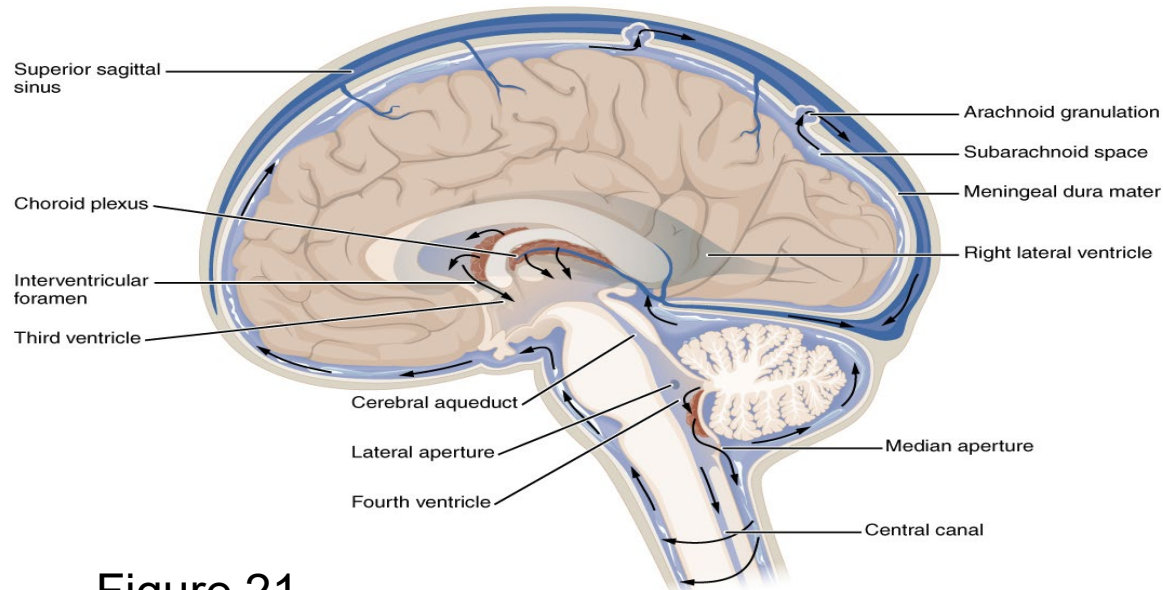
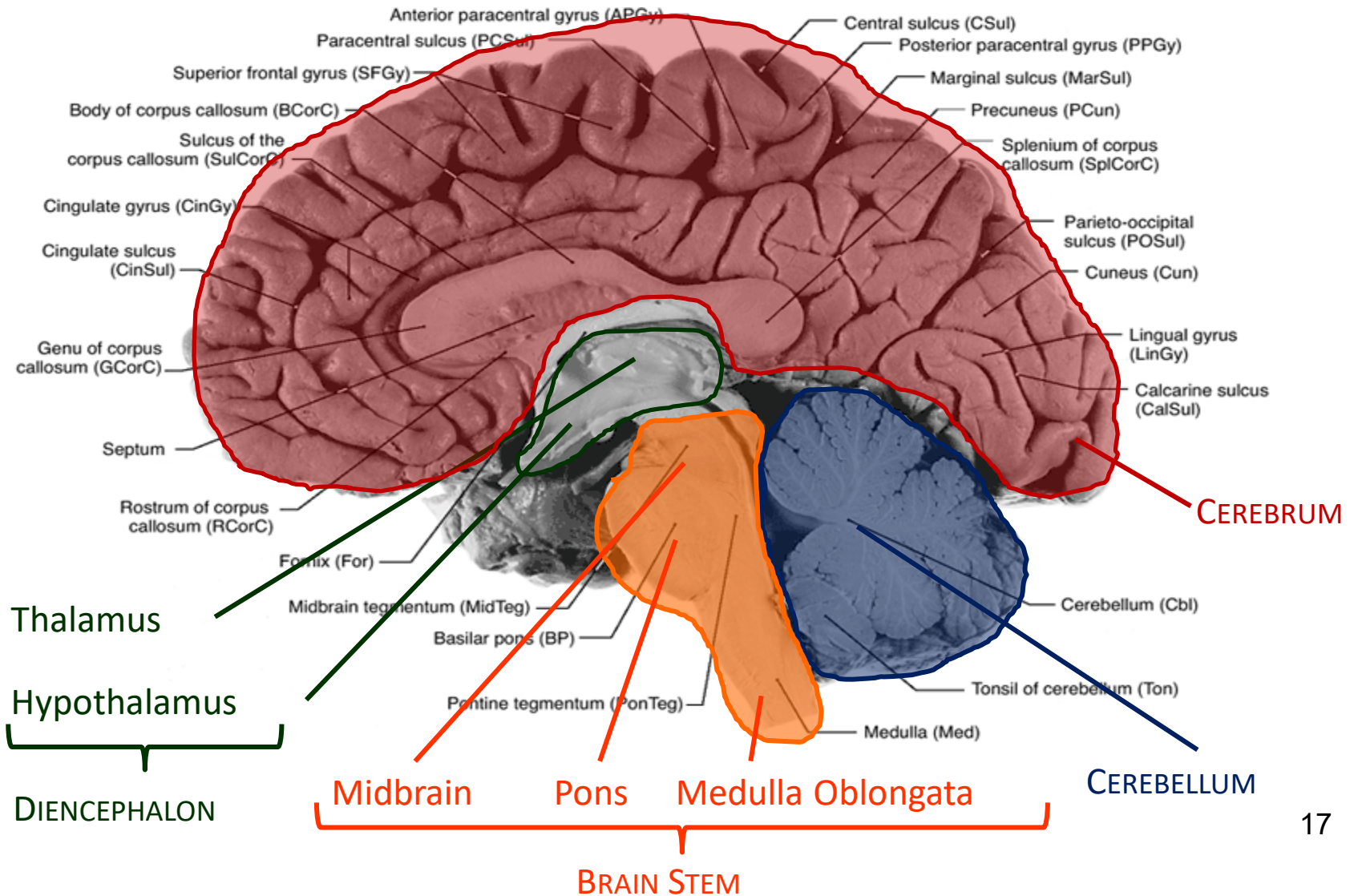


Figure 21

- Filled with **cerebrospinal fluid** CSF that circulates to remove metabolic wastes from the interstitial fluids of nervous tissues and return them to the blood stream
- CSF is water, small molecules, electrolytes, oxygen and carbon dioxide
- Four brain ventricles are continuous with one another and with the cavity in the spinal cord

The Brain: 4 major regions



Cerebrum

- **Wrinkled** and thin layer of **grey matter** that wraps around both hemispheres, the cerebral cortex, and several deep nuclei
- Two halves: right and left hemispheres
- Controls our ability to read, write, speak, think, remember, feel, and move

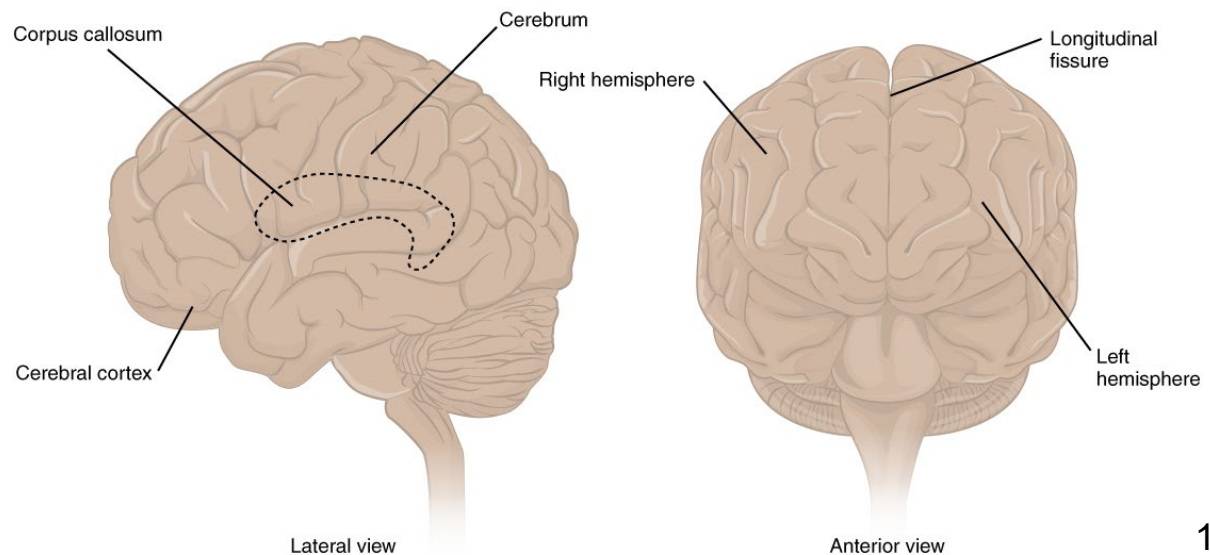
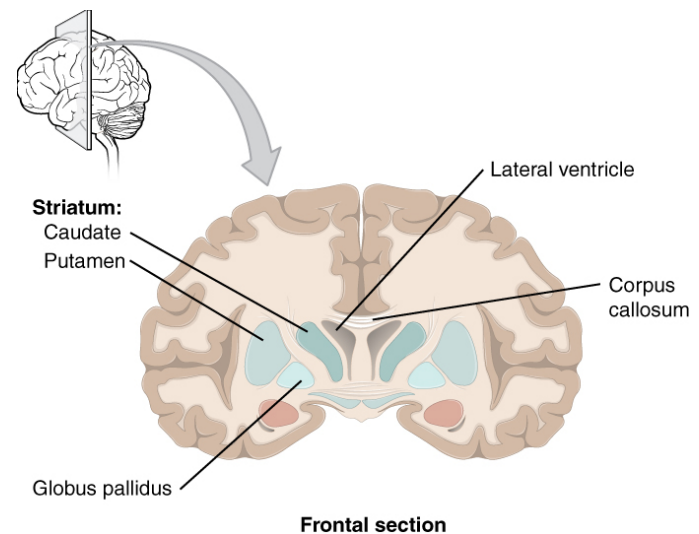
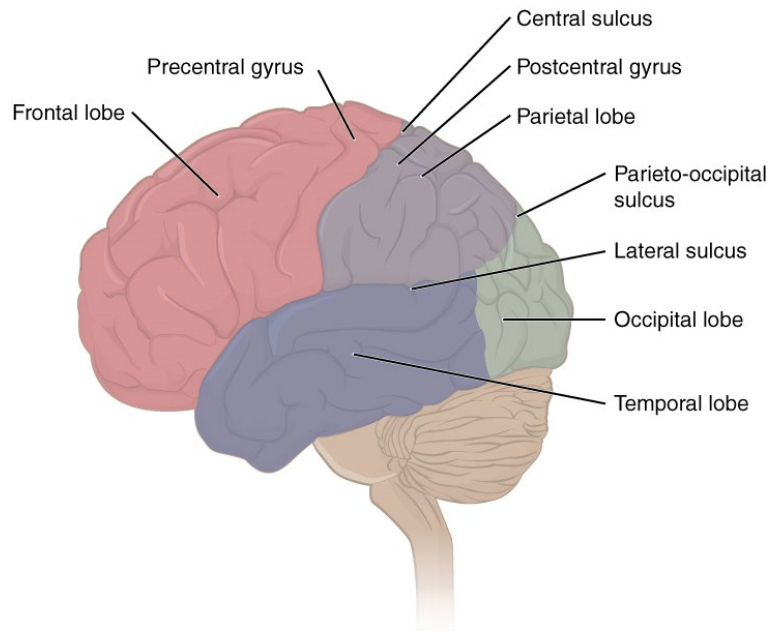


Figure 13

Cerebrum

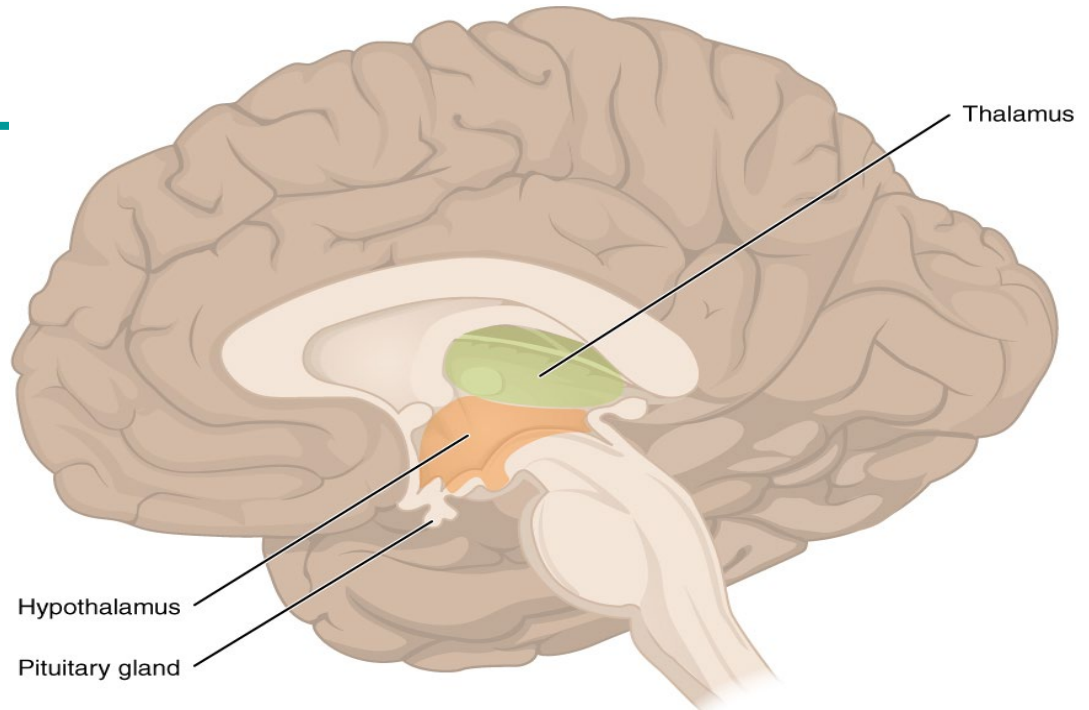
- Four external lobes: frontal, parietal, temporal and occipital lobes
- Beneath the cerebral cortex = basal nuclei



Figures 14 and 15

Figure 16

Diencephalon



- ‘Through brain’
- Connects the cerebrum and the rest of the nervous system (except olfaction system)
- Includes the thalamus, hypothalamus, epithalamus and the subthalamus

Thalamus

- A collection of nuclei that relay information between the cerebral cortex and the periphery, spinal cord, or brain stem.
- Egg-shaped structure
- **Receives and passes on sensory information** (except smell)
- Sorts out, edits and relays impulses of similar function
- Associated with the interpretation of pain and pleasure

Hypothalamus

- Under the thalamus
- Controls :
 - **autonomic nervous system** (involuntary transmissions from the central nervous system)
 - Heart rate, body temperature, movement of food, appetite, thirst, sleep (aka. Homeostasis)
 - production of **hormones** by acting on the pituitary gland
- The hypothalamus is the principal intermediary between the nervous and endocrine systems

Brain stem

- The section between the brain and spinal cord
- Controls automatic behaviours necessary for **survival**
- A **pathway** for axons between higher and lower brain centres
- Associated with ten out of twelve pairs of cranial nerves
- Divided into three parts:
 - **Midbrain**
 - **Pons**
 - **Medulla oblongata**

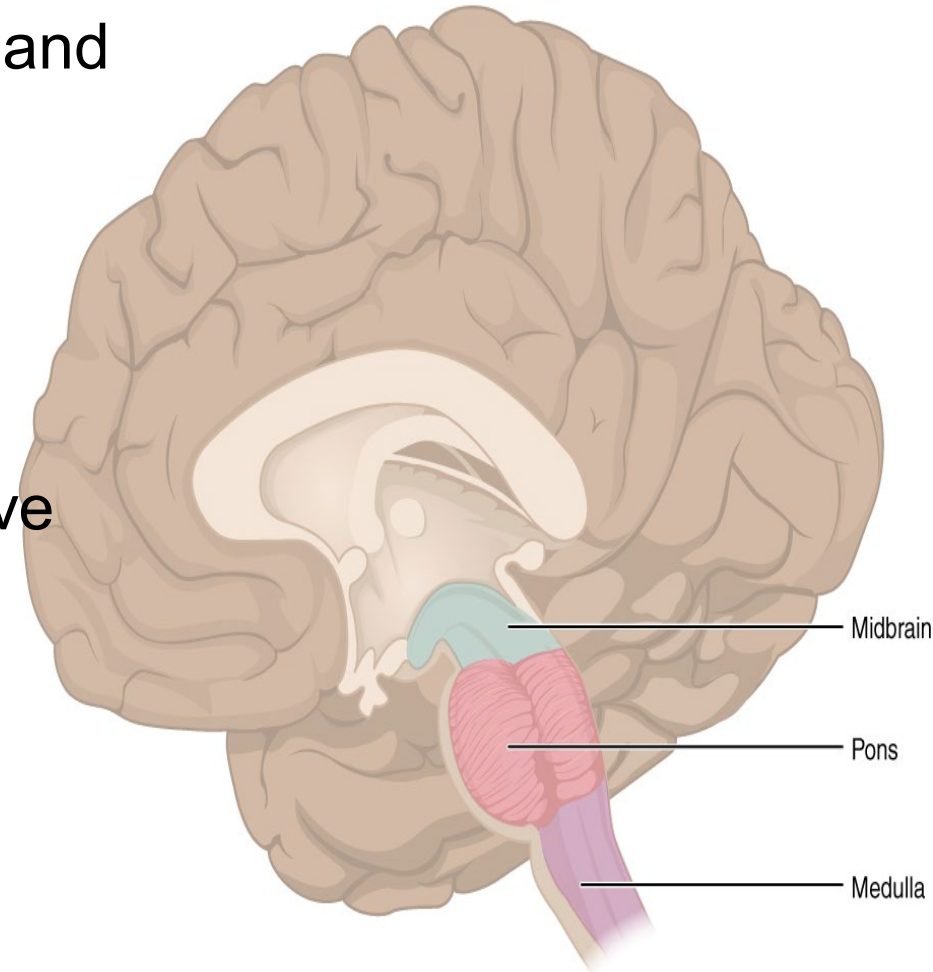
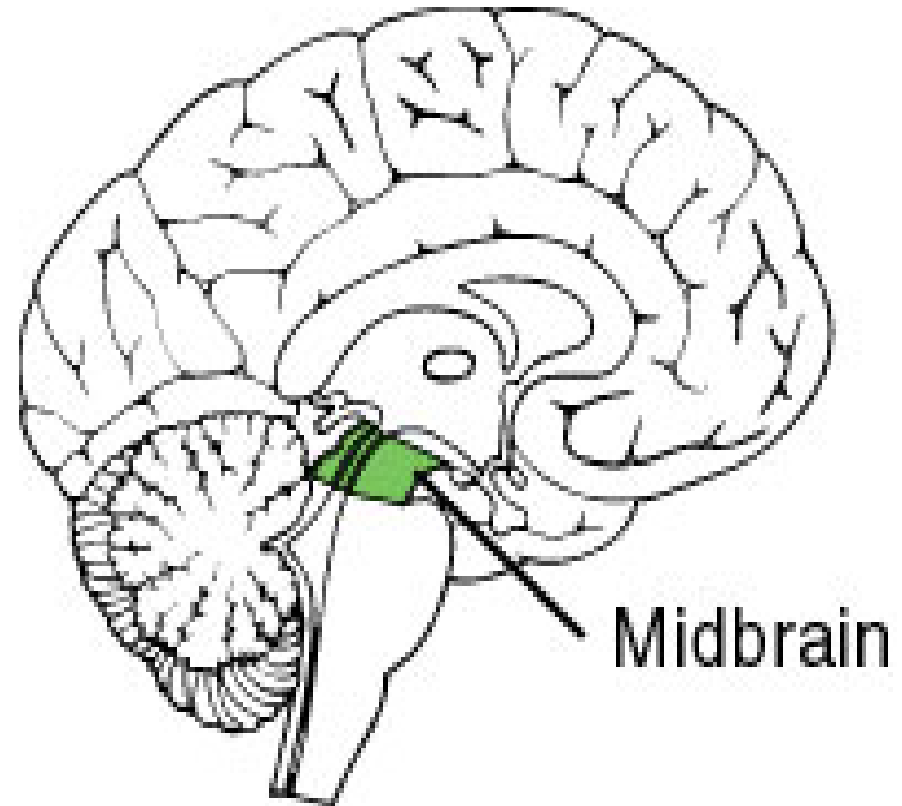


Figure 17

Midbrain

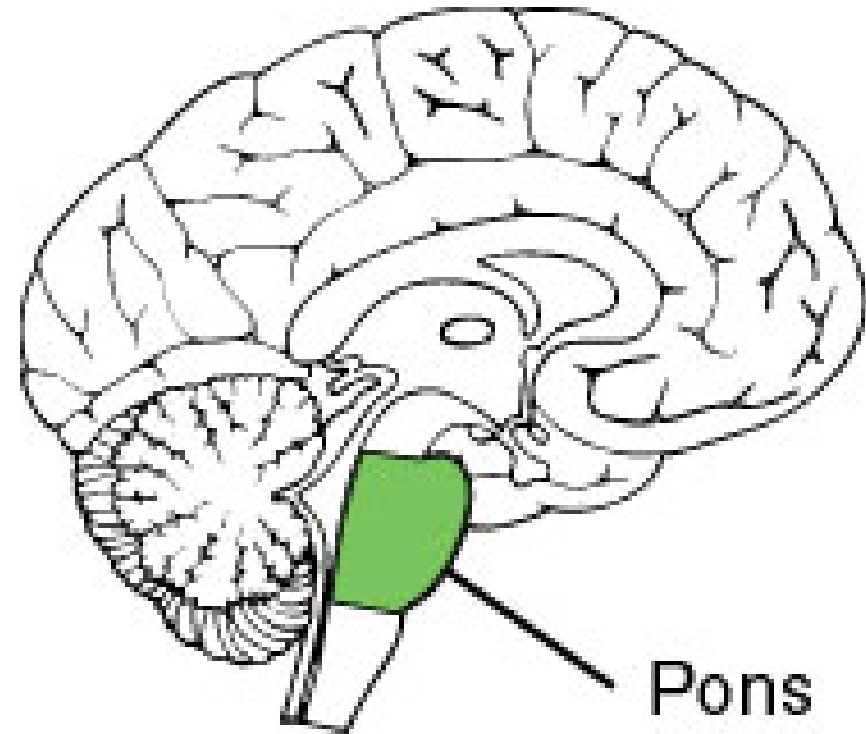
- Between the thalamus and the pons
- 4 colliculi (little hills)
- Reflex center for head and eye movements in response to sight and sounds



14.T01c

Pons

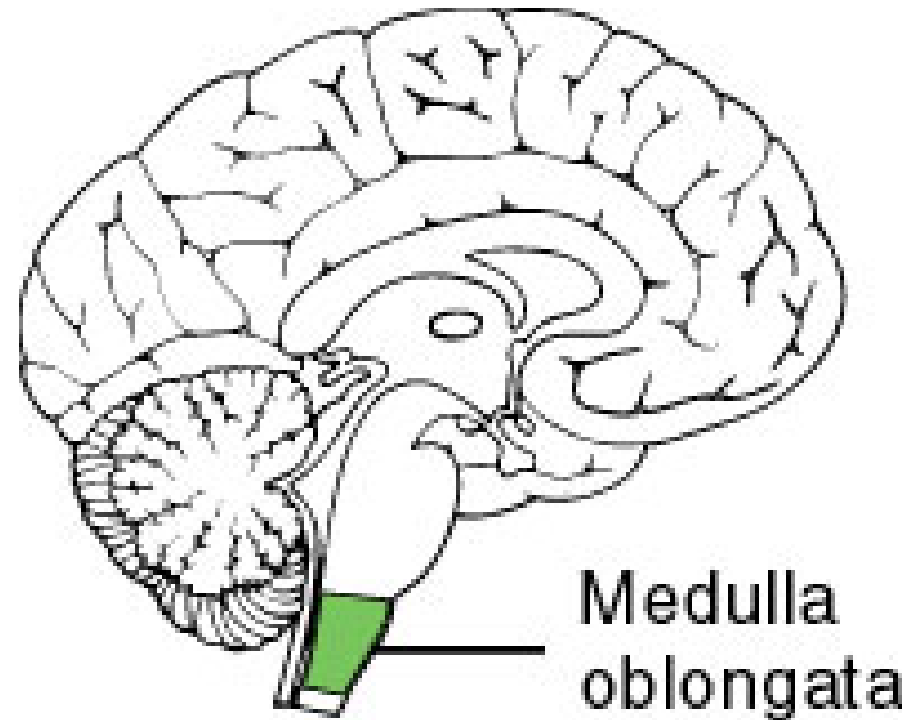
- Bulging brain stem region between the midbrain and the medulla oblongata
- Also forms bridge between cerebellum and brain stem
- White matter
- All sensory and motor fibers pass through the pons
- Helps to regulate breathing



14.T01b

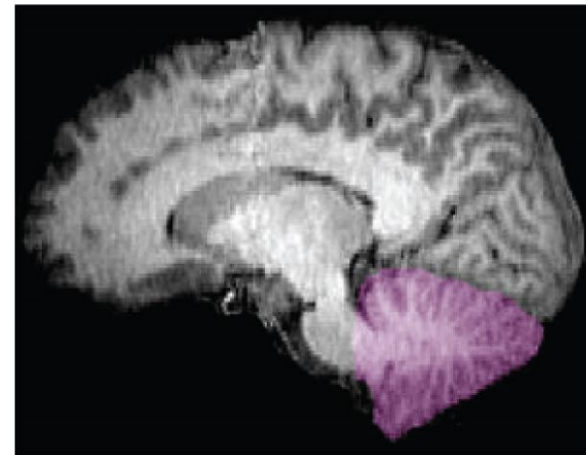
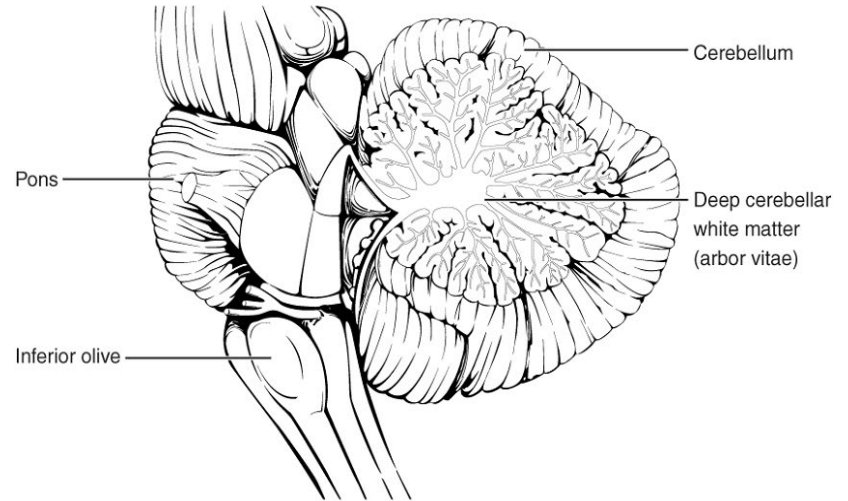
Medulla

- Most inferior part of the brain stem
- Gray matter
- Controls heart contractions, diameter of blood vessels, rate of breathing etc.
- Crossover of motor fibres occurs here (i.e., damage to the left motor nerves causes right-sided paralysis)



14.T01a

- “Little brain”
- Coordinates smooth movements and responsible for fine motor control
- Maintains posture
- Maintains balance using sensory input from inner ear



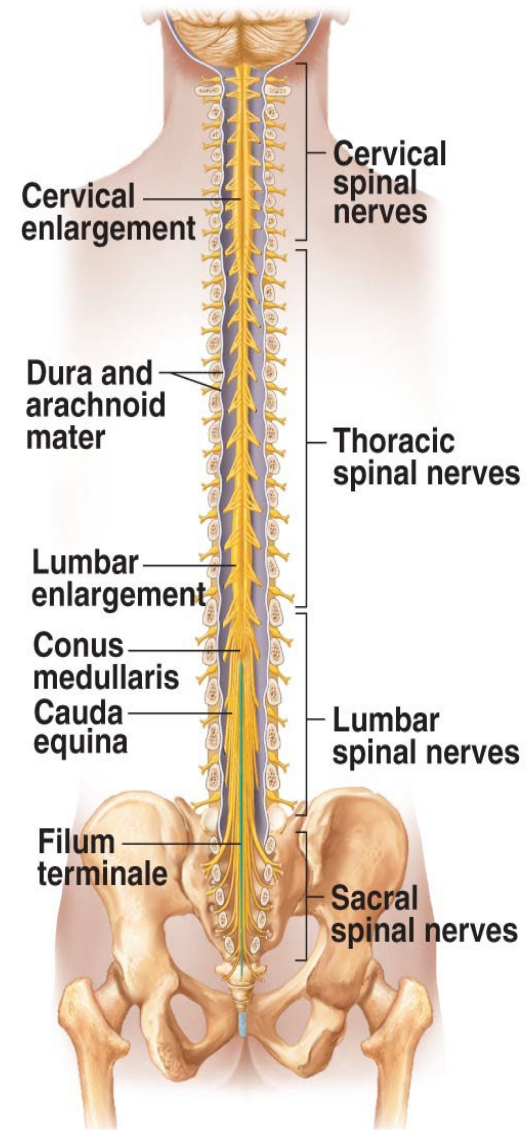
Don't confuse the cerebrum with the cerebellum!

Summary of brain region functions

Division	Areas	Functions
Cerebrum	<ul style="list-style-type: none"> •Cerebral cortex •Basal ganglia •Hippocampus •etc 	<ul style="list-style-type: none"> •Sensory functions: perception and interpretation of sensations. •Associative functions: learning, memory, emotions. •Motor functions: Planning, execution, and control of movement.
Diencephalon	Thalamus	<ul style="list-style-type: none"> •Sensory functions: relay station of all sensory pathways, except olfaction •Motor functions: control of movement
	Hypothalamus	Control of vegetative (bodily) functions through: <ul style="list-style-type: none"> •Autonomic nervous system •Endocrine system (controlling the pituitary gland)
Brain Stem	Midbrain	Control of body movements, including gaze.
	Pons	<ul style="list-style-type: none"> •Passageway of fibres from cerebellum and spinal cord •Site of the pneumotaxic and apneustic centers
	Medulla Oblongata	<ul style="list-style-type: none"> •Passageway of fibres from spinal cord •Site of respiratory and cardiovascular centers, and other autonomic reflex centers
Cerebellum		Control of movement, gait, posture and balance

Spinal Cord

- Continues from the medulla oblongata and ends between the first and second lumbar vertebra
- From there, a number of **nerves** start and angle out to various parts of the lower body
- Structure of the spinal cord includes 31 segments, each have its own spinal nerve
- Grey matter inside and white matter outside



(a) The spinal cord and its nerve roots, with the bony vertebral arches removed. The dura mater and arachnoid mater are cut open and reflected laterally.

Grey horns and white columns

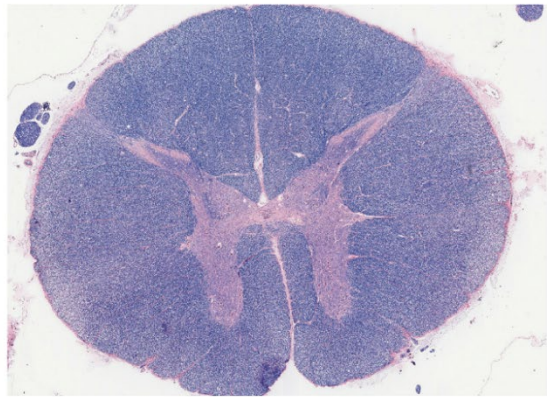
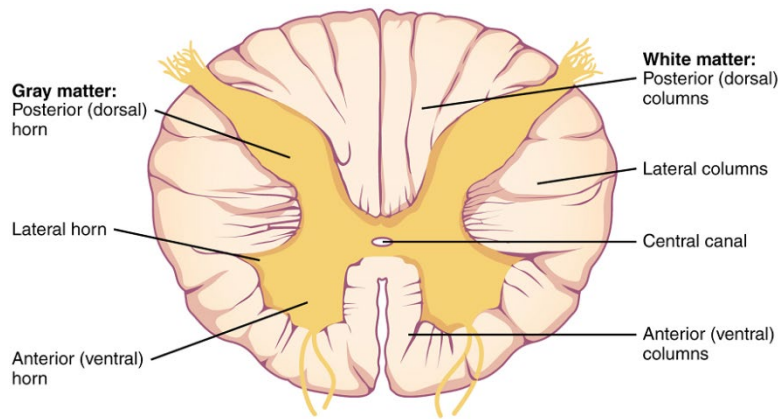
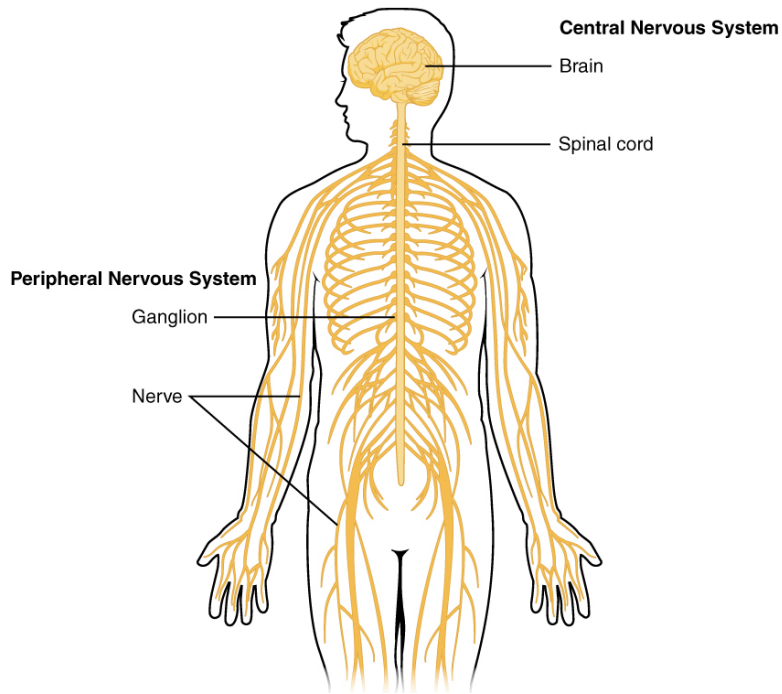


Figure 19

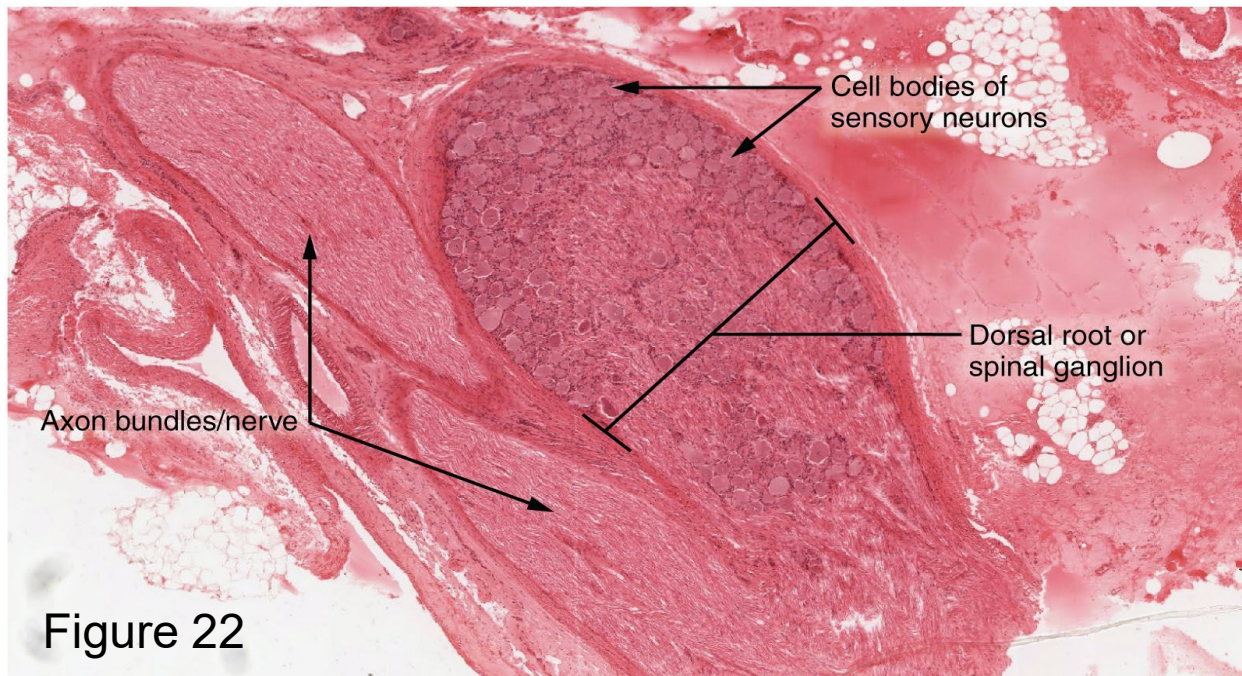
- Gray matter in the spinal column looks like a bulbous H
- **Posterior horns** = sensory processing
- **Anterior horns** = motor signals
- **Lateral horns** = autonomic nervous system
- White matter in the spinal column is in columns
- **Ascending tracts** = sensory information to the brain
- **Descending tracts** = motor commands from the brain



THE PERIPHERAL NERVOUS SYSTEM

Ganglia

- A ganglion is a group of **neuron cell bodies** in the periphery
- sensory ganglia (dorsal root ganglion which are cell bodies of neurons with axons that are sensory endings in the periphery) or autonomic ganglia



Nerves

- Bundles of axons in the PNS are referred to as nerves
- Nerves are composed of more than just nervous tissue (connective tissue like blood vessels)
- Nerves are associated with the region of the CNS to which they are connected, either as **cranial nerves** (12 pairs) connected to the brain or **spinal nerves** (31 pairs) connected to the spinal cord.
- **Cranial nerves** = sensory and motor functions of the head and neck
- **Spinal nerves** = combined sensory and motor axons that separate into two nerve roots

Somatic

nervous system

- Responsible for **conscious perception** of the environment and for our voluntary responses to that perception by means of skeletal muscles
- Peripheral sensory neurons receive input from environmental stimuli, but the neurons that produce motor responses originate in the central nervous system
- Demonstrated by a **reflex**

Reflex arc

- Fast, automatic, unplanned sequence of actions in response to a stimulus
- A stereotyped response to a stimulus
- Important defense mechanism
 - Brain not involved immediately
- If the effector is a skeletal muscle – somatic **reflex**
- if the effector is a smooth muscle, cardiac muscle or gland, the reflex is an **autonomic (visceral) reflex**
- **Example the stretch reflex:** which the nervous system responds to the stretching of a muscle (the stimulus) with contraction of that same muscle (the response).

Components of a reflex arc

1. Tapping of the patellar tendon with a hammer causes the stretching of muscle fibers in the quadriceps muscle, which stimulates sensory neurons innervating those fibers.
2. In the sensory neuron, a nerve impulse (action potential) is generated, which travels along the sensory nerve fiber from the muscle, through the dorsal root ganglion, to the spinal cord.
3. The sensory neuron stimulates a motor neuron in the ventral horn motor of the spinal cord.
4. That motor neuron sends a nerve impulse (action potential) along its axon.
5. This impulse reaches the quadriceps muscle, causing its contraction and the extension of the leg (a kick).

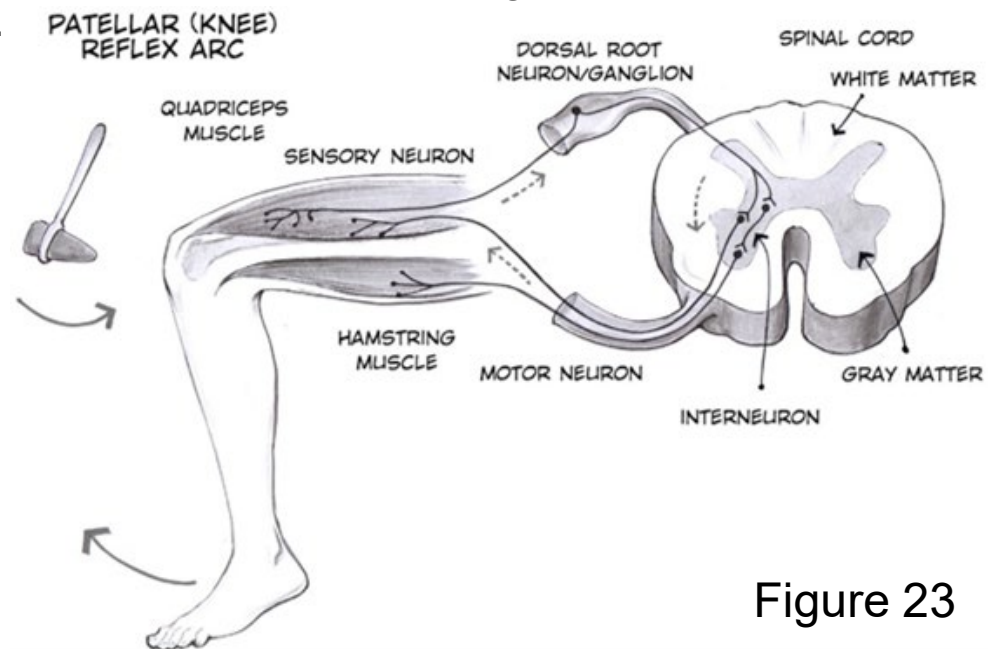
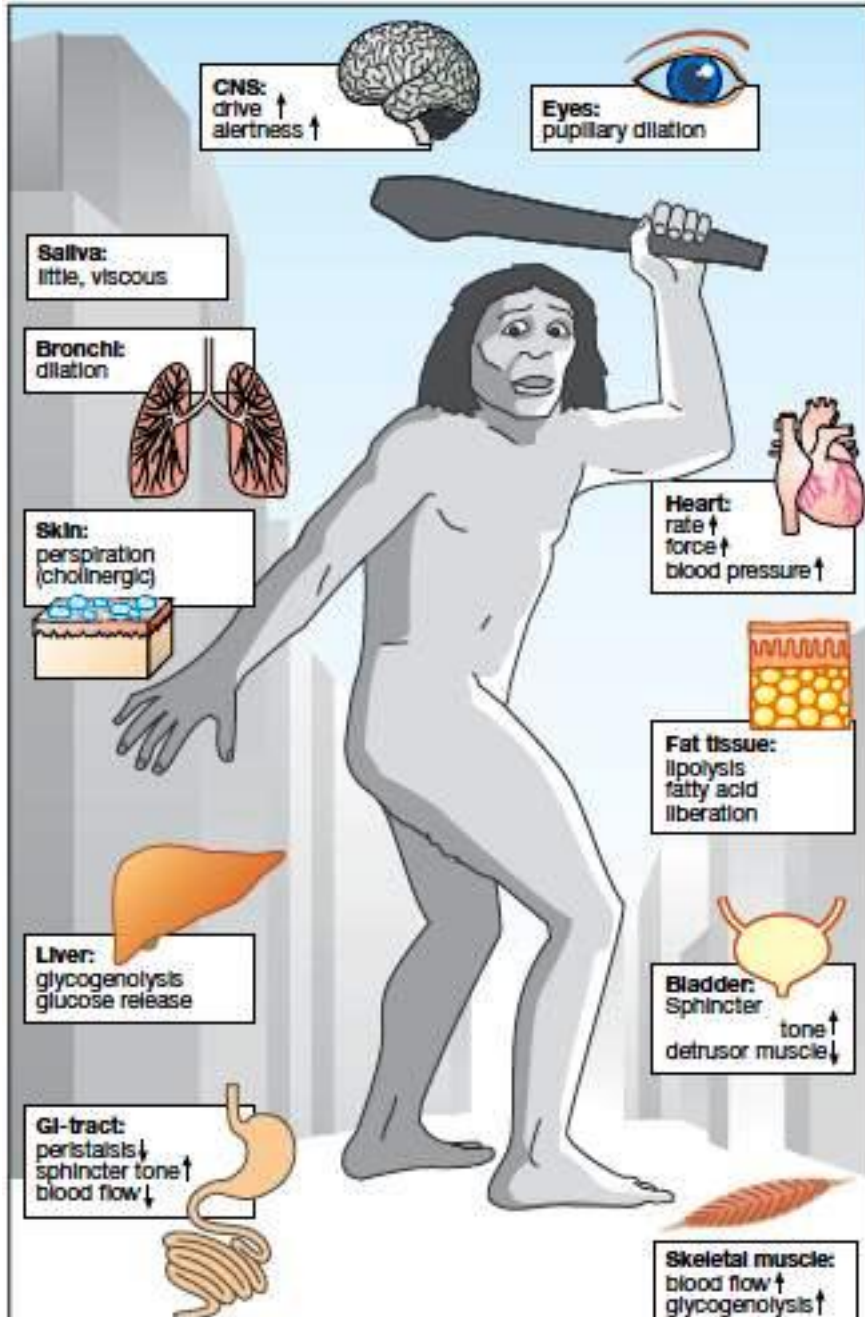
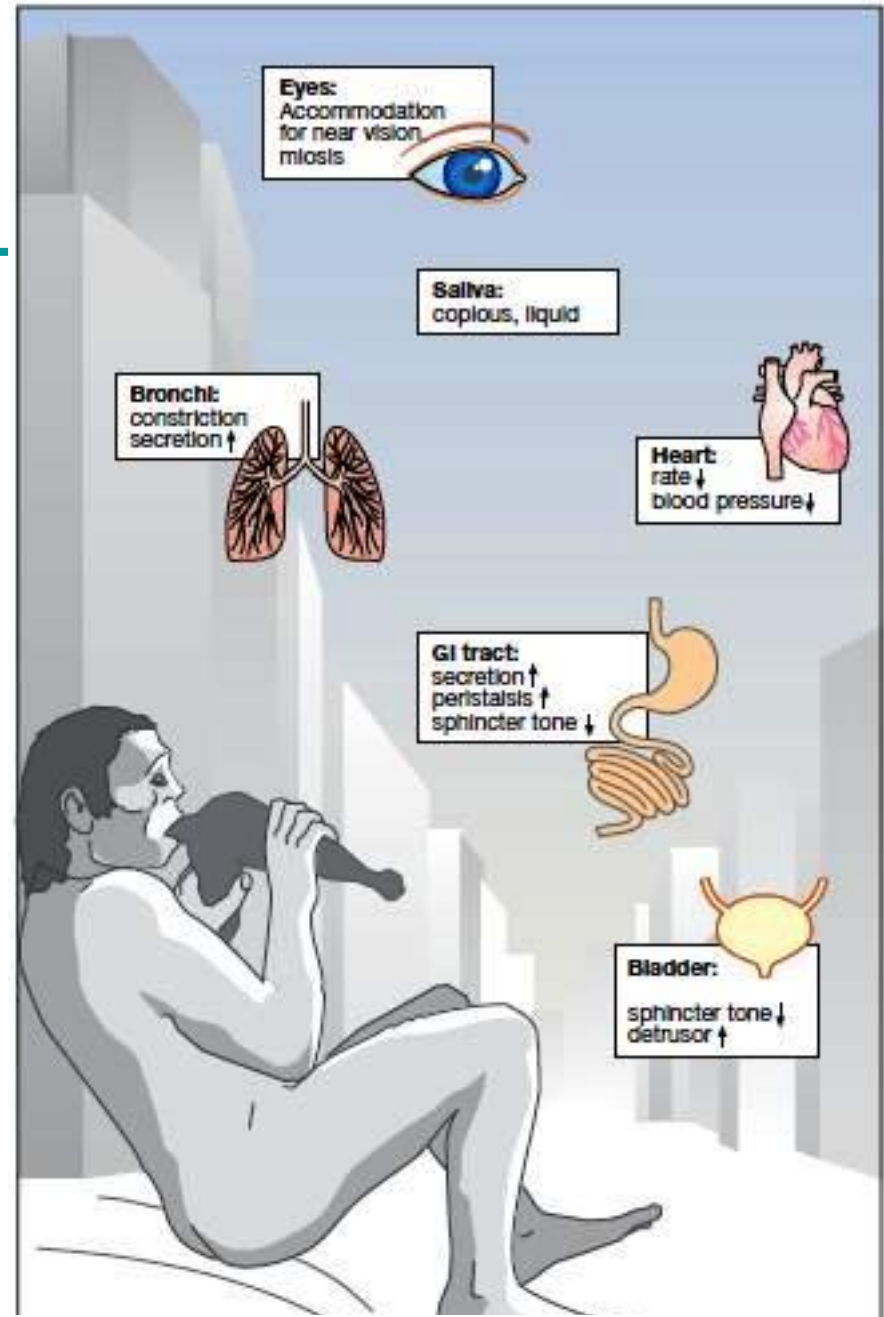


Figure 23

- “**Fight-or-flight response**,” which refers to the preparation of the body to either run away from a threat or to stand and fight in the face of that threat.
- The autonomic nervous system controls cardiac and smooth muscle, as well as glandular tissue.
- Divided into **sympathetic** and **parasympathetic** divisions
- Divisions are often antagonistic (work against each other)



Sympathetic activation



Parasympathetic activation

Nervous system

Objectives 1-6

1. Describe the organization of the nervous system and explain the functions of its principal components.
2. Describe the structure of the following: neuron, glia, ganglion, nerve, gray matter, tract, white matter, sensory neuron, motor neuron.
3. Name, locate and describe the functions of the main areas of the human brain.
4. Describe the structure and explain the functions of the spinal cord.
5. Describe the components of a reflex arc and explain how a reflex arc works.
6. Describe the function of the autonomic nervous system (ANS) and compare the specific functions of the parasympathetic and sympathetic divisions of the ANS.



How a signal is propagated down a neuron

NEURONAL SIGNALLING

Nervous system

Objectives 7-10

7. Describe the resting membrane potential of a neuron and explain how it is maintained.
8. Explain how a neuronal action potential is generated.
9. Explain how neuronal action potentials travel down the axon.
10. Explain the process of neurotransmission, and name three different neurotransmitters.

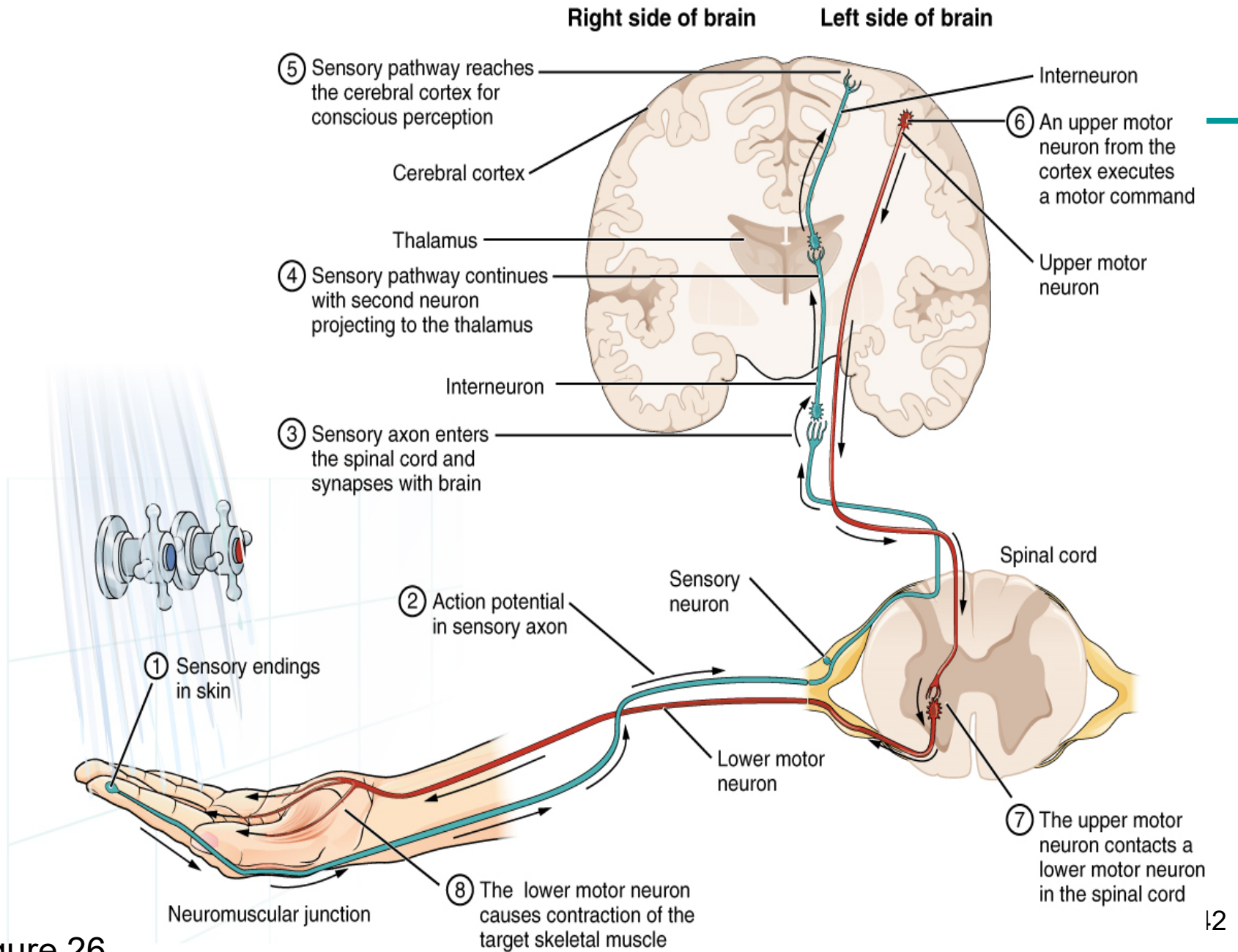
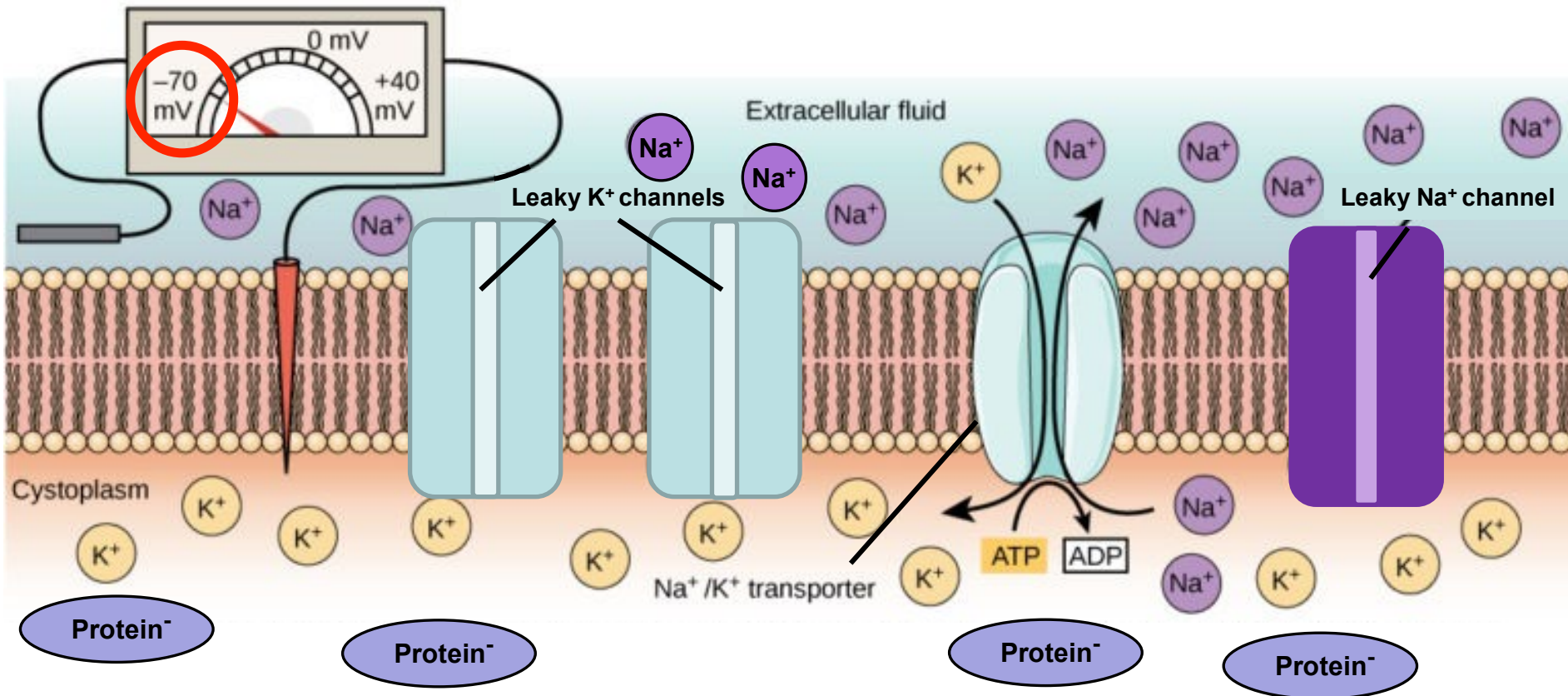


Figure 26

Sodium/ Potassium pump

(a) Resting potential



- This transporter pumps **3 Na⁺** out of the cell for every **2 K⁺** pumped into the cell making the inside of the cell membrane being more negative relative to the outside

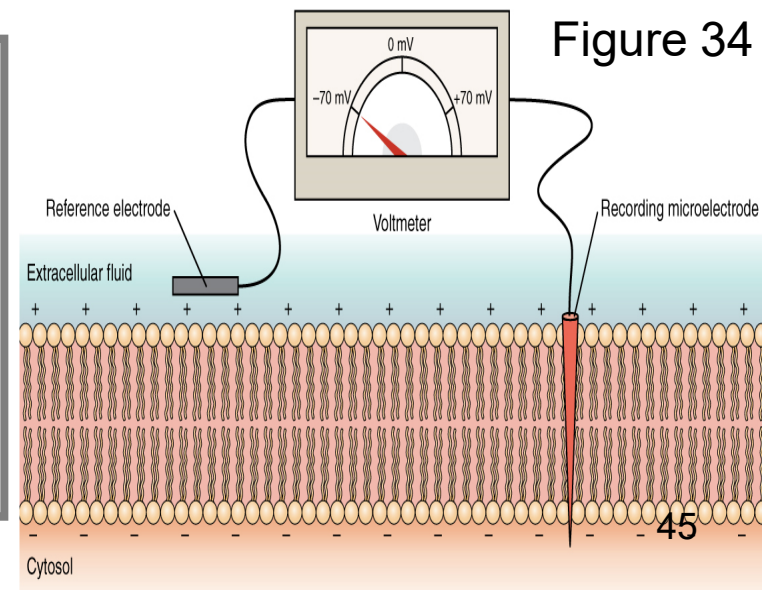
Leaky ion channels

- Because of Na^+/K^+ pumps, K^+ levels are higher **intracellularly** compared with **extracellularly**
- K^+ leak channels allow K^+ to leave the cell by facilitated diffusion, down its concentration gradient
- Exit of K^+ carries positive charge out of the cell (negative proteins stay inside cell)
- This contributes to the inside of the cell being more negative than the outside
- Na^+ does not leak in as much as K^+ leaks out

The resting membrane potential

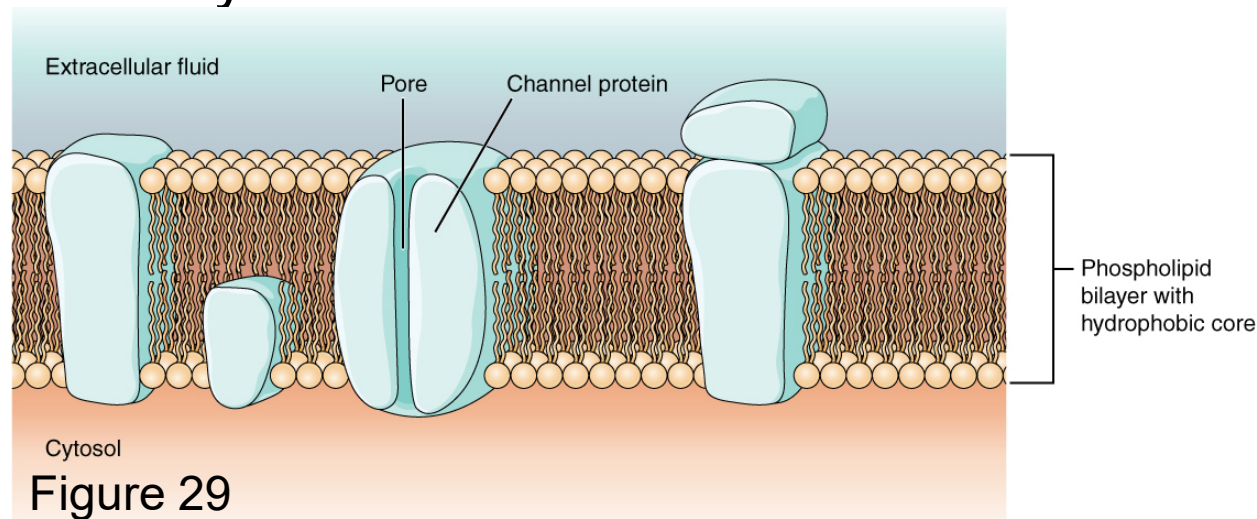
- When cell is at rest, the channels are closed
- Present in all cells, commonly -70 mV and is balanced by ion leakage and ion pumping
- The **inside** of the plasma membrane is **negative** relative to the outside of the plasma membrane
- The resting membrane potential is due to three key factors:

1. Action of Sodium-Potassium Pump: **3 Na⁺** pumped out for every **2 K⁺** pumped in
2. Intracellular **protein anions** are trapped
3. Plasma membrane is more **permeable to potassium** than to sodium



Excitable membranes

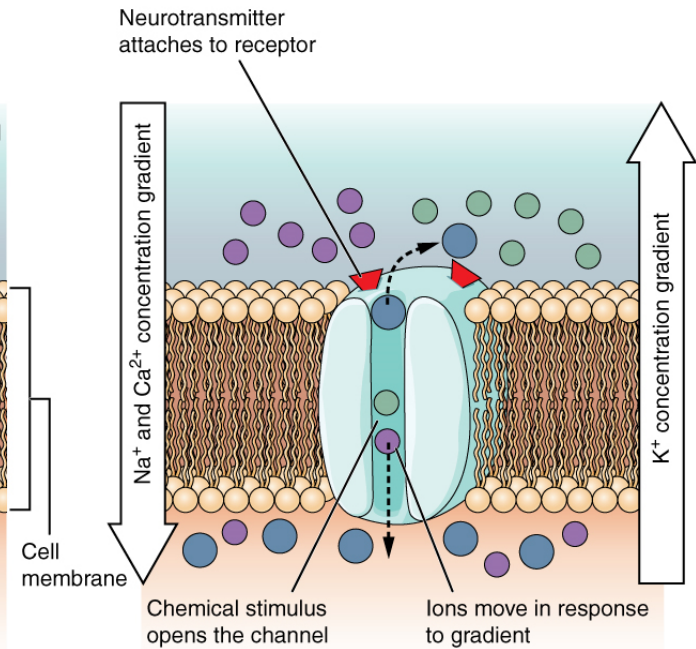
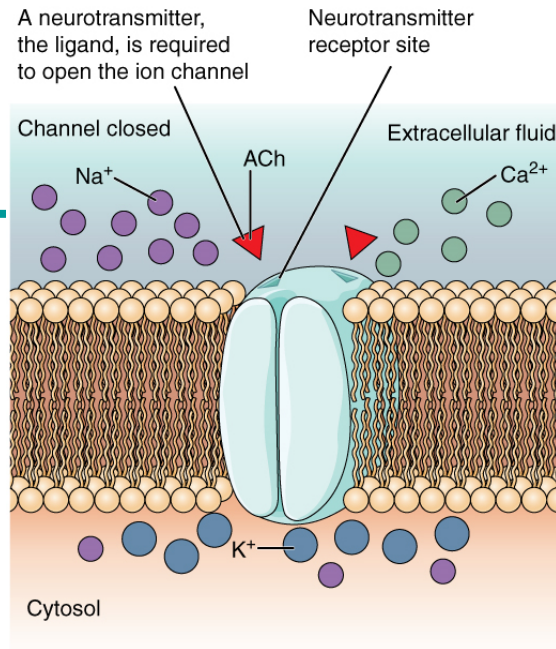
- To understand how neurons are able to communicate, it is necessary to describe the role of an **excitable membrane** in generating these signals.
- The basis of this communication is the **action potential**, which demonstrates how changes in the membrane can constitute a signal.
- Cell membranes regulate the movement of ion between the extracellular fluid and the cytosol
- Interest in Na^+ and K^+ , movement affects membrane voltage



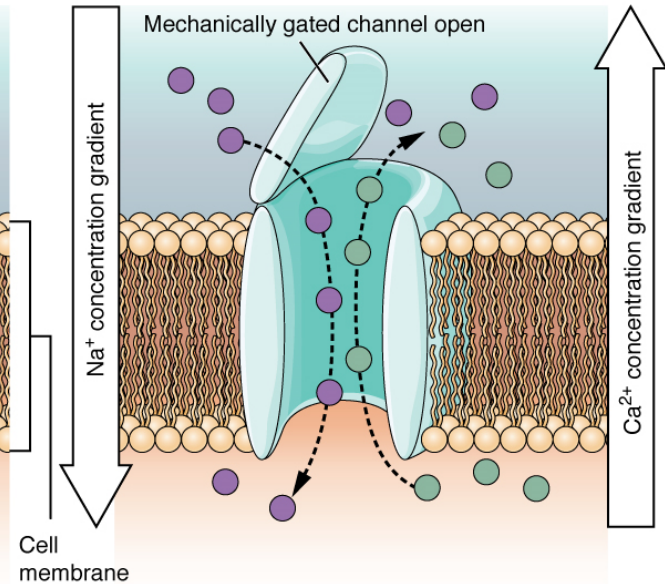
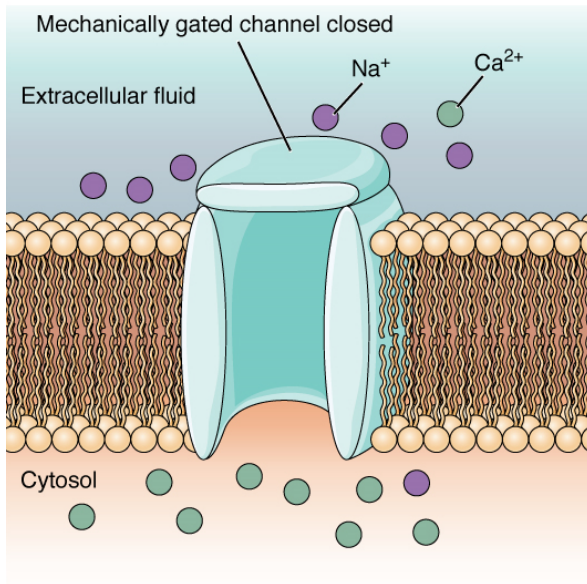
Gated channels

- Some cells can be excitable, meaning that they contain special gated ion channels that open upon the correct stimulus:
 1. Ligand -gated channels – open with binding of a specific neurotransmitter
 2. **Mechanically-gated channels** – open or close in response to mechanical stimulation (vibration, touch, pressure)
 3. Voltage -gated channels – open and close in response to membrane potential
 4. **Leak channels** – random opening and closing

Ligand-Gated Channels

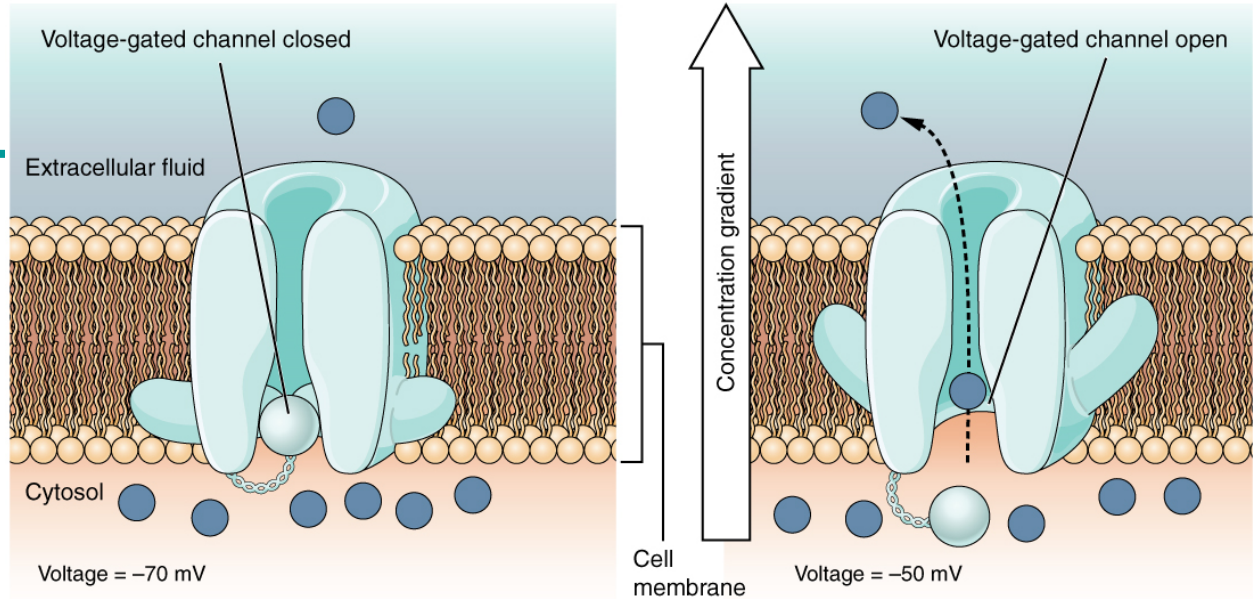


Mechanically Gated Channels

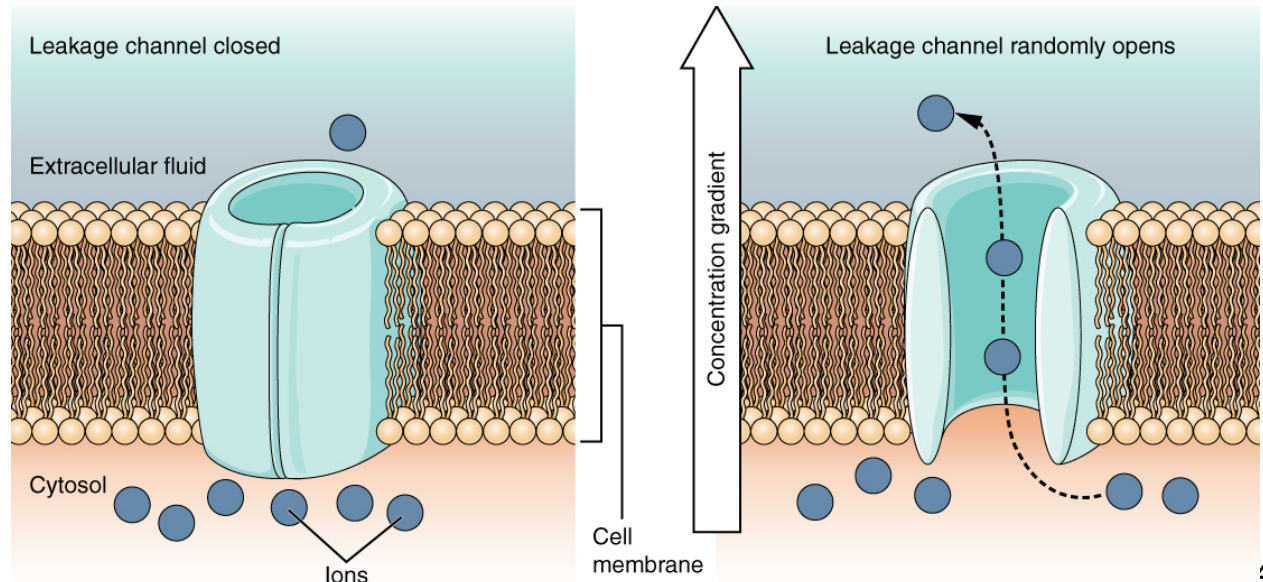


Figures 30 and 31

Voltage-Gated Channels



Leakage Channels

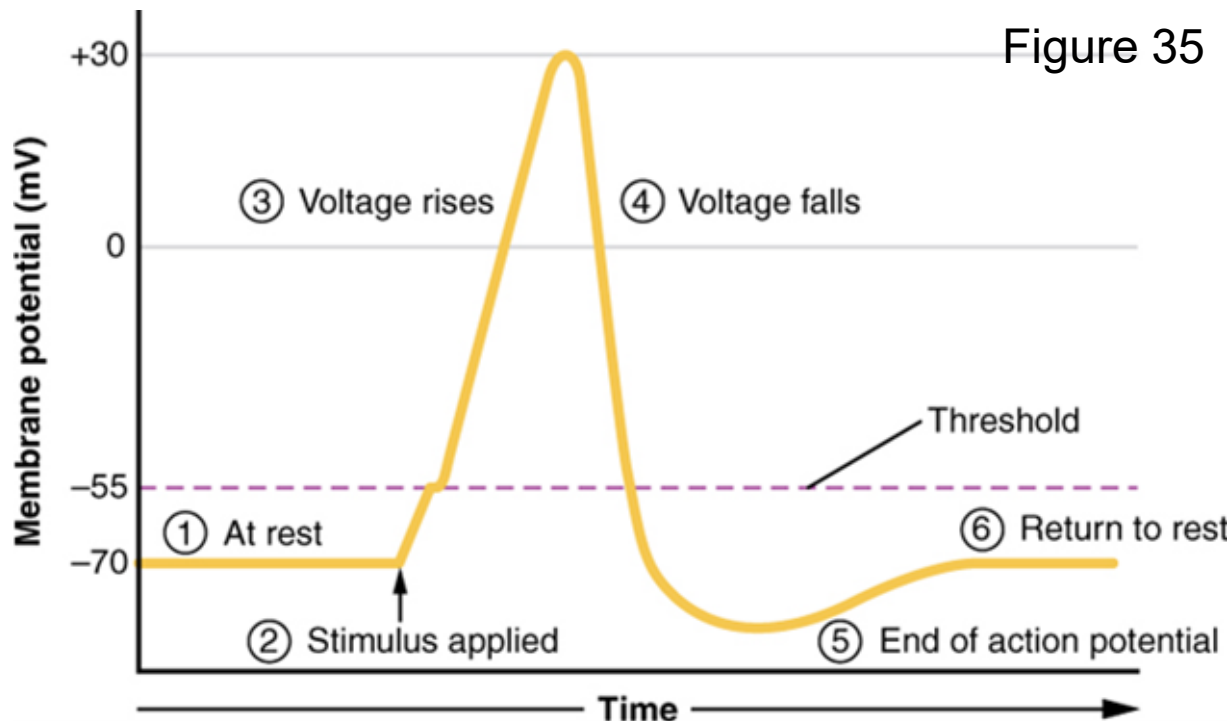


Figures 32 and 33

study for quiz

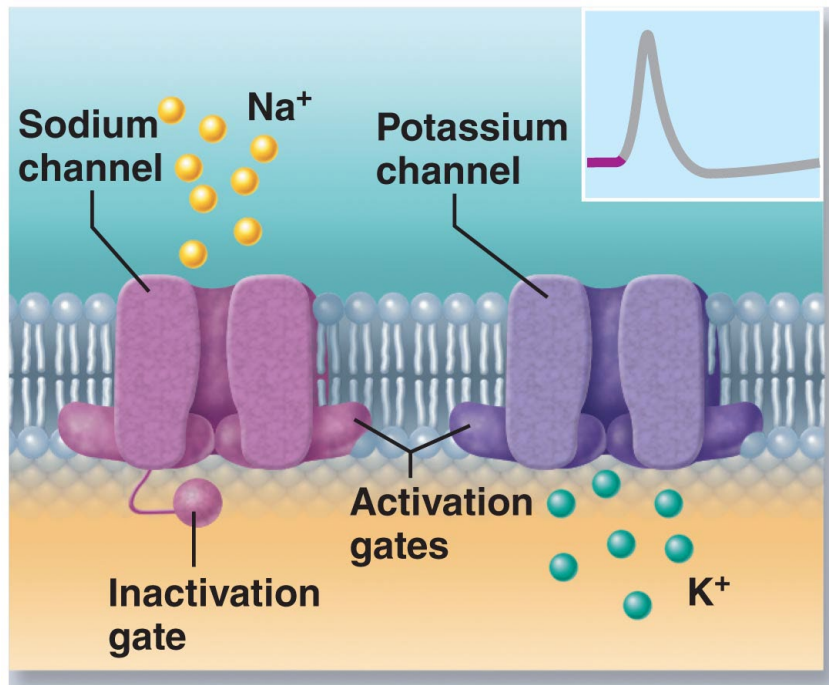
Action potential

- This is how an electrical impulse can travel along the membrane of a nerve or muscle cell
- There is a reversal of charge across a segment of the membrane during an action potential
- The inside of the membrane becomes positively charged while the outside becomes negatively charged



Action potential- resting stage

The events



① Resting state

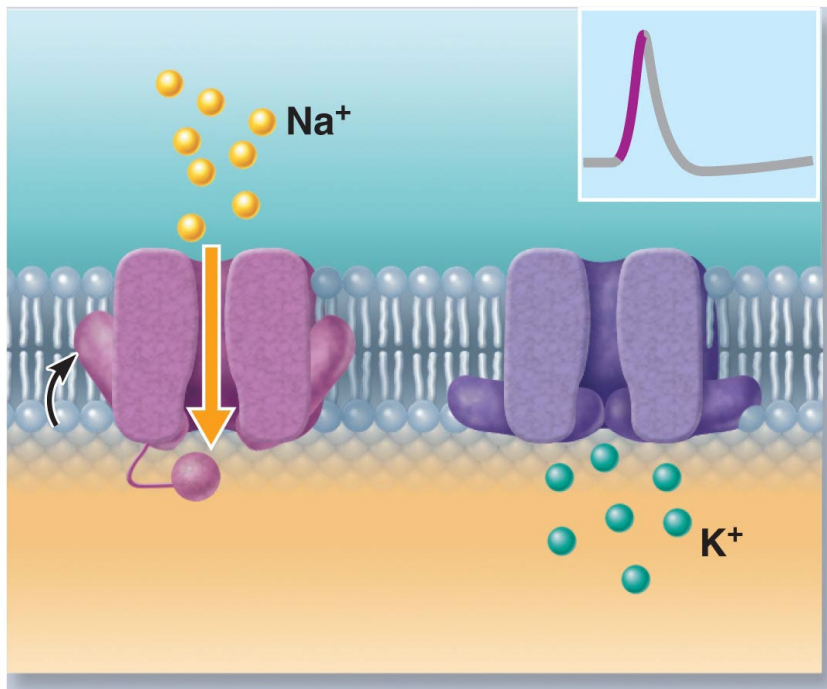
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- All gated channels are closed
- Membrane potential at -70 mV

Action potential-

depolarization

The events



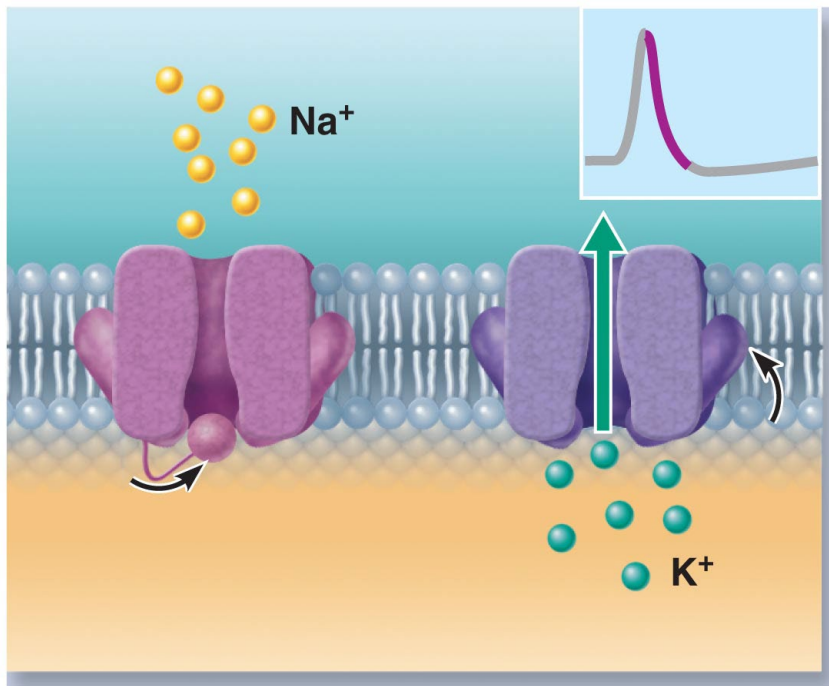
- Voltage-gated Na⁺ channels open
- Na⁺ rushes **into** the cell
- As a result, the membrane potential increases to about +30 mV

② Depolarization

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Action potential- repolarization

The events



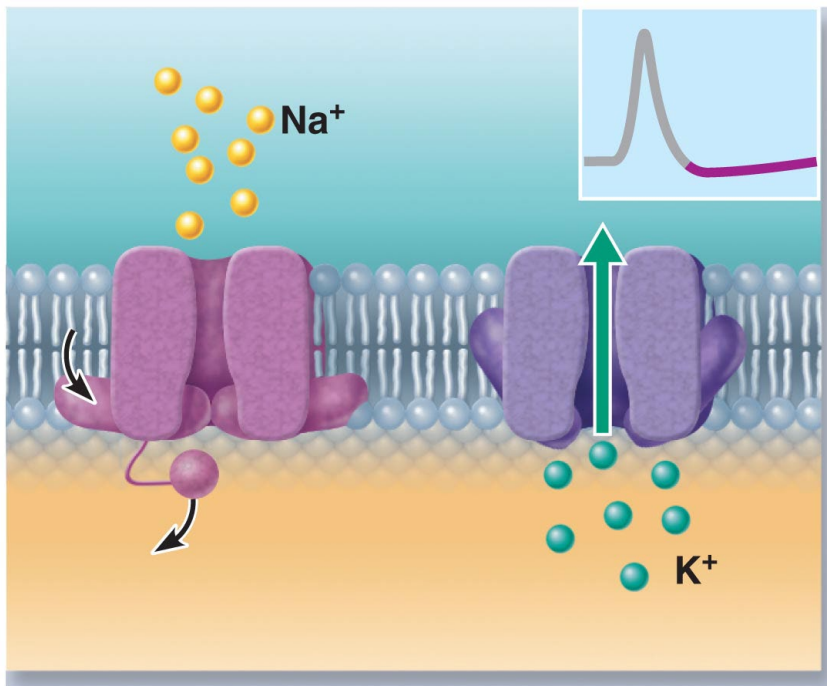
- Voltage-gated Na⁺ channels close
- Voltage-gated K⁺ channels open
- K⁺ rush **out** of the cell

③ Repolarization

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Action potential- hyperpolarization

The events



- Voltage-gated Na⁺ channels are **reset**, but voltage-gated K⁺ channels remain open for slightly longer
- As a result, the membrane potential falls below -70 mV
- However, as more time passes, the membrane is brought back to -70 mV due to the action of Na⁺K⁺ pumps

4 Hyperpolarization

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Phases of the action potential

- Resting state (resting membrane potential)
- Depolarization (Na^+ gates open)
- Repolarization (Na^+ gates close, K^+ gates open)
- Hyperpolarization (K^+ gates close, Na^+K^+ pump takes over)
- An action potential that occurs at one point along a membrane will cause another action potential to occur in an adjacent region of the membrane (“propagation”)

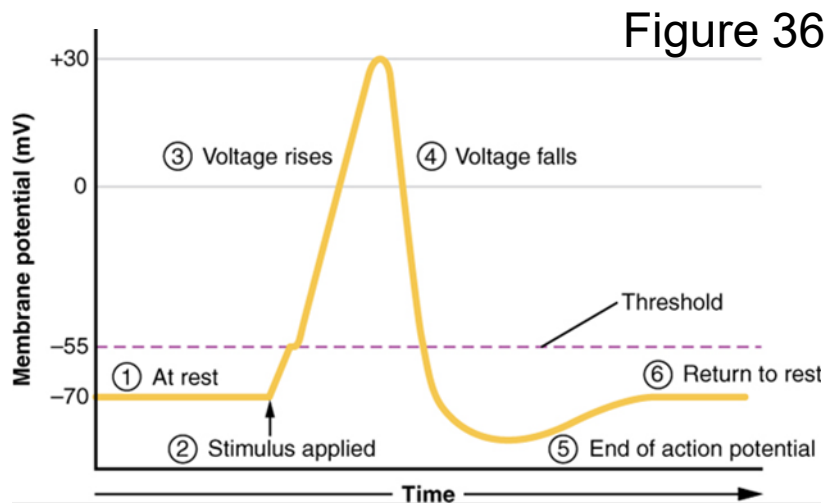


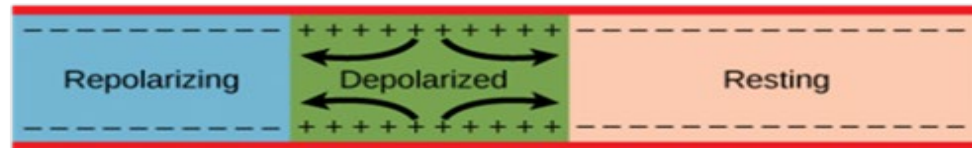
Figure 37



a. In response to a signal, the soma end of the axon becomes depolarized.



b. The depolarization spreads down the axon. Meanwhile, the first part of the membrane repolarizes. Because Na^+ channels are inactivated and additional K^+ channels have opened, the membrane cannot depolarize again.



c. The action potential continues to travel down the axon.



- The action potential in one section of the axon will **stimulate** the voltage-gated channels and start an action potential in the next section of the axon

Be able to describe the events of an action potential as well as the propagation of an action potential

Action potential propagation

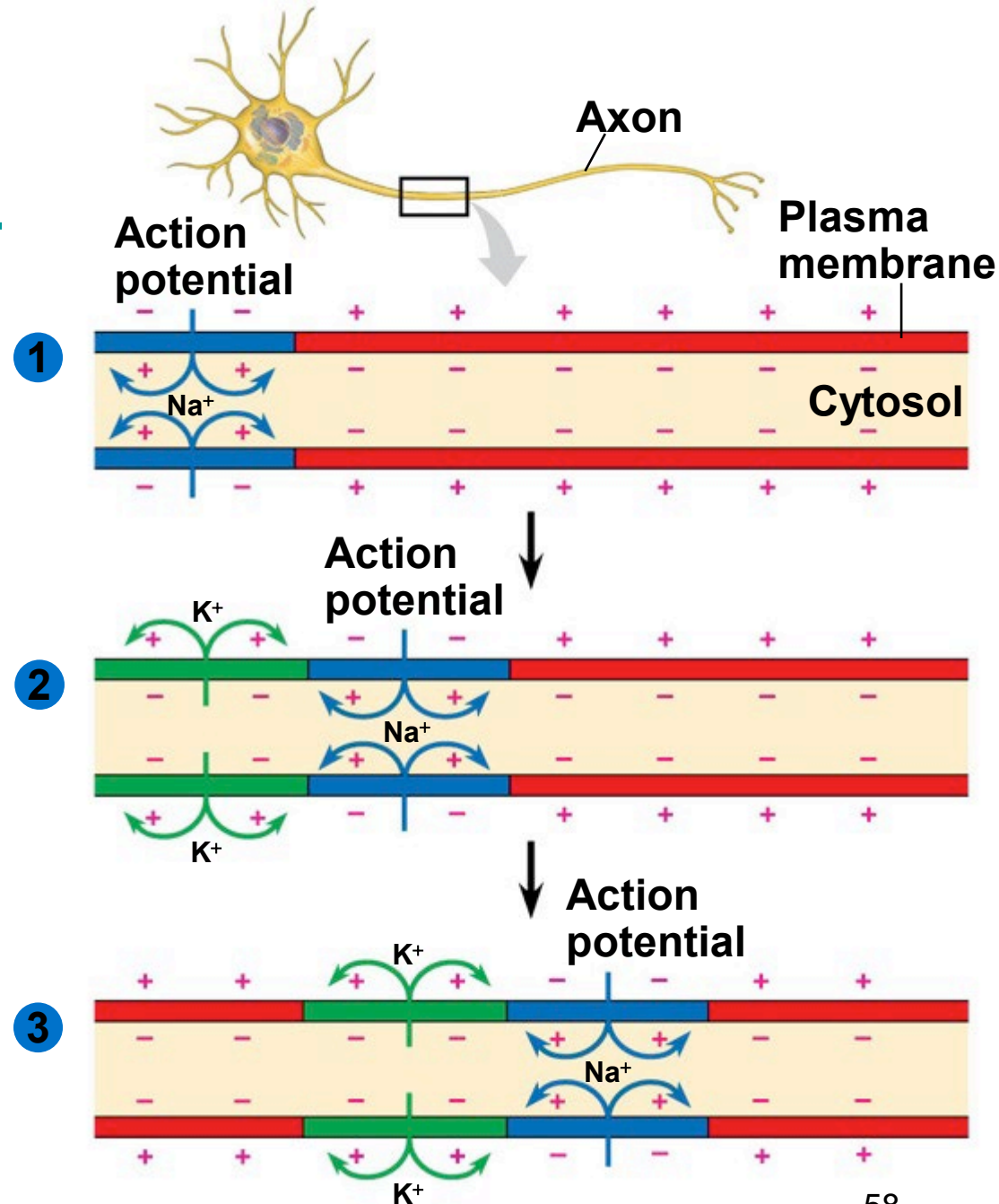


Propagation of the action potential

An action potential is generated as Na^+ flows inward in one location.

The depolarization of the action potential **spreads to the neighbouring region** of the membrane initiating the action potential there. To the left of this region, the **membrane is repolarizing** as K^+ flows outward.

The depolarization-repolarization process is repeated in the next region of the membrane.

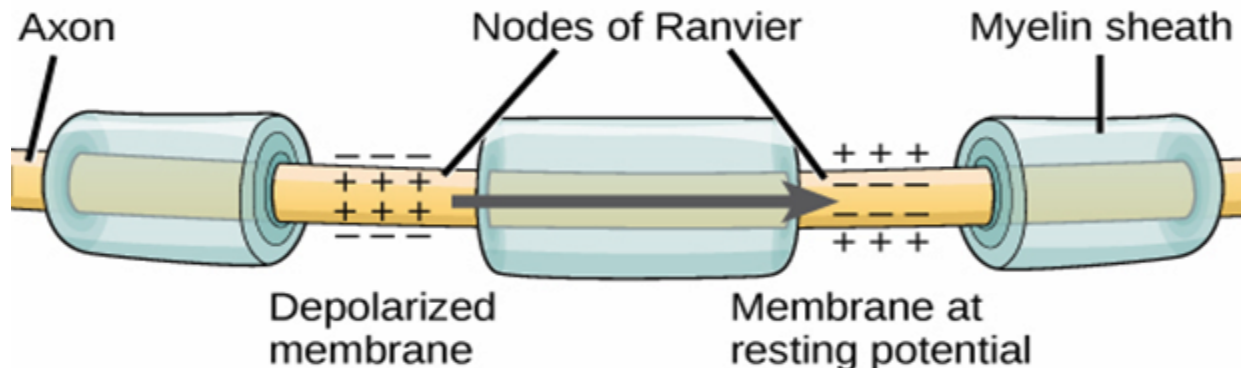


Why does an action potential only move in one direction ?

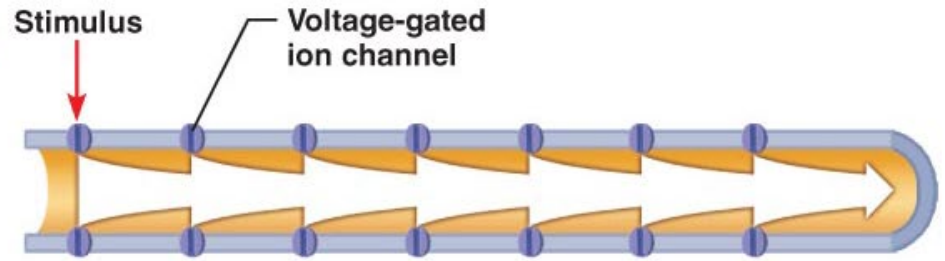
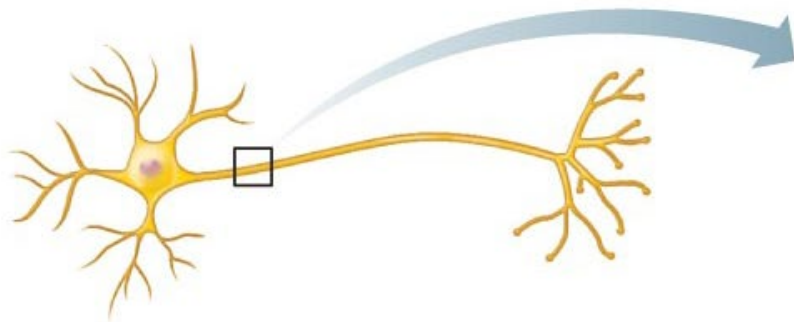
- Refractory period
 - After voltage-gated Na^+ channels close, they are **desensitized** for a period of time while it “resets” itself (inactivation gate blocks channel)
 - Therefore, during membrane depolarization, voltage-gated Na^+ channels in the previous section of the membrane are still desensitized and cannot open again

Saltatory conduction

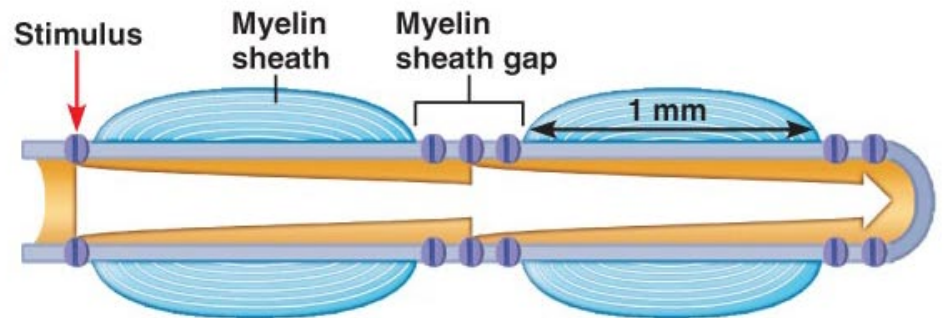
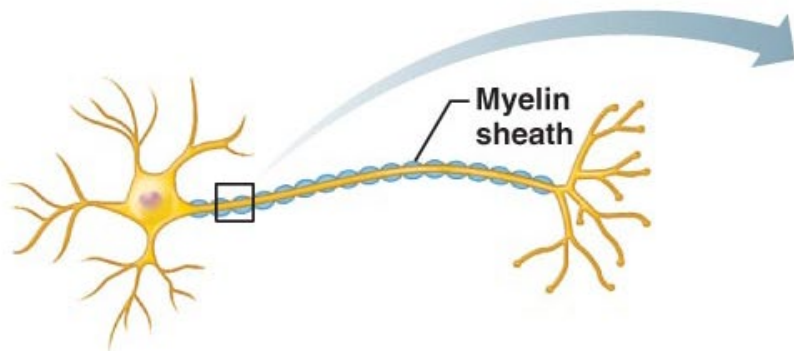
Figure 38



- Special mode of action potential propagation
- No voltage gated Na^+ channels until first **node of Ranvier**
- Events:
 1. Action potential at the first node
 2. Ionic currents travel through the intracellular fluid
 3. Action potential is then generated at the second node
- As a result, the action potential appears to “**leap**” from node to node
- Two advantages: **speed and less ATP is used**

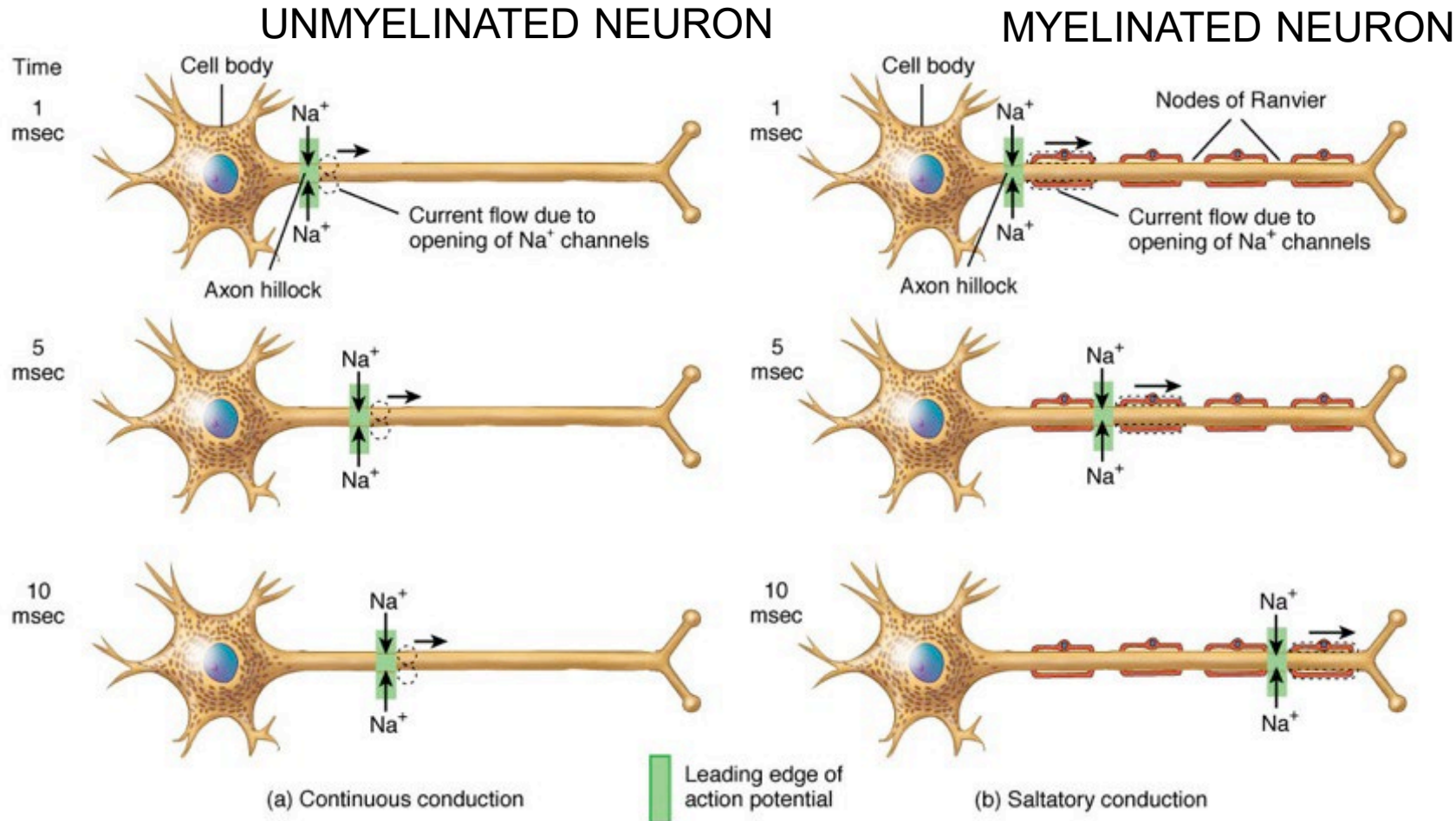


(b) In nonmyelinated axons, conduction is slow (continuous conduction). Voltage-gated Na^+ and K^+ channels regenerate the action potential at each point along the axon, so voltage does not decay. Conduction is *slow* because it takes time for ions and for gates of channel proteins to move, and this must occur before voltage can be regenerated.



(c) In myelinated axons, conduction is fast (saltatory conduction). Myelin keeps current in axons (voltage doesn't decay much). APs are generated *only* in the myelin sheath gaps and appear to jump *rapidly* from gap to gap.

Effect of myelin sheath on speed of action potential transmission



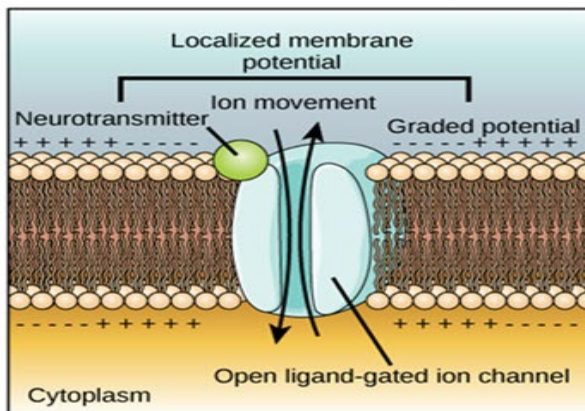
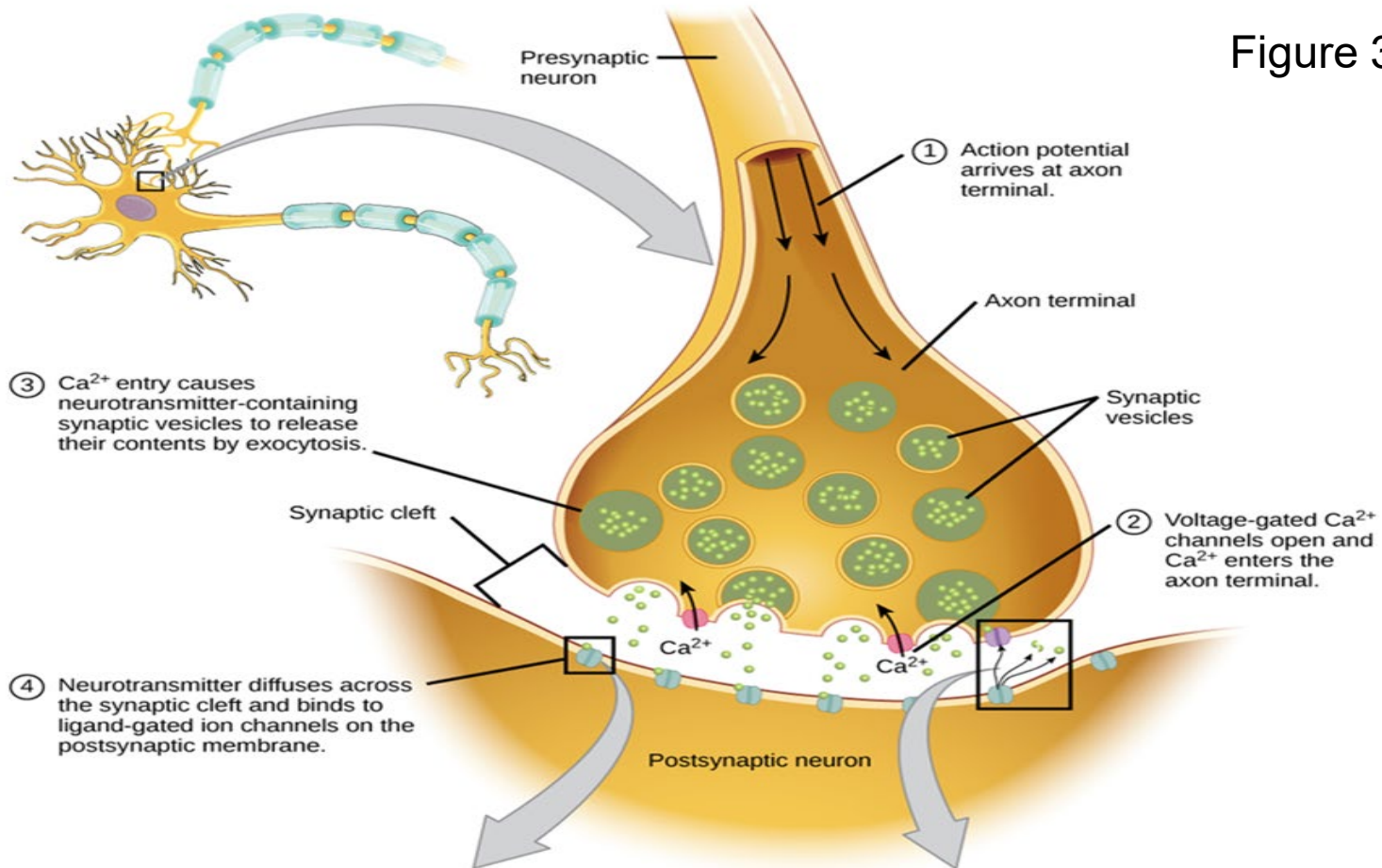
Synapses

- A connection between electrically active cells
- Two kinds:
 - **Electrical synapses** (direct connection between the two cells so that ions can pass directly from one cell to the next)
 - **Chemical synapses** (transmission of chemical information from one cell to the next via a neurotransmitter)
- At least 30 different neurotransmitters have been identified, each having a specific function (examples: acetylcholine, epinephrine, glycine)
- A neurotransmitter can be **inhibitory** or **excitatory**, depending upon the area of the nervous system it is used in

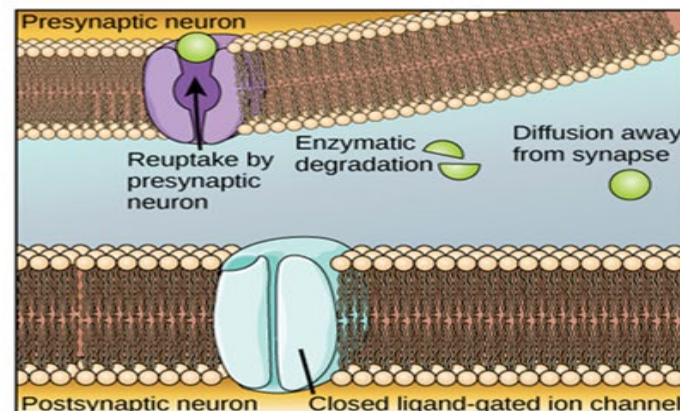
Neurotransmission

1. The action potential reaches the axon bulb (end of axon) of the **presynaptic neuron**.
2. This activates **voltage-gated** Ca^{2+} channels, opening them. Ca^{2+} floods down its gradient into the axon bulb.
3. Ca^{2+} causes synaptic vesicles (containing a specific neurotransmitter) to move to the axon end. These vesicles fuse with the membrane, resulting in **exocytosis** of the neurotransmitter into the synaptic cleft.
4. Neurotransmitters **diffuse** across the synaptic cleft and bind to ligand-gated receptors/channels on the postsynaptic neuron.
5. These ion channels open, starting an **action potential**
6. The neurotransmitter is **removed** from the synaptic cleft by diffusion, due to the action of enzymes that break it down chemically or by transporters in the presynaptic cell membrane.

Figure 39



⑤ Binding of neurotransmitter opens ligand-gated ion channels, resulting in graded potentials.



⑥ Reuptake by the presynaptic neuron, enzymatic degradation, and diffusion reduce neurotransmitter levels, terminating the signal.

Nervous system

Objectives 1-10

1. Describe the organization of the nervous system and explain the functions of its principal components.
2. Describe the structure of the following: neuron, glia, ganglion, nerve, gray matter, tract, white matter, sensory neuron, motor neuron.
3. Name, locate and describe the functions of the main areas of the human brain.
4. Describe the structure and explain the functions of the spinal cord.
5. Describe the components of a reflex arc and explain how a reflex arc works.
6. Describe the function of the autonomic nervous system (ANS) and compare the specific functions of the parasympathetic and sympathetic divisions of the ANS.
7. Describe the resting membrane potential of a neuron and explain how it is maintained.
8. Explain how a neuronal action potential is generated.
9. Explain how neuronal action potentials travel down the axon.
10. Explain the process of neurotransmission, and name three different neurotransmitters.