# Nervous System

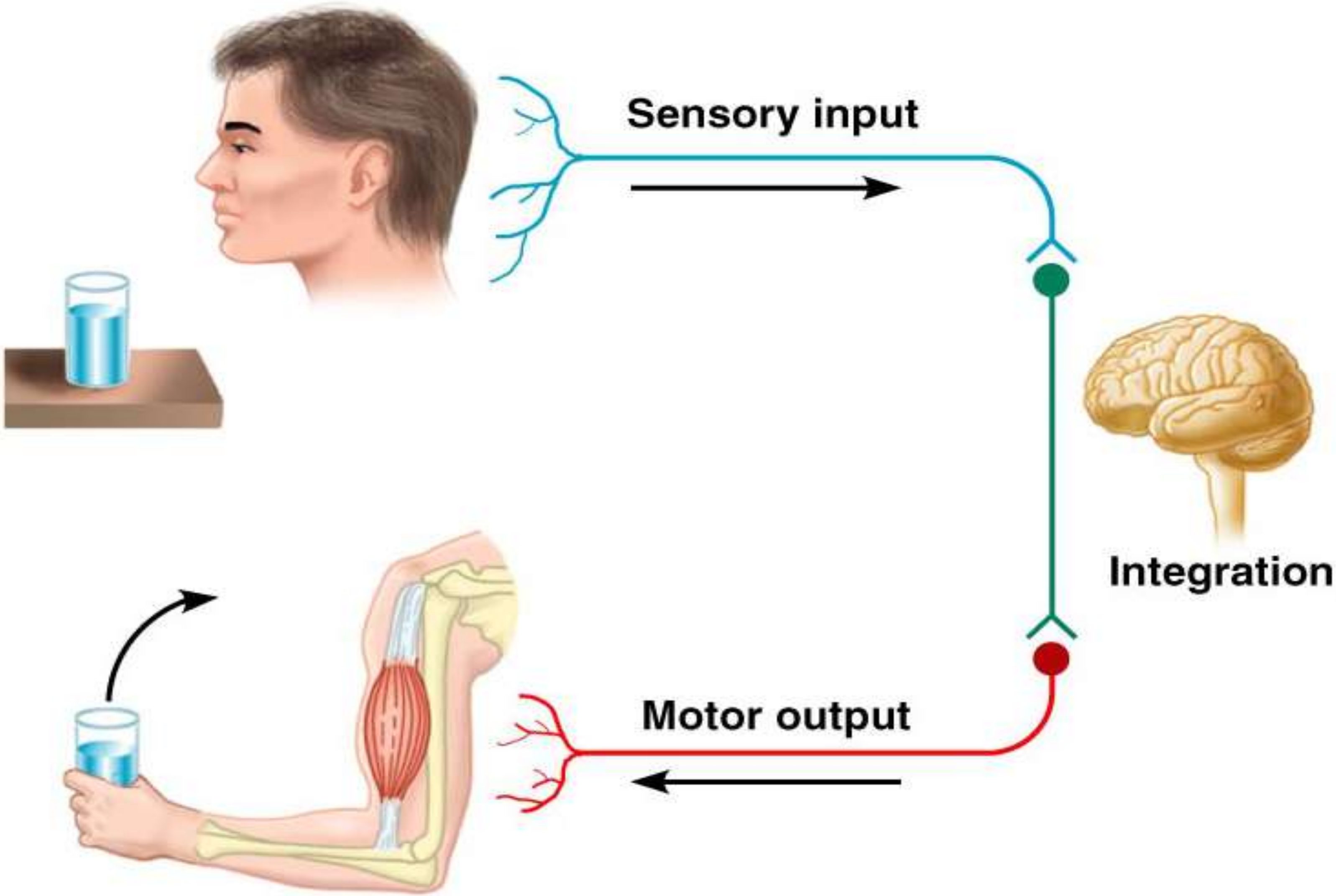
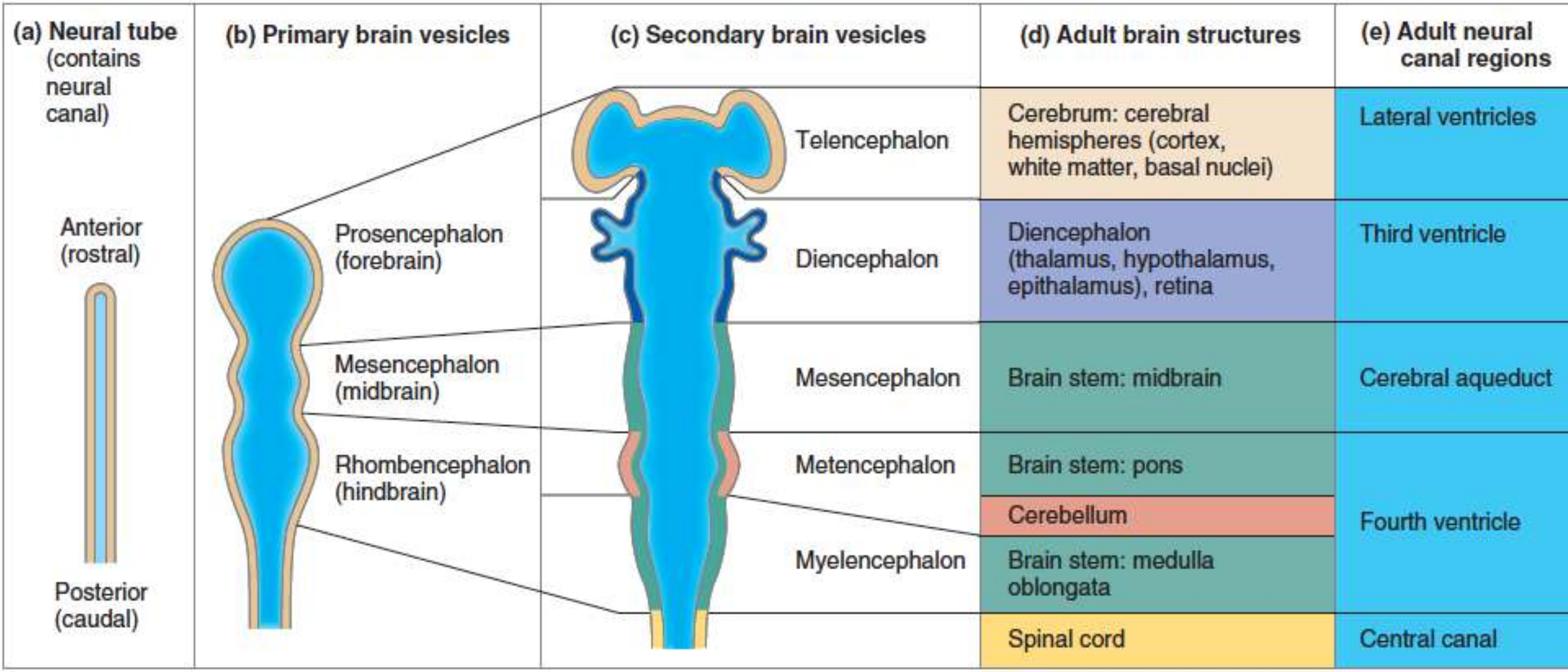


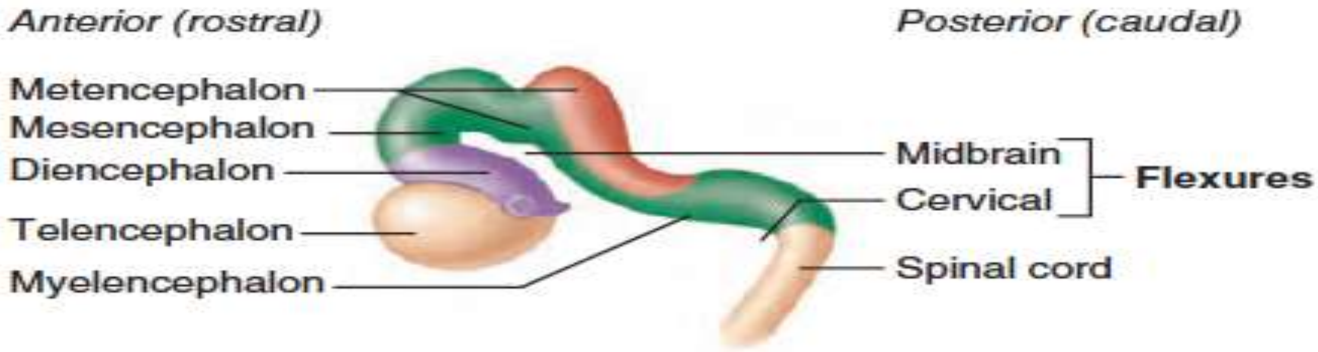

Figure 11.1

# Embryonic development of the human brain.

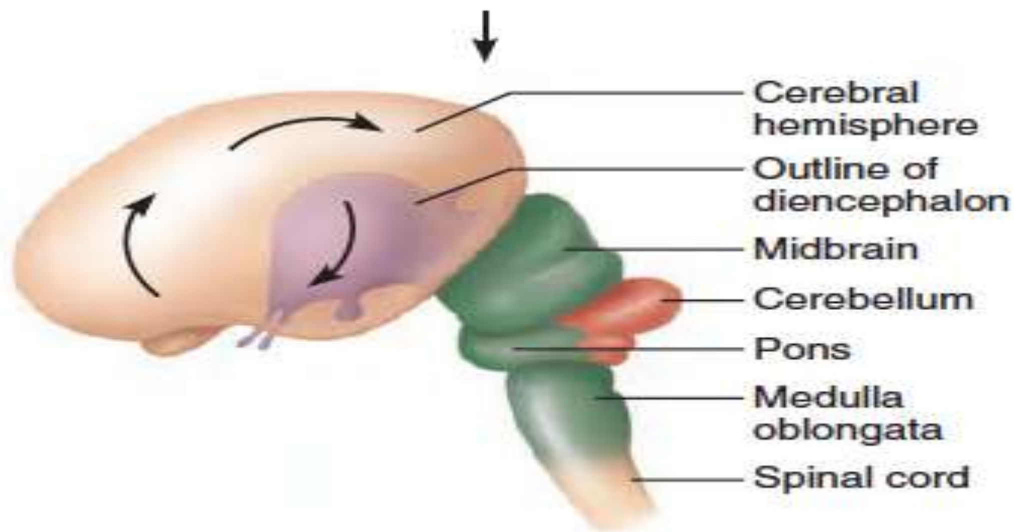



**(a)** Formed by week 4, the neural tube quickly subdivides into **(b)** the primary brain vesicles, which subsequently form **(c)** the secondary brain vesicles by week 5. These five vesicles differentiate into **(d)** the adult brain structures. **(e)** The adult structures derived from the neural canal.

# Brain Development

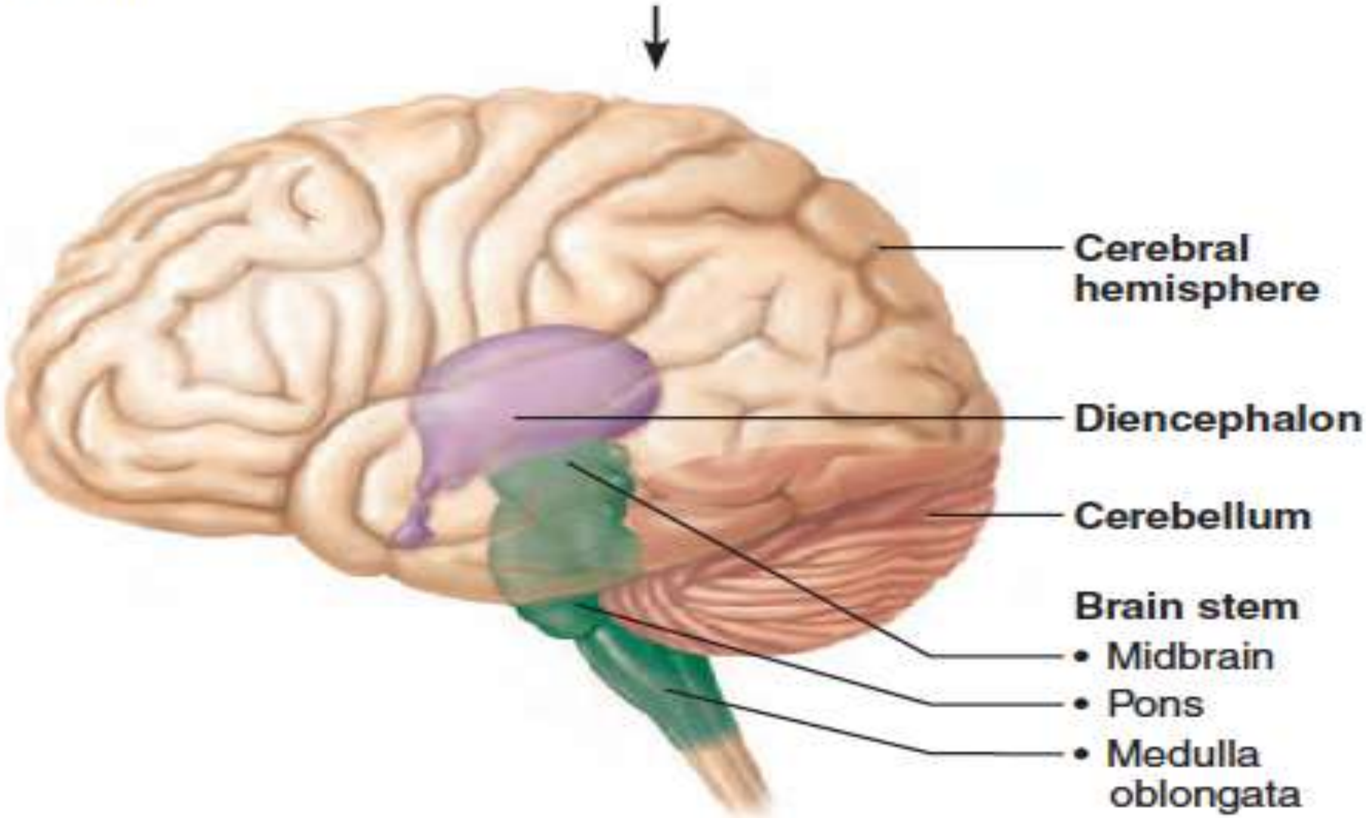



**(a) Week 5:** Two major flexures form, causing the telencephalon and diencephalon to angle toward the brain stem.




**(b) Week 13:** Cerebral hemispheres develop and grow posterolaterally to enclose the diencephalon and the rostral brain stem.

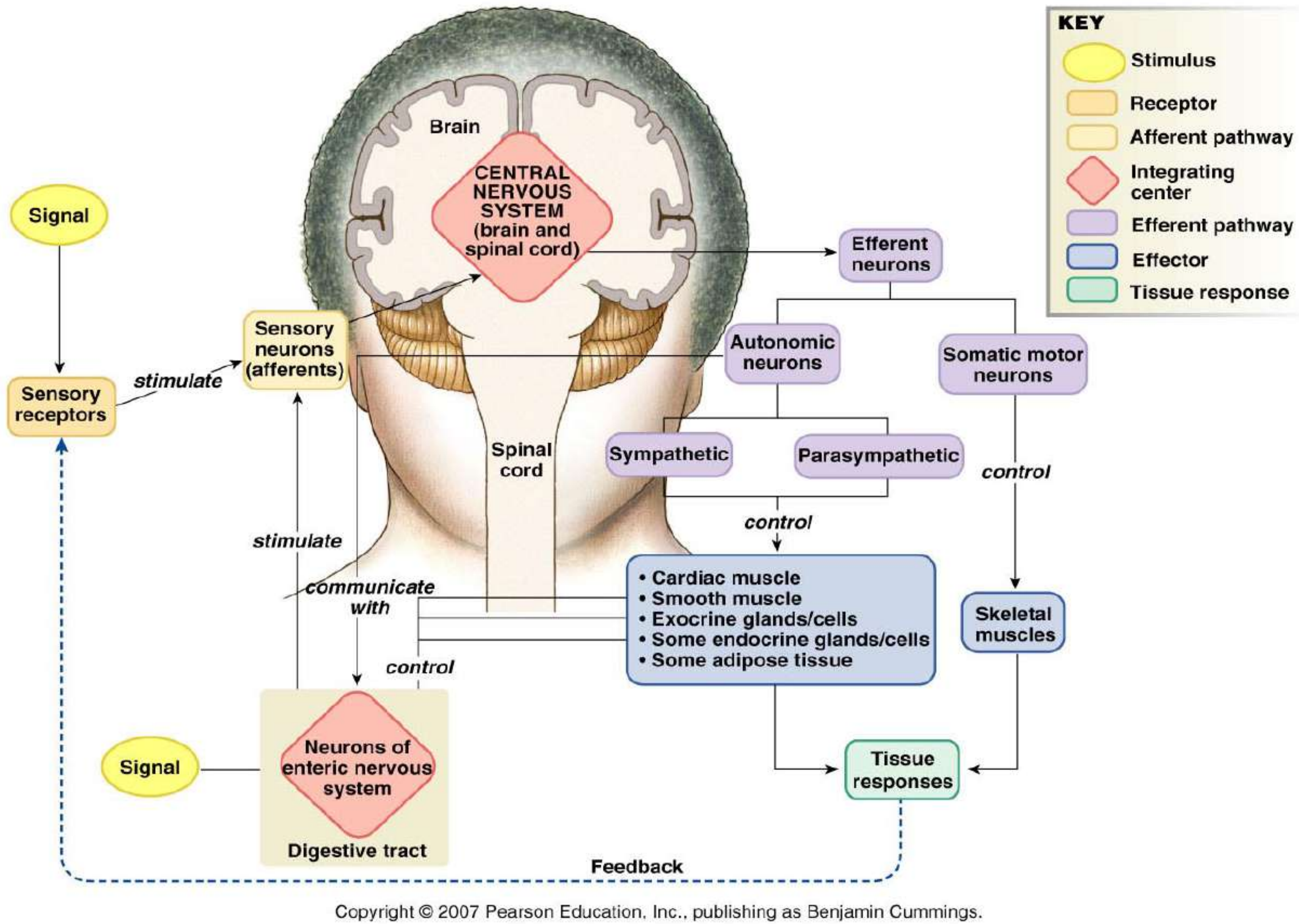
# Brain Development

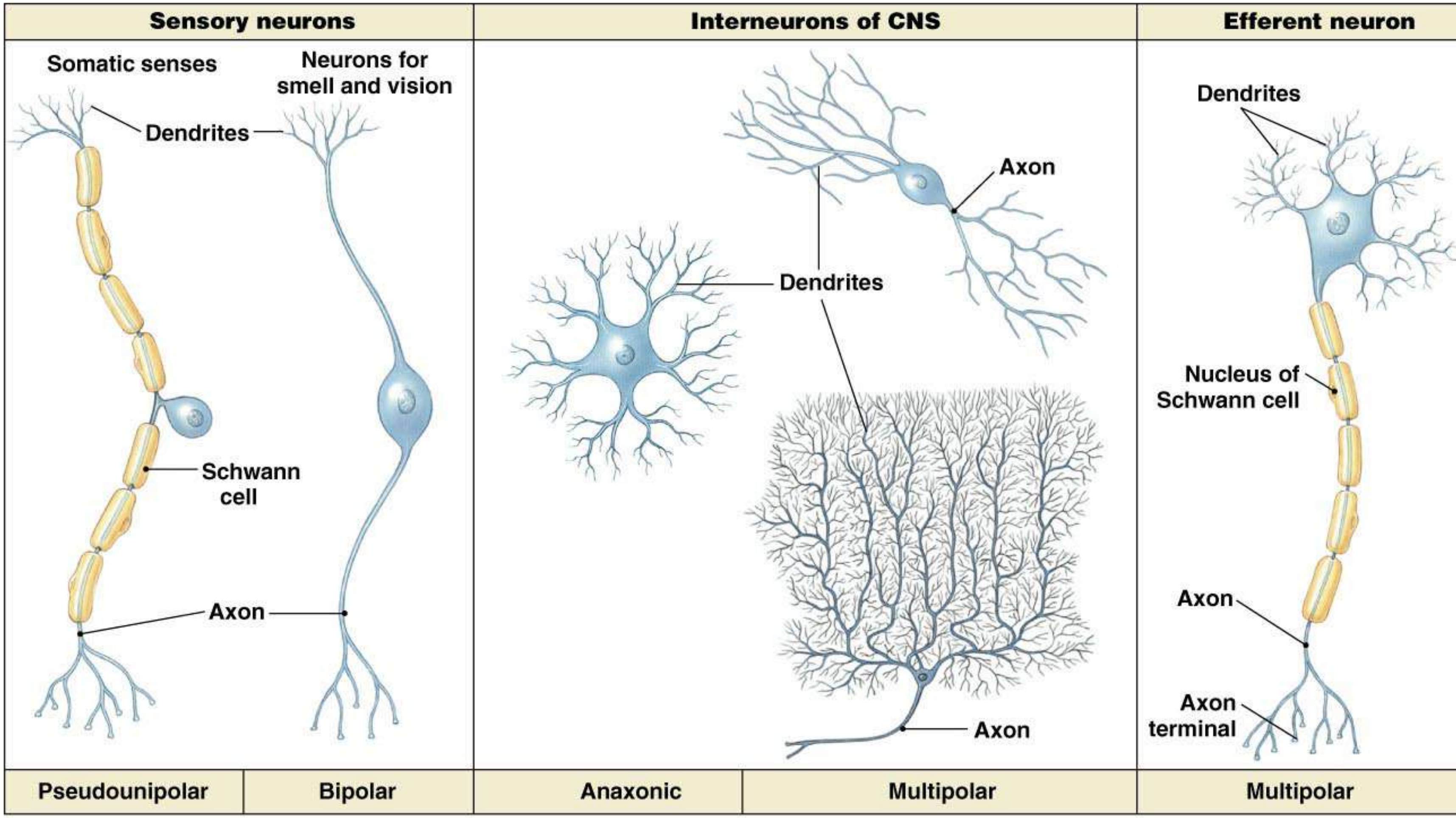



(c) **Birth:** Shows adult pattern of structures and convolutions.

Initially, the cerebral surface is smooth. Folding in month 6, and convolutions become more obvious as development continues

# Nervous System






**(a)** Pseudounipolar neurons have a single process called the axon. During development, the dendrite fused with the axon.

**(b)** Bipolar neurons have two relatively equal fibers extending off the central cell body.

**(c)** Anaxonic CNS interneurons have no apparent axon.

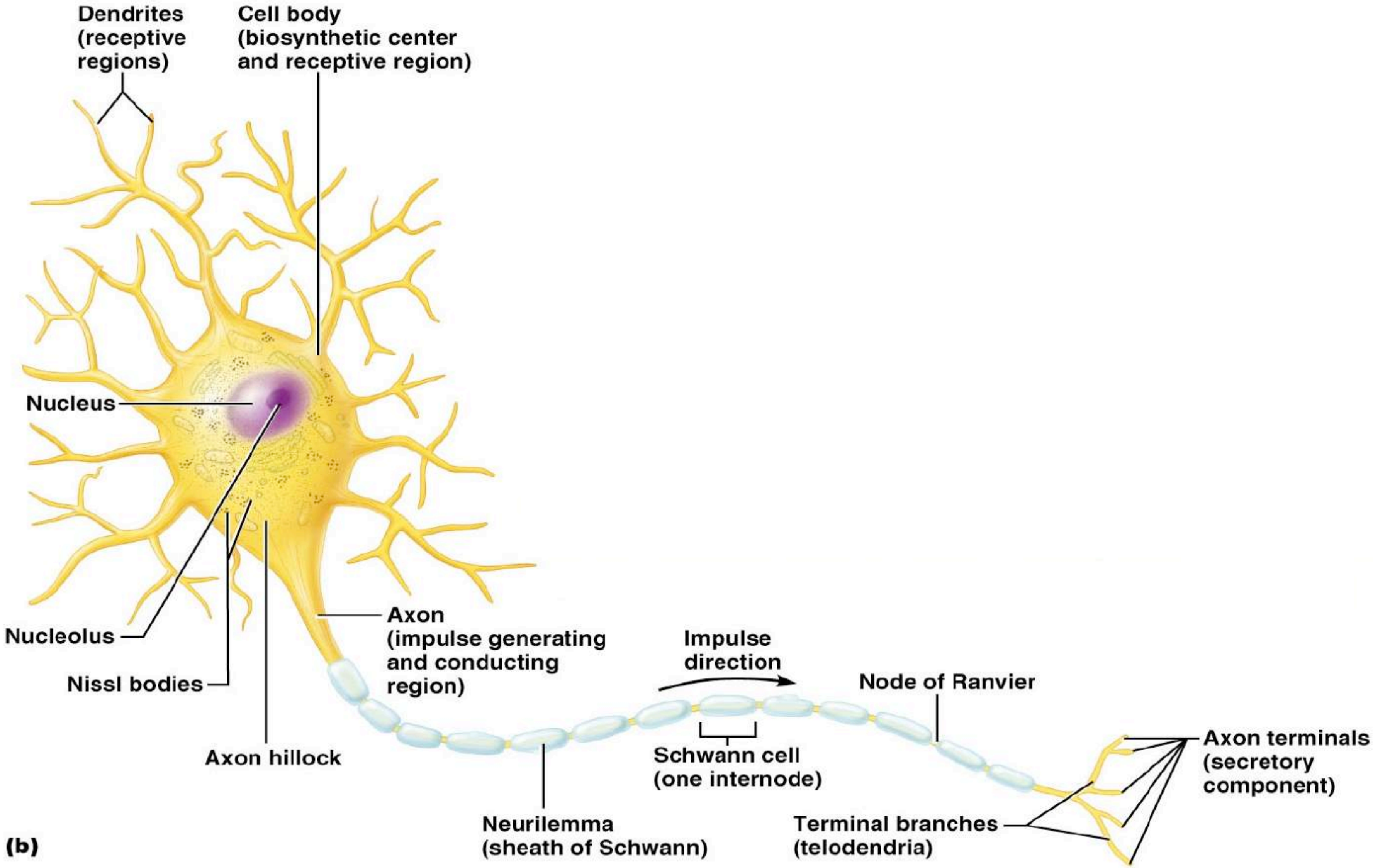
**(d)** Multipolar CNS interneurons are highly branched but lack long extensions.

**(e)** A typical multipolar efferent neuron has five to seven dendrites, each branching four to six times. A single long axon may branch several times and end at enlarged axon terminals.



Figure 8-3 - Overview

# Neurons (Nerve Cells)



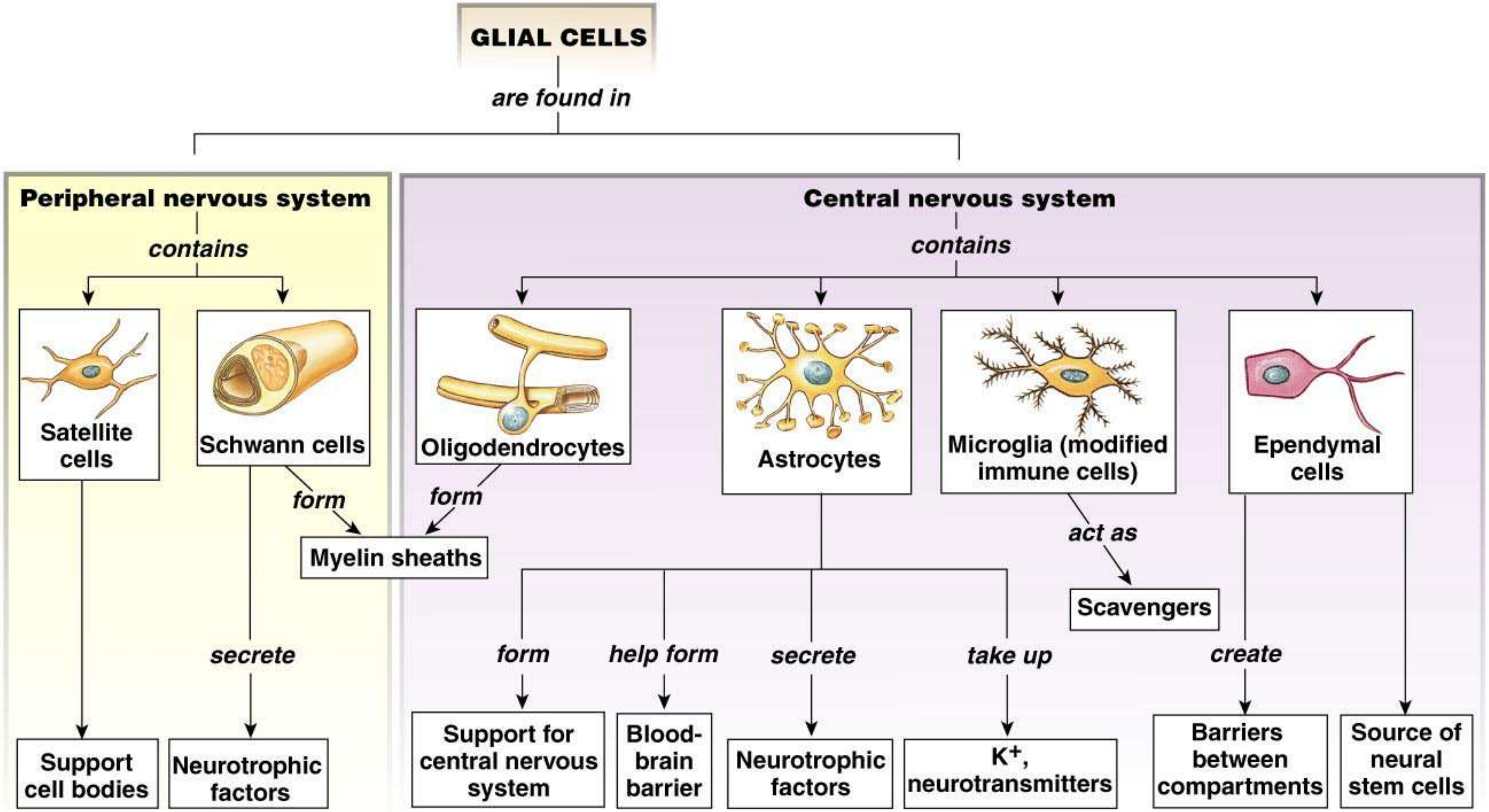





Figure 8-5 – Overview (1 of 3)

**(a) Glial cells of the central nervous system**

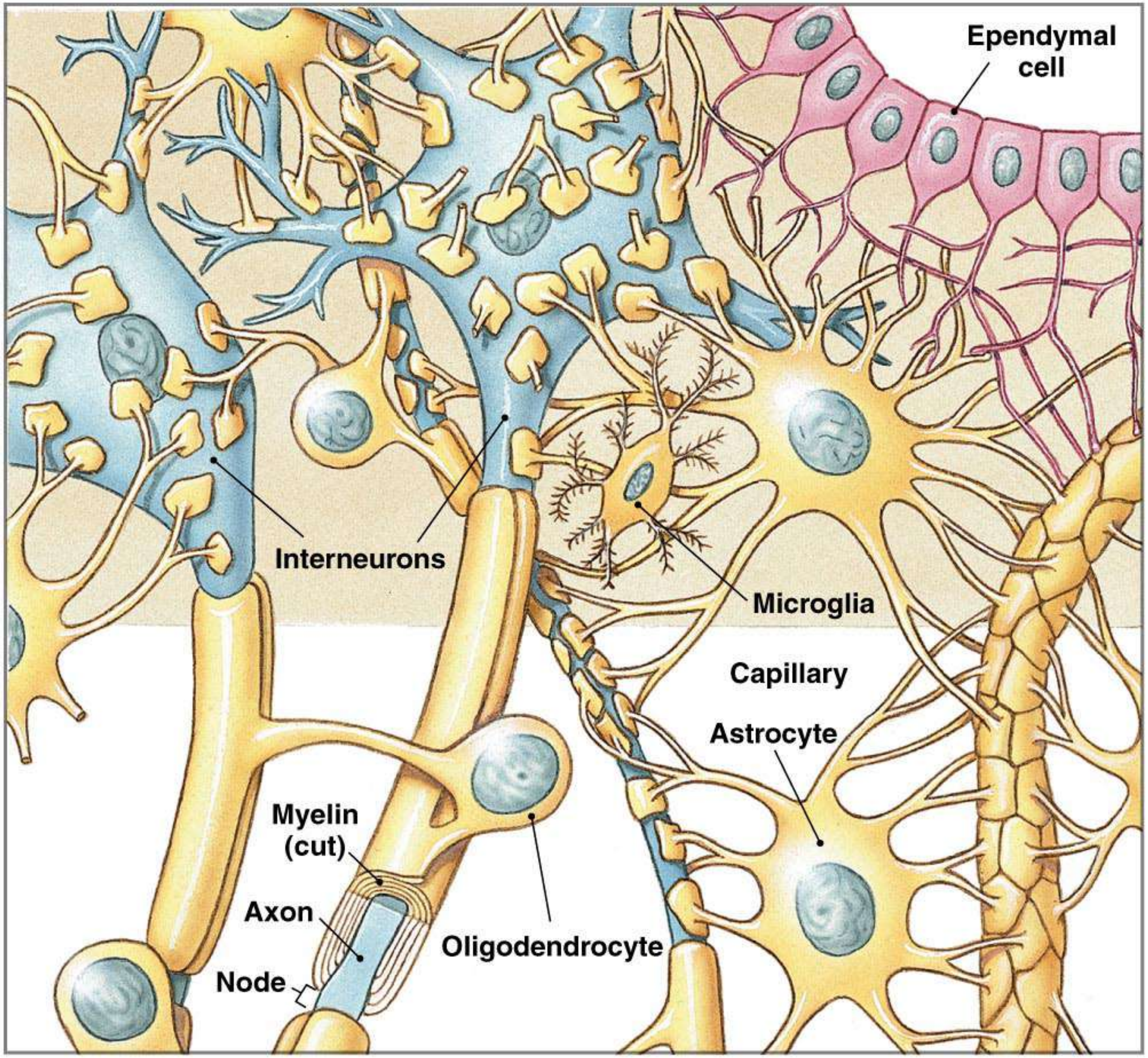





Figure 8-6a

# Membrane Potential

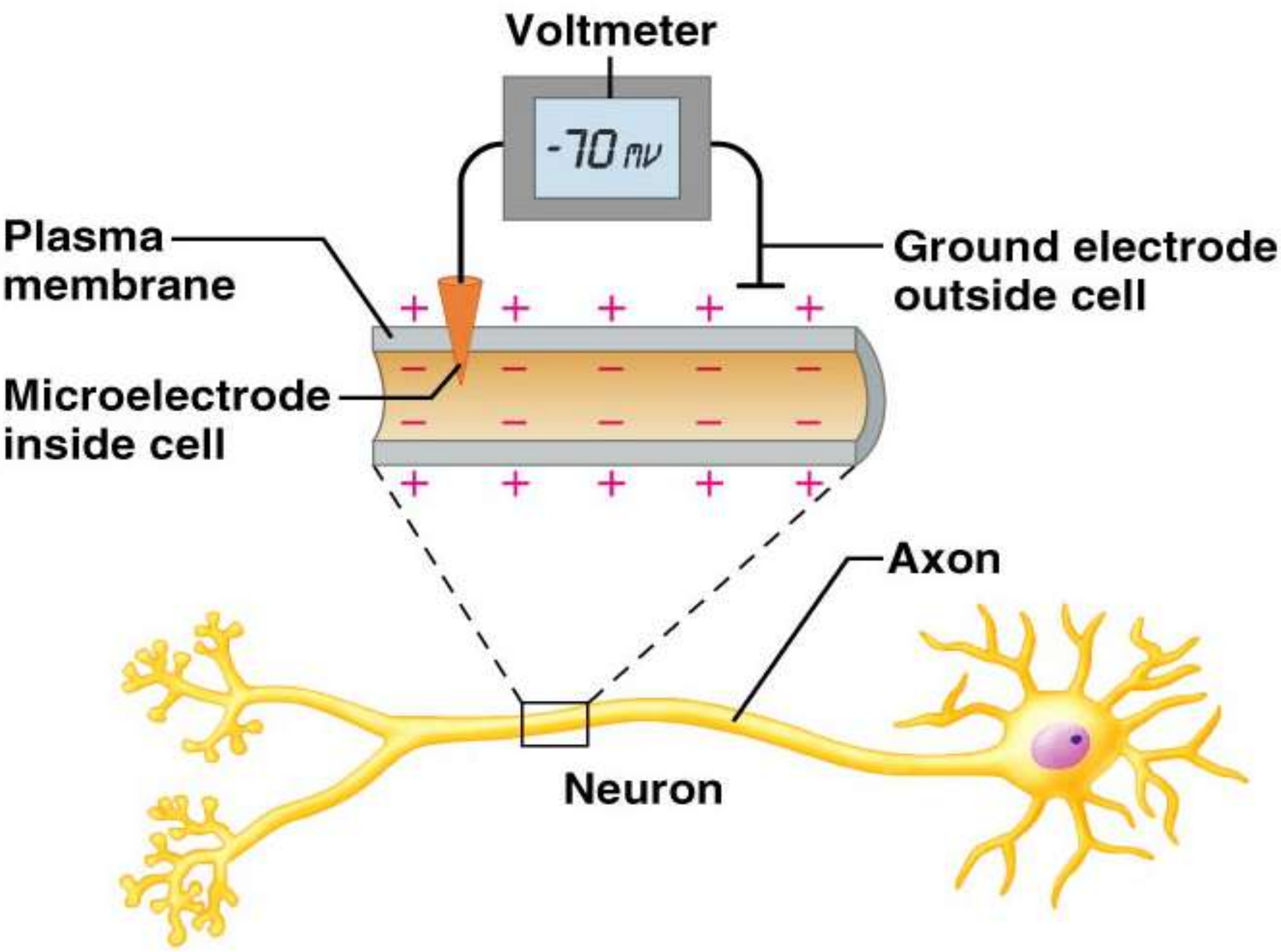



Figure 11.7

# Resting Membrane Potential ($V_r$)

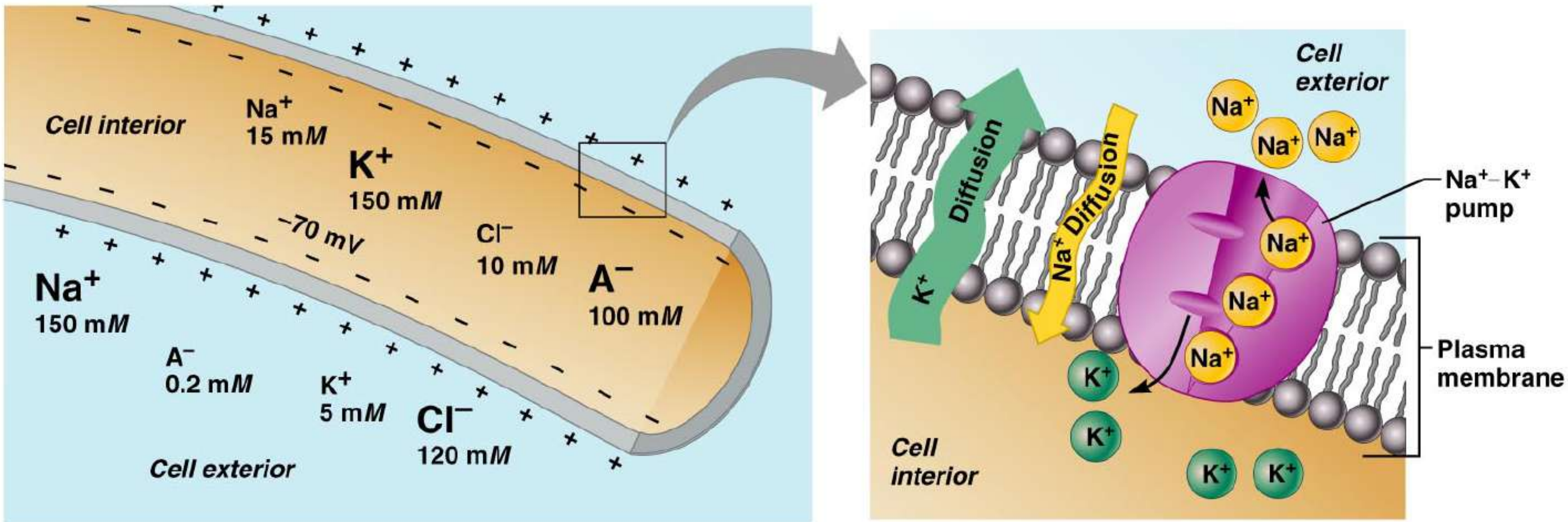



Figure 11.8

# Changes in Membrane Potential

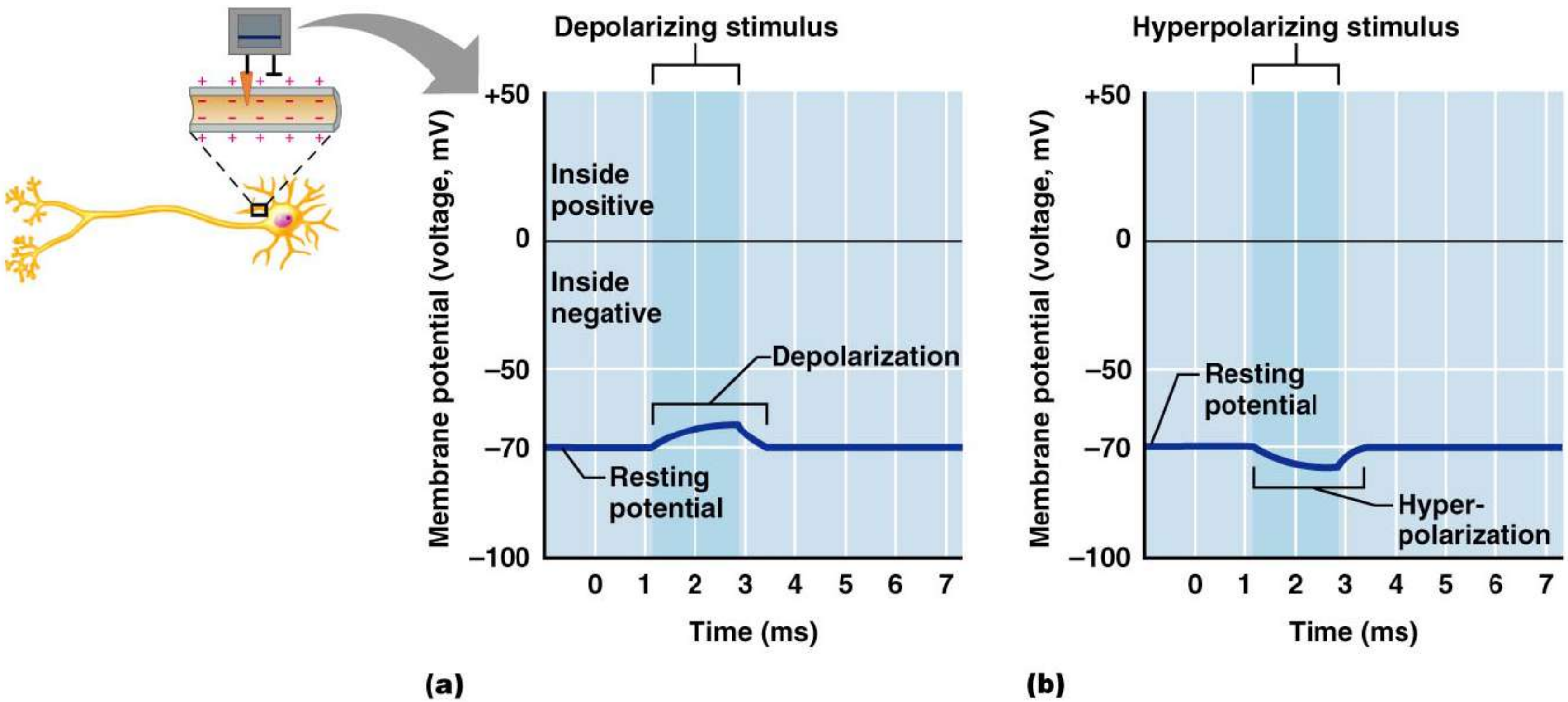



Figure 11.9

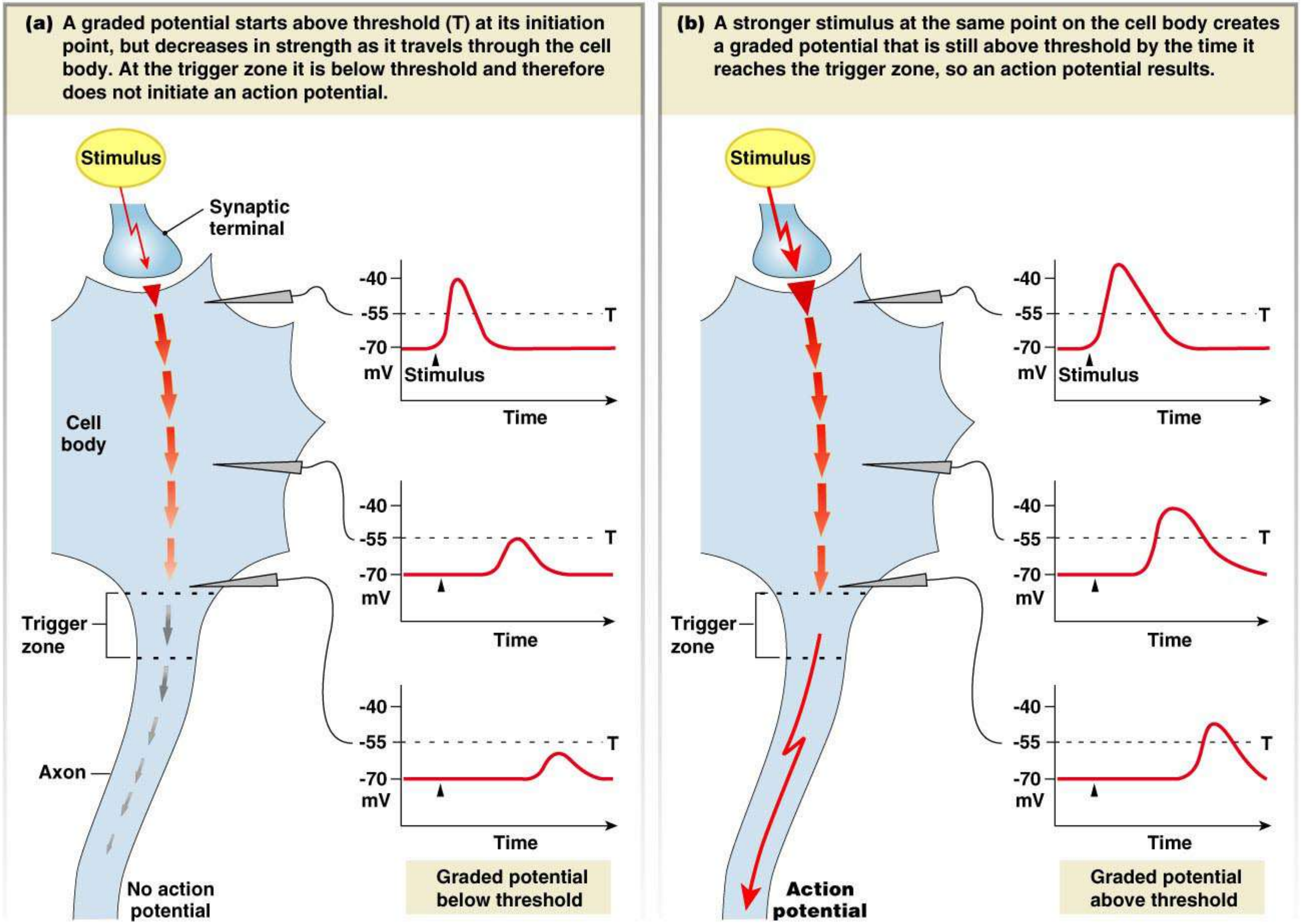
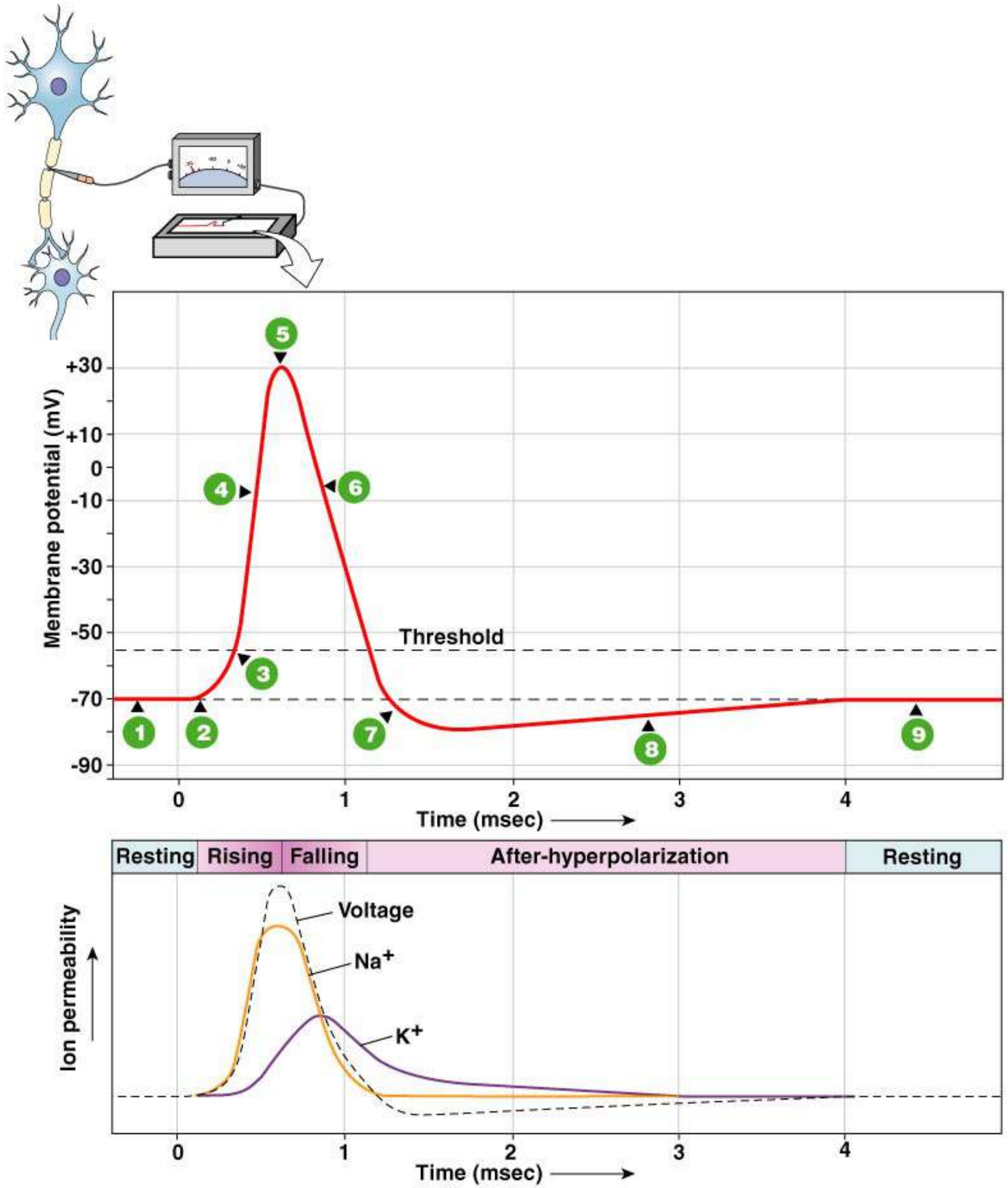





Figure 8-8 - Overview




1. Resting membrane potential
2. Depolarizing stimulus
3. Membrane depolarizes to threshold. Voltage-gated $Na^+$ channels open and $Na^+$ enters cell. Voltage-gated $K^+$ channels begin to open slowly.
4. Rapid $Na^+$ entry depolarizes cell.
5. $Na^+$ channels close and slower $K^+$ channels open.
6. $K^+$ moves from cell to extracellular fluid.
7. $K^+$ channels remain open and additional $K^+$ leaves cell, hyperpolarizing it.
8. Voltage-gated $K^+$ channels close, less $K^+$ leaks out of the cell.
9. Cell returns to resting ion permeability and resting membrane potential.



Figure 8-9 - Overview

# Phases of the Action Potential

- 1 – resting state
- 2 – depolarization phase
- 3 – repolarization phase
- 4 – hyperpolarization

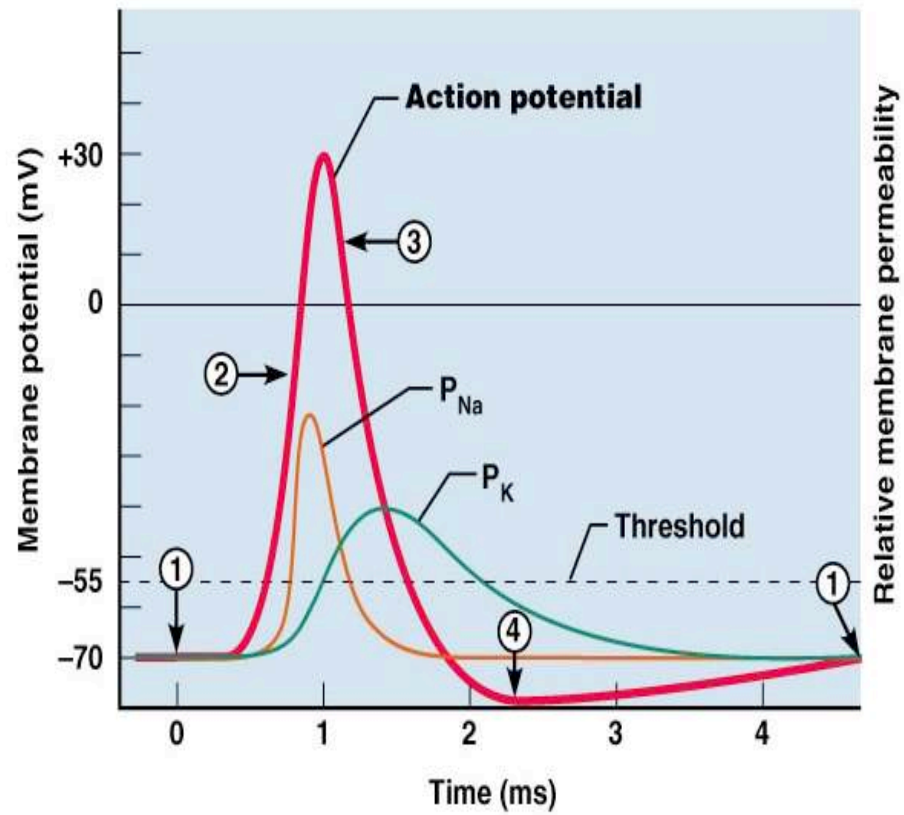



Figure 11.12

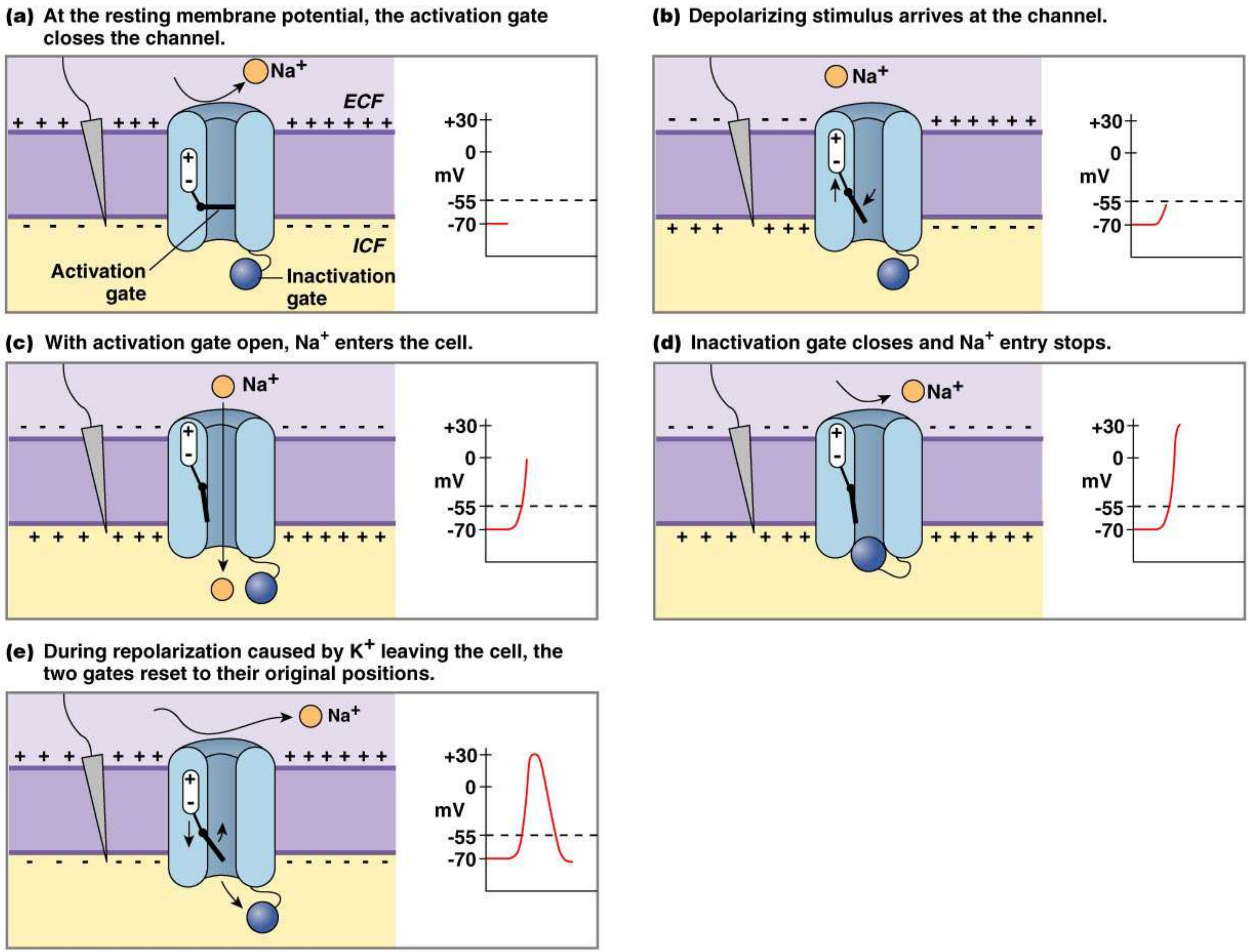
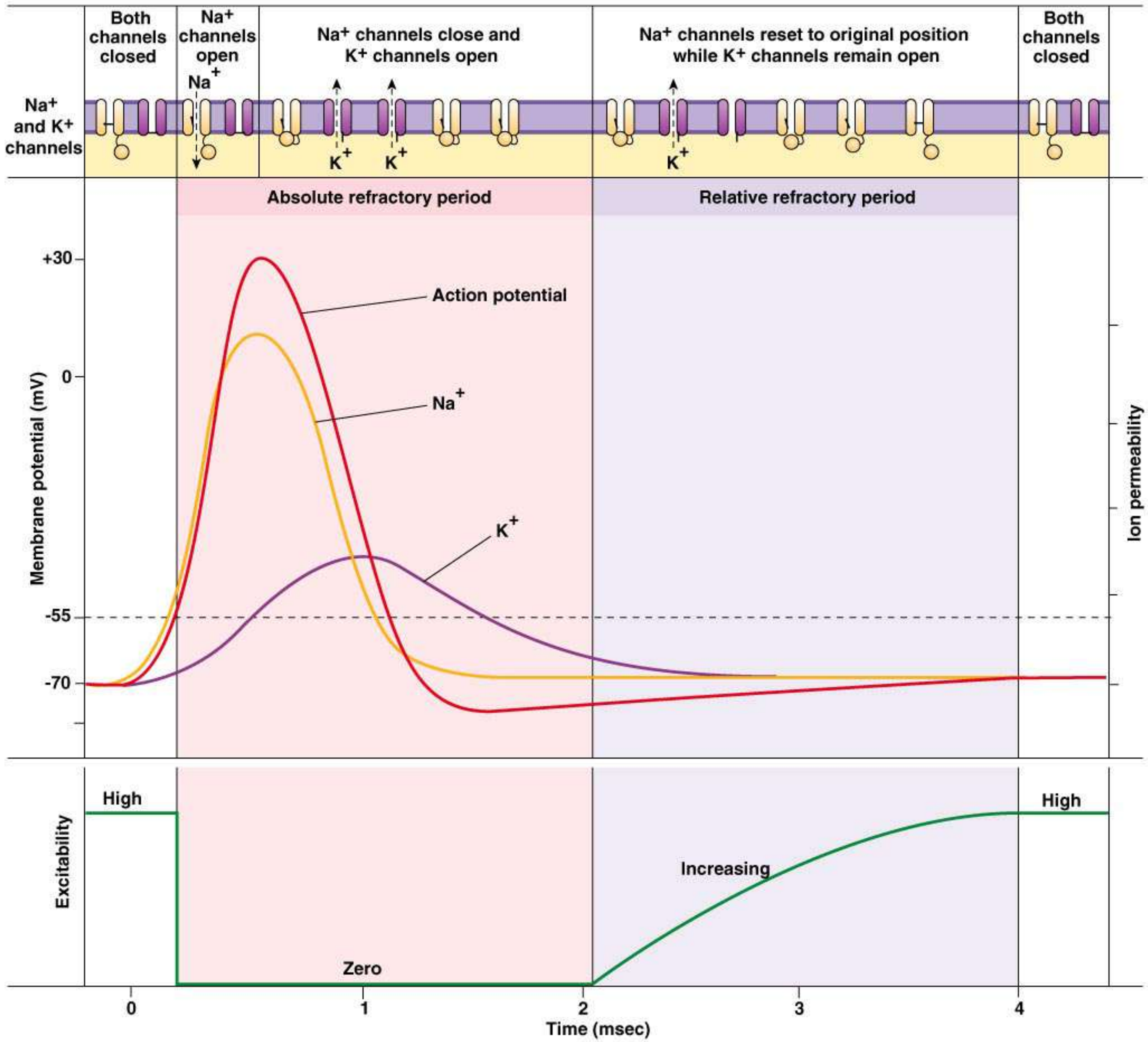





Figure 8-10 - Overview



Both channels closed
Na+ channels open
Na+
Na+ channels close and K+ channels open
Na+ channels reset to original position while K+ channels remain open
Both channels closed
Na+ and K+ channels
K+
K+
K+
Absolute refractory period
Relative refractory period
+30
0
-55
-70
Membrane potential (mV)
Action potential
Na+
K+
Ion permeability
Excitability
High
Zero
Increasing
High
0
1
2
3
4
Time (msec)




Figure 8-12

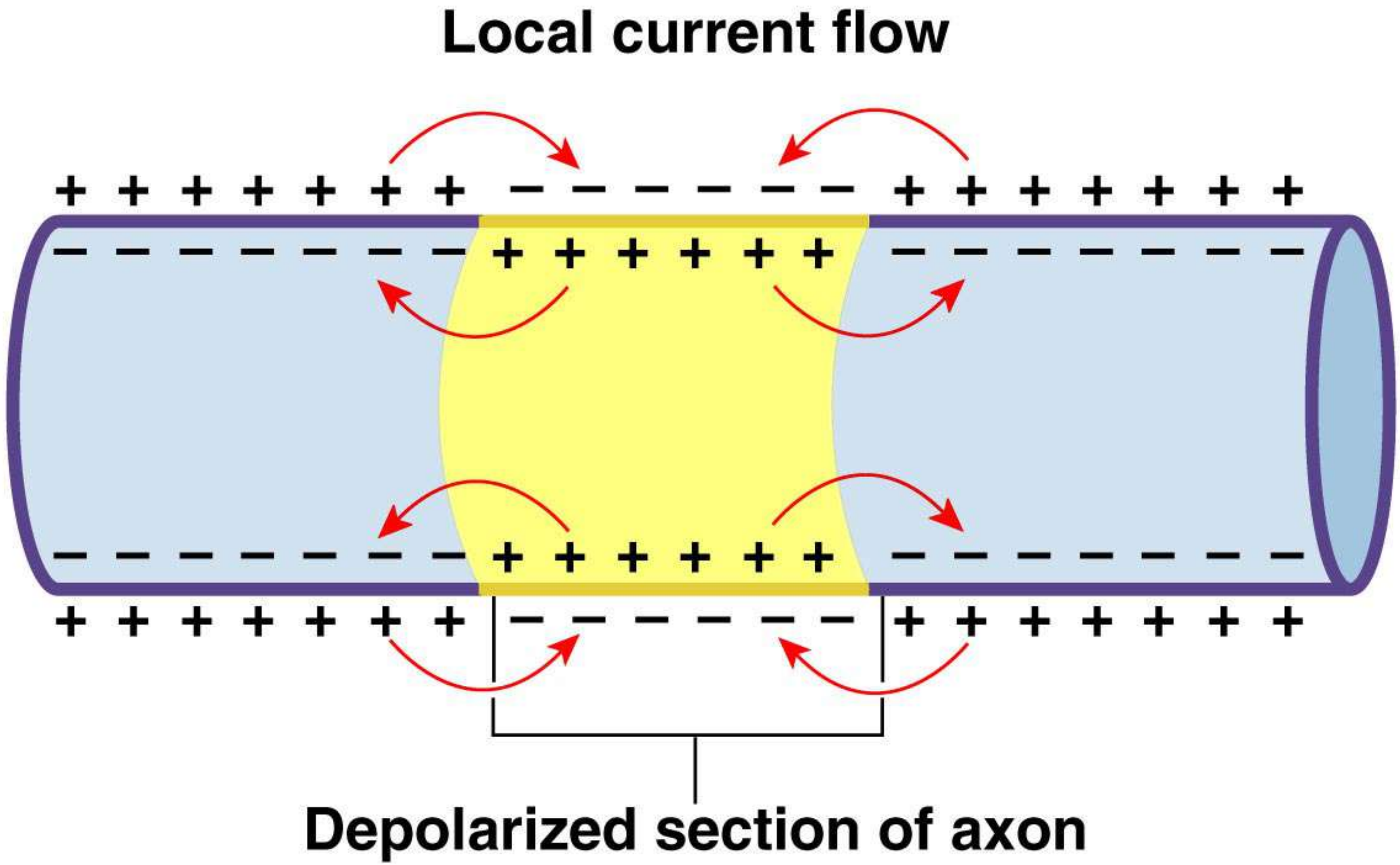




Figure 8-14

# Saltatory Conduction

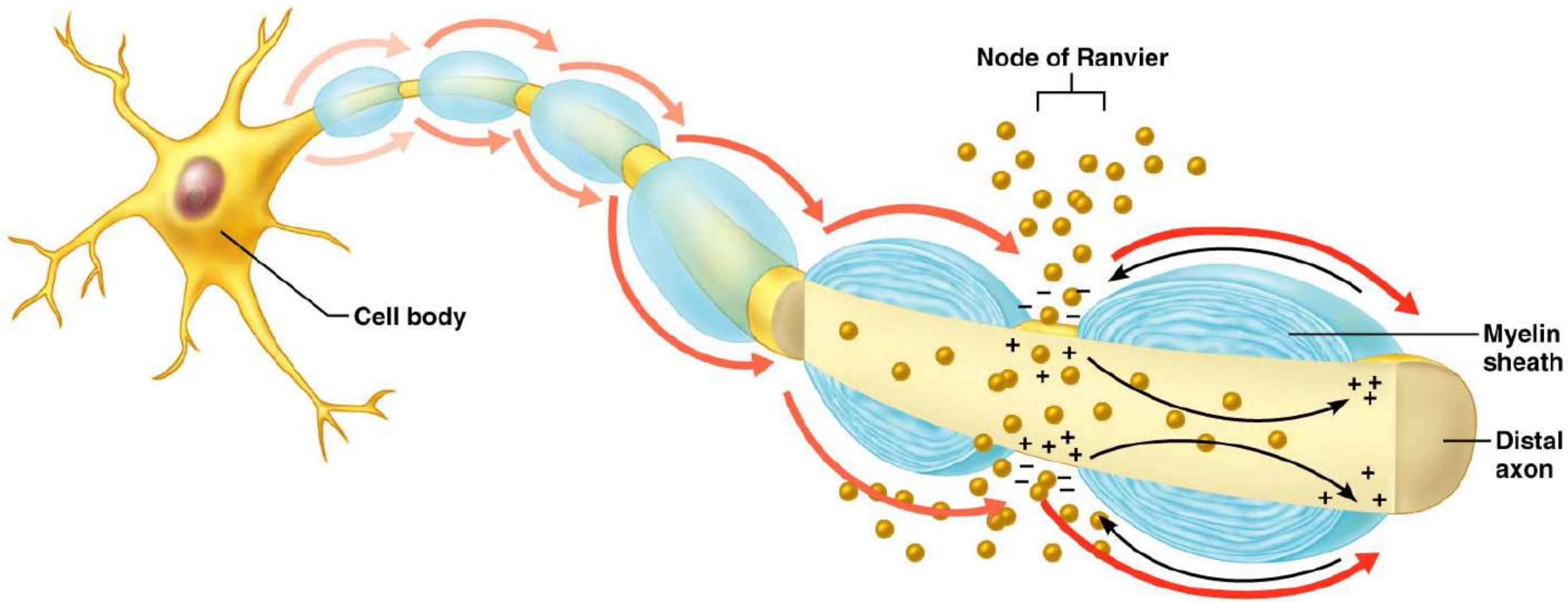



Figure 11.16

# Synapses

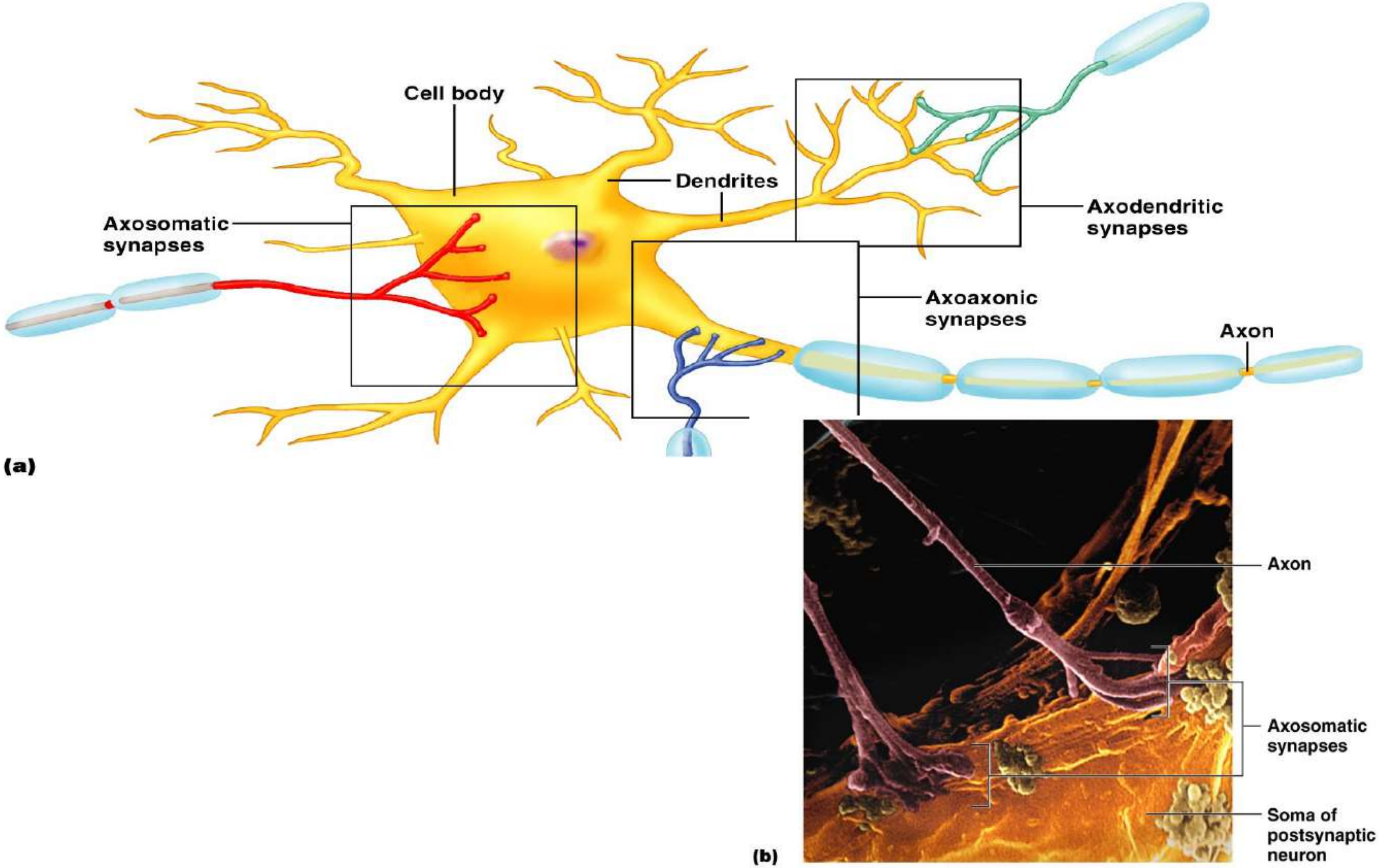



Figure 11.17

# Synapse

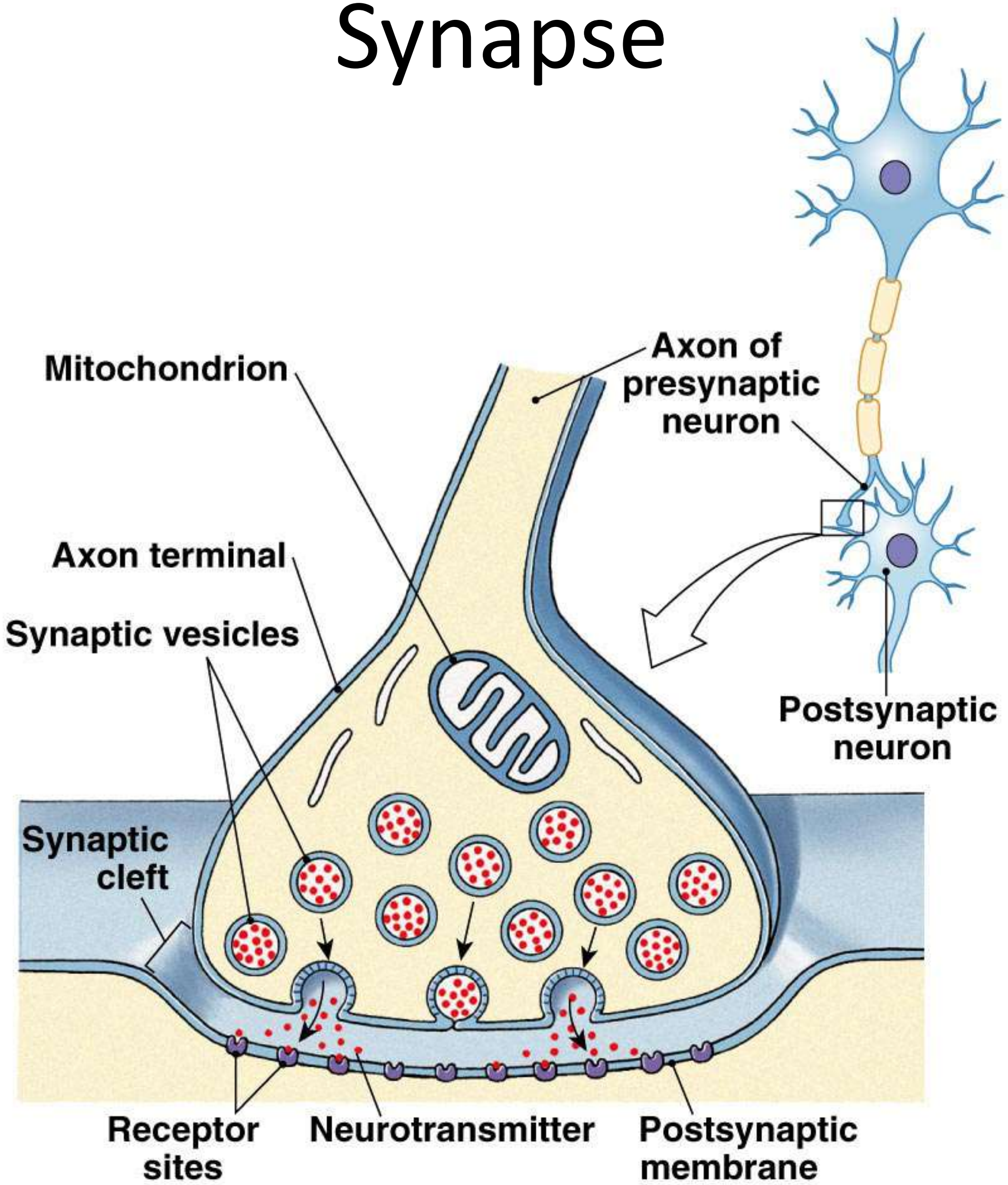
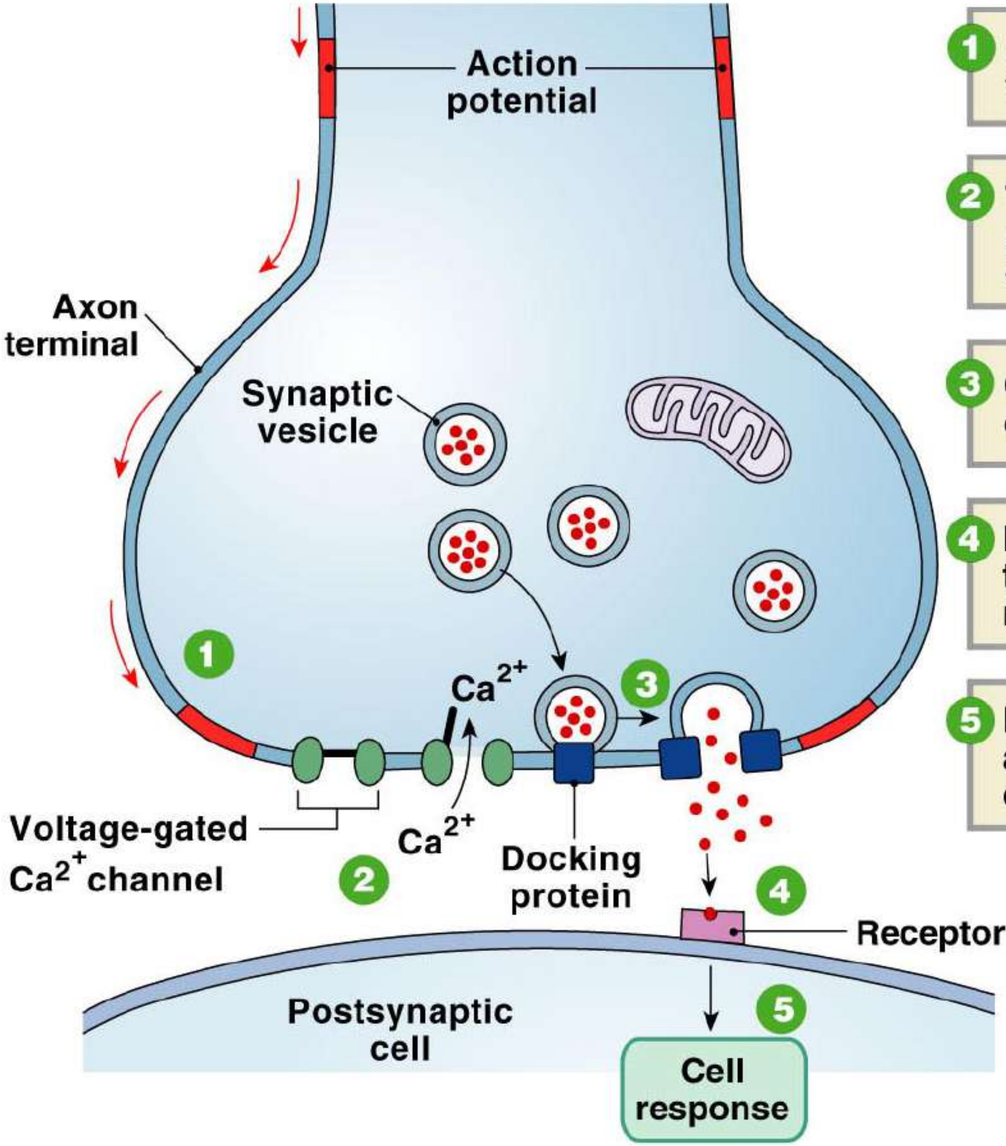




Figure 8-20

# Synaptic Transmission




1. An action potential depolarizes the axon terminal.
2. The depolarization opens voltage-gated $Ca^{2+}$ channels and $Ca^{2+}$ enters the cell.
3. Calcium entry triggers exocytosis of synaptic vesicle contents.
4. Neurotransmitter diffuses across the synaptic cleft and binds with receptors on the postsynaptic cell.
5. Neurotransmitter binding initiates a response in the postsynaptic cell.



Figure 8-21 - Overview

# Synaptic Cleft: Information Transfer

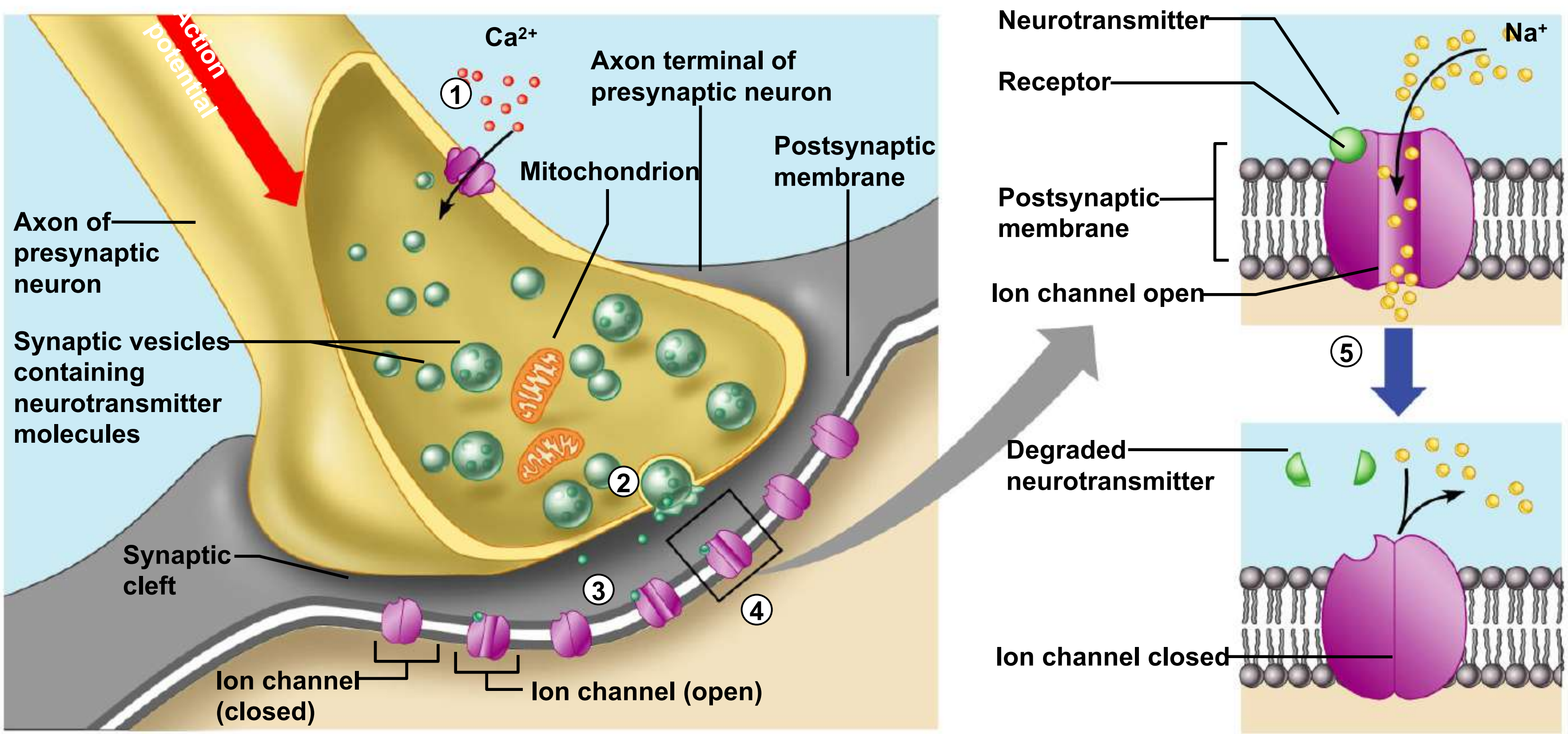



Figure 11.18

# Inactivation of Neurotransmitters

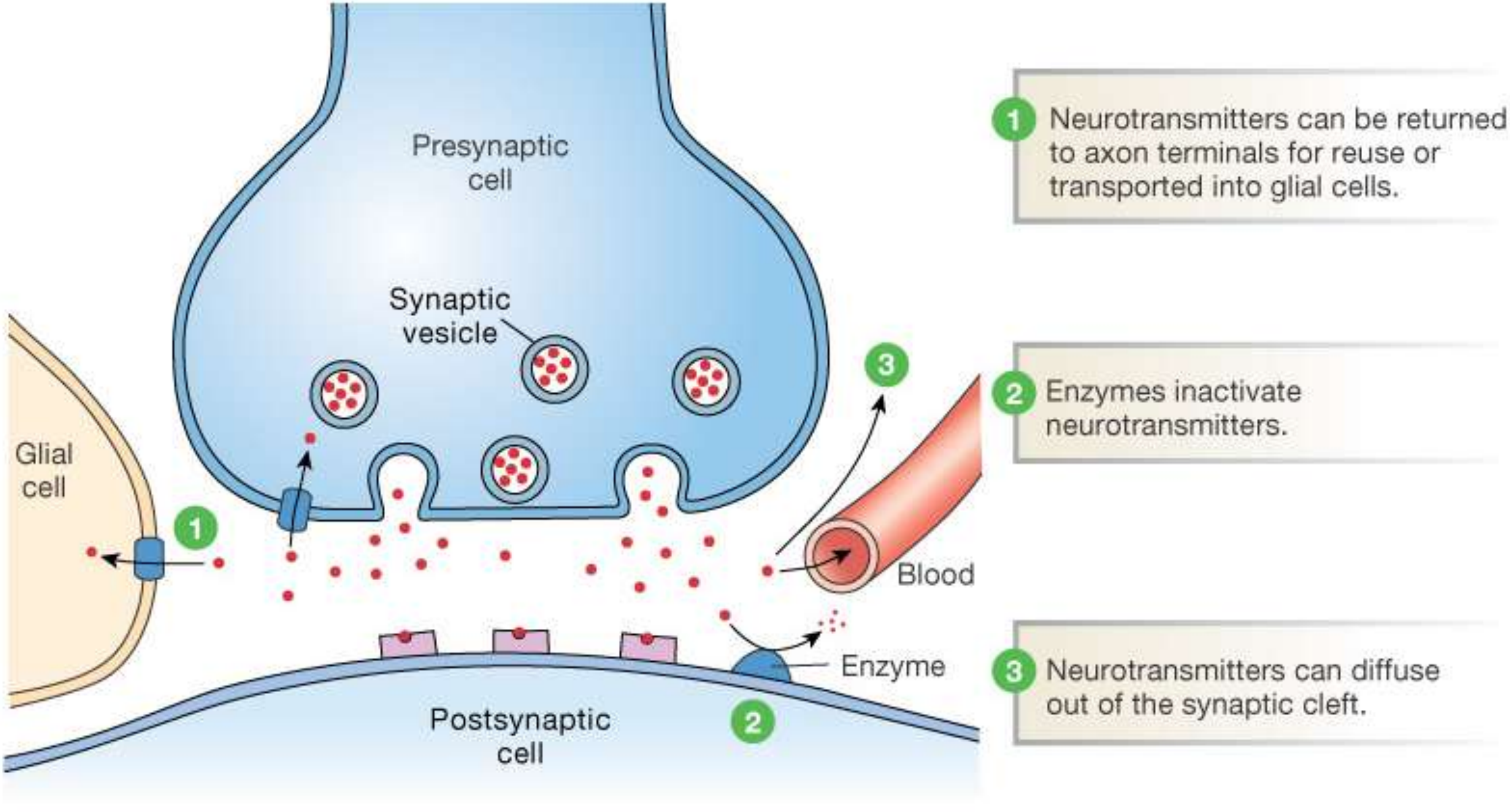
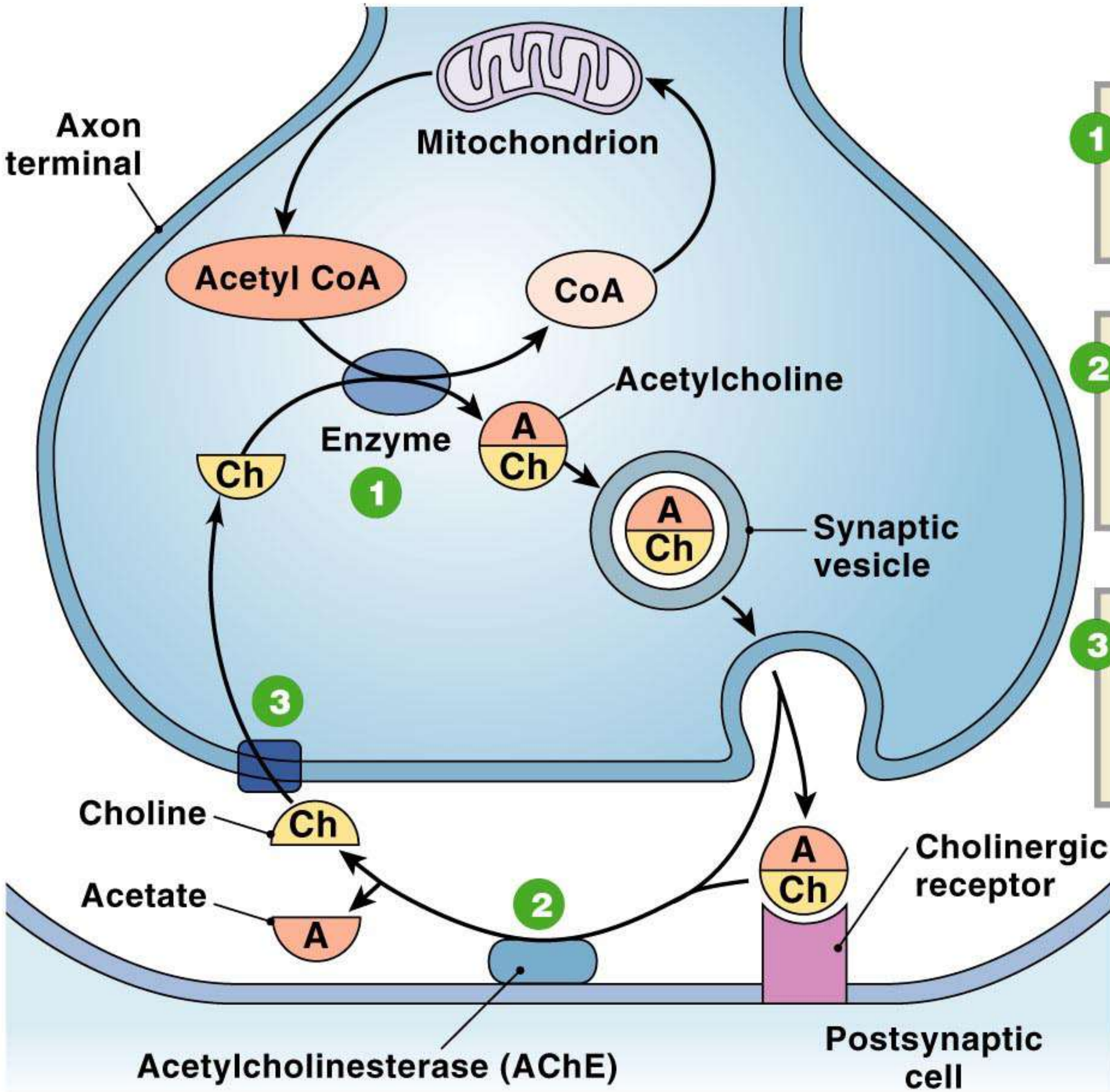



Figure 8-23: Inactivation of neurotransmitters




1 **Acetylcholine** (ACh) is made from choline and acetyl CoA.

2 In the synaptic cleft ACh is rapidly broken down by the enzyme **acetylcholinesterase.**

3 Choline is transported back into the axon terminal and is used to make more ACh.

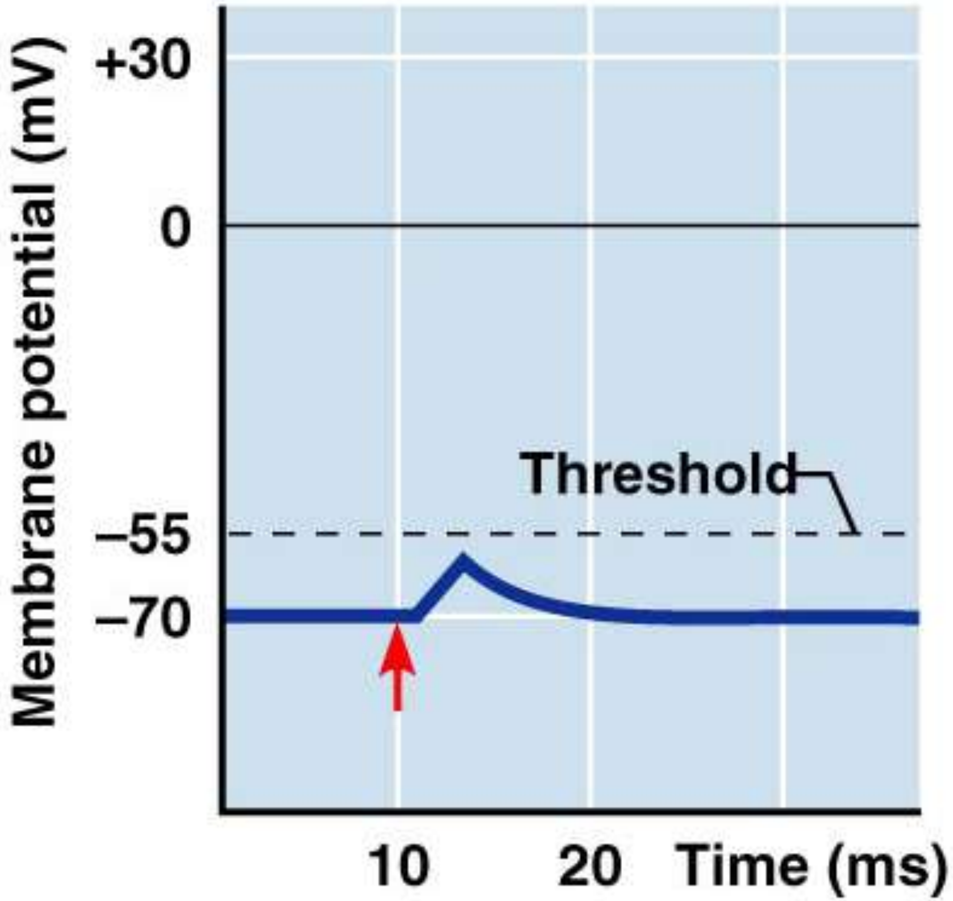


Figure 8-22 - Overview

# Excitatory Postsynaptic Potentials

- EPSPs are graded potentials that can initiate an action potential in an axon
  - Use only chemically gated channels
  - $Na^+$ and $K^+$ flow in opposite directions at the same time
- Postsynaptic membranes do not generate action potentials

# Excitatory Postsynaptic Potential



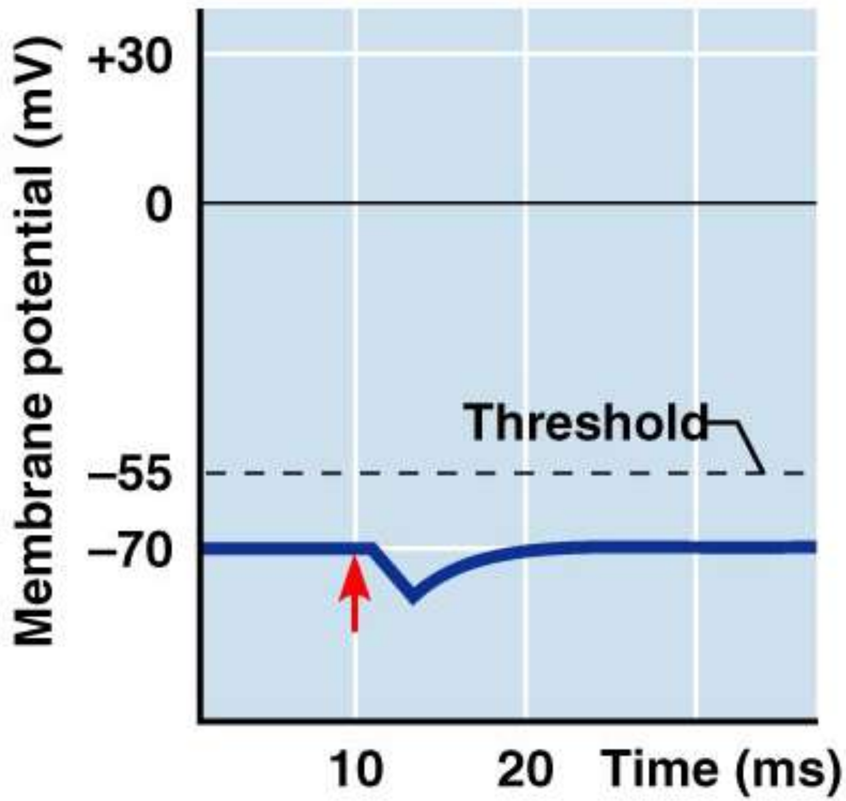

**(a) Excitatory postsynaptic potential (EPSP)**

Figure 11.19a

# Inhibitory Synapses and IPSPs

- Neurotransmitter binding to a receptor at inhibitory synapses:
  - Causes the membrane to become more permeable to potassium and chloride ions
  - Leaves the charge on the inner surface negative
  - Reduces the postsynaptic neuron's ability to produce an action potential

# Inhibitory Postsynaptic (IPSP)



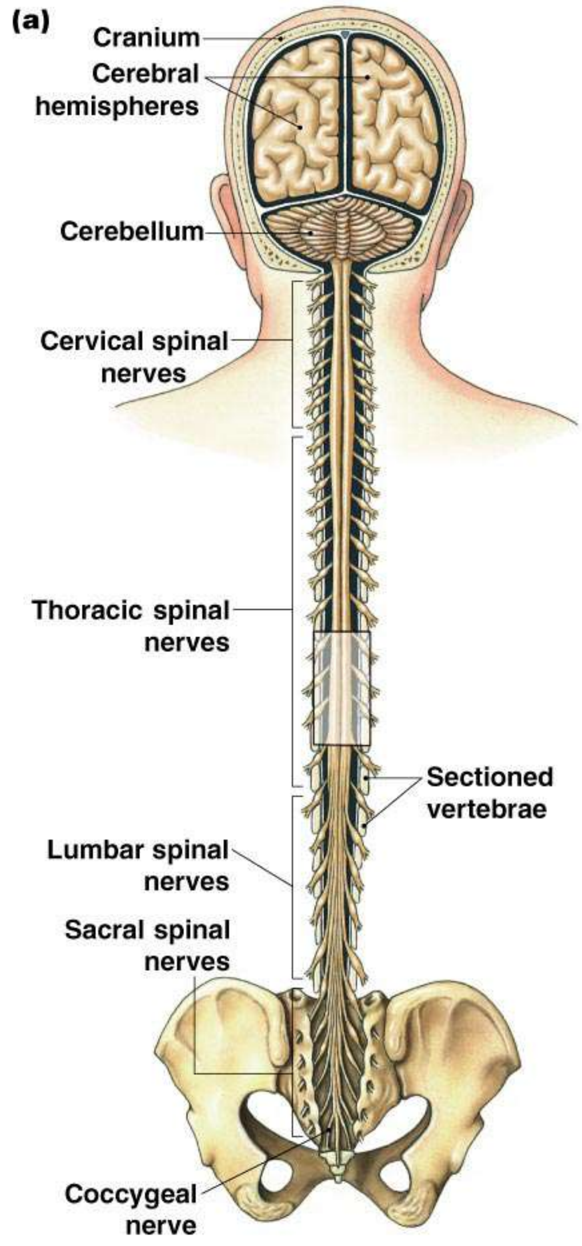

**(b) Inhibitory postsynaptic potential (IPSP)**

Figure 11.19b

# Chemical Neurotransmitters

- Acetylcholine (ACh)
- Biogenic amines
- Amino acids
- Peptides
- Novel messengers: ATP and dissolved gases NO and CO

# Central Nervous System (CNS)



(a)
Cranium
Cerebral hemispheres
Cerebellum
Cervical spinal nerves
Thoracic spinal nerves
Sectioned vertebrae
Lumbar spinal nerves
Sacral spinal nerves
Coccygeal nerve




Figure 9-4a

# Human Brain: Ventral Aspect

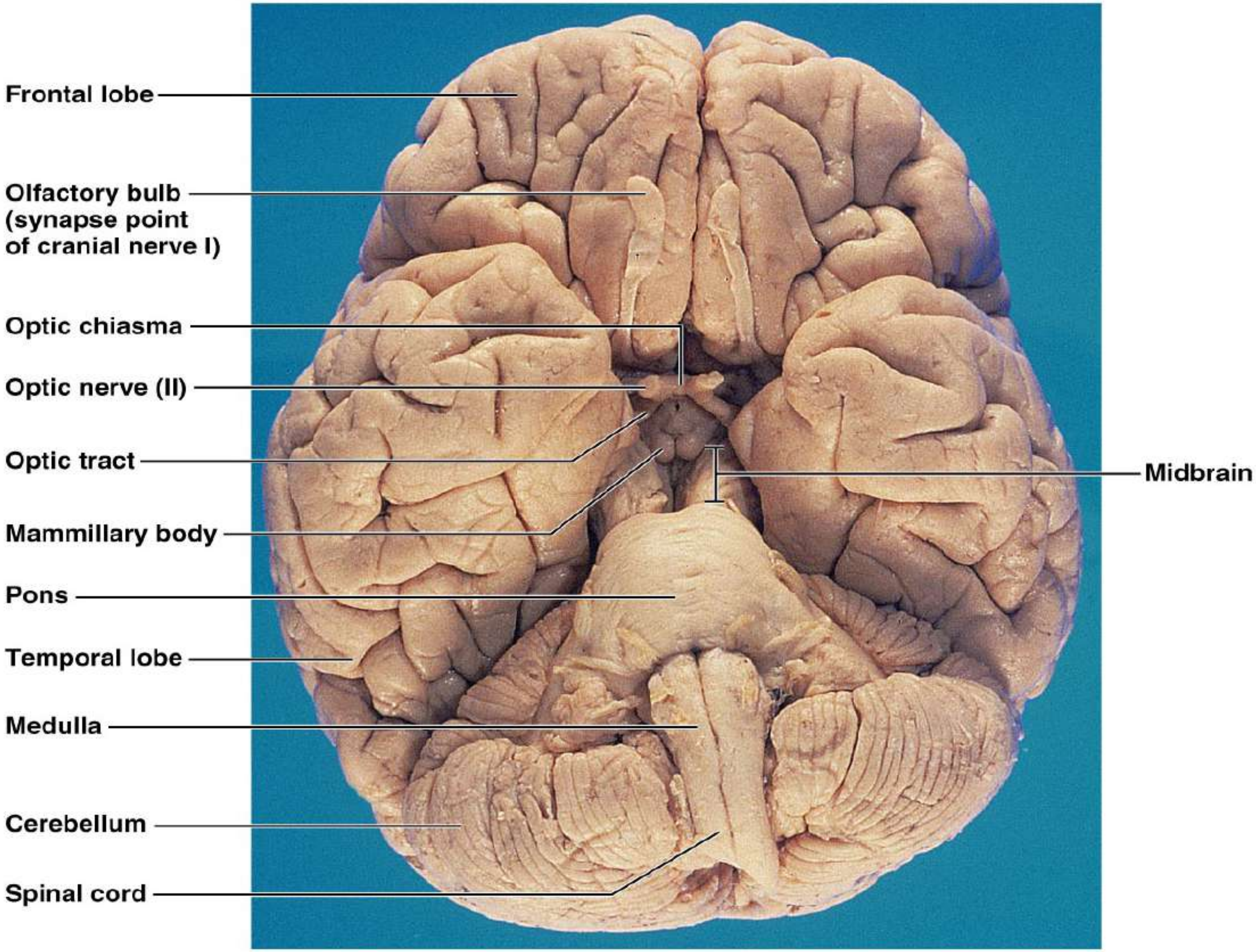



Figure 12.14

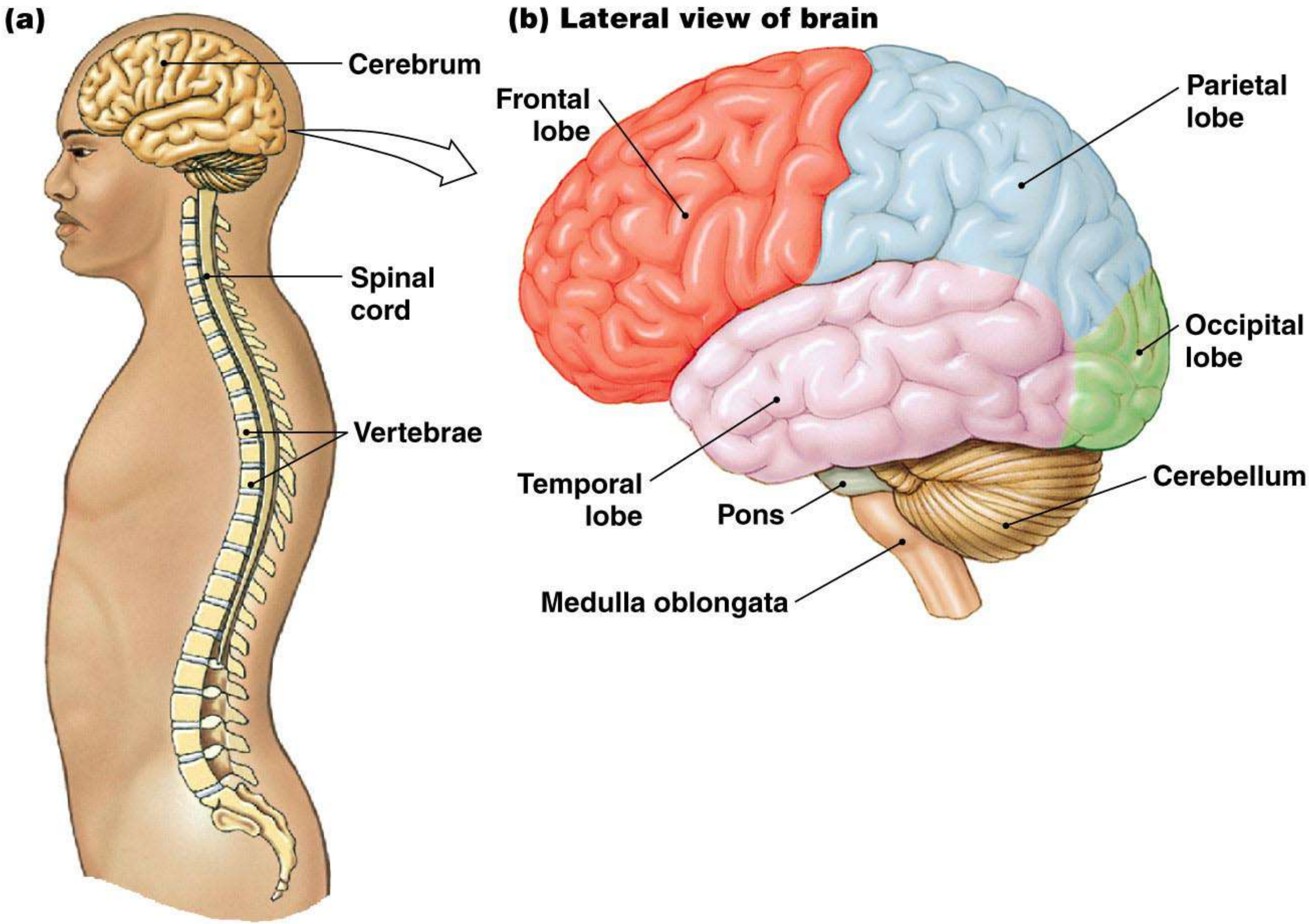
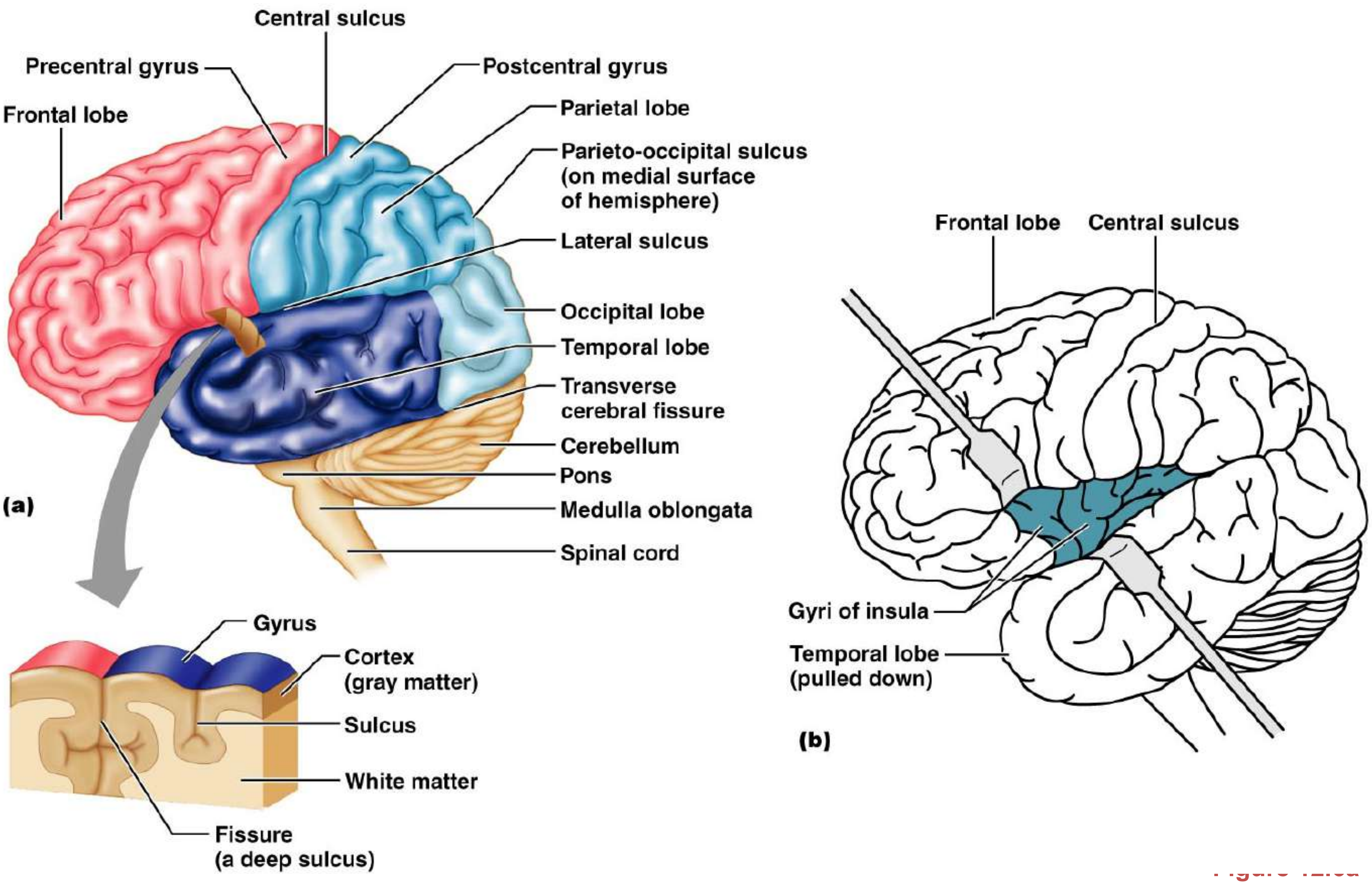





Figure 9-9a–b (1 of 5)

# Brain Lobes


Central sulcus
Precentral gyrus
Frontal lobe
Postcentral gyrus
Parietal lobe
Parieto-occipital sulcus
(on medial surface
of hemisphere)
Lateral sulcus
Occipital lobe
Temporal lobe
Transverse
cerebral fissure
Cerebellum
Pons
Medulla oblongata
Spinal cord
(a)
Gyrus
Cortex
(gray matter)
Sulcus
White matter
Fissure
(a deep sulcus)
Frontal lobe
Central sulcus
Gyri of insula
Temporal lobe
(pulled down)
(b)

# Functional Areas of the Cerebral

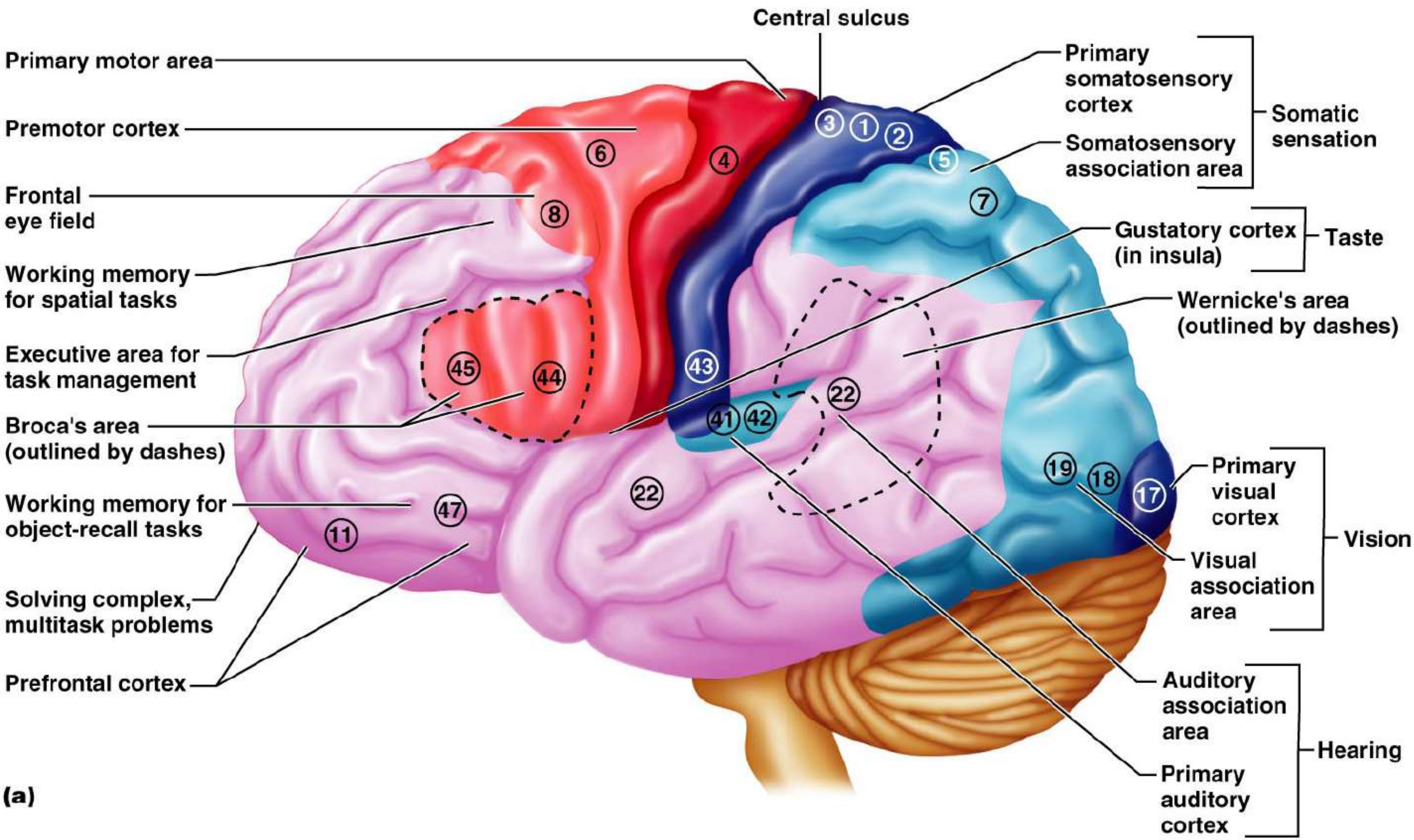



Figure 12.8a

# Primary Motor Cortex Homunculus

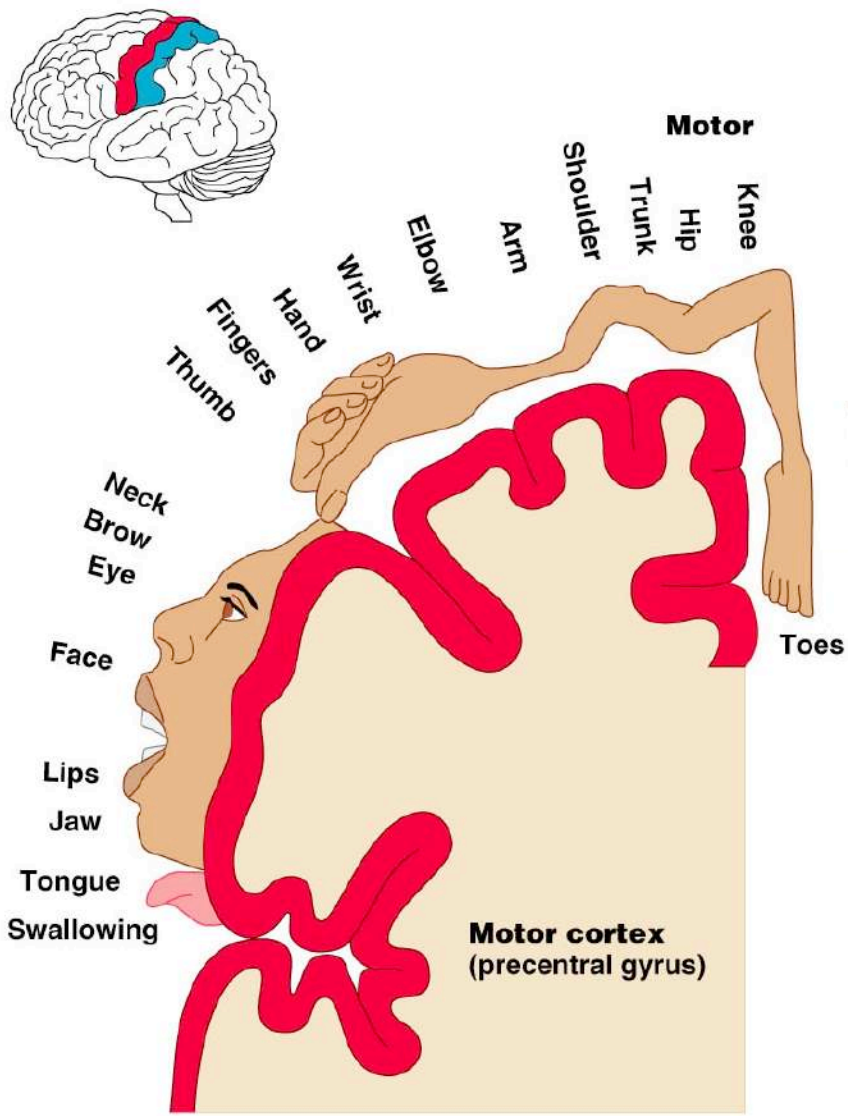



Figure 12.9.1

# Primary Somatosensory Cortex

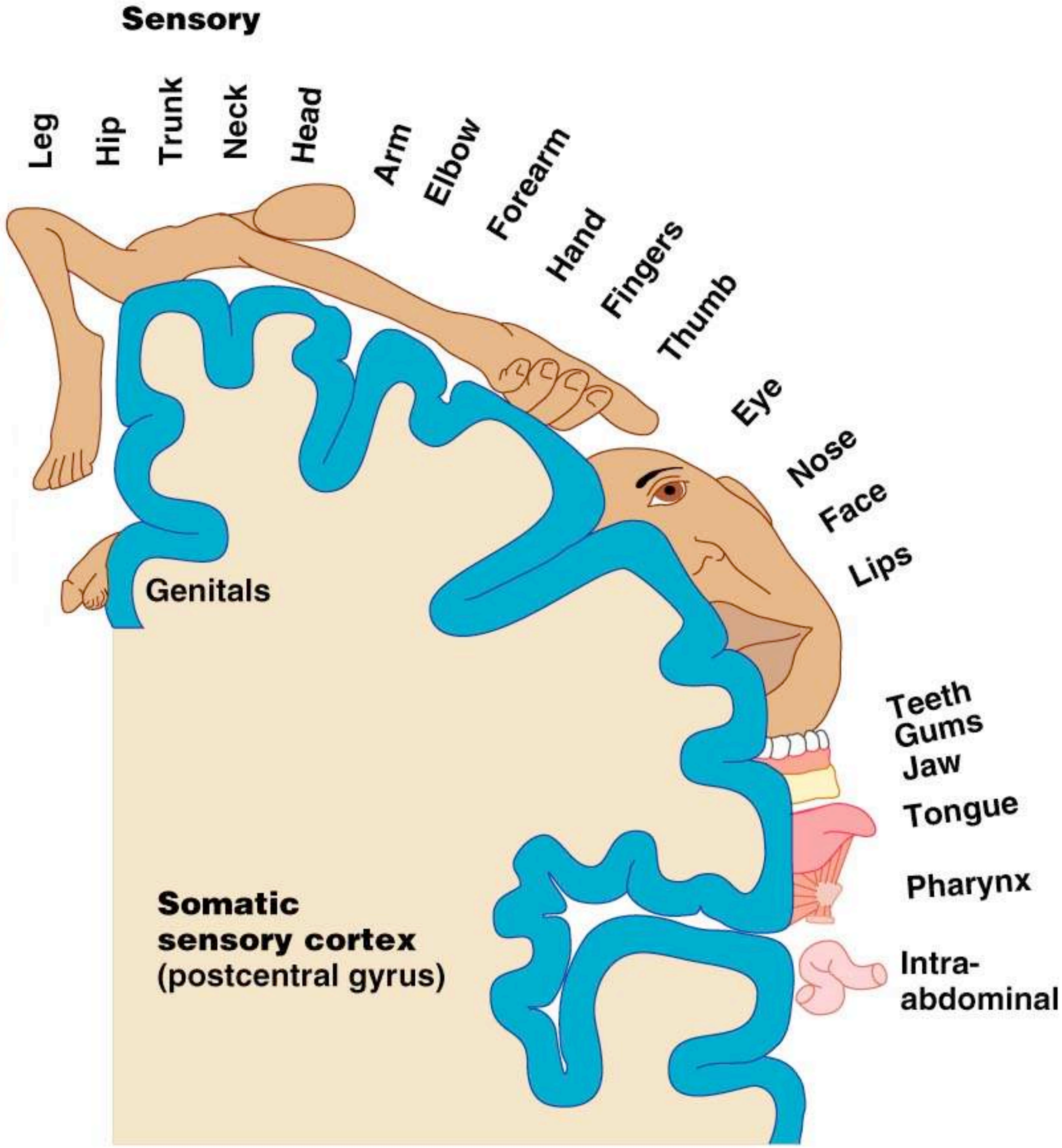



Figure 12.9.2

# Fiber Tracts in White Matter

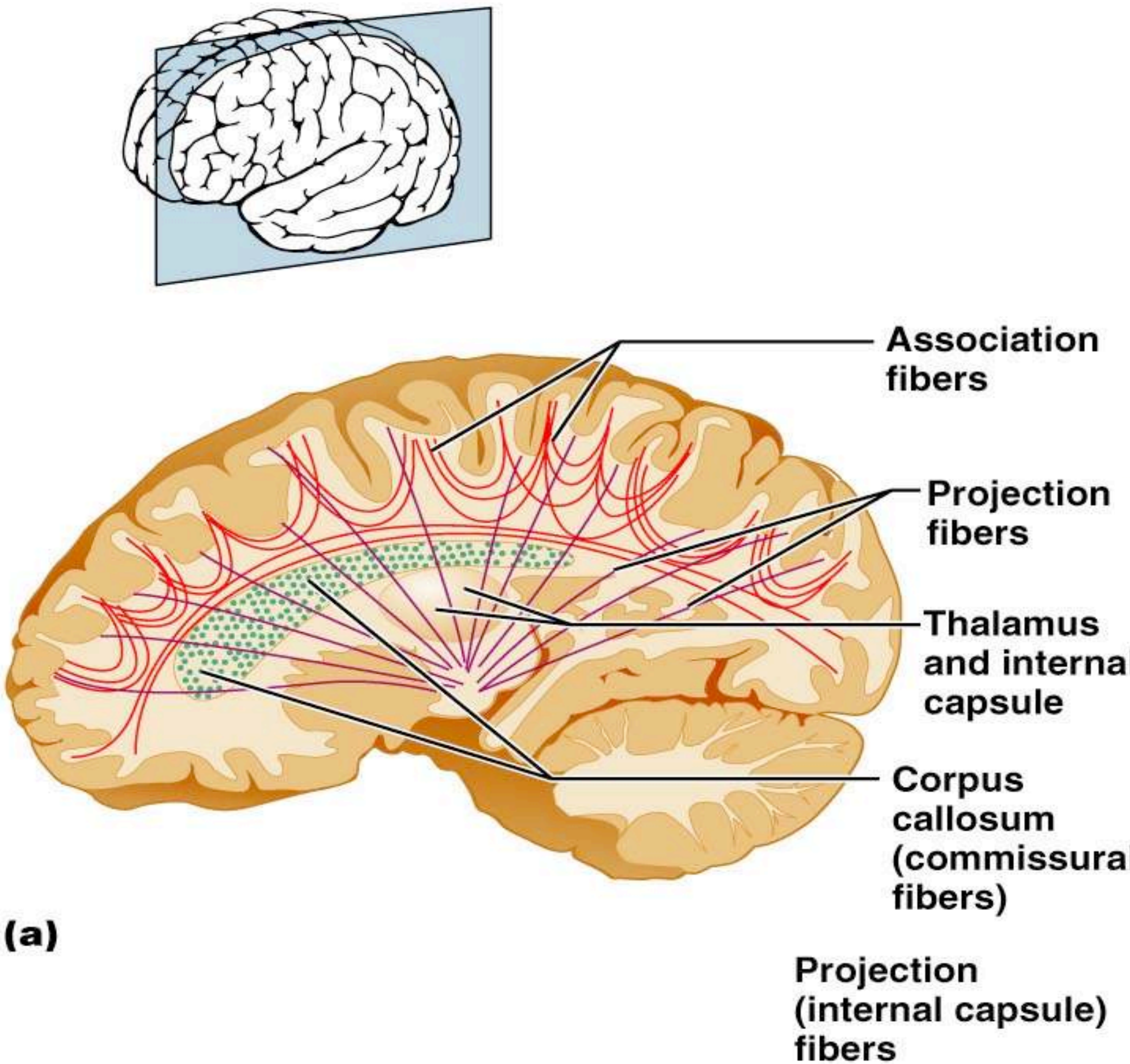
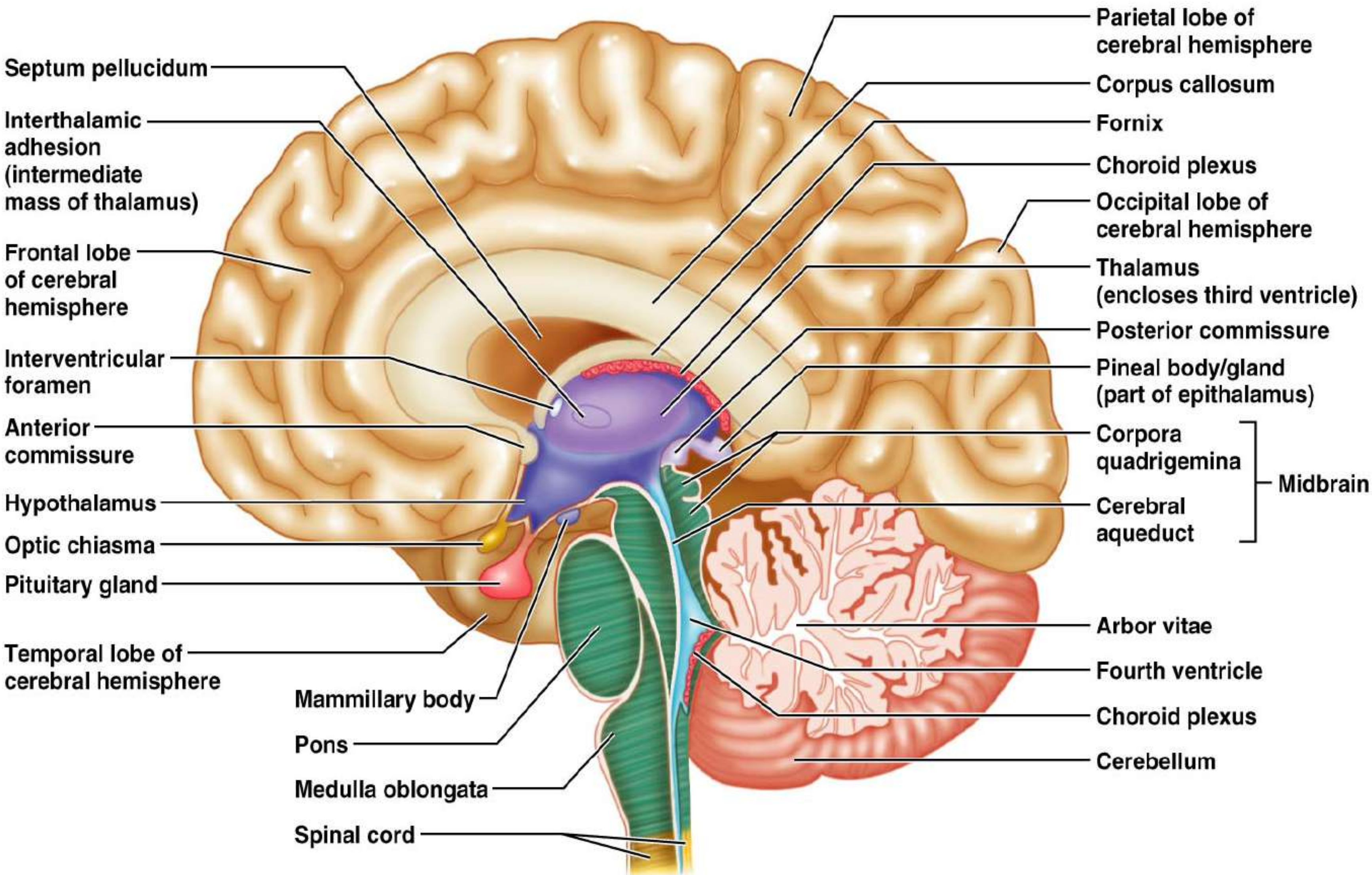



Figure 12.10a



Septum pellucidum
Interthalamic adhesion (intermediate mass of thalamus)
Frontal lobe of cerebral hemisphere
Interventricular foramen
Anterior commissure
Hypothalamus
Optic chiasma
Pituitary gland
Temporal lobe of cerebral hemisphere
Mammillary body
Pons
Medulla oblongata
Spinal cord
Parietal lobe of cerebral hemisphere
Corpus callosum
Fornix
Choroid plexus
Occipital lobe of cerebral hemisphere
Thalamus (encloses third ventricle)
Posterior commissure
Pineal body/gland (part of epithalamus)
Corpora quadrigemina
Cerebral aqueduct
Midbrain
Arbor vitae
Fourth ventricle
Choroid plexus
Cerebellum


Figure 12.12

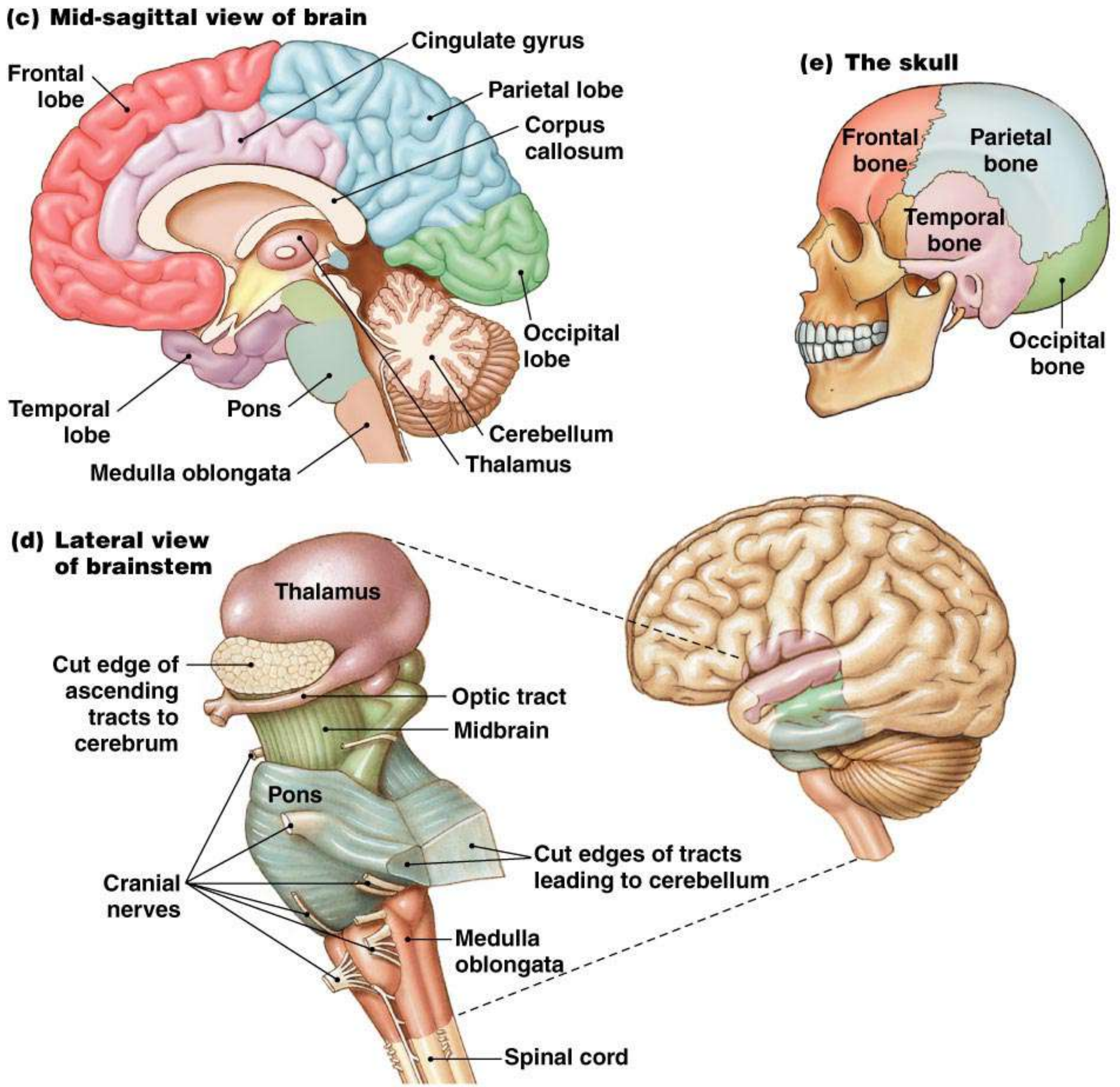





Figure 9-9c–e (2 of 5)

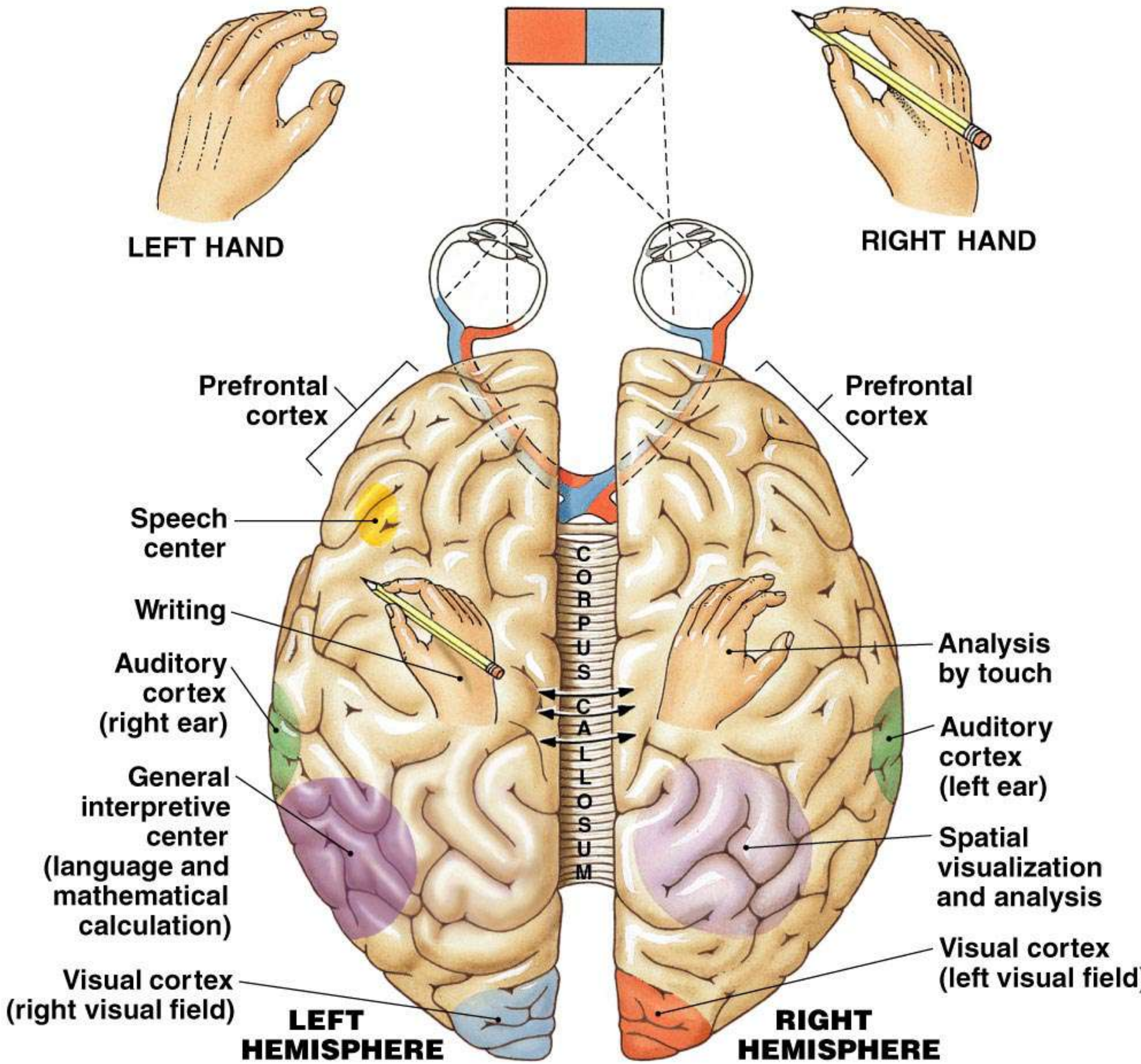

LEFT HAND
RIGHT HAND
Prefrontal cortex
Prefrontal cortex
Speech center
Writing
Auditory cortex (right ear)
General interpretive center (language and mathematical calculation)
Visual cortex (right visual field)
CORPUS CALLOSUM
Analysis by touch
Auditory cortex (left ear)
Spatial visualization and analysis
Visual cortex (left visual field)
LEFT HEMISPHERE
RIGHT HEMISPHERE



Figure 9-16

# Spinal Cord

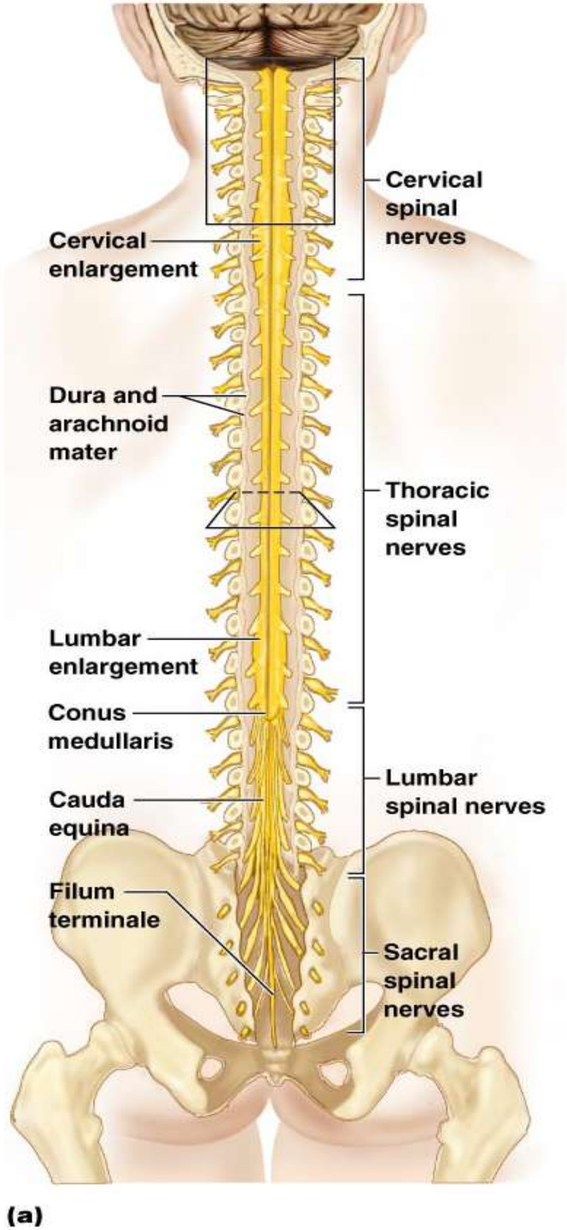
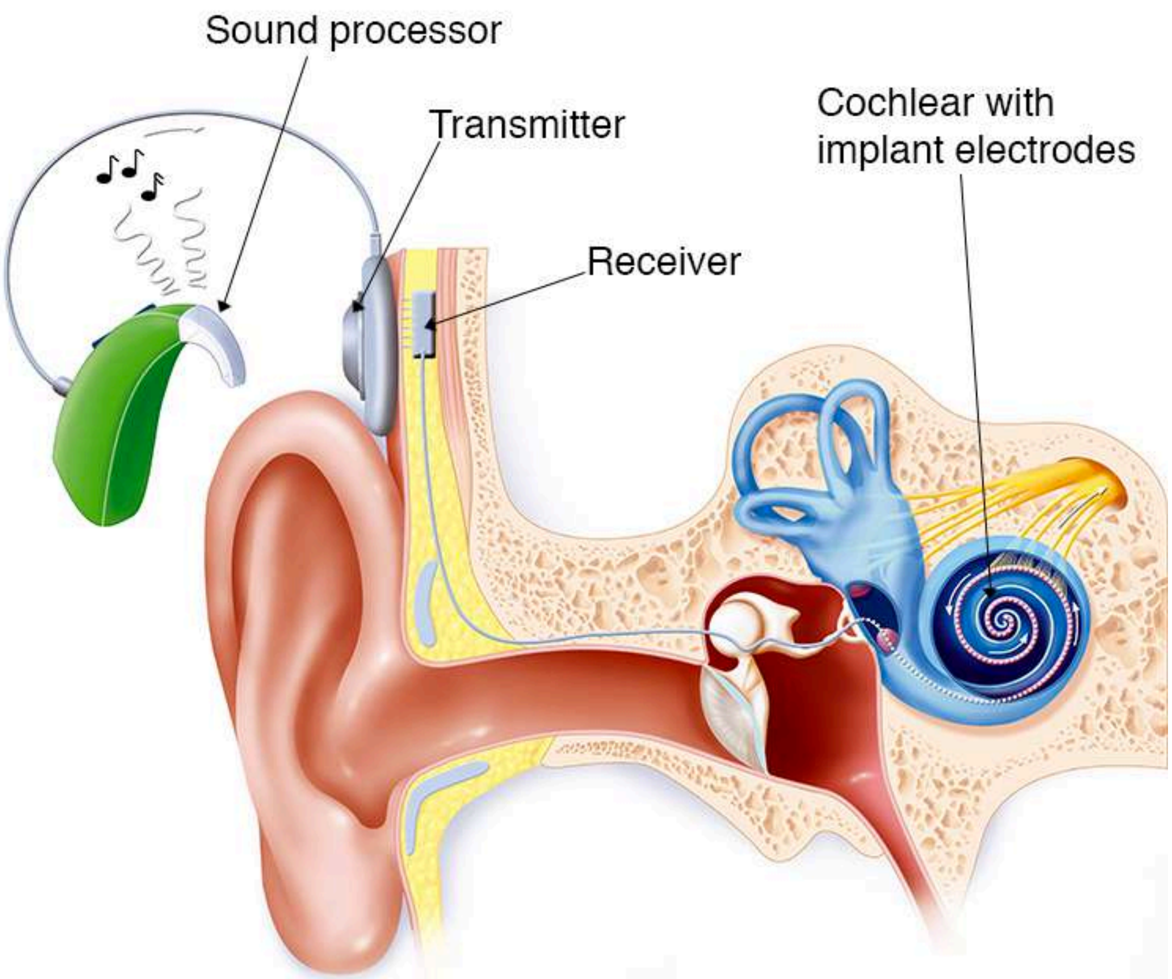



Figure 12.29a


Sound processor
Transmitter
Receiver
Cochlear with
implant electrodes

# Gray Matter and Spinal Roots

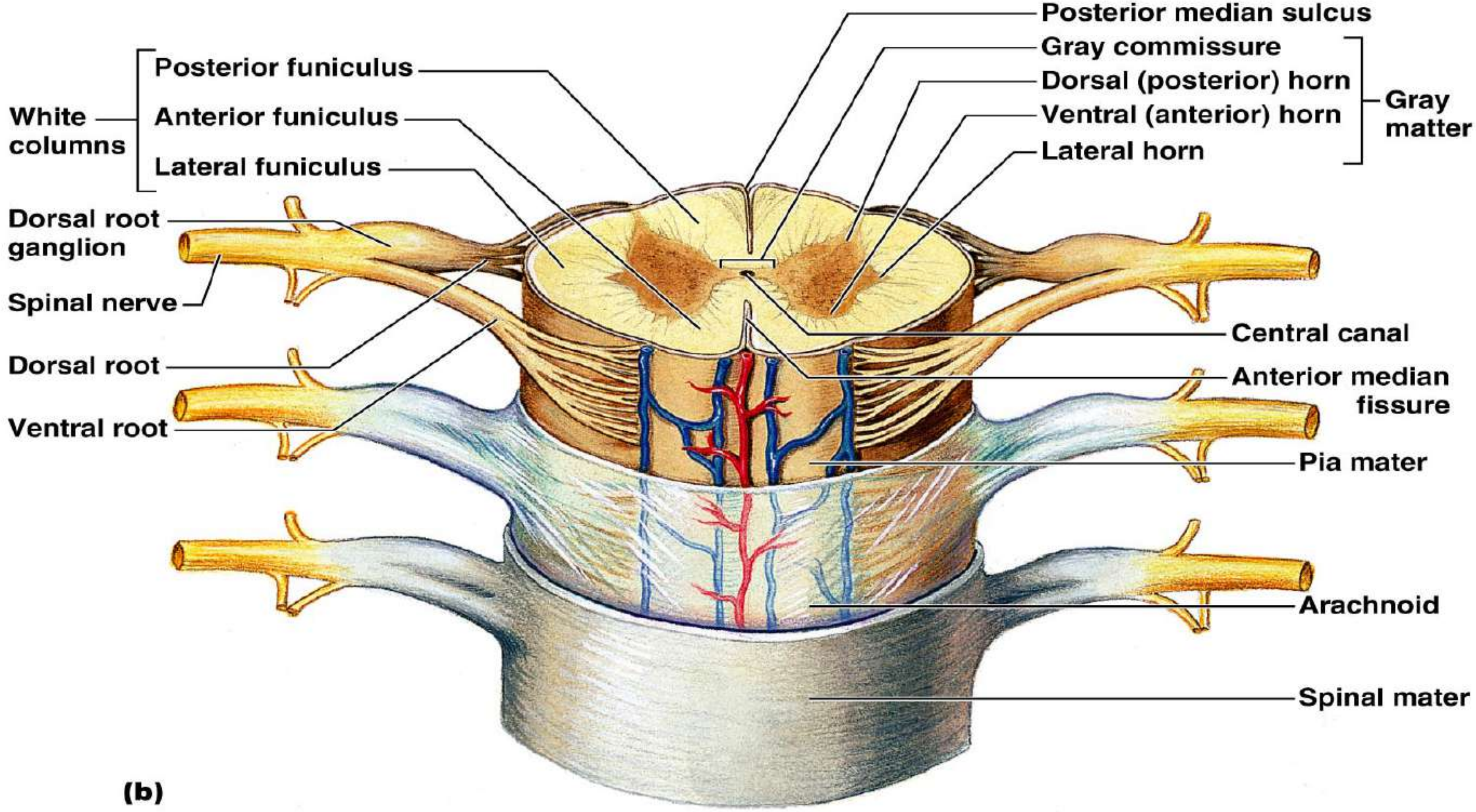



Figure 12.31b

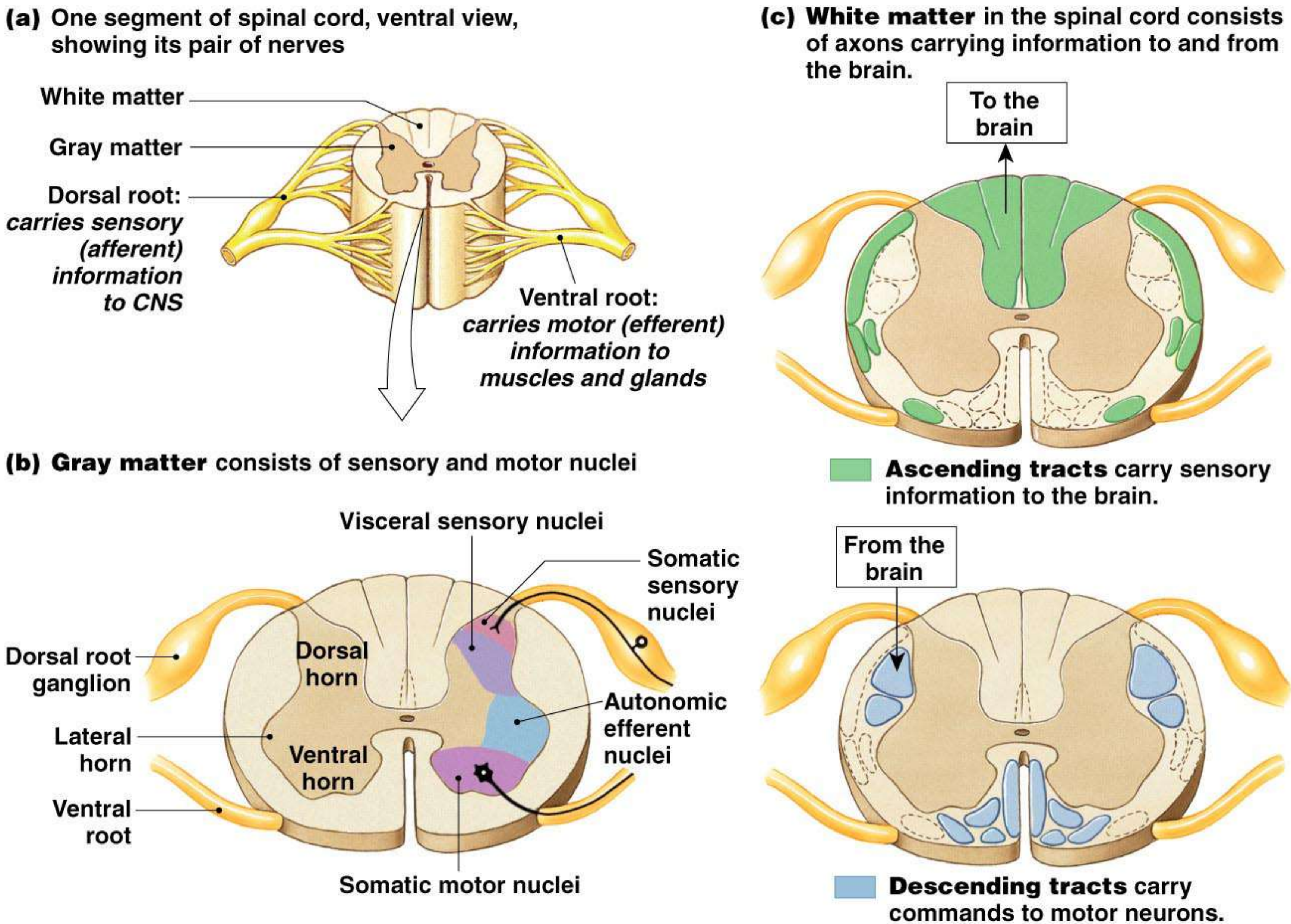





Figure 9-7 - Overview

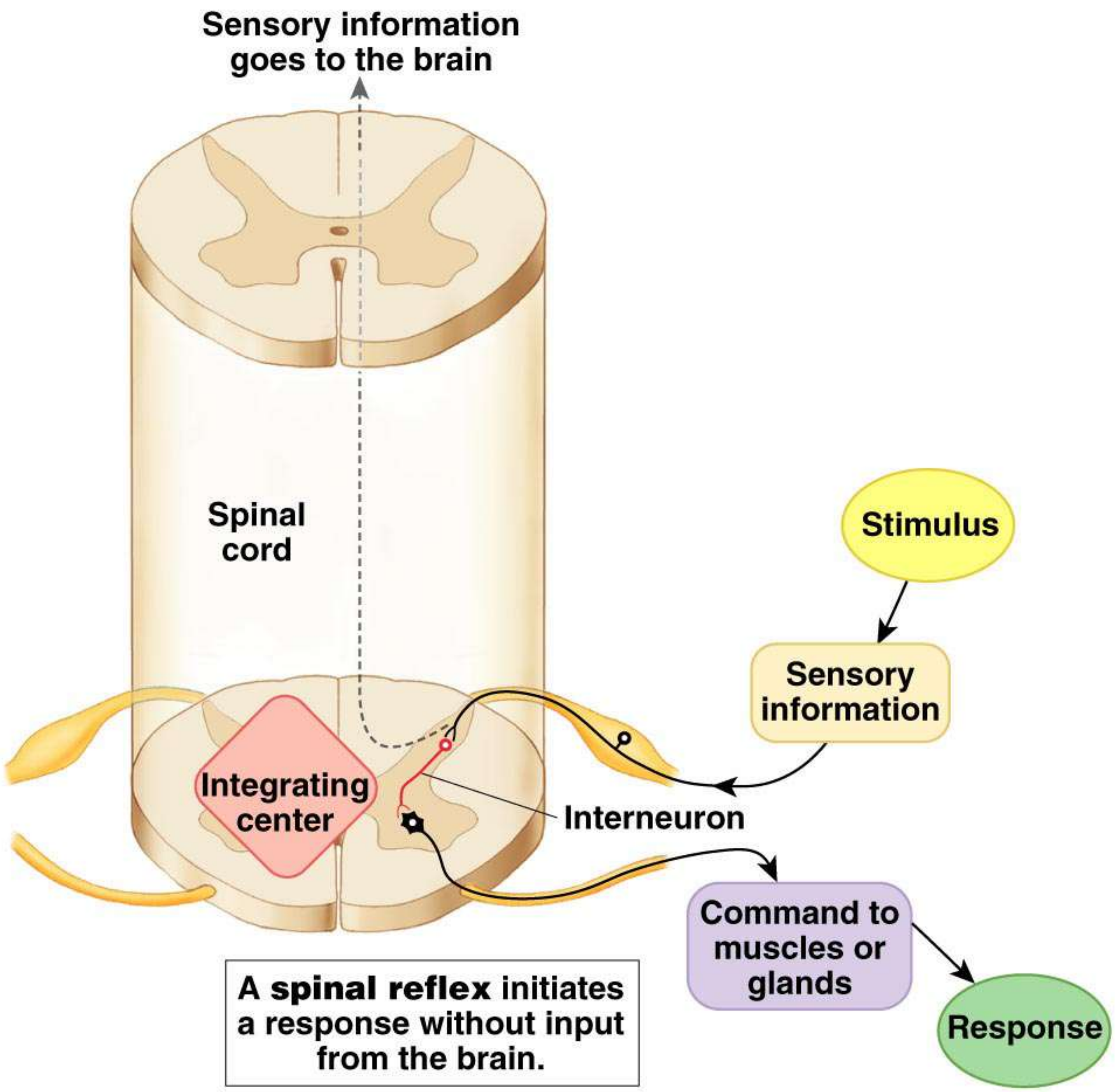
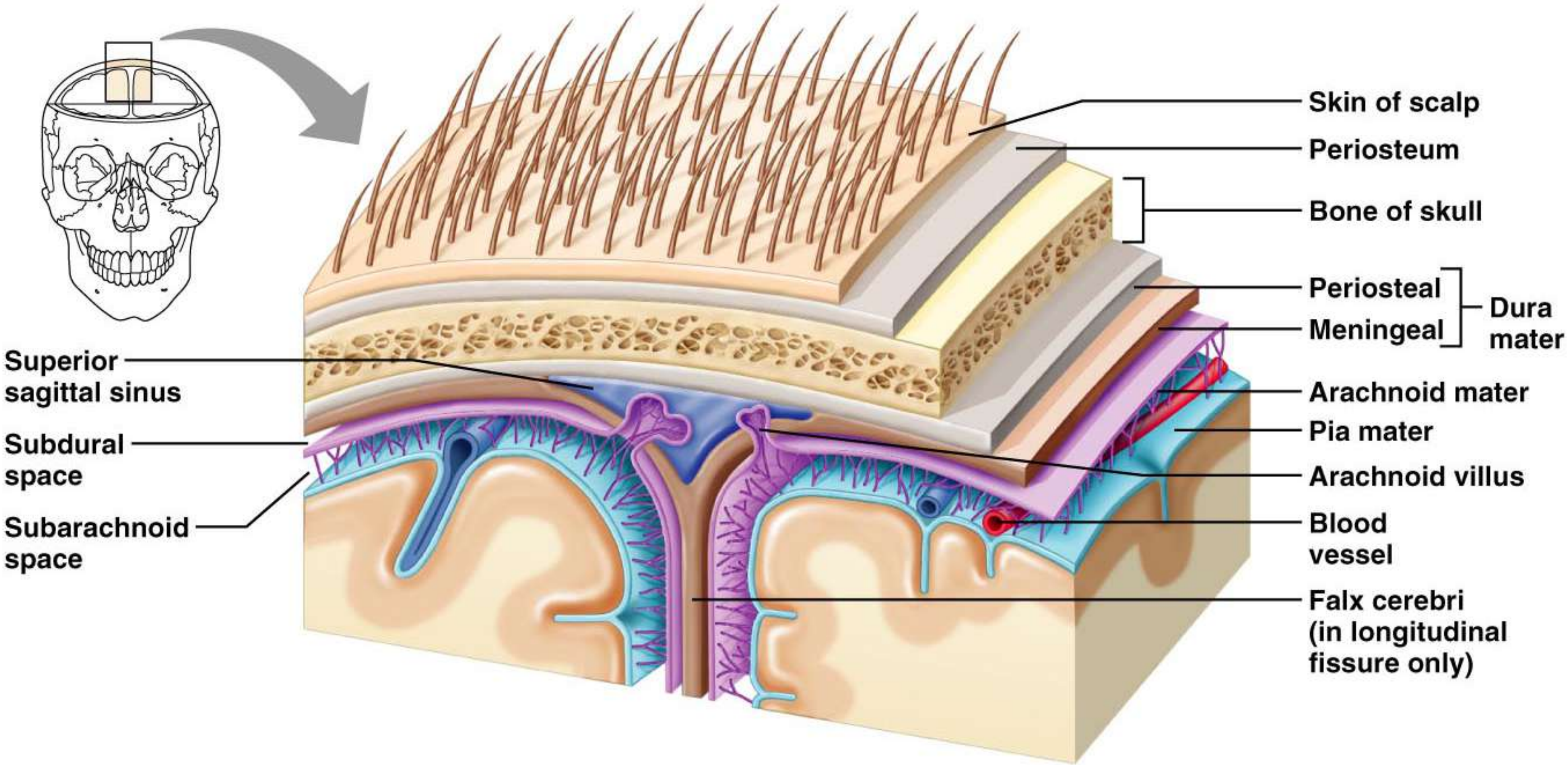

Sensory information
goes to the brain
Spinal
cord
Stimulus
Sensory
information
Integrating
center
Interneuron
Command to
muscles or
glands
Response
A **spinal reflex** initiates
a response without input
from the brain.



Figure 9-8

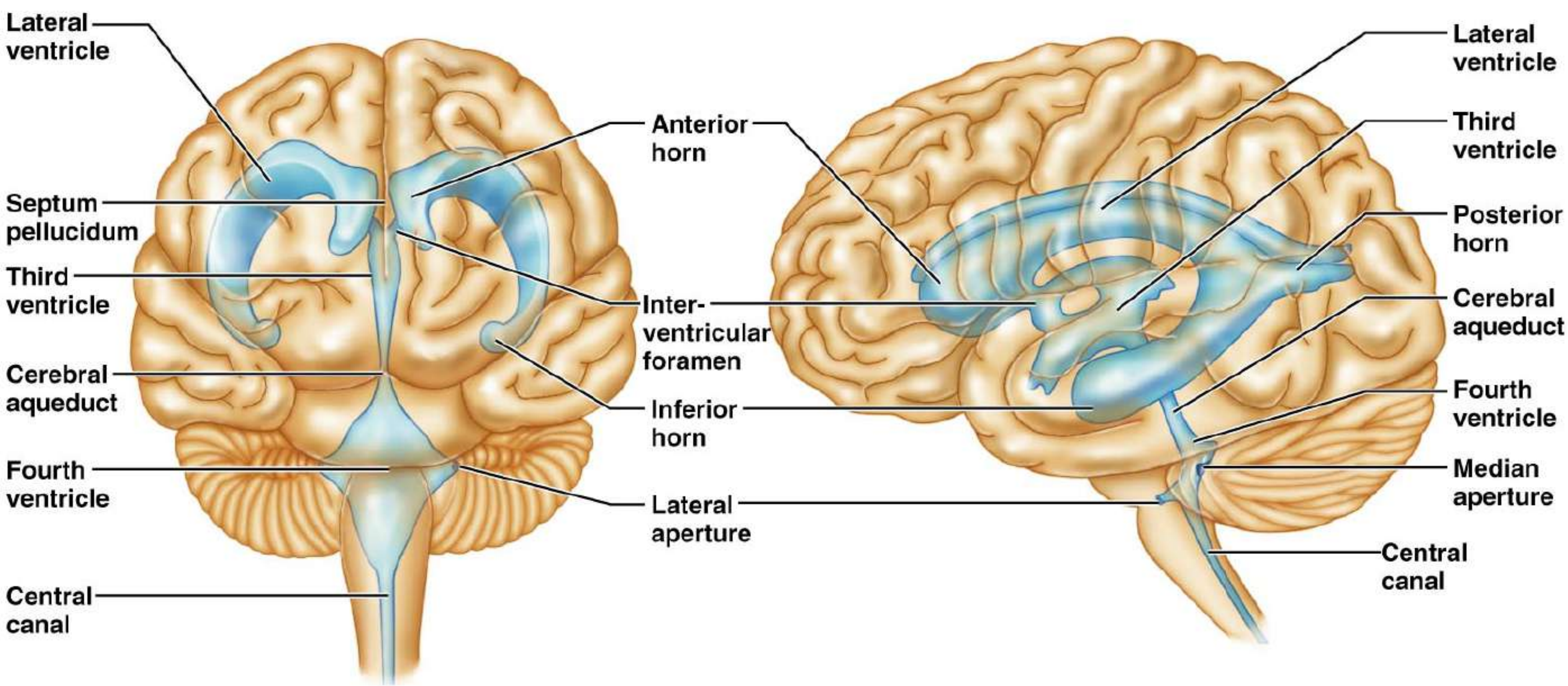
# Meninges




(a)

Figure 12.24a

# Ventricles of the Brain




(a) Anterior view

(b) Left lateral view

Figure 12.5

# Cerebrospinal Fluid (CSF)

- Watery solution similar in composition to blood plasma
- Contains less protein and different ion concentrations than plasma
- Forms a liquid cushion that gives buoyancy to the CNS organs

# Cerebrospinal Fluid (CSF)

- Prevents the brain from crushing under its own weight
- Protects the CNS from blows and other trauma
- Nourishes the brain and carries chemical signals throughout it

# Circulation of CSF

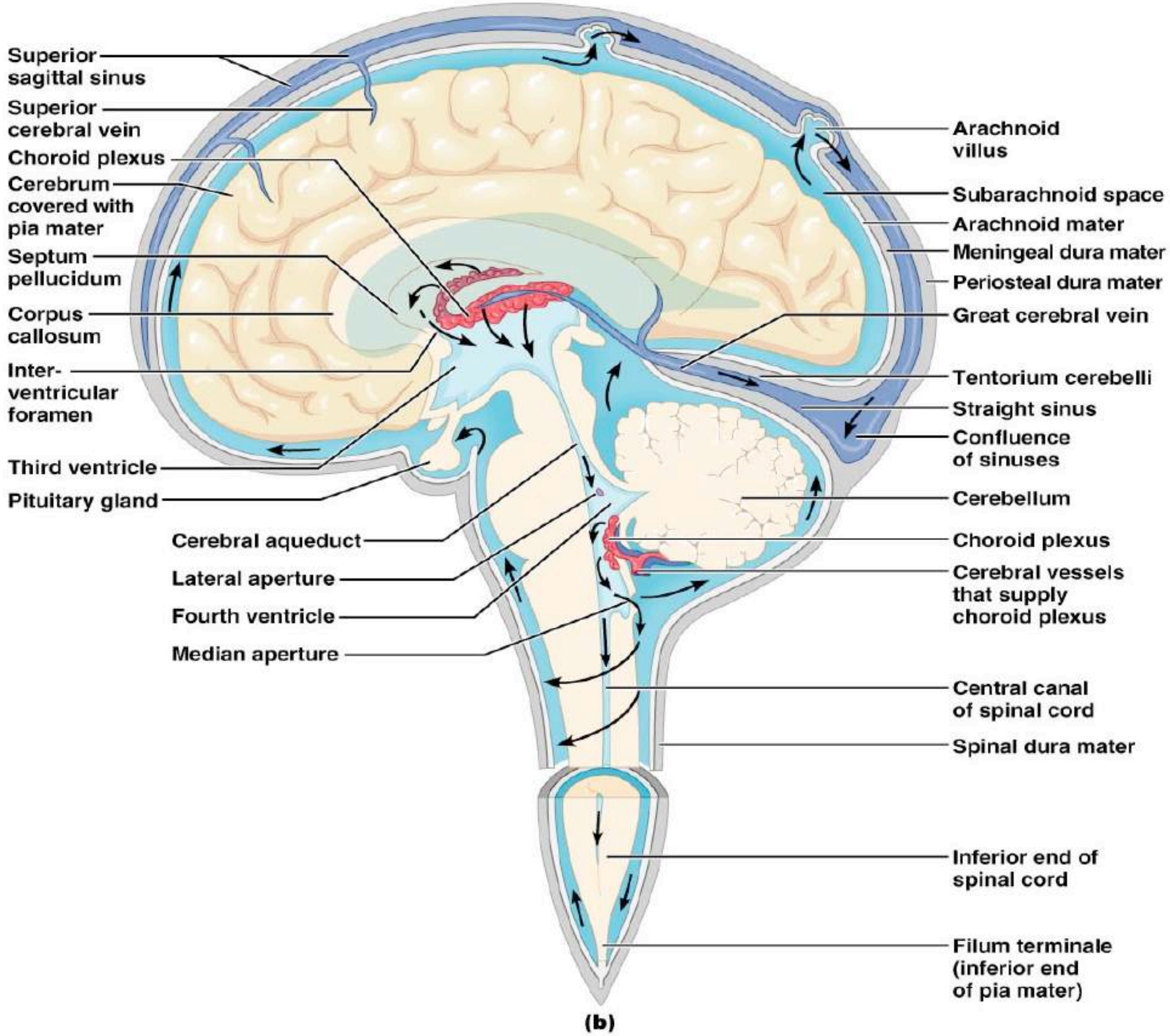



Figure 12.26b

# PNS in the Nervous System

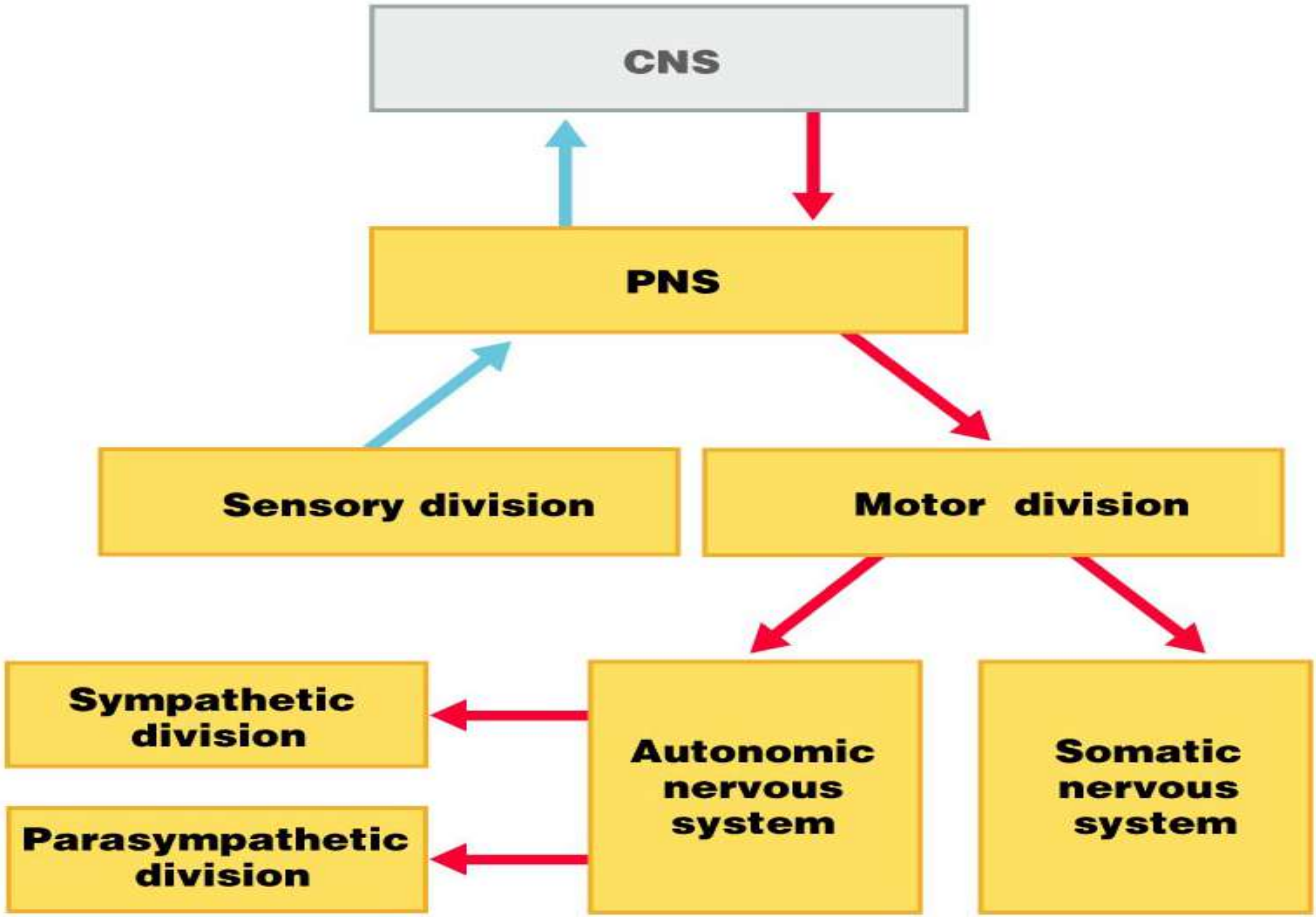



Figure 13.1

# Structure of a Nerve

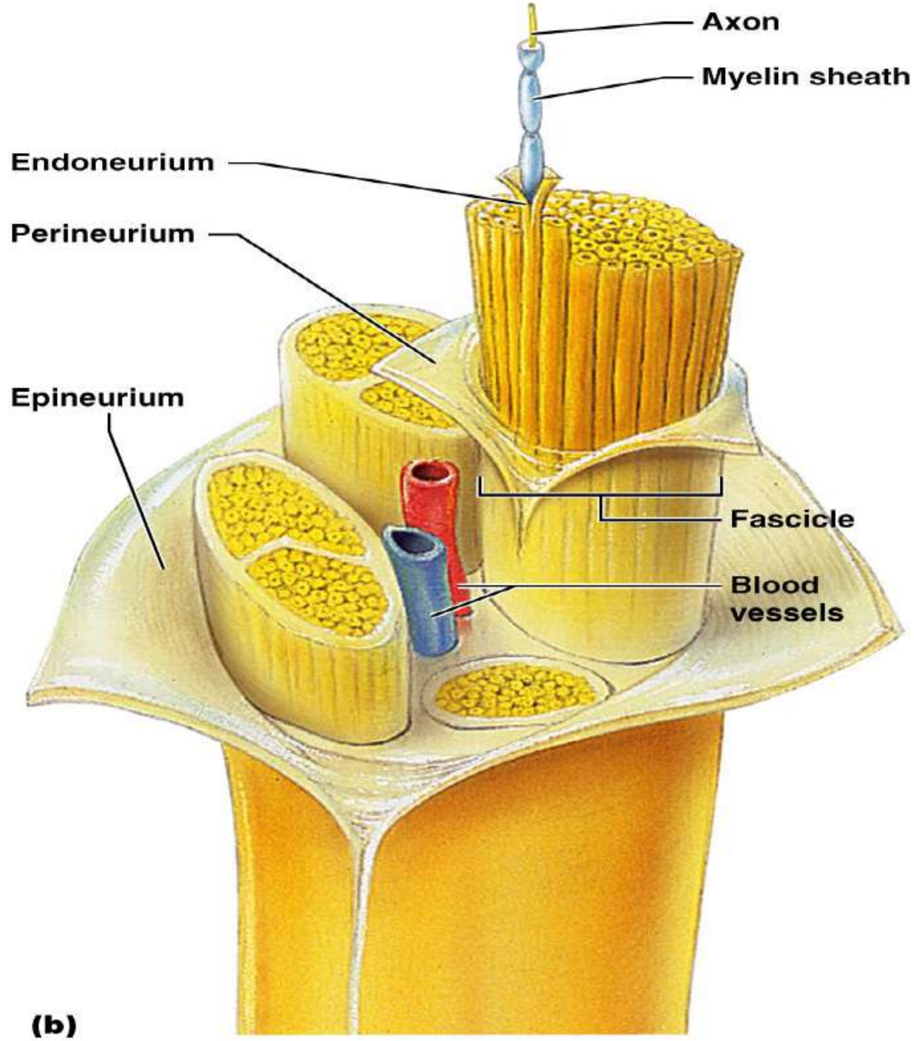



Figure 13.3b

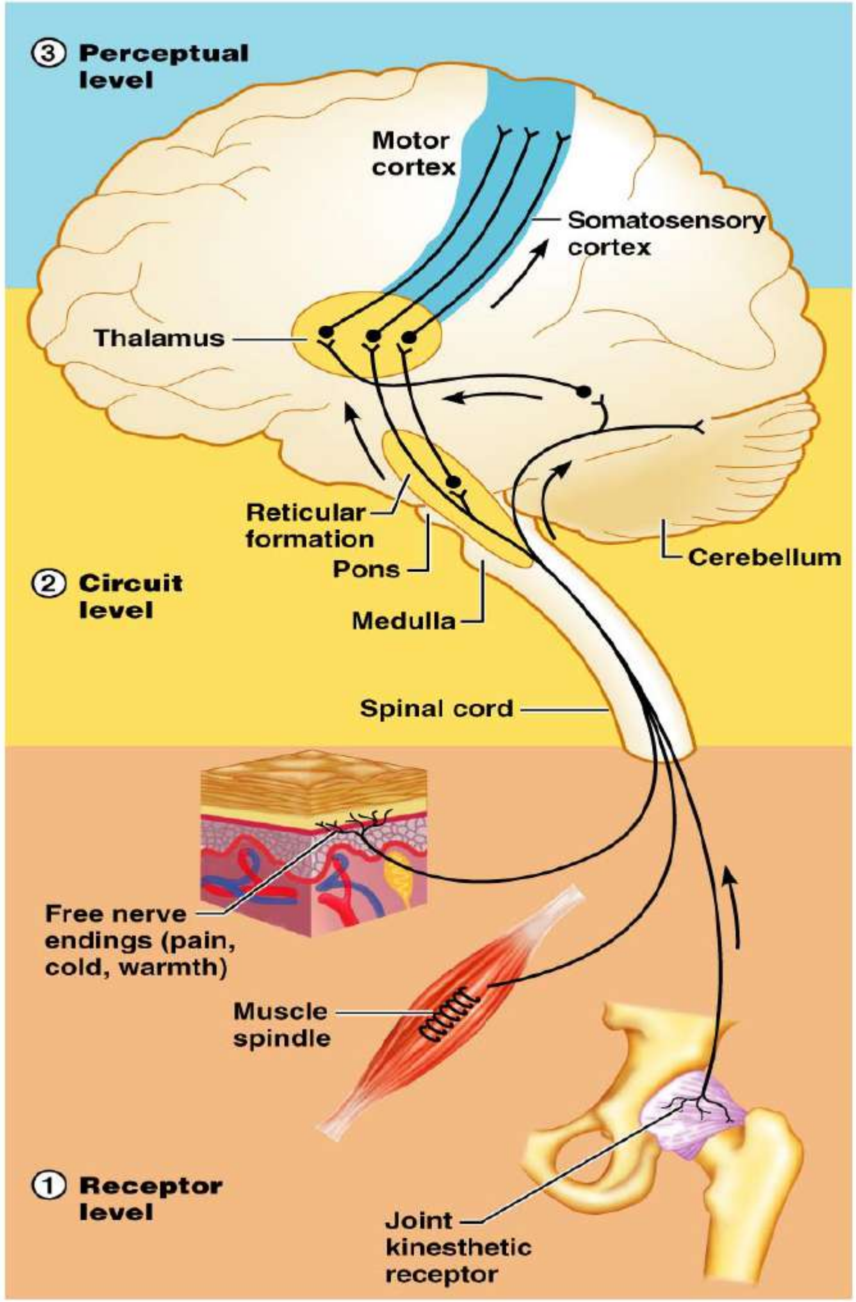

③ Perceptual level
Motor cortex
Somatosensory cortex
Thalamus
Reticular formation
Pons
Medulla
Cerebellum
② Circuit level
Spinal cord
Free nerve endings (pain, cold, warmth)
Muscle spindle
① Receptor level
Joint kinesthetic receptor

Figure 13.2

# Comparison of Somatic and Autonomic Systems

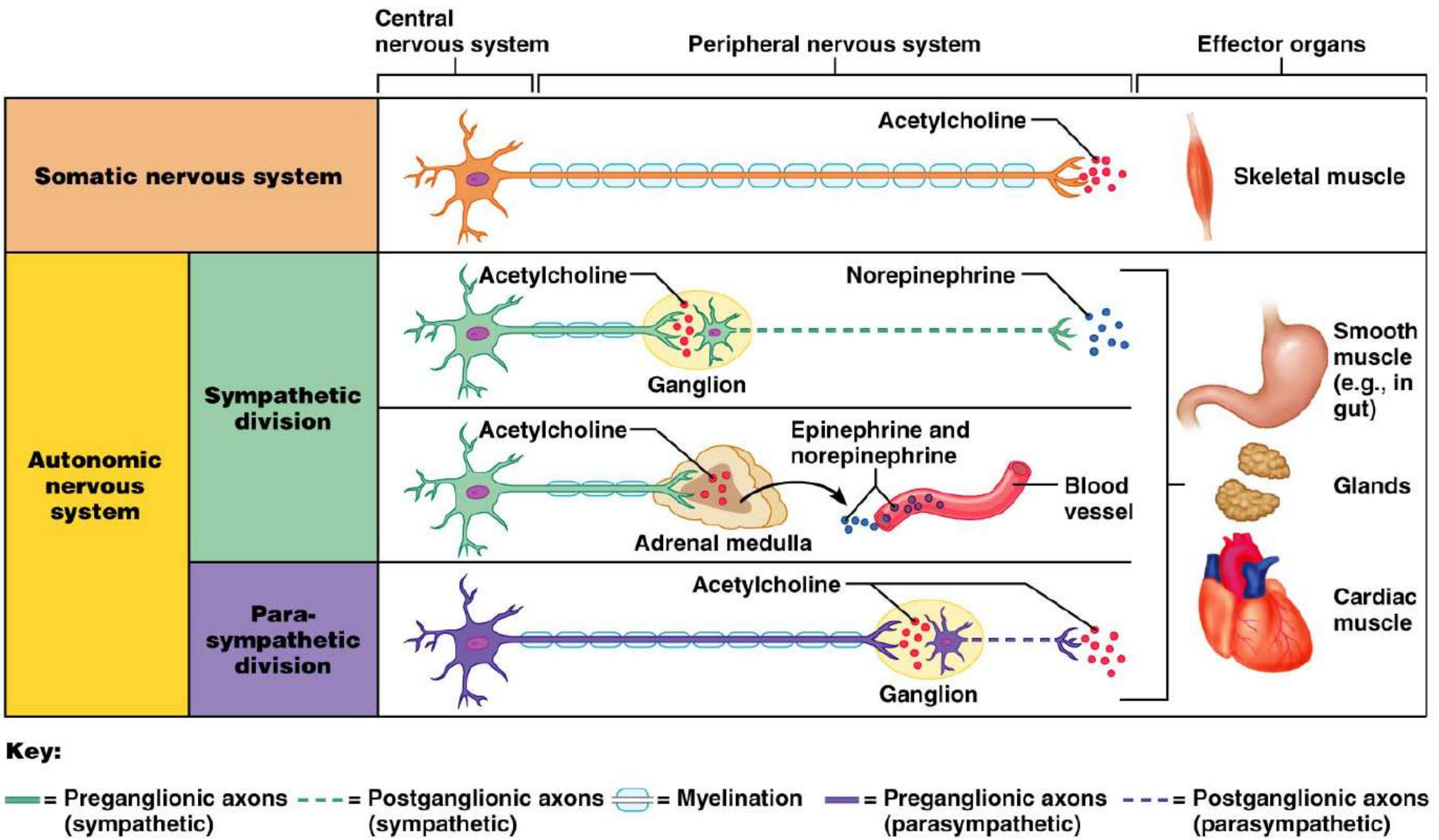



Figure 14.2

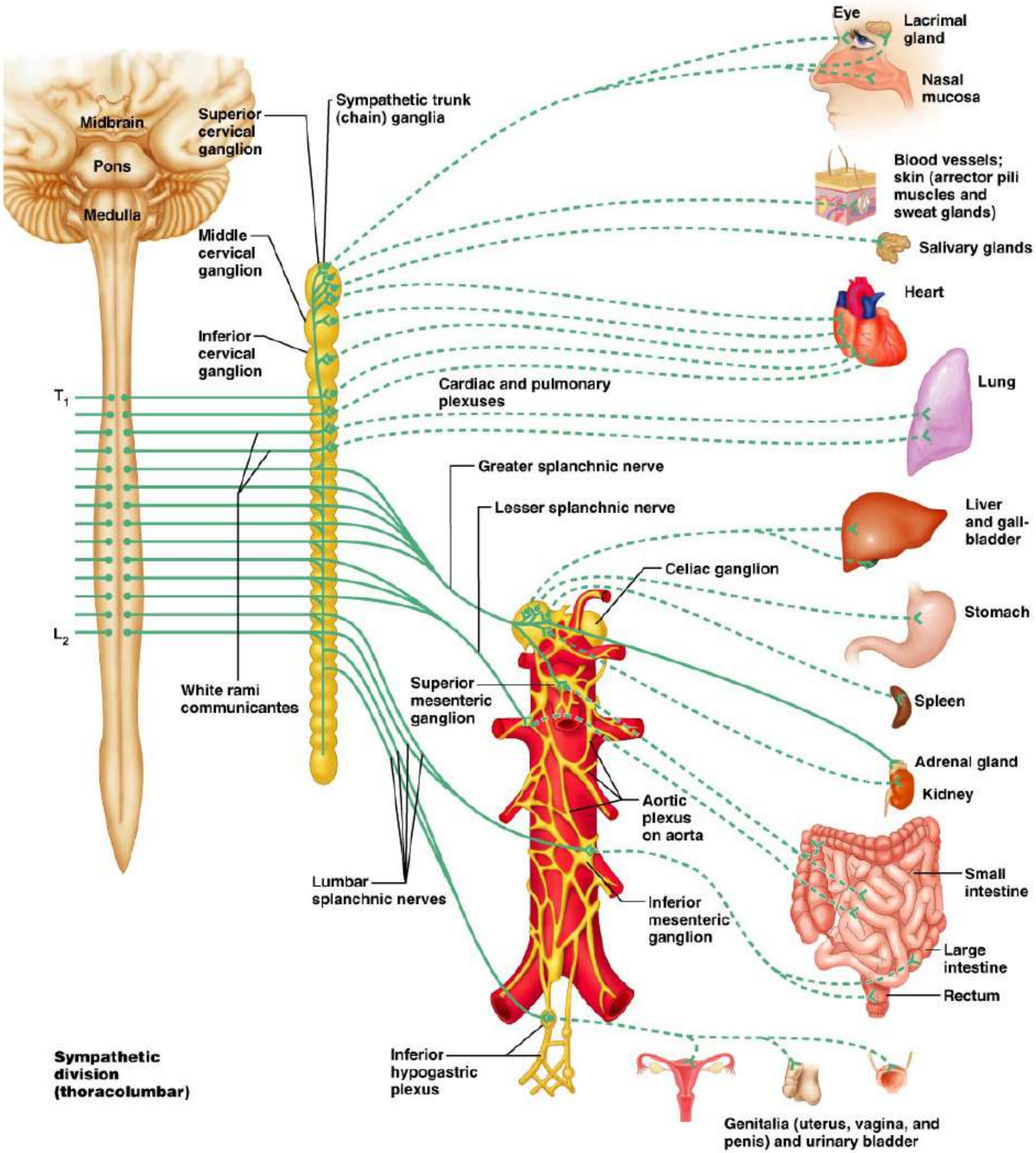

Eye
Lacrimal gland
Nasal mucosa
Midbrain
Pons
Medulla
Superior cervical ganglion
Sympathetic trunk (chain) ganglia
Blood vessels; skin (arrector pili muscles and sweat glands)
Salivary glands
Middle cervical ganglion
Heart
Inferior cervical ganglion
Lung
Cardiac and pulmonary plexuses
$T_1$
Greater splanchnic nerve
Lesser splanchnic nerve
Liver and gall-bladder
Celiac ganglion
Stomach
$L_2$
Superior mesenteric ganglion
White rami communicantes
Spleen
Adrenal gland
Kidney
Aortic plexus on aorta
Small intestine
Lumbar splanchnic nerves
Inferior mesenteric ganglion
Large intestine
Rectum
Sympathetic division (thoracolumbar)
Inferior hypogastric plexus
Genitalia (uterus, vagina, and penis) and urinary bladder

Figure 14.5

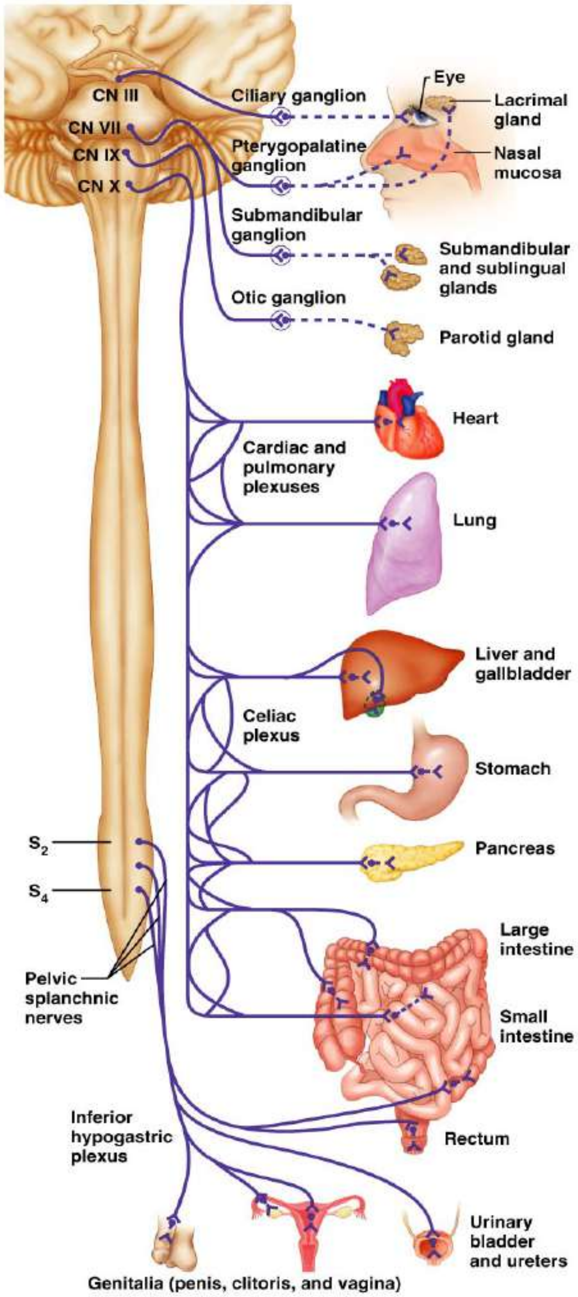

CN III
CN VII
CN IX
CN X
Ciliary ganglion
Pterygopalatine ganglion
Submandibular ganglion
Otic ganglion
Eye
Lacrimal gland
Nasal mucosa
Submandibular and sublingual glands
Parotid gland
Heart
Cardiac and pulmonary plexuses
Lung
Liver and gallbladder
Celiac plexus
Stomach
Pancreas
$S_2$
$S_4$
Pelvic splanchnic nerves
Large intestine
Small intestine
Inferior hypogastric plexus
Rectum
Urinary bladder and ureters
Genitalia (penis, clitoris, and vagina)

Figure 14.4

# Cranial Nerves

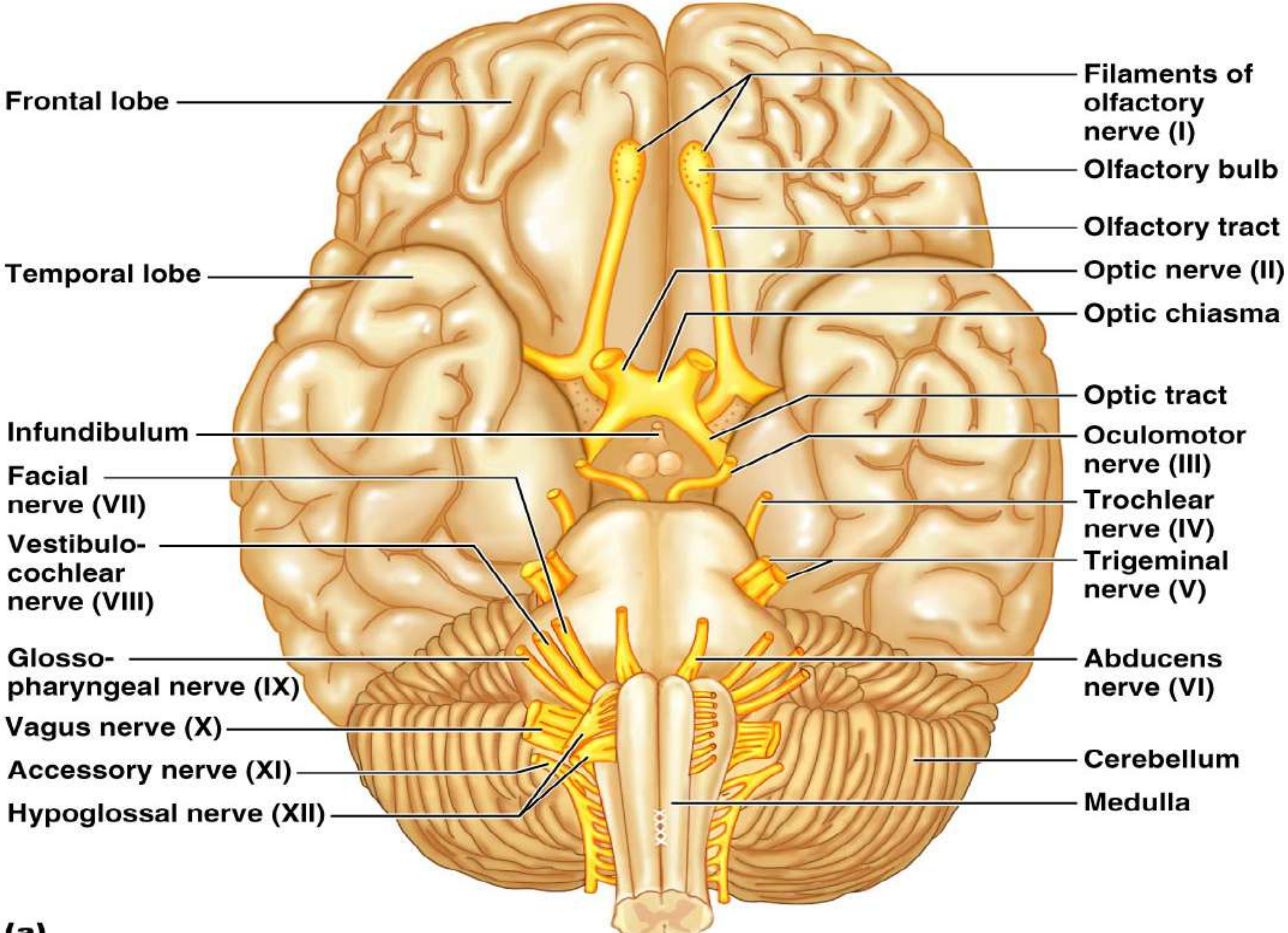



Figure 13.5a

# Summary of Function of Cranial

| Cranial nerves I – VI | Sensory function | Motor function | PS* fibers |
|---|---|---|---|
| I Olfactory | Yes (smell) | No | No |
| II Optic | Yes (vision) | No | No |
| III Oculomotor | No | Yes | Yes |
| IV Trochlear | No | Yes | No |
| V Trigeminal | Yes (general sensation) | Yes | No |
| VI Abducens | No | Yes | No |

| Cranial nerves VII – XII | Sensory function | Motor function | PS* fibers |
|---|---|---|---|
| VII Facial | Yes (taste) | Yes | Yes |
| VIII Vestibulocochlear | Yes (hearing and balance) | Some | No |
| IX Glossopharyngeal | Yes (taste) | Yes | Yes |
| X Vagus | Yes (taste) | Yes | Yes |
| XI Accessory | No | Yes | No |
| XII Hypoglossal | No | Yes | No |

**(b)** *PS = parasympathetic

Figure 13.5b

# Cranial Nerve I: Olfactory

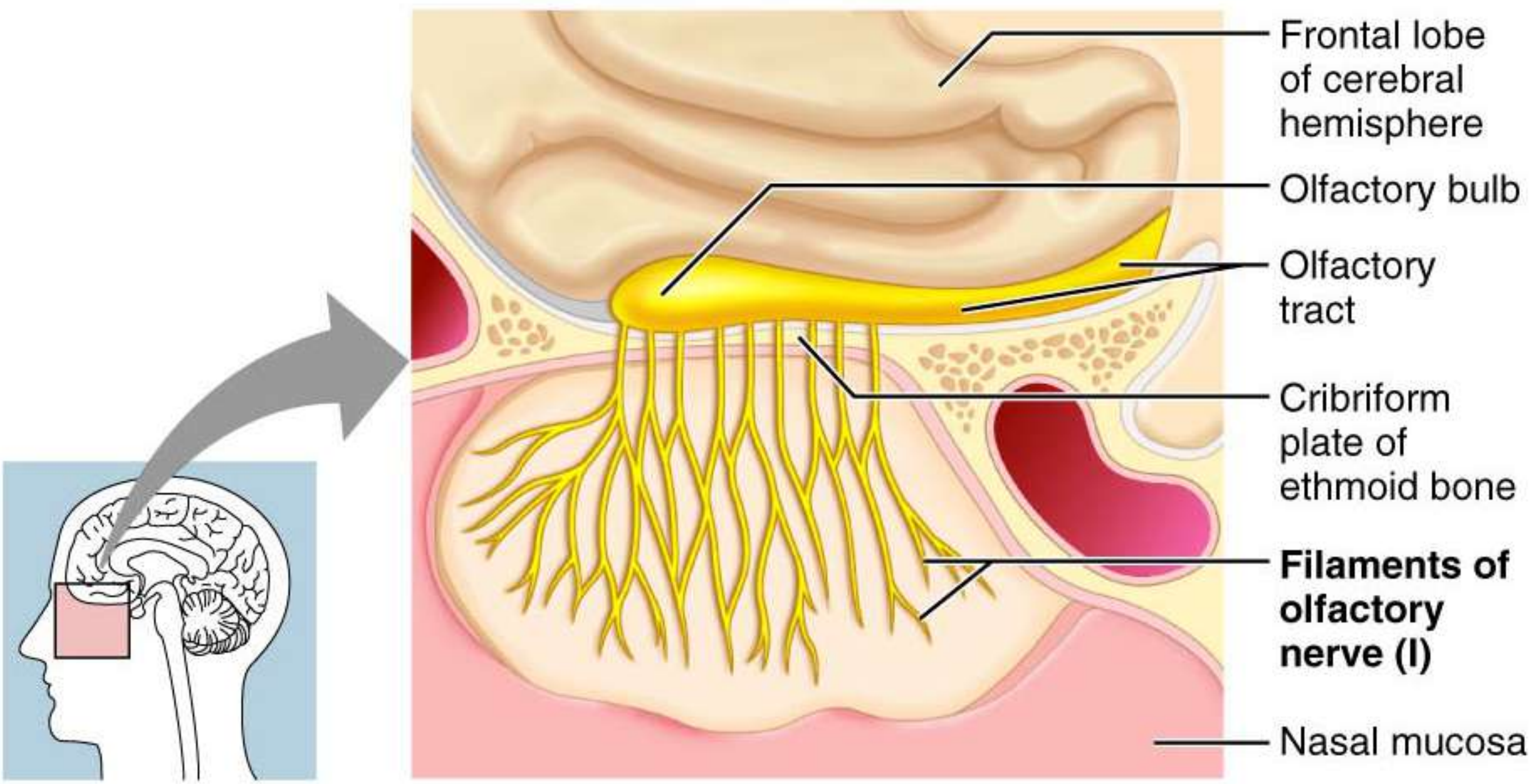



Figure I from Table 13.2

# Cranial Nerve II: Optic

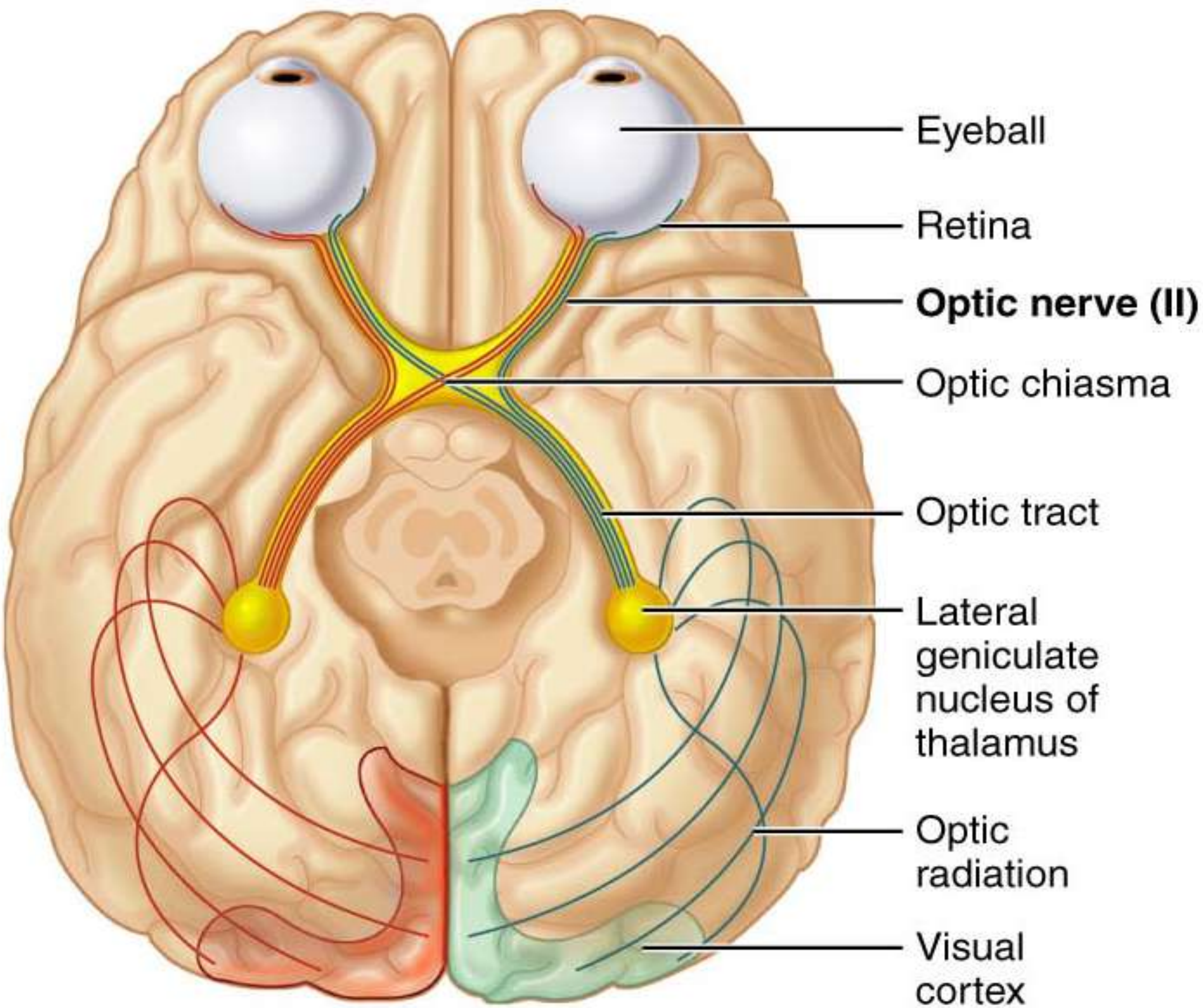
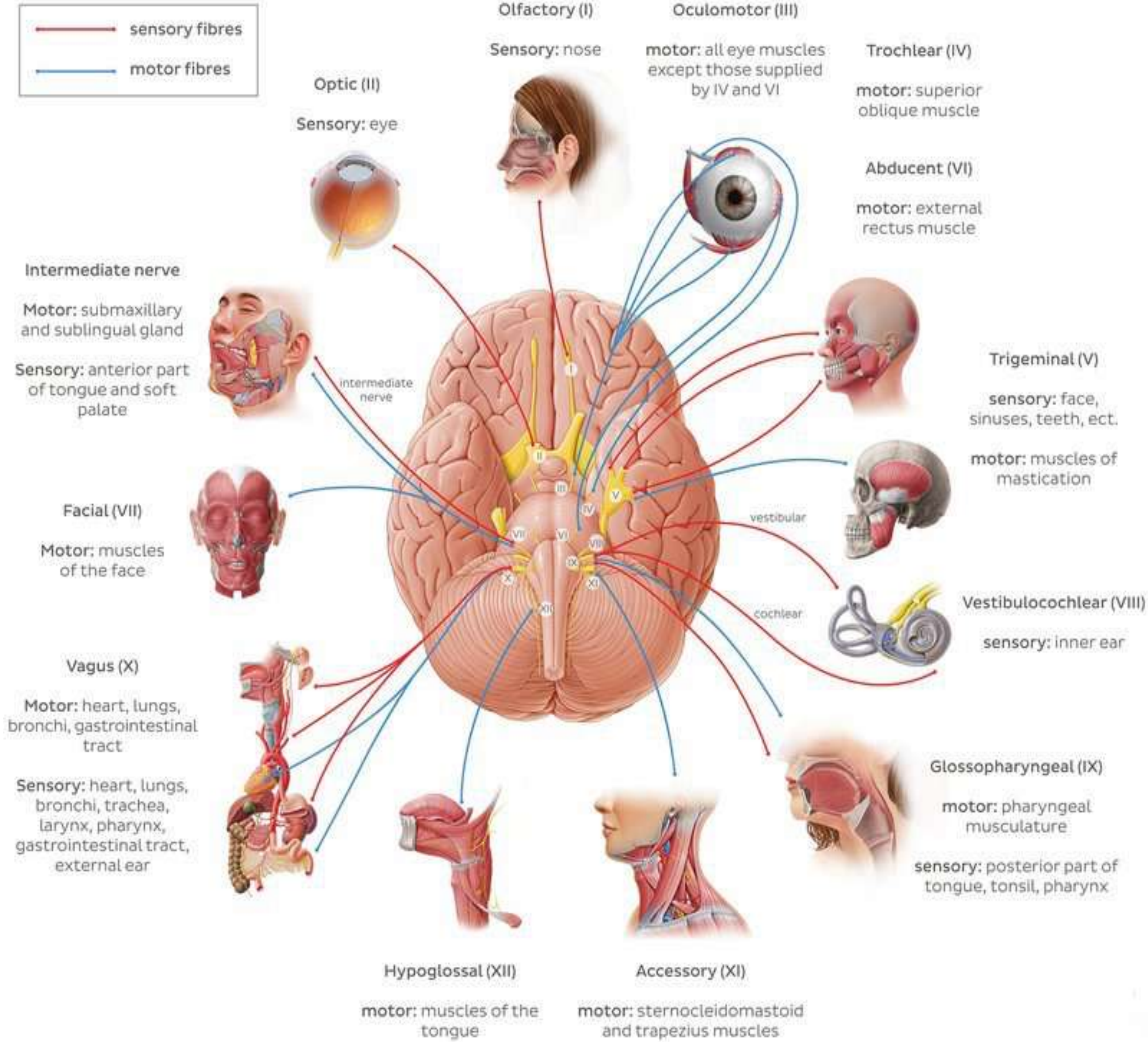
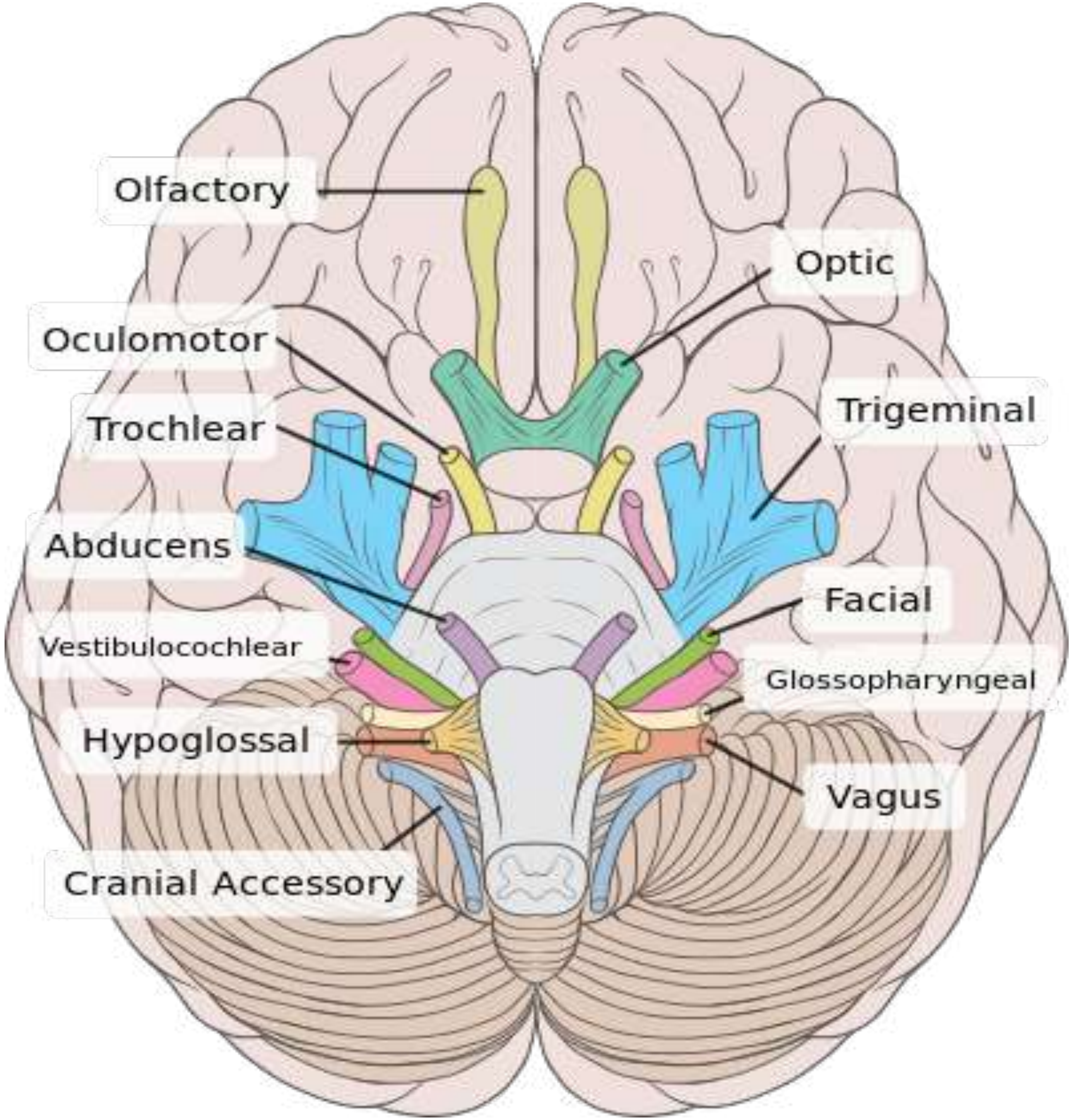
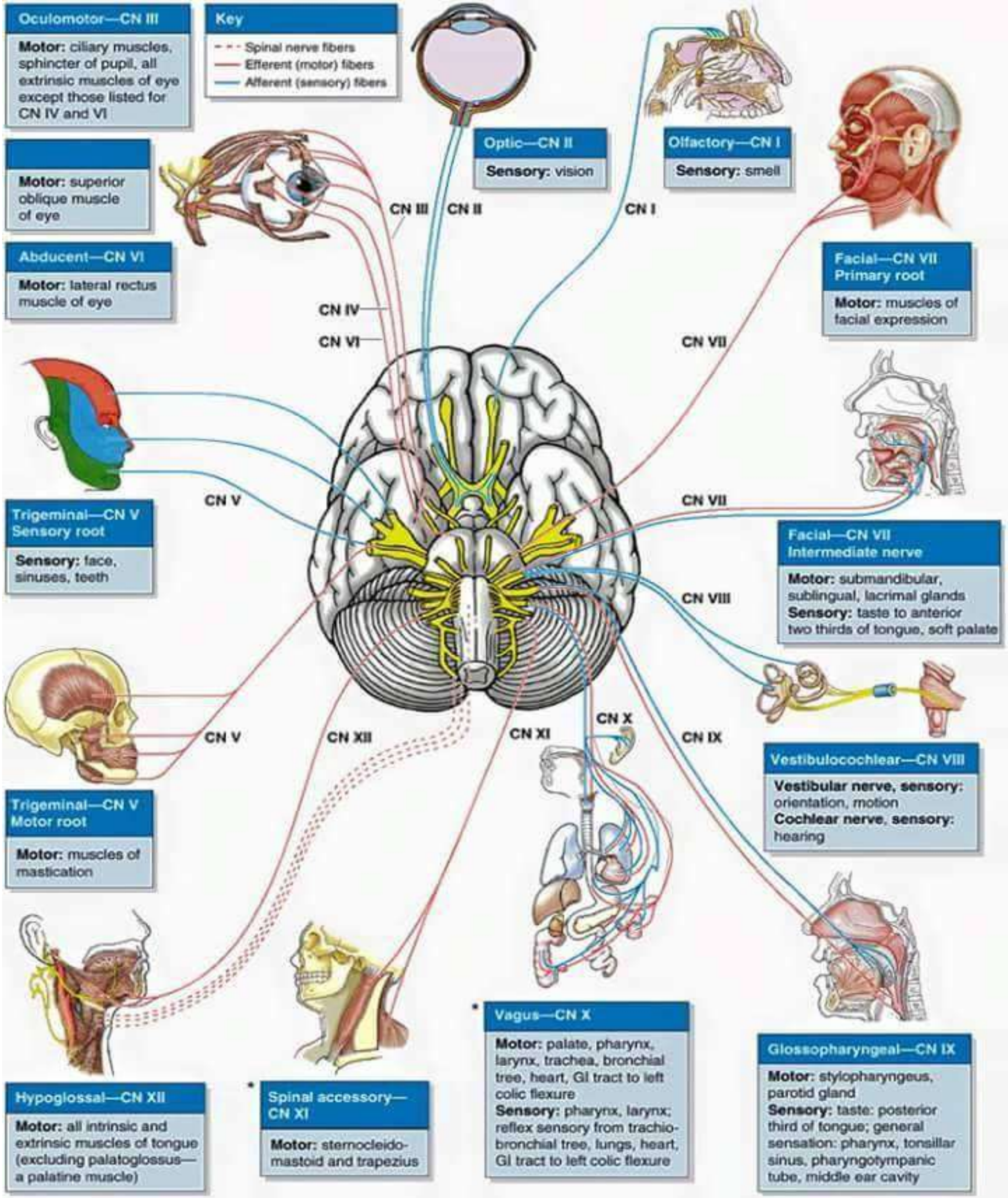



Figure II from Table 13.2


sensory fibres
motor fibres
Olfactory (I)
Sensory: nose
Oculomotor (III)
motor: all eye muscles except those supplied by IV and VI
Trochlear (IV)
motor: superior oblique muscle
Abducent (VI)
motor: external rectus muscle
Optic (II)
Sensory: eye
Intermediate nerve
Motor: submaxillary and sublingual gland
Sensory: anterior part of tongue and soft palate
intermediate nerve
Trigeminal (V)
sensory: face, sinuses, teeth, ect.
motor: muscles of mastication
Facial (VII)
Motor: muscles of the face
vestibular
cochlear
Vestibulocochlear (VIII)
sensory: inner ear
Vagus (X)
Motor: heart, lungs, bronchi, gastrointestinal tract
Sensory: heart, lungs, bronchi, trachea, larynx, pharynx, gastrointestinal tract, external ear
Glossopharyngeal (IX)
motor: pharyngeal musculature
sensory: posterior part of tongue, tonsil, pharynx
Hypoglossal (XII)
motor: muscles of the tongue
Accessory (XI)
motor: sternocleidomastoid and trapezius muscles


Olfactory
Optic
Oculomotor
Trigeminal
Trochlear
Abducens
Facial
Vestibulocochlear
Glossopharyngeal
Hypoglossal
Vagus
Cranial Accessory


Oculomotor—CN III
Motor: ciliary muscles, sphincter of pupil, all extrinsic muscles of eye except those listed for CN IV and VI
Key
Spinal nerve fibers
Efferent (motor) fibers
Afferent (sensory) fibers
Motor: superior oblique muscle of eye
Abducent—CN VI
Motor: lateral rectus muscle of eye
Optic—CN II
Sensory: vision
Olfactory—CN I
Sensory: smell
CN III
CN II
CN I
CN IV
CN VI
Facial—CN VII Primary root
Motor: muscles of facial expression
CN VII
CN V
Trigeminal—CN V Sensory root
Sensory: face, sinuses, teeth
CN VII
Facial—CN VII Intermediate nerve
Motor: submandibular, sublingual, lacrimal glands
Sensory: taste to anterior two thirds of tongue, soft palate
CN VIII
CN V
CN XII
CN XI
CN X
CN IX
Trigeminal—CN V Motor root
Motor: muscles of mastication
Vestibulocochlear—CN VIII
Vestibular nerve, sensory: orientation, motion
Cochlear nerve, sensory: hearing
Vagus—CN X
Motor: palate, pharynx, larynx, trachea, bronchial tree, heart, GI tract to left colic flexure
Sensory: pharynx, larynx; reflex sensory from trachiobronchial tree, lungs, heart, GI tract to left colic flexure
Glossopharyngeal—CN IX
Motor: stylopharyngeus, parotid gland
Sensory: taste: posterior third of tongue; general sensation: pharynx, tonsillar sinus, pharyngotympanic tube, middle ear cavity
Hypoglossal—CN XII
Motor: all intrinsic and extrinsic muscles of tongue (excluding palatoglossus—a palatine muscle)
Spinal accessory—CN XI
Motor: sternocleidomastoid and trapezius

# Cranial Nerve III: Oculomotor

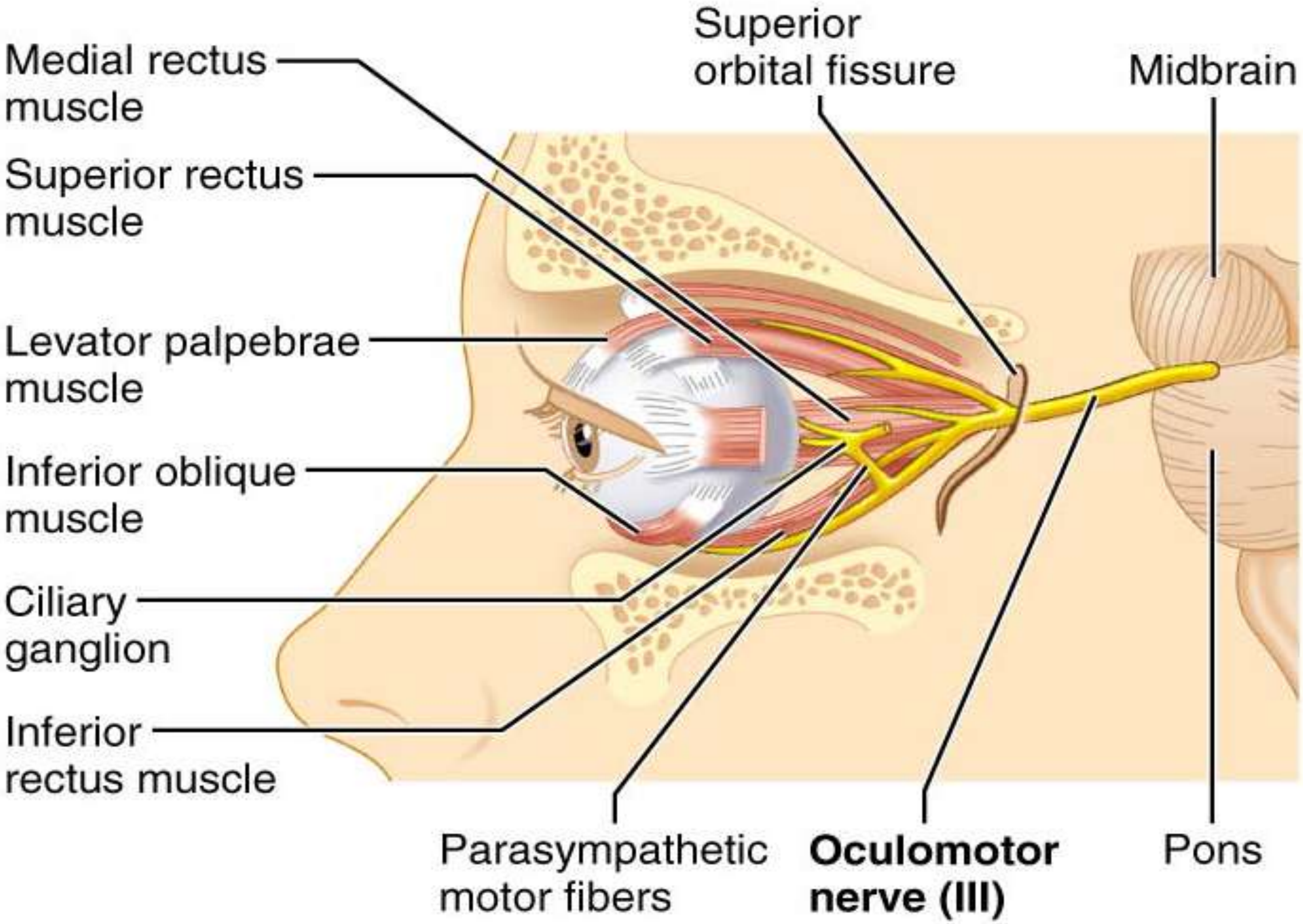



Figure III from Table 13.2

# Referred Pain

- Pain stimuli arising from the viscera are perceived as somatic in origin
- This may be due to the fact that visceral pain afferents travel along the same pathways as somatic pain fibers

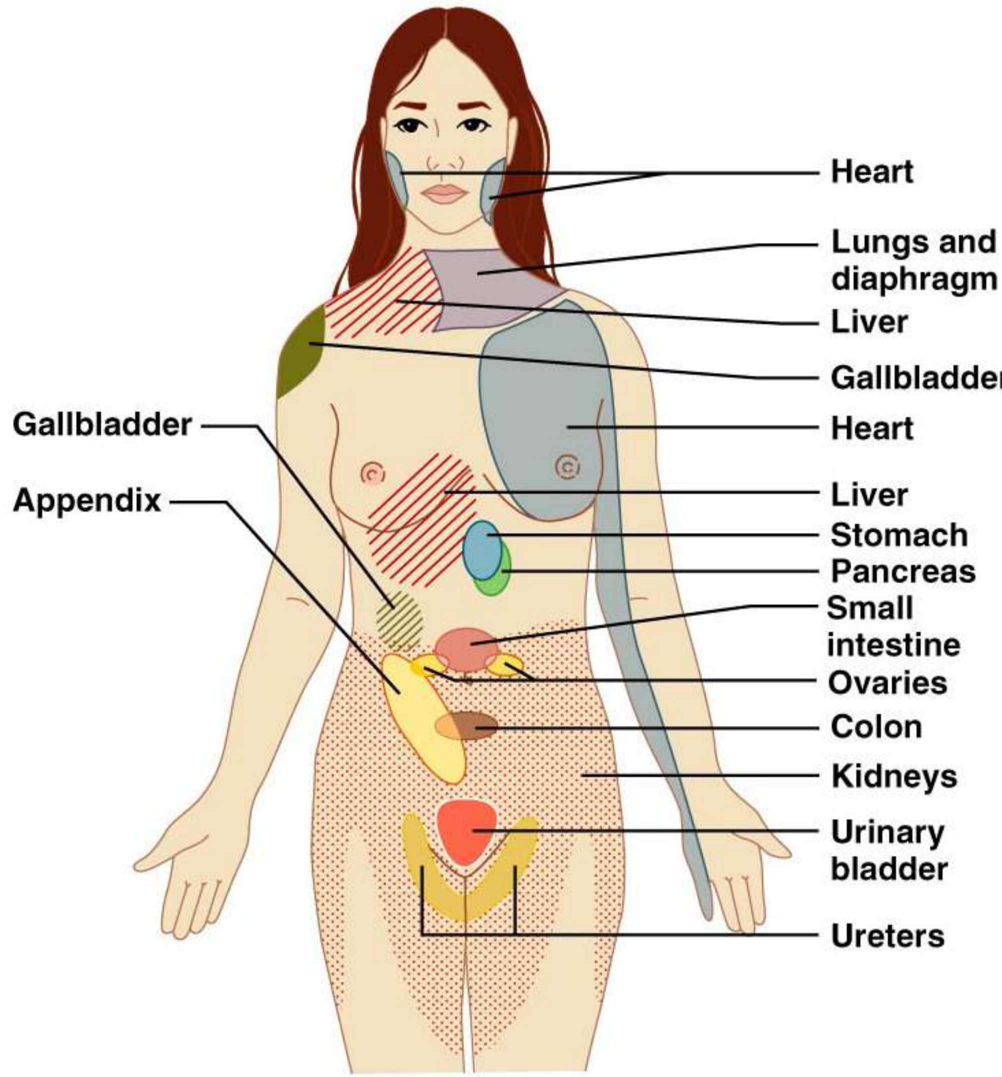



Figure 14.8