Table 10-1

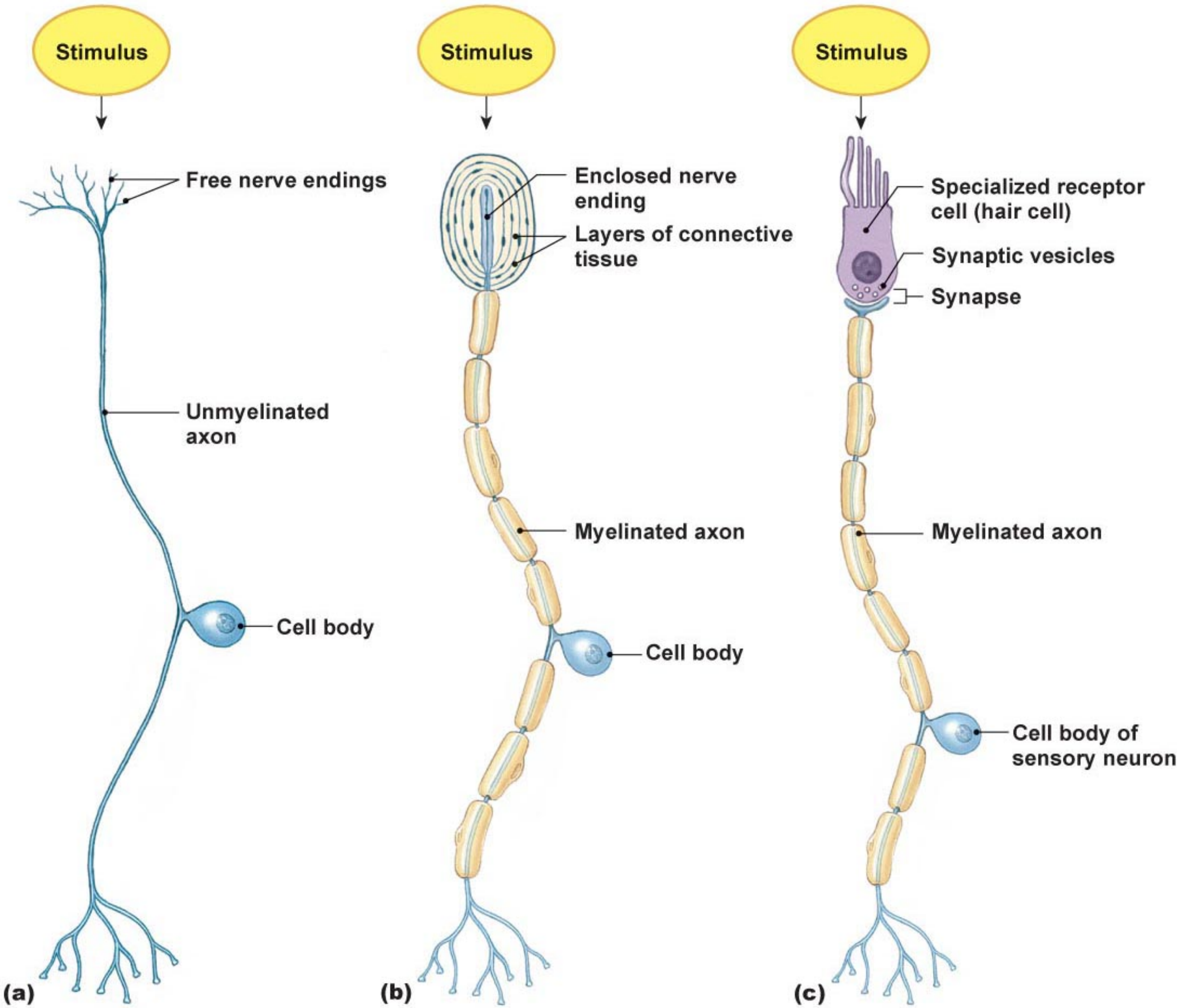
TABLE 10-1 Information Processing by the Sensory Division

STIMULUS PROCESSING IS USUALLY CONSCIOUS	
SPECIAL SENSES	SOMATIC SENSES
Vision	Touch
Hearing	Temperature
Taste	Pain
Smell	Itch
Equilibrium	Proprioception
PROCESSING IS USUALLY SUBCONSCIOUS	
SOMATIC STIMULI	VISCERAL STIMULI
Muscle length and tension	Blood pressure
Proprioception	• Distension of gastrointestinal tract • Blood glucose concentration • Internal body temperature • Osmolarity of body fluids • Lung inflation • pH of cerebrospinal fluid • pH and oxygen content of blood

Table 10-2

TABLE 10-2	Types of Sensory Receptors
TYPE OF RECEPTOR	EXAMPLES OF STIMULI
Chemoreceptors	Oxygen, pH, various organic molecules such as glucose
Mechanoreceptors	Pressure (baroreceptors), cell stretch (osmoreceptors), vibration, acceleration, sound
Photoreceptors	Photons of light
Thermoreceptors	Varying degrees of heat

Figure 10-1



Stimulus
Free nerve endings
Unmyelinated axon
Cell body
(a)
Stimulus
Enclosed nerve ending
Layers of connective tissue
Myelinated axon
Cell body
(b)
Stimulus
Specialized receptor cell (hair cell)
Synaptic vesicles
Synapse
Myelinated axon
Cell body of sensory neuron
(c)

Figure 10-2, overview

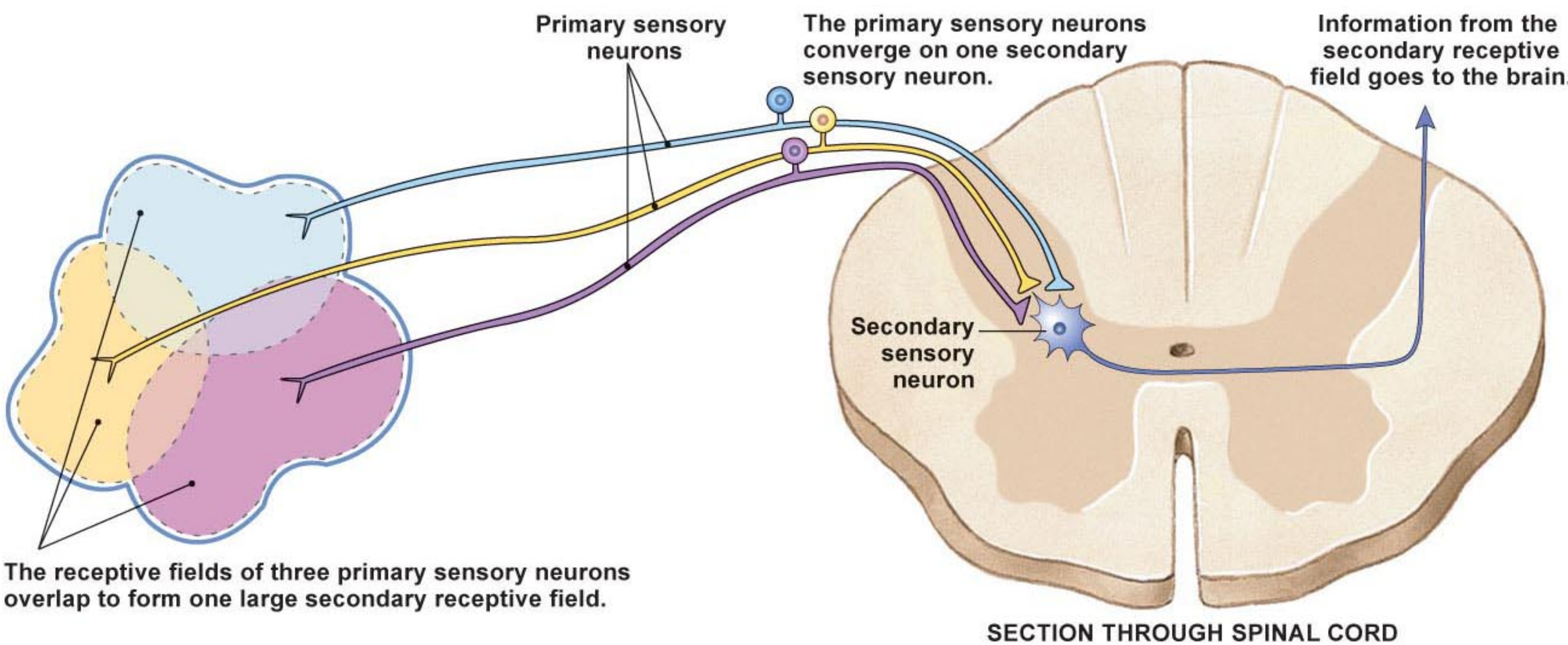
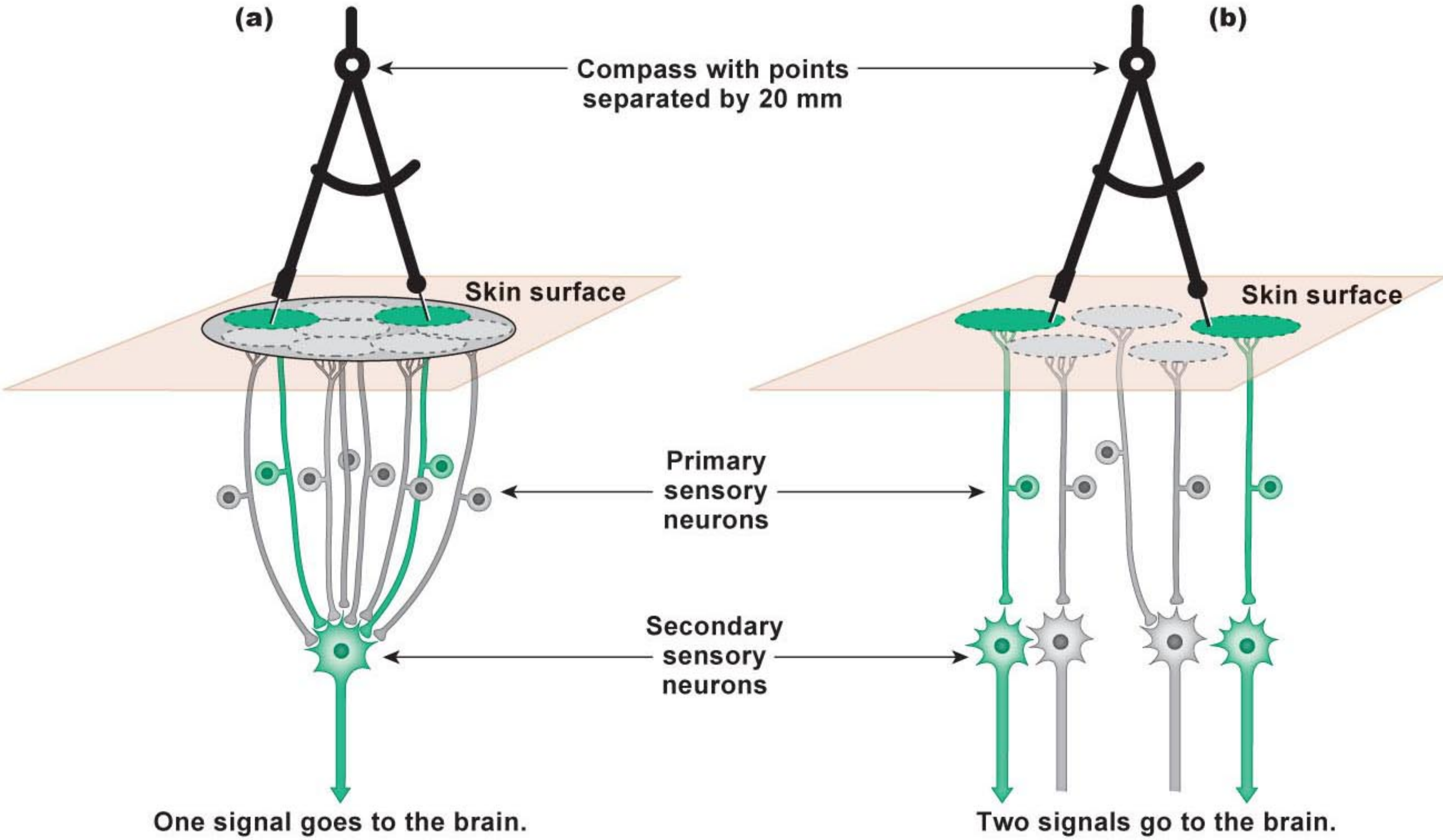


Table 10-3

TABLE 10-3 Sensory Pathways

	STIMULUS	
	FINE TOUCH, PROPRIOCEPTION, VIBRATION	IRRITANTS, TEMPERATURE, COARSE TOUCH
Primary sensory neuron terminates in:	Medulla	Dorsal horn of spinal cord
	Path crosses midline of body.	Path crosses midline of body.
Secondary sensory neuron terminates in:	Thalamus	Thalamus
Tertiary sensory neuron terminates in:	Somatosensory cortex	Somatosensory cortex

Figure 10-3



(a)
(b)
Compass with points
separated by 20 mm
Skin surface
Skin surface
Primary
sensory
neurons
Secondary
sensory
neurons
One signal goes to the brain.
Two signals go to the brain.

Figure 10-4, overview

1. Olfactory pathways from the nose project through the olfactory bulb to the olfactory cortex.
2. Most sensory pathways project to the thalamus. The thalamus modifies and relays information to cortical centers.
3. Equilibrium pathways project primarily to the cerebellum.

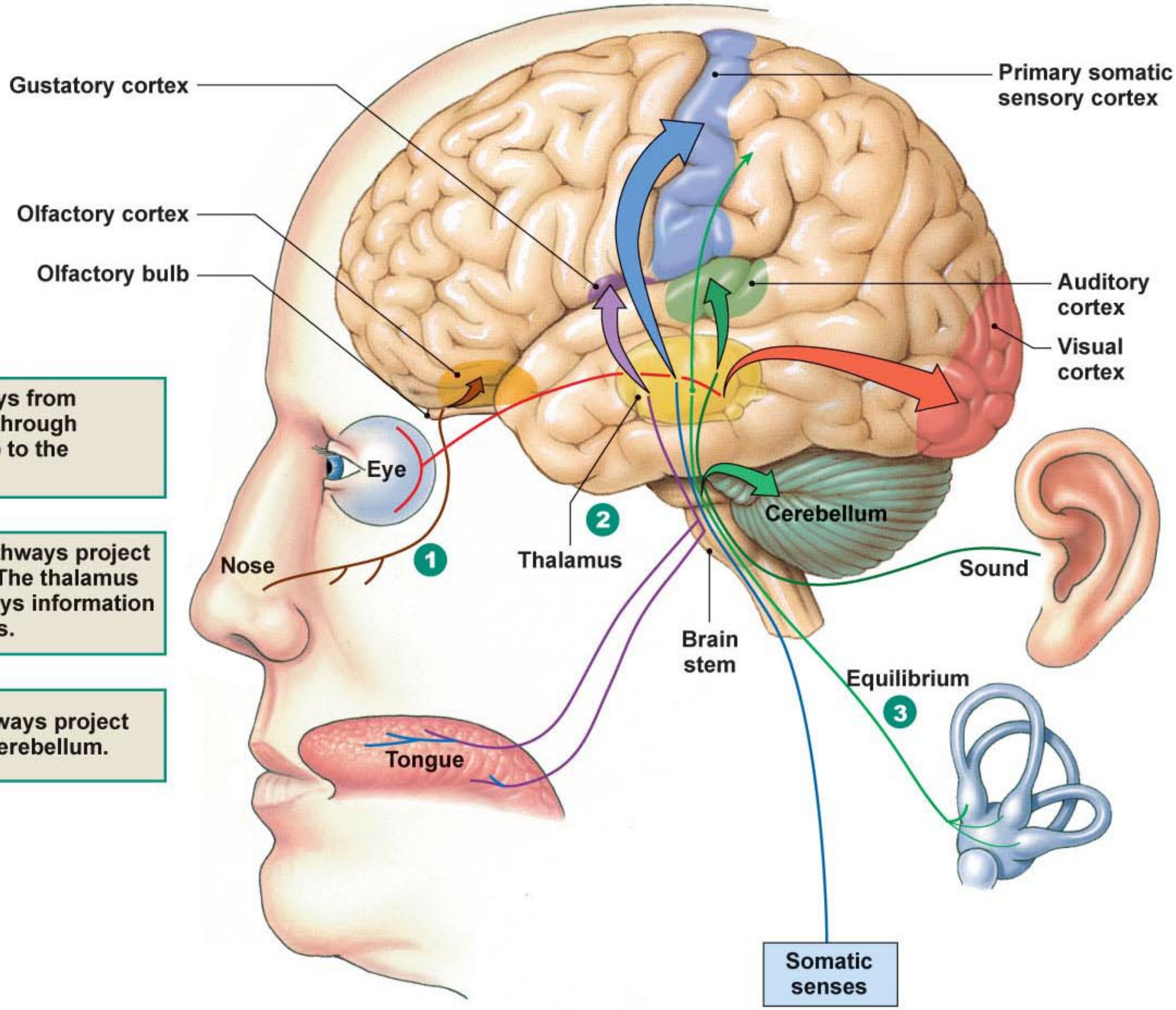


Figure 10-5

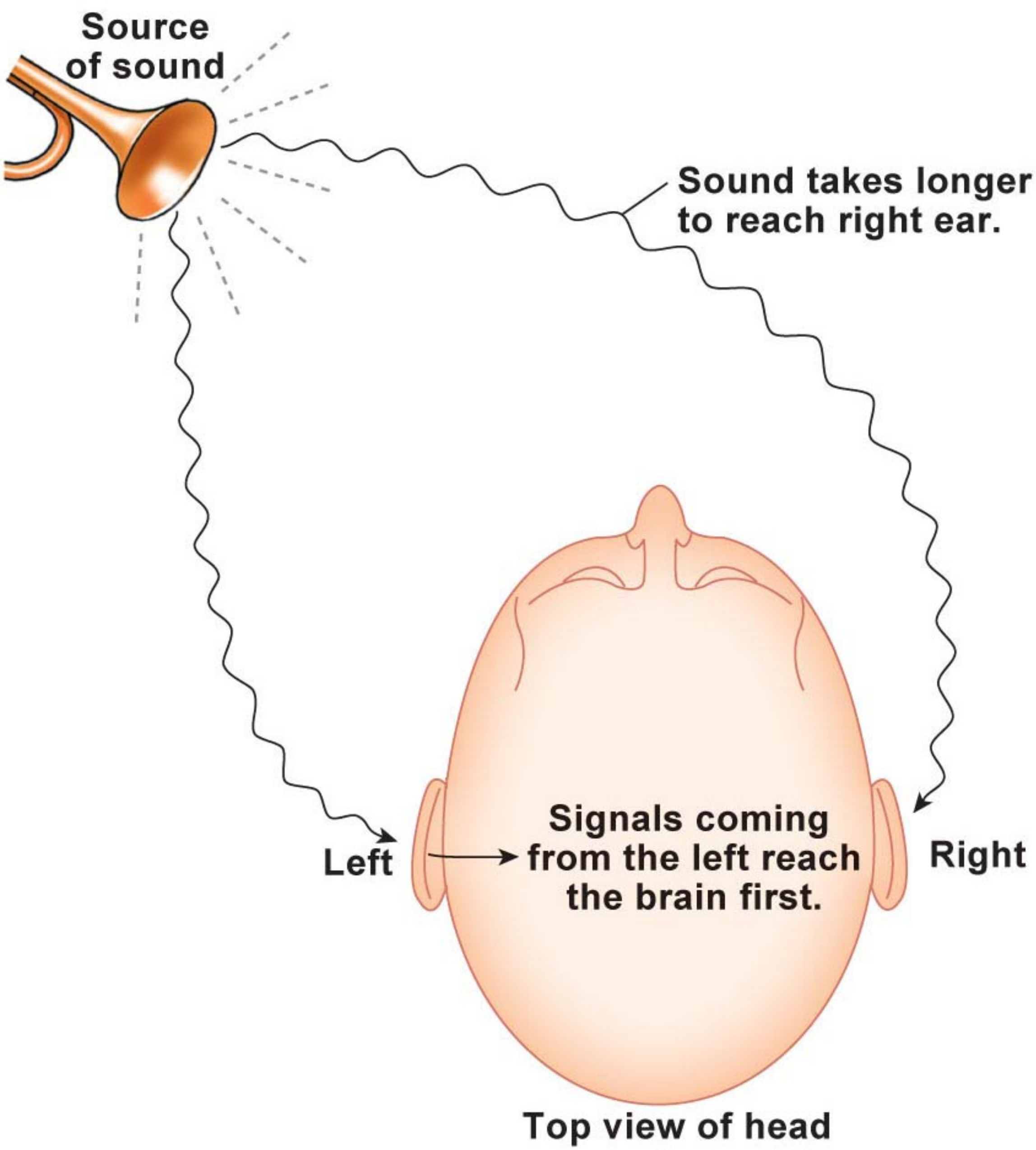
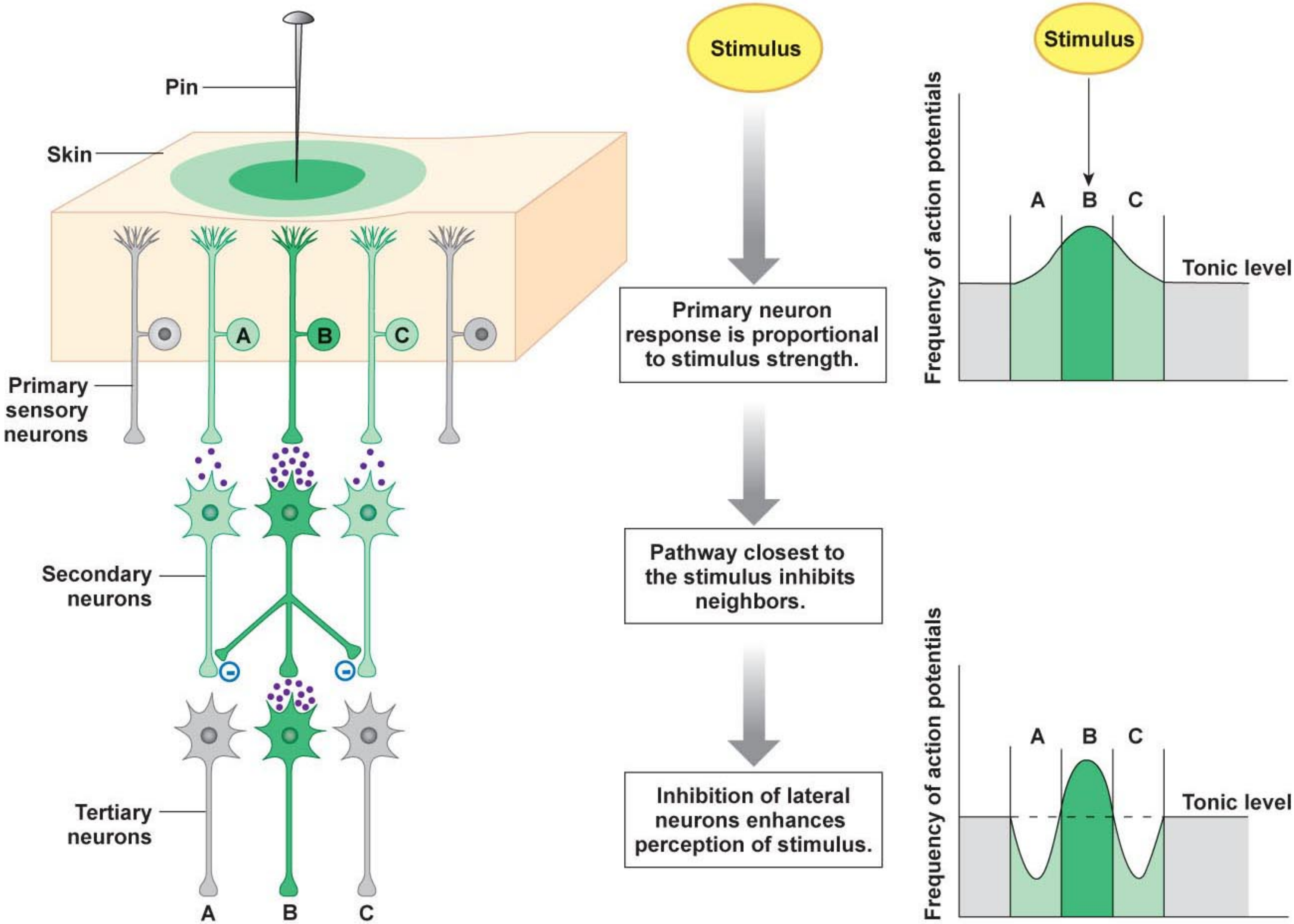

Source
of sound
Sound takes longer
to reach right ear.
Left
Signals coming
from the left reach
the brain first.
Right
Top view of head

Figure 10-6



Pin
Skin
A
B
C
Primary sensory neurons
Secondary neurons
Tertiary neurons
A
B
C
Stimulus
Primary neuron response is proportional to stimulus strength.
Pathway closest to the stimulus inhibits neighbors.
Inhibition of lateral neurons enhances perception of stimulus.
Stimulus
Frequency of action potentials
A
B
C
Tonic level
Frequency of action potentials
A
B
C
Tonic level

Figure 10-7

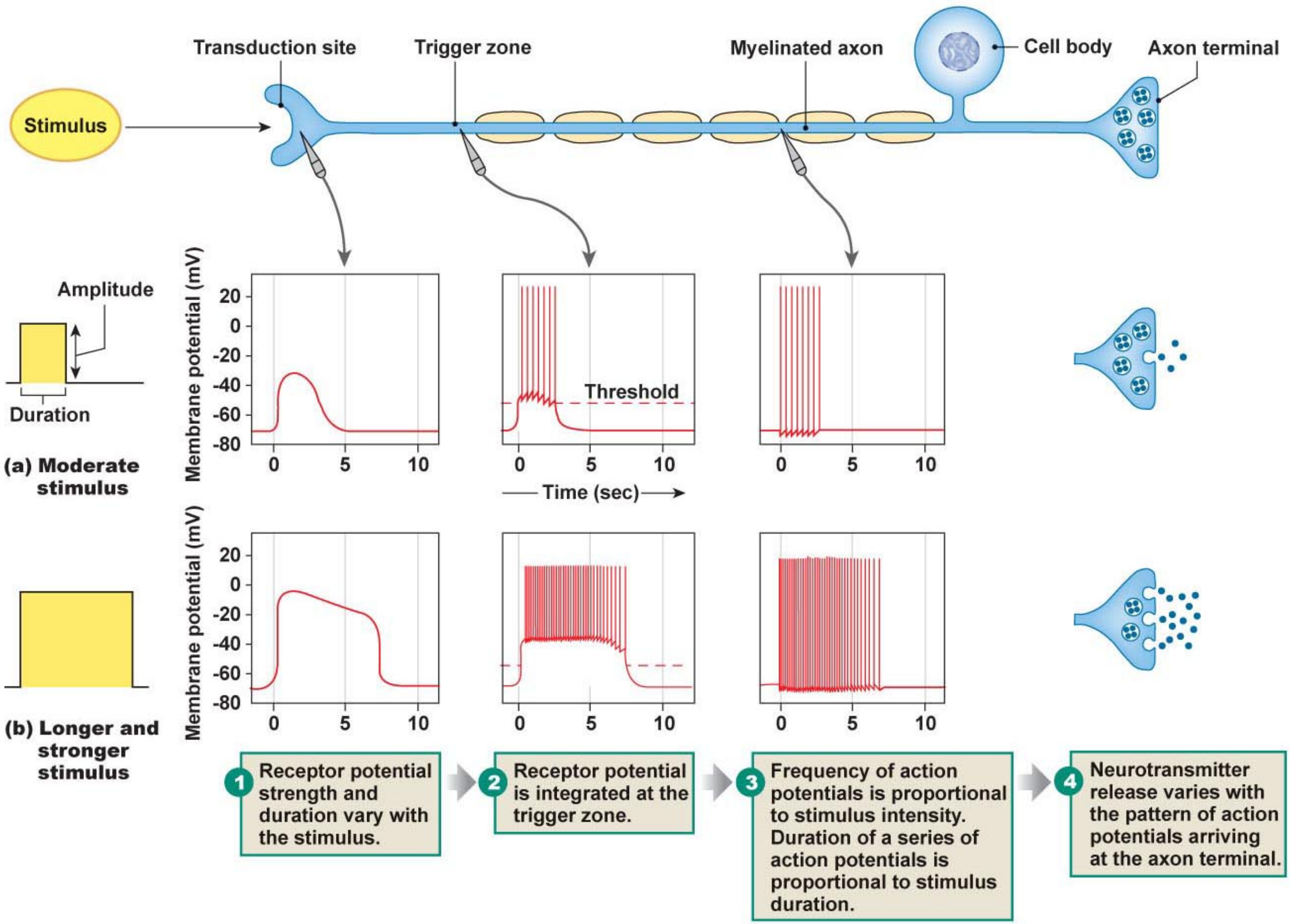

Transduction site
Trigger zone
Myelinated axon
Cell body
Axon terminal
Stimulus
Amplitude
Duration
(a) Moderate stimulus
(b) Longer and stronger stimulus
Membrane potential (mV)
20
0
-20
-40
-60
-80
0
5
10
Threshold
Time (sec)
1 Receptor potential strength and duration vary with the stimulus.
2 Receptor potential is integrated at the trigger zone.
3 Frequency of action potentials is proportional to stimulus intensity. Duration of a series of action potentials is proportional to stimulus duration.
4 Neurotransmitter release varies with the pattern of action potentials arriving at the axon terminal.

Figure 10-9, overview

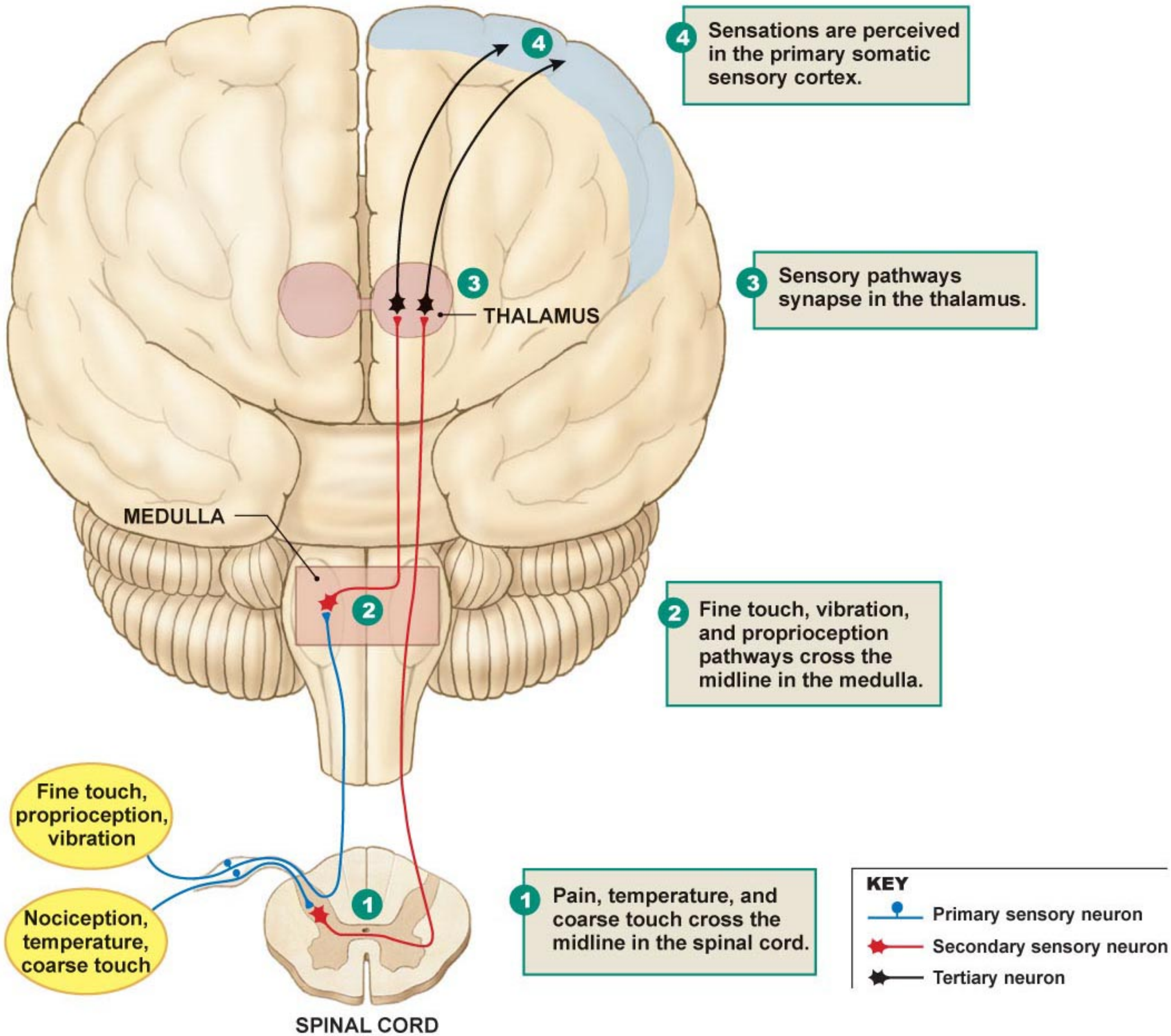
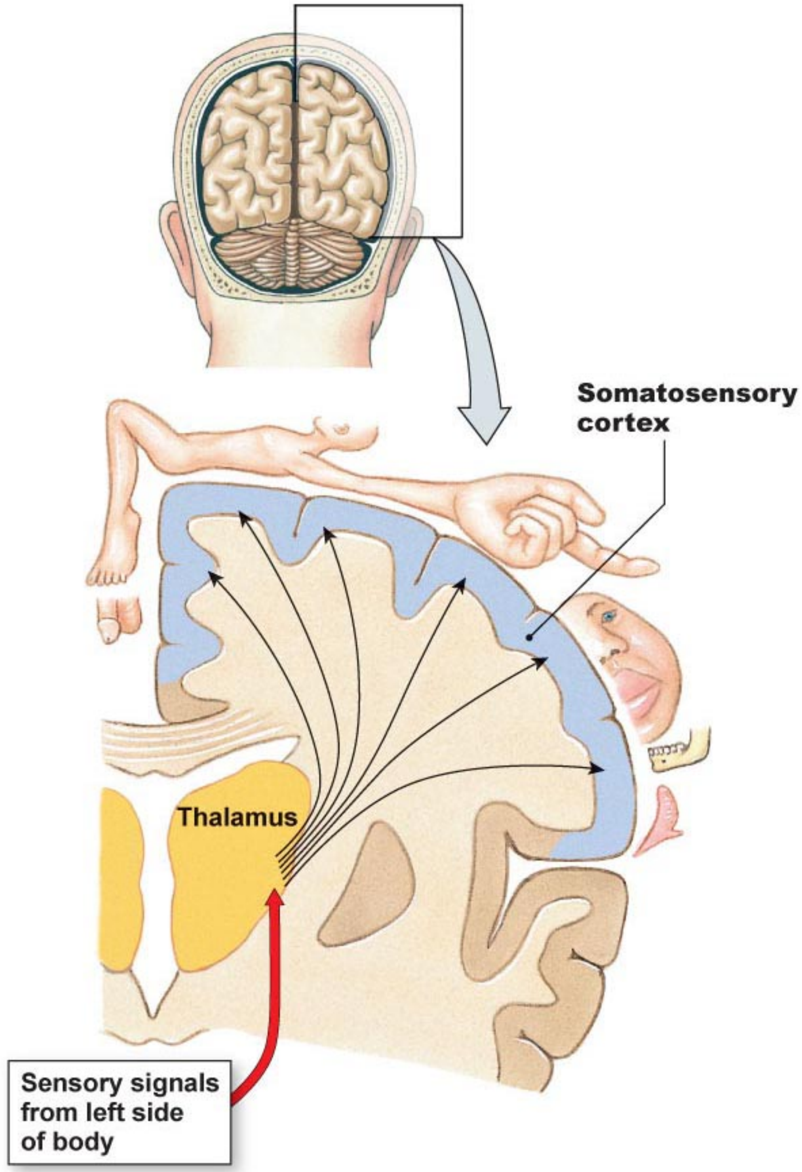


Figure 10-10



Cross section of the right cerebral hemisphere
and sensory areas of the cerebral cortex

Figure 10-11

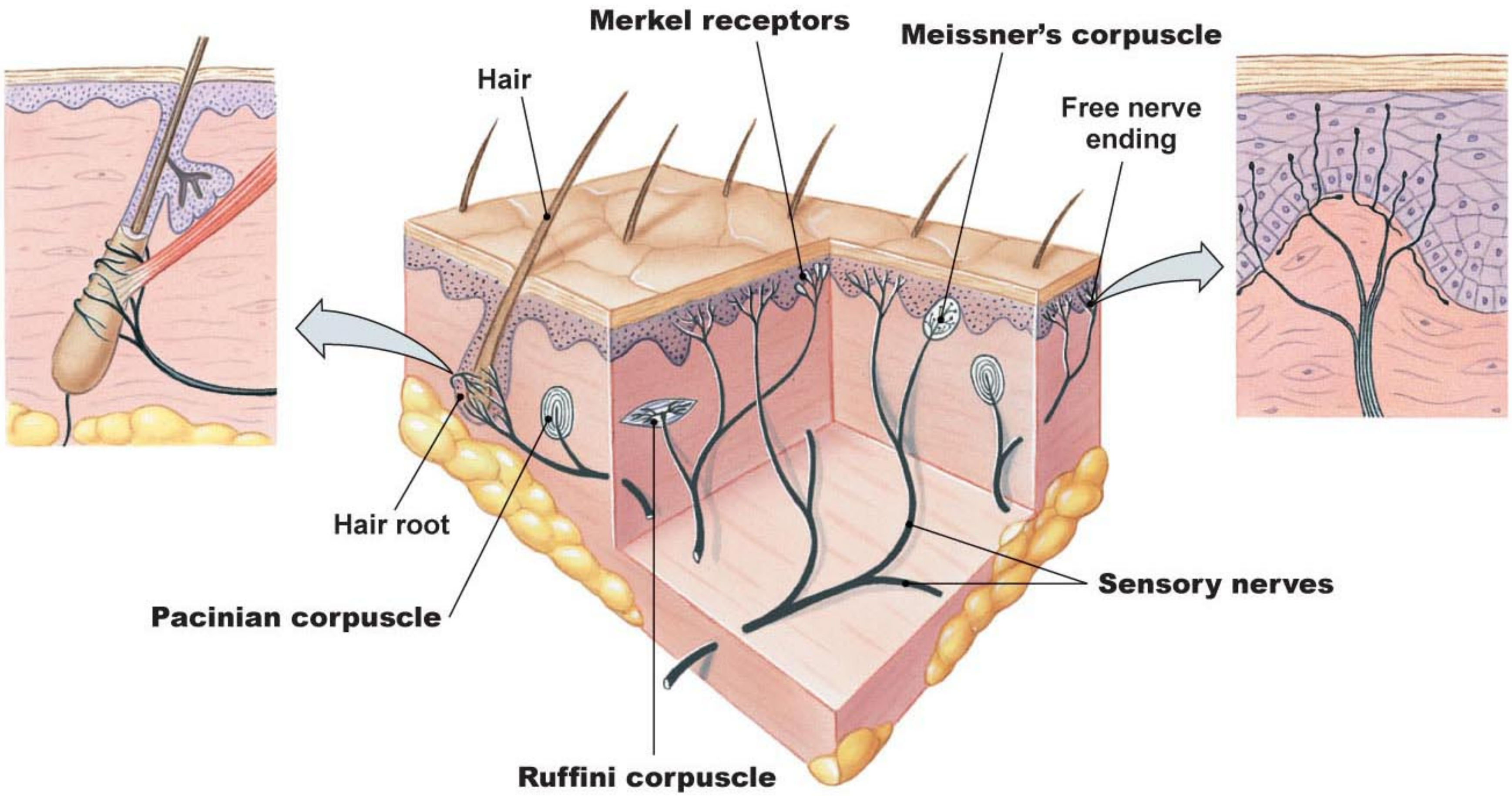

Merkel receptors
Meissner's corpuscle
Hair
Free nerve
ending
Hair root
Pacinian corpuscle
Sensory nerves
Ruffini corpuscle

Figure 10-12

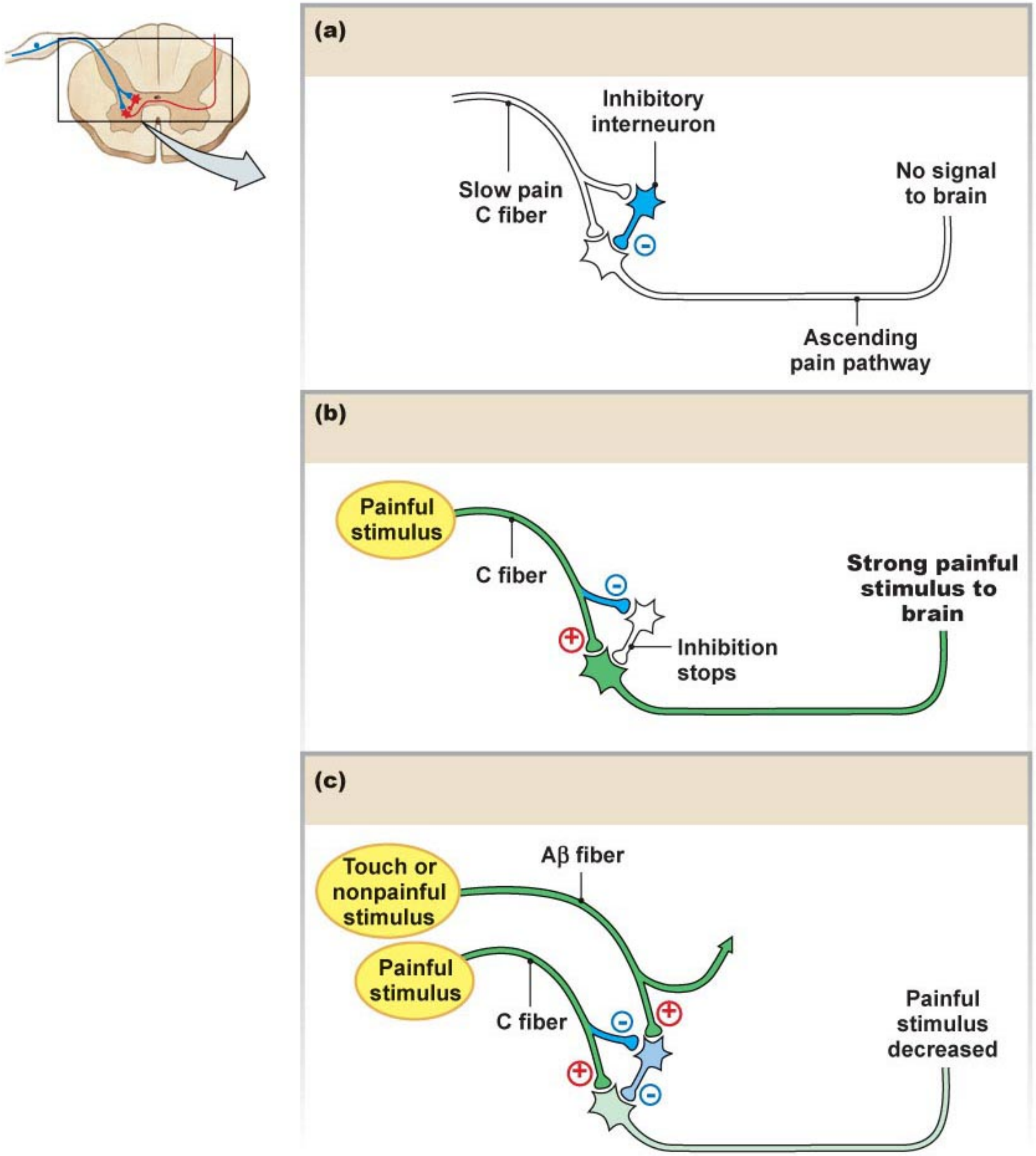
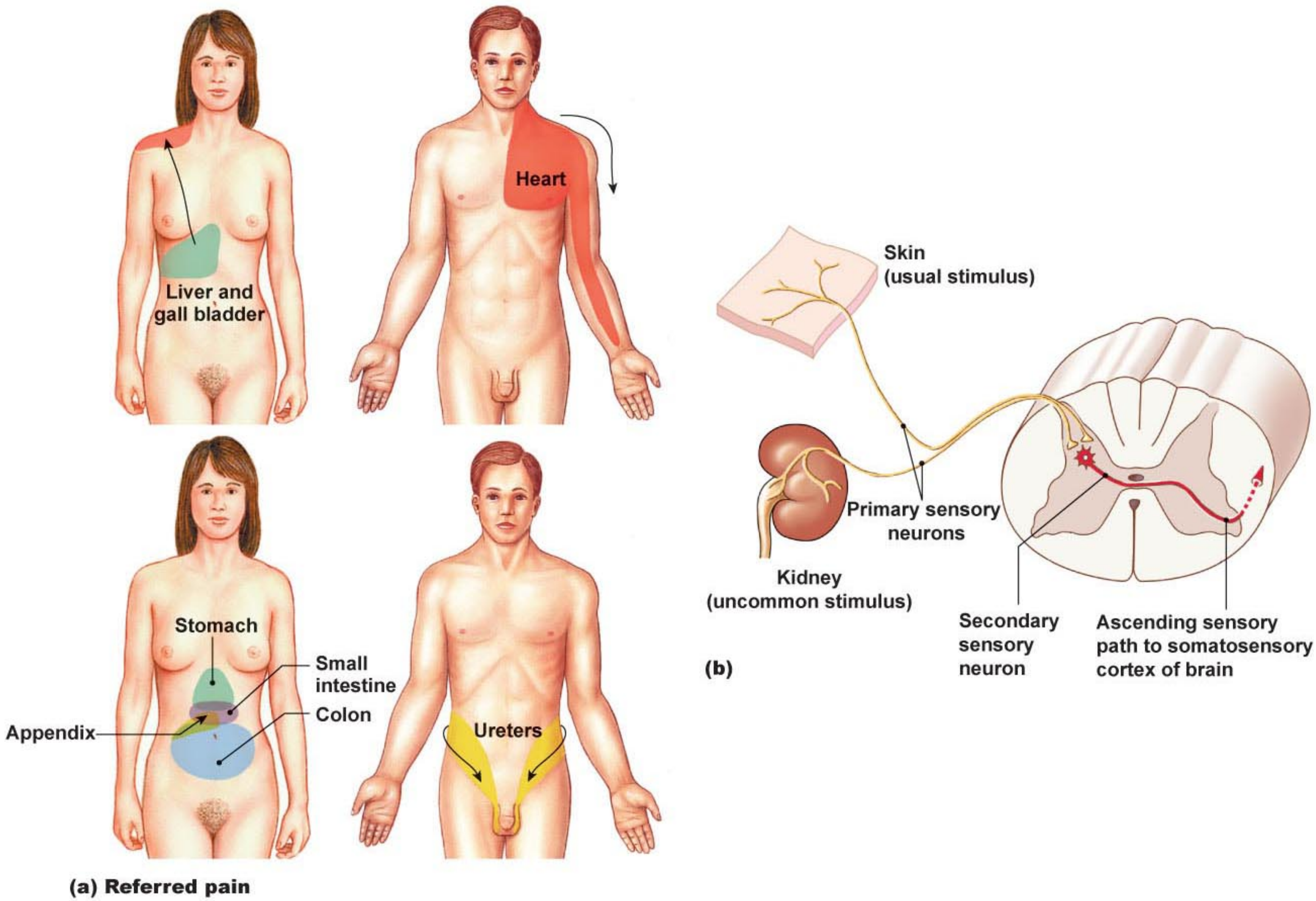

(a)
Inhibitory interneuron
Slow pain C fiber
No signal to brain
Ascending pain pathway
(b)
Painful stimulus
C fiber
Strong painful stimulus to brain
Inhibition stops
(c)
Aβ fiber
Touch or nonpainful stimulus
Painful stimulus
C fiber
Painful stimulus decreased

Figure 10-13



Liver and gall bladder
Heart
Stomach
Small intestine
Colon
Appendix
Ureters
(a) Referred pain
Skin (usual stimulus)
Kidney (uncommon stimulus)
Primary sensory neurons
Secondary sensory neuron
Ascending sensory path to somatosensory cortex of brain
(b)

Figure 10-14

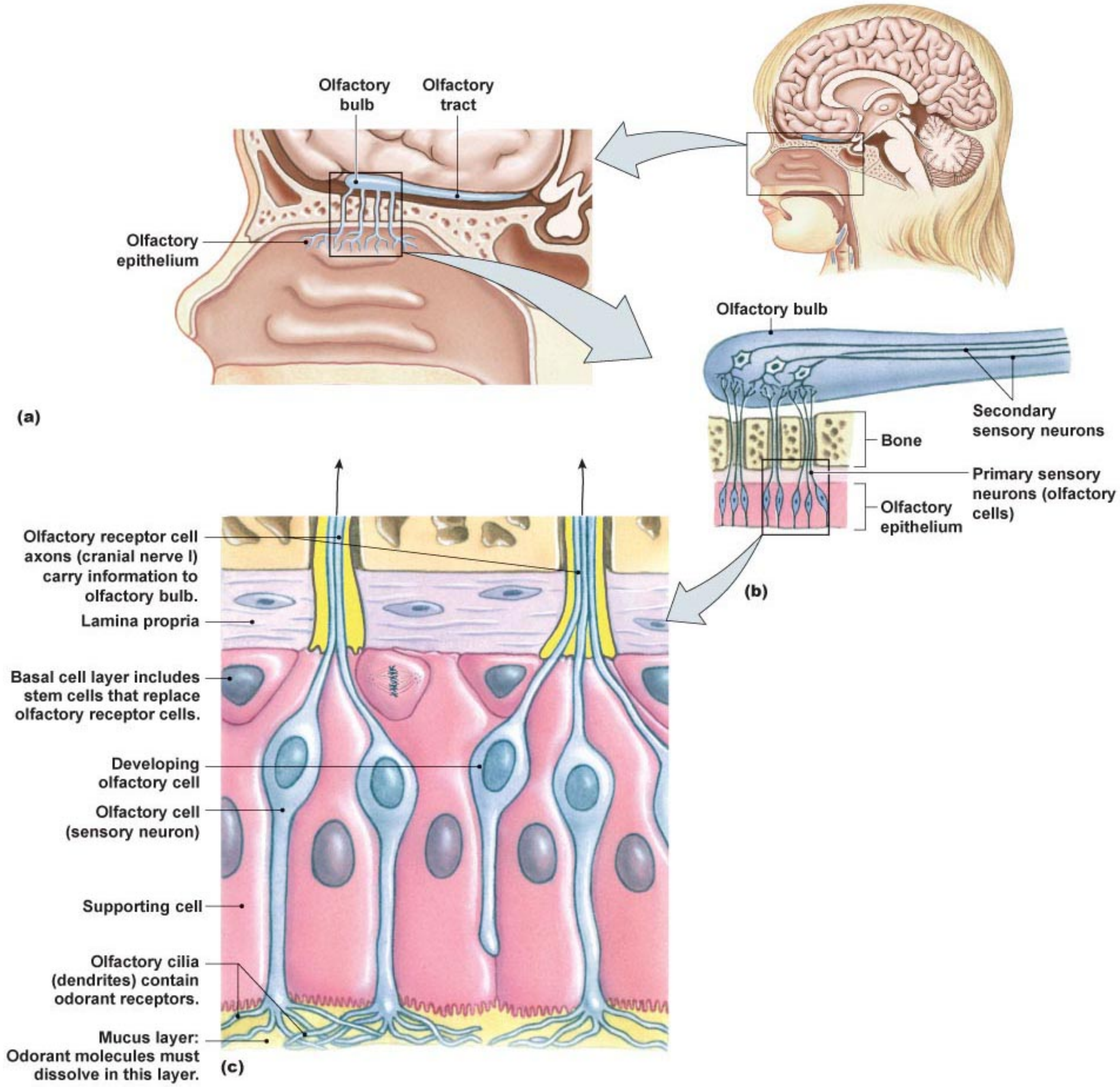
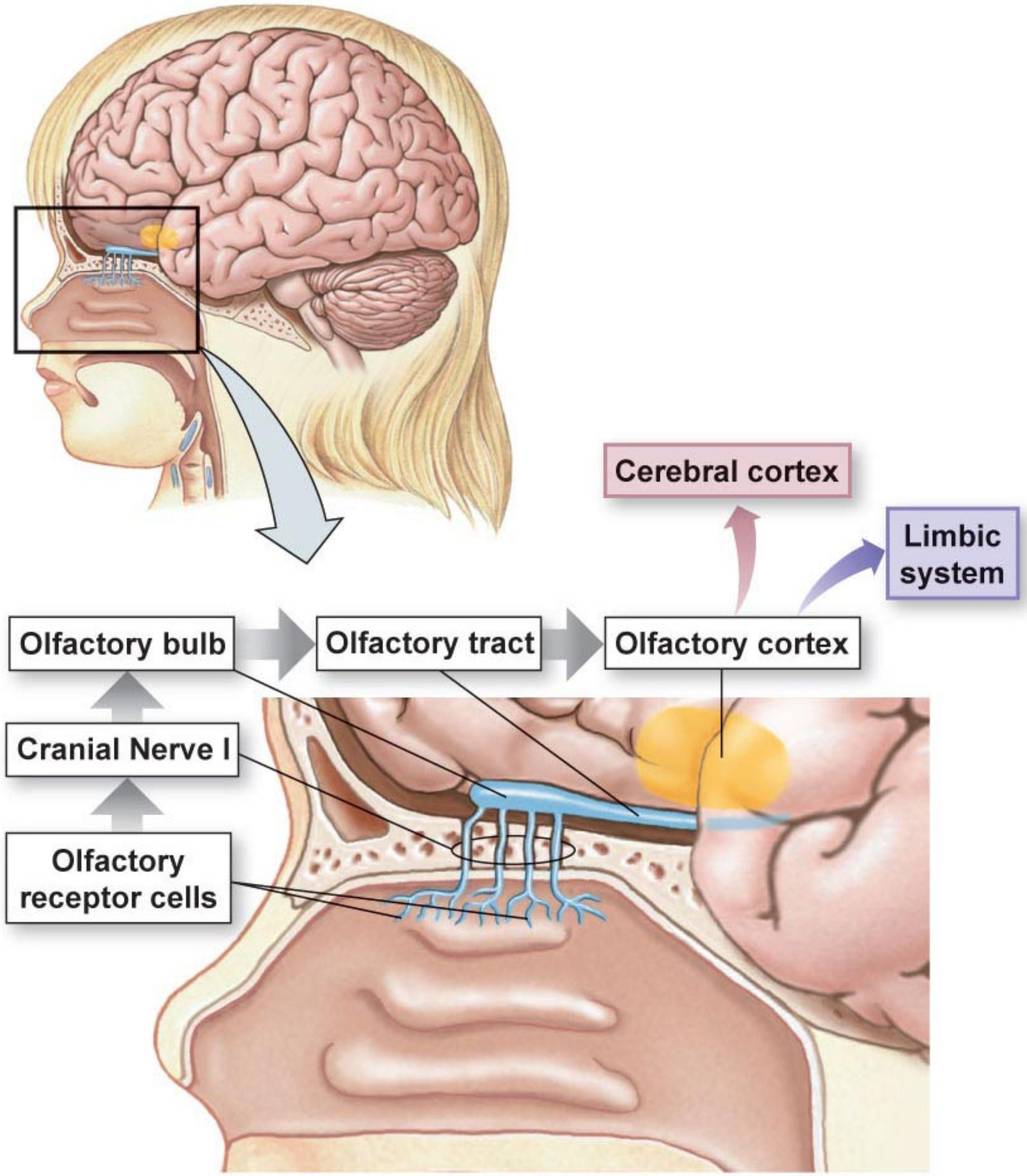
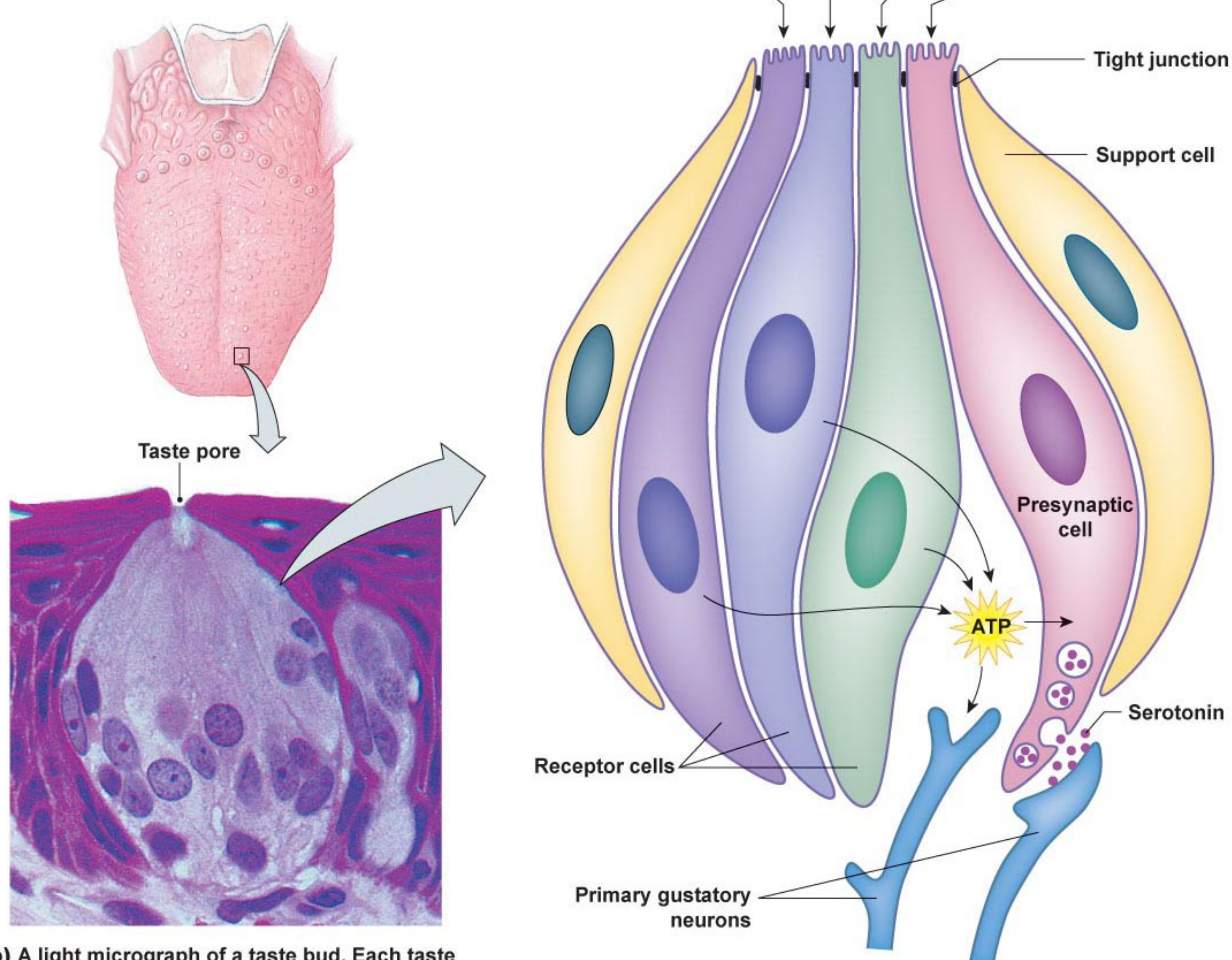

Olfactory bulb
Olfactory tract
Olfactory epithelium
(a)
Olfactory bulb
Secondary sensory neurons
Bone
Primary sensory neurons (olfactory cells)
Olfactory epithelium
(b)
Olfactory receptor cell axons (cranial nerve I) carry information to olfactory bulb.
Lamina propria
Basal cell layer includes stem cells that replace olfactory receptor cells.
Developing olfactory cell
Olfactory cell (sensory neuron)
Supporting cell
Olfactory cilia (dendrites) contain odorant receptors.
Mucus layer: Odorant molecules must dissolve in this layer.
(c)

Figure 10-15



Cerebral cortex
Limbic system
Olfactory bulb
Olfactory tract
Olfactory cortex
Cranial Nerve I
Olfactory receptor cells

Figure 10-16



(a) Taste buds are located on the dorsal surface of the tongue.

(b) A light micrograph of a taste bud. Each taste bud is composed of taste cells and support cells, joined near the apical surface with tight junctions.

(c) Taste ligands create Ca^{2+} signals that release serotonin or ATP.

Figure 10-17, overview

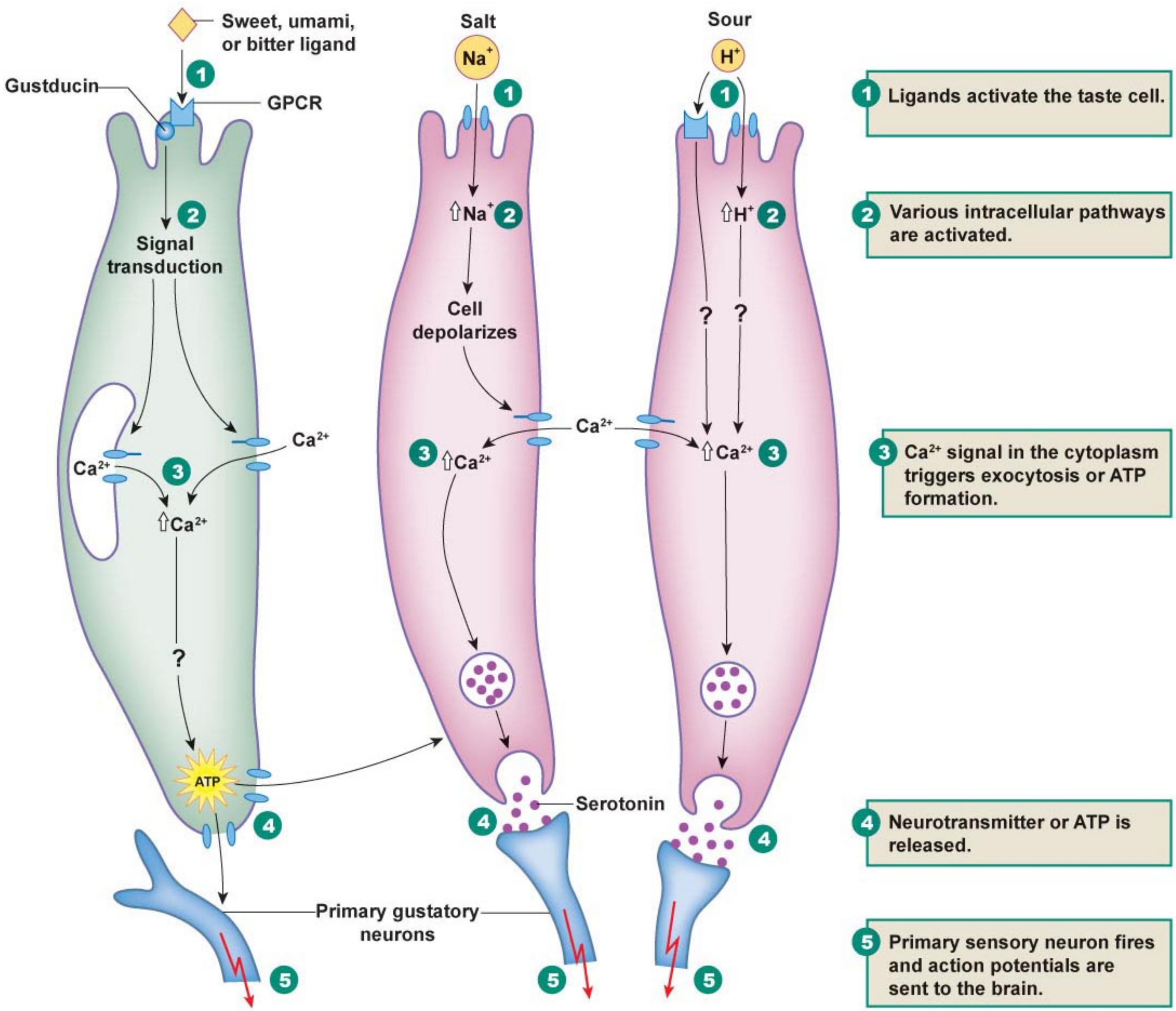
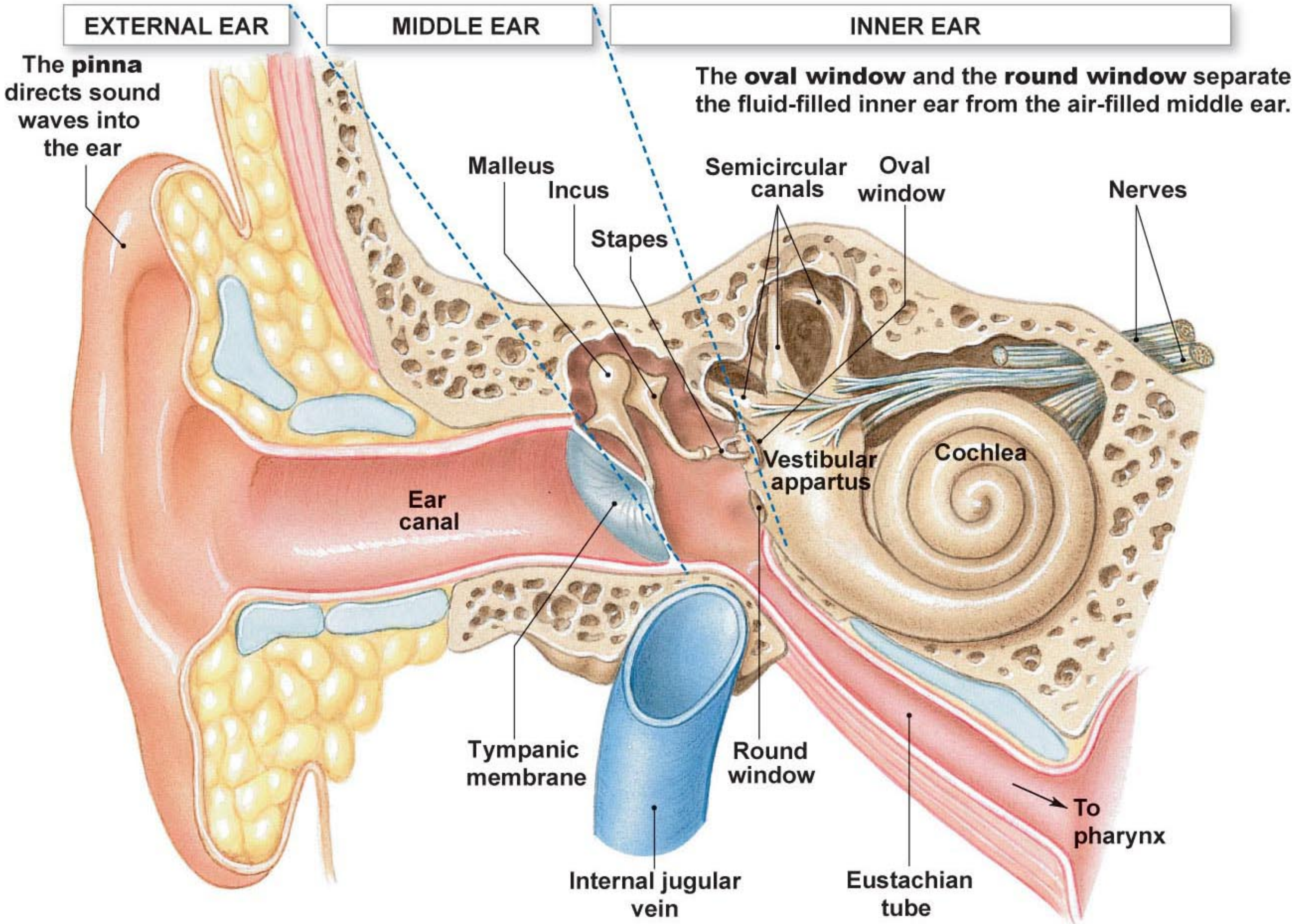
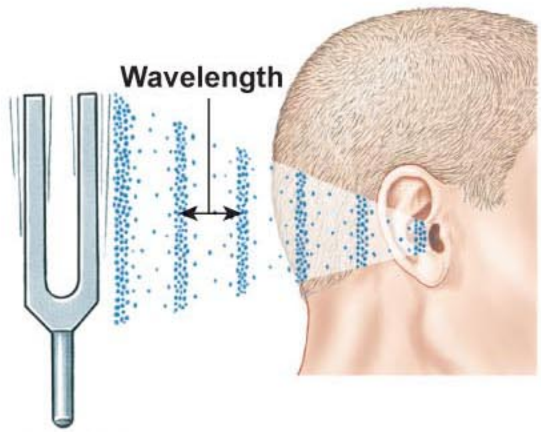


Figure 10-18

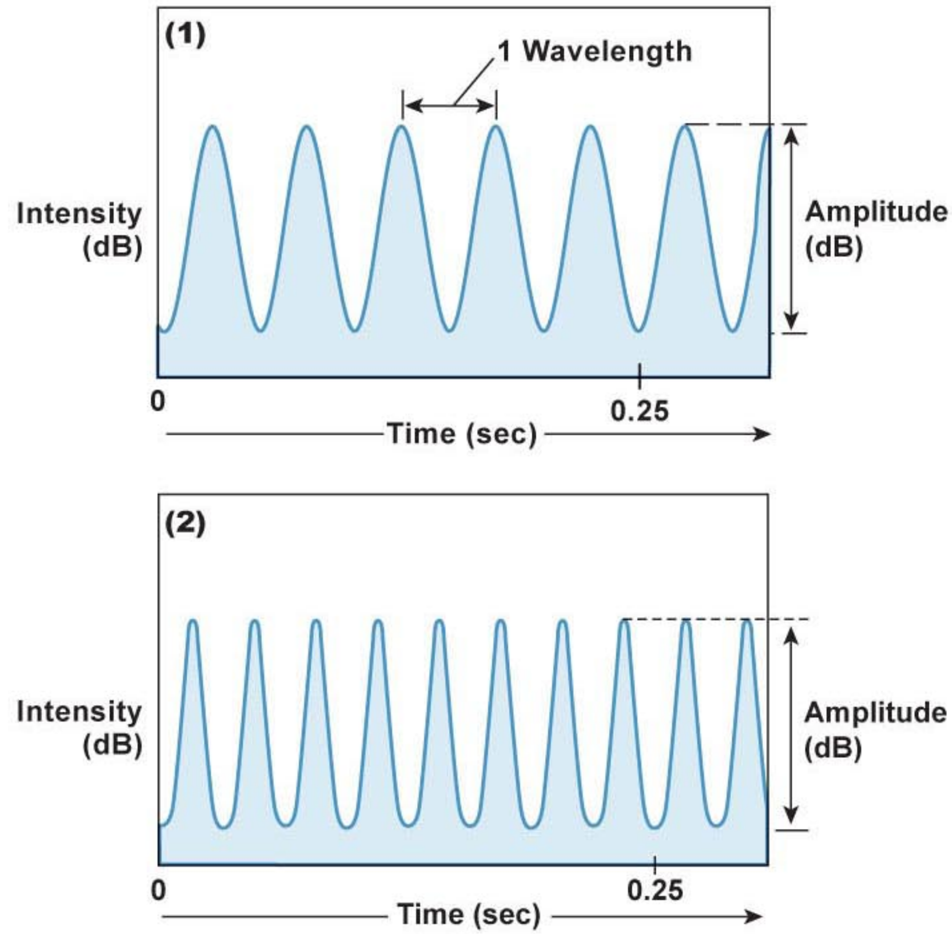


EXTERNAL EAR
MIDDLE EAR
INNER EAR
The **pinna** directs sound waves into the ear
The **oval window** and the **round window** separate the fluid-filled inner ear from the air-filled middle ear.
Malleus
Incus
Stapes
Semicircular canals
Oval window
Nerves
Vestibular appartus
Cochlea
Ear canal
Tympanic membrane
Round window
To pharynx
Internal jugular vein
Eustachian tube

Figure 10-19



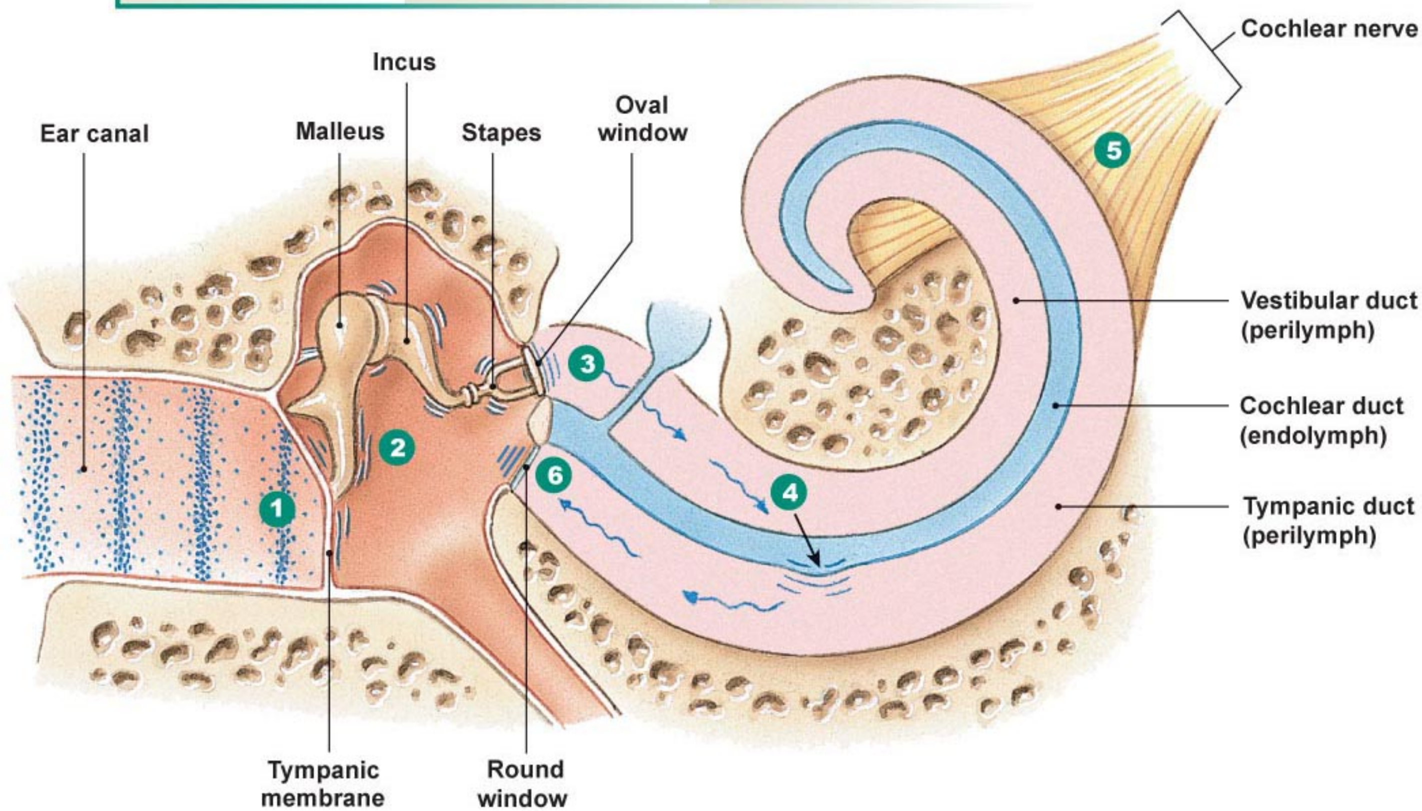
(a) Sound waves alternate peaks of compressed air and valleys where the air is less compressed.



(b) Sound waves are distinguished by their amplitude, measured in decibels (dB), and frequency, measured in hertz (Hz).

Figure 10-20, overview-0

1. Sound waves strike the tympanic membrane and become vibrations.
2. The sound wave energy is transferred to the three bones of the middle ear, which vibrate.
3. The stapes is attached to the membrane of the oval window. Vibrations of the oval window create fluid waves within the cochlea.



4. The fluid waves push on the flexible membranes of the cochlear duct. Hair cells bend and ion channels open, creating an electrical signal that alters neurotransmitter release.
5. Neurotransmitter release onto sensory neurons creates action potentials that travel through the cochlear nerve to the brain.
6. Energy from the waves transfers across the cochlear duct into the tympanic duct and is dissipated back into the middle ear at the round window.

Figure 10-21, overview

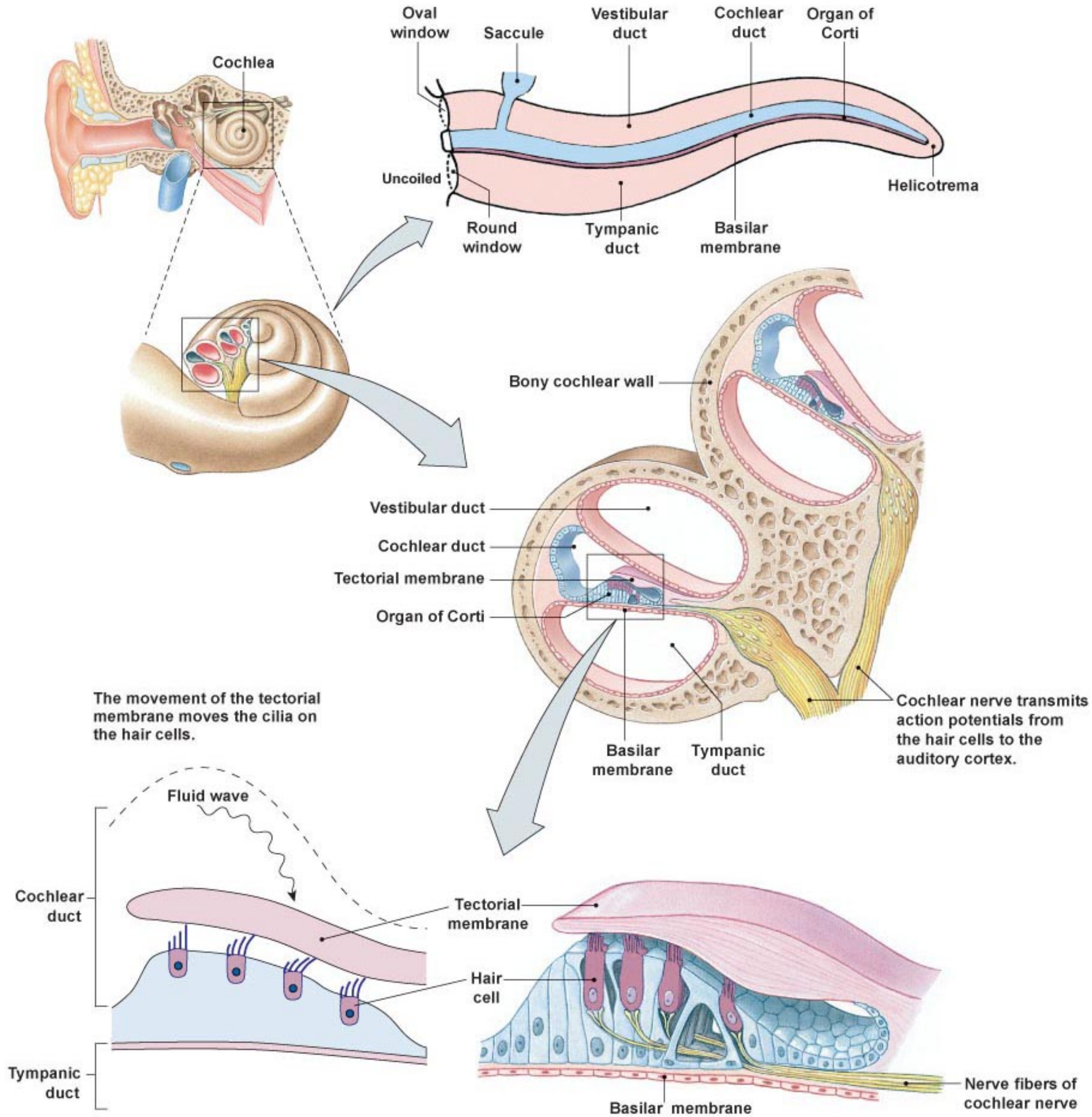


Figure 10-22

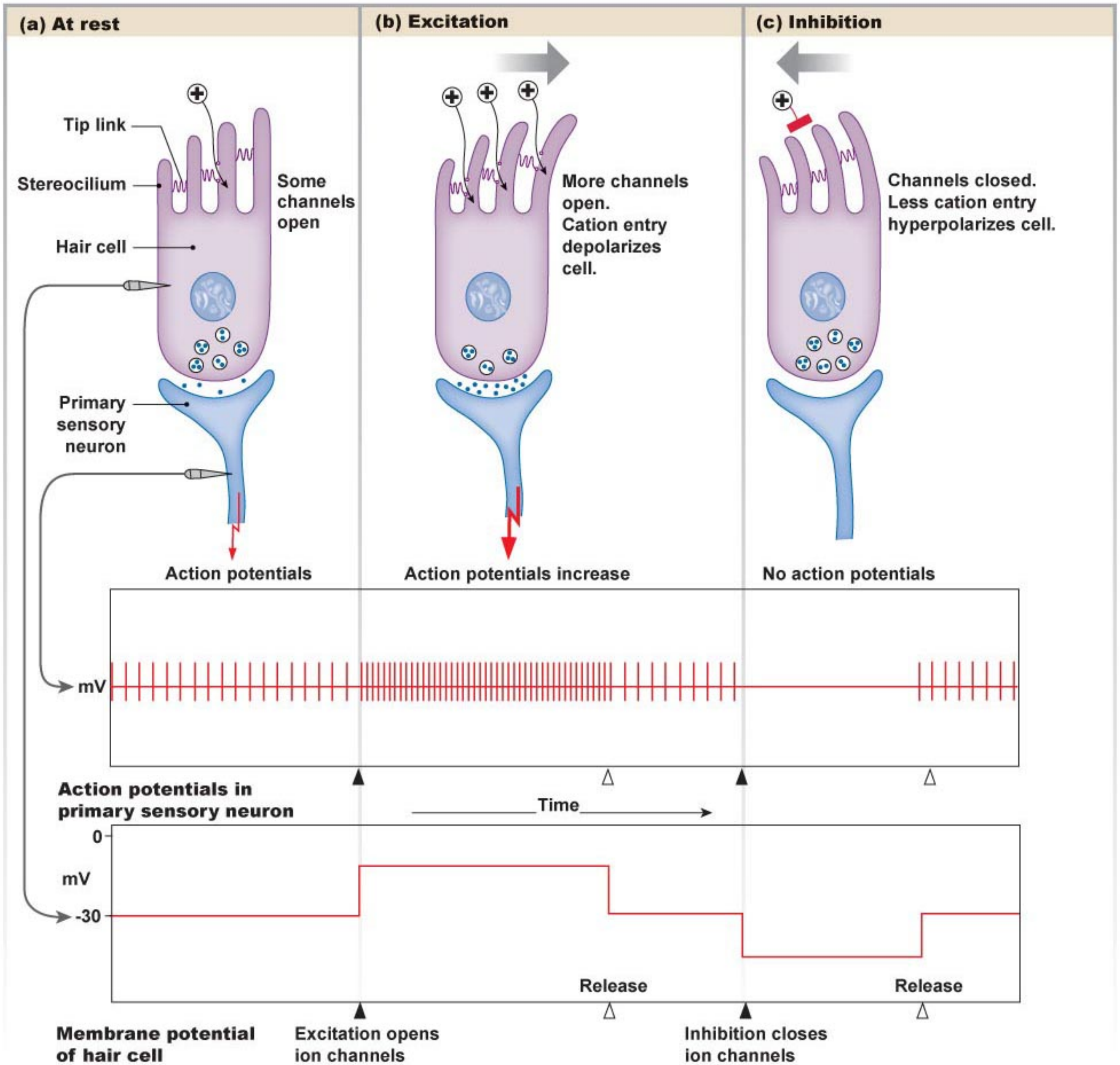

(a) At rest
(b) Excitation
(c) Inhibition
Tip link
Stereocilium
Hair cell
Primary sensory neuron
Some channels open
More channels open. Cation entry depolarizes cell.
Channels closed. Less cation entry hyperpolarizes cell.
Action potentials
Action potentials increase
No action potentials
mV
Action potentials in primary sensory neuron
Time
0
mV
-30
Release
Release
Membrane potential of hair cell
Excitation opens ion channels
Inhibition closes ion channels

Figure 10-23

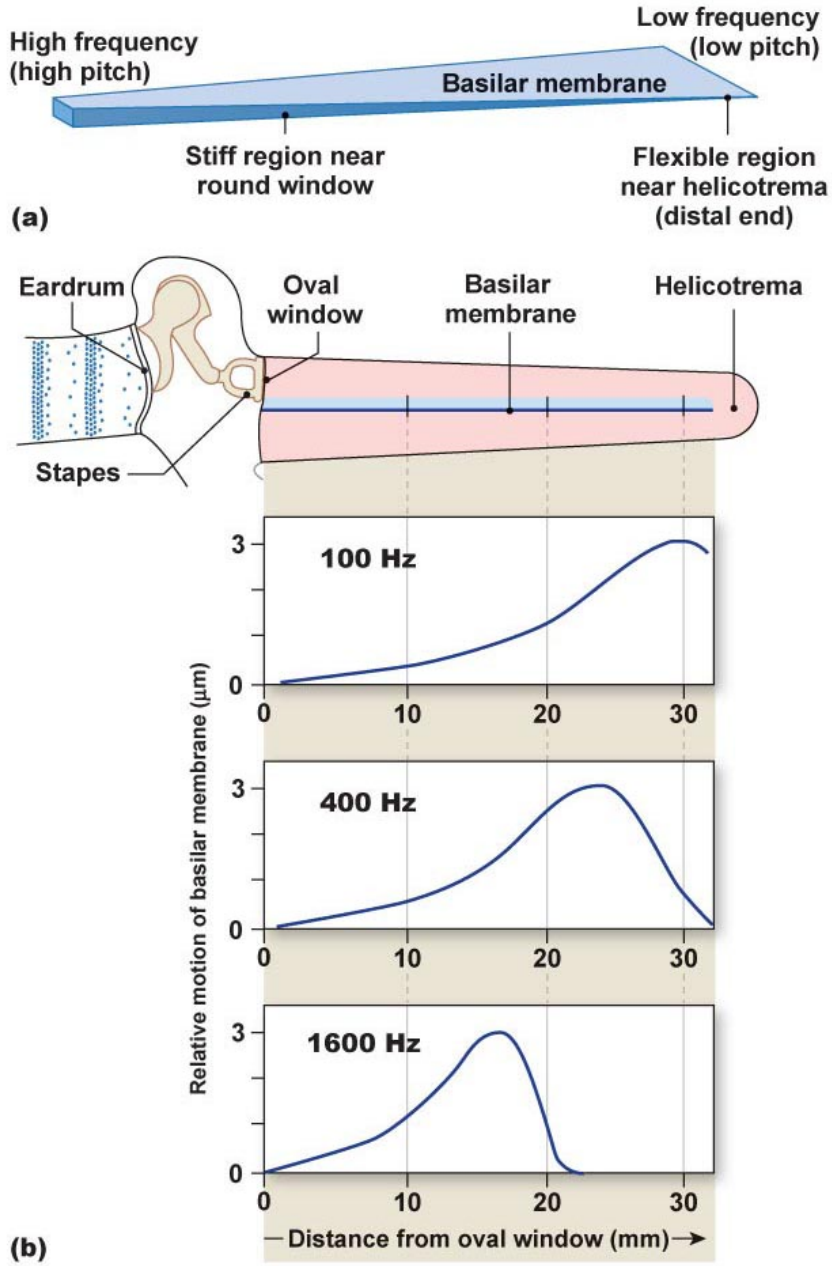
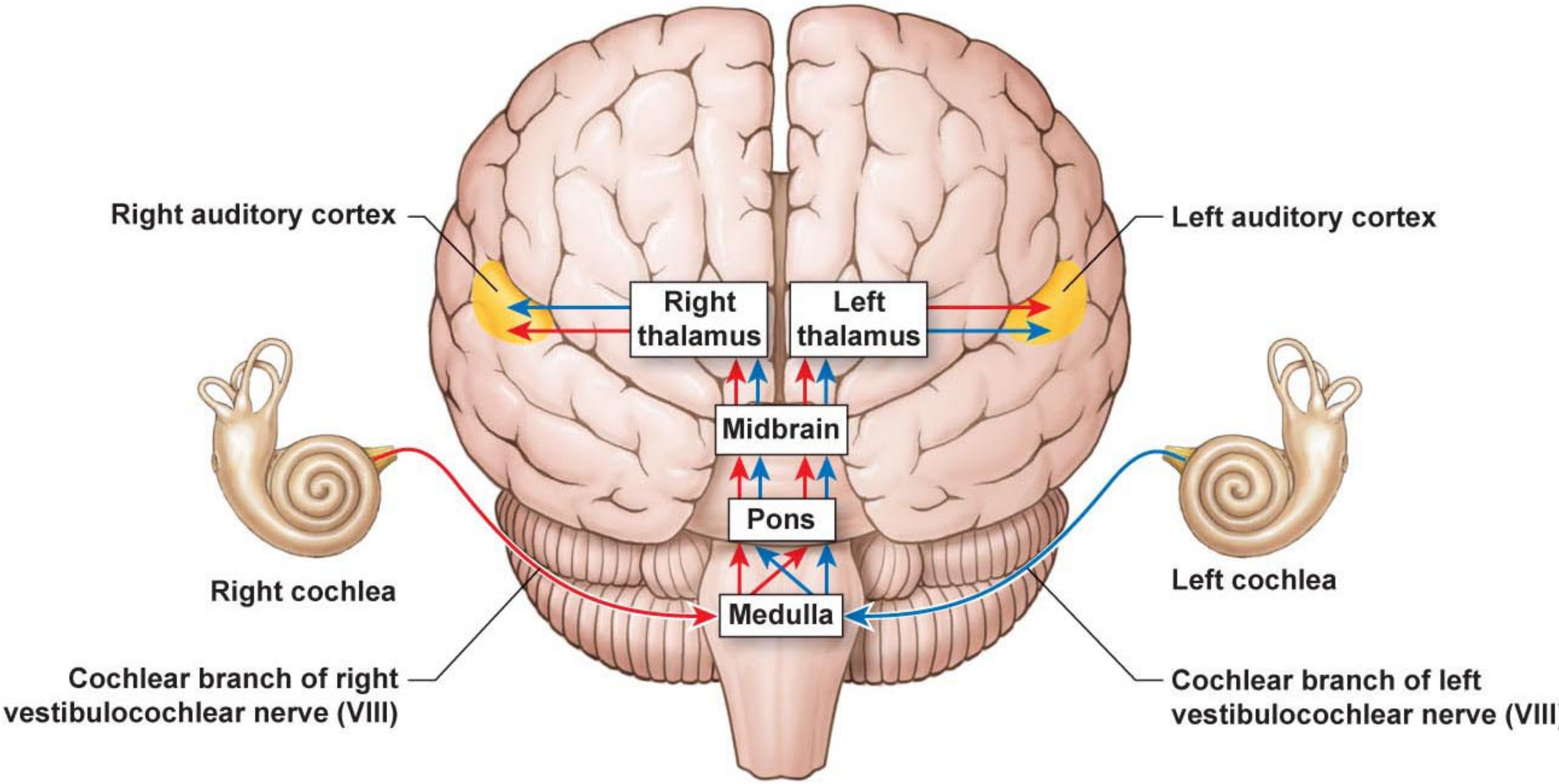
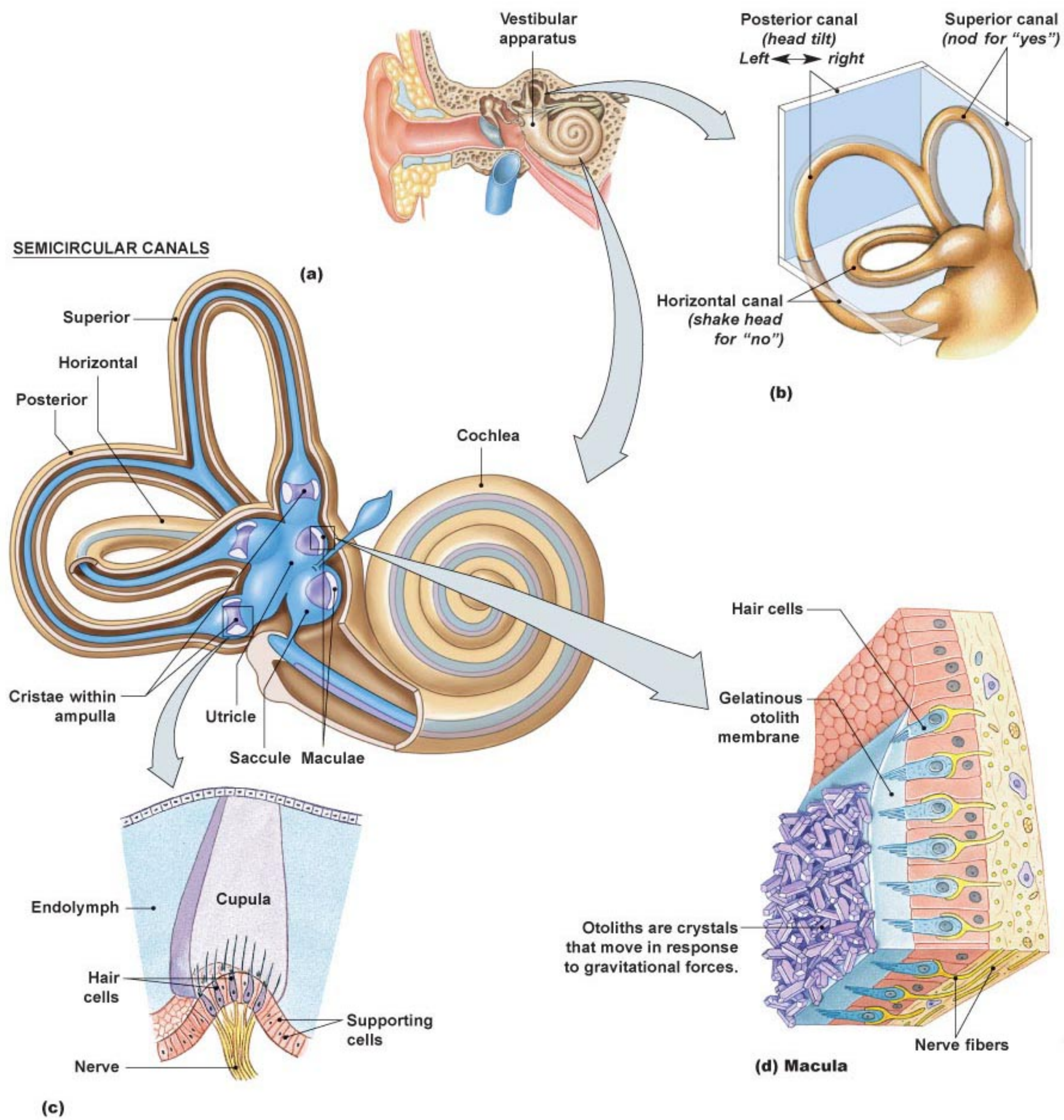

High frequency (high pitch)
Low frequency (low pitch)
Basilar membrane
Stiff region near round window
Flexible region near helicotrema (distal end)
(a)
Eardrum
Oval window
Basilar membrane
Helicotrema
Stapes
100 Hz
400 Hz
1600 Hz
3
0
0
10
20
30
Relative motion of basilar membrane (µm)
Distance from oval window (mm)
(b)

Figure 10-24



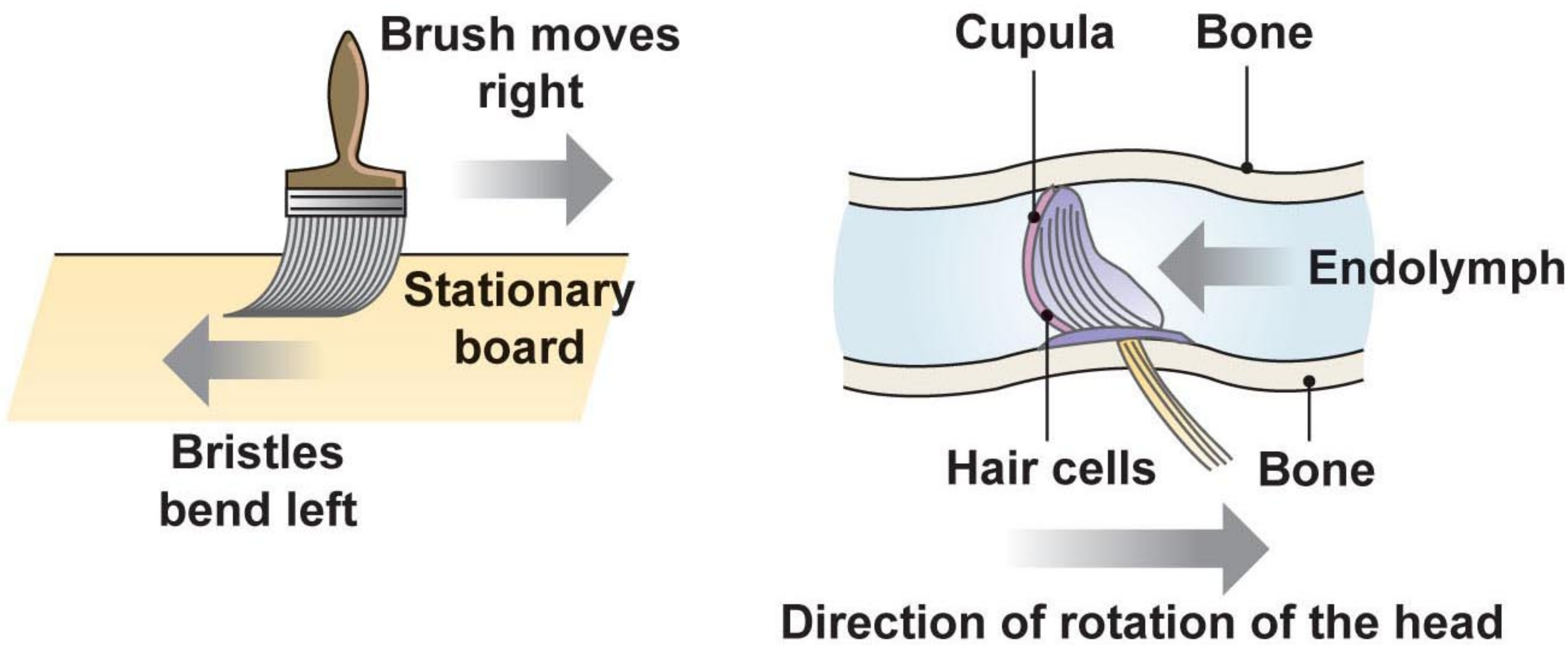
Right auditory cortex
Left auditory cortex
Right thalamus
Left thalamus
Midbrain
Pons
Medulla
Right cochlea
Left cochlea
Cochlear branch of right vestibulocochlear nerve (VIII)
Cochlear branch of left vestibulocochlear nerve (VIII)

Figure 10-25



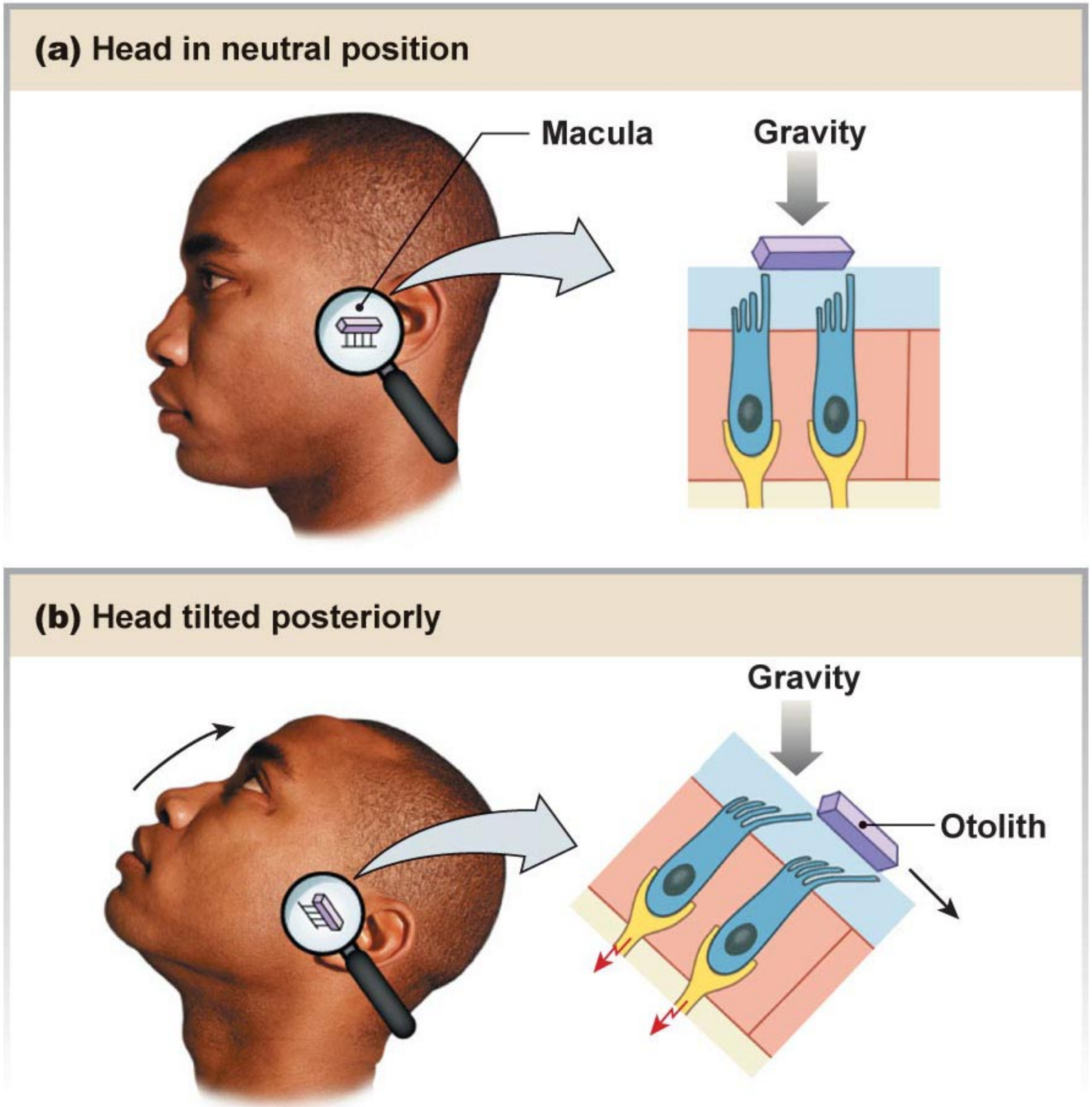
Vestibular apparatus
Posterior canal (head tilt) Left ↔ right
Superior canal (nod for "yes")
Horizontal canal (shake head for "no")
(b)
SEMICIRCULAR CANALS
(a)
Superior
Horizontal
Posterior
Cochlea
Cristae within ampulla
Utricle
Saccule
Maculae
Endolymph
Cupula
Hair cells
Supporting cells
Nerve
(c)
Hair cells
Gelatinous otolith membrane
Otoliths are crystals that move in response to gravitational forces.
Nerve fibers
(d) Macula

Figure 10-26



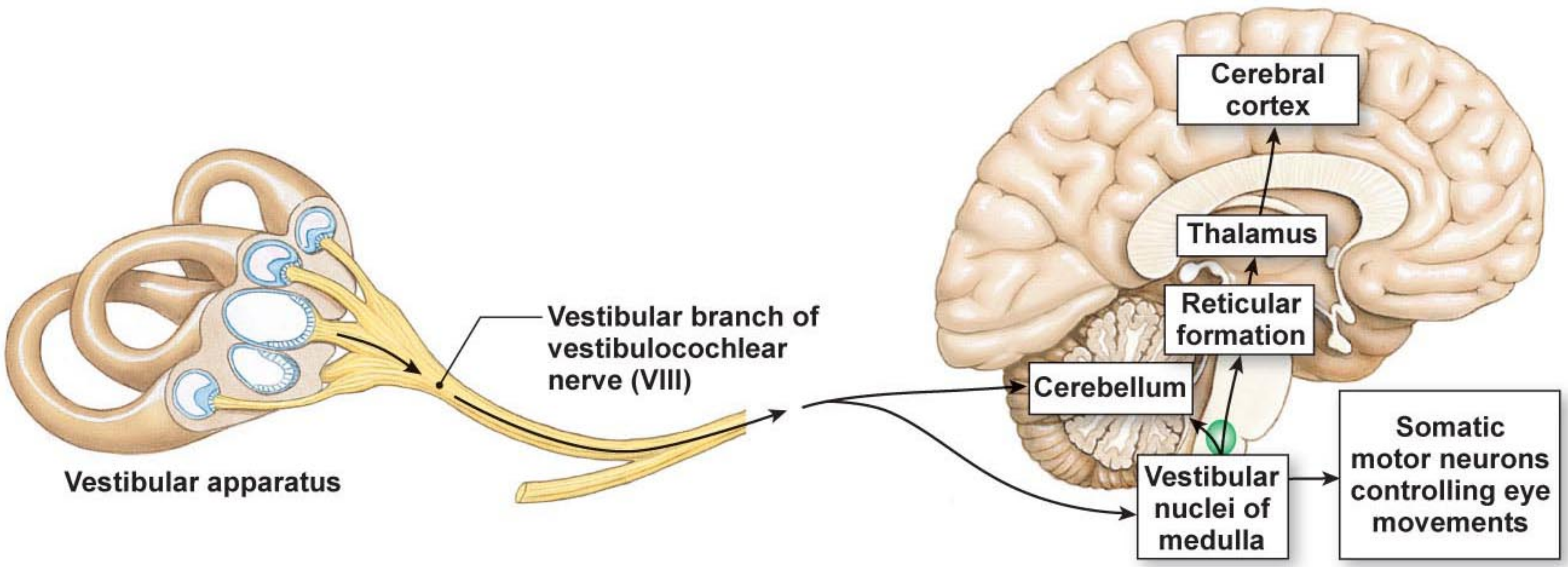
When the head turns right, endolymph pushes the cupula to the left.

Figure 10-27



(a) Head in neutral position
Macula
Gravity
(b) Head tilted posteriorly
Gravity
Otolith

Figure 10-28



Vestibular apparatus
Vestibular branch of vestibulocochlear nerve (VIII)
Cerebral cortex
Thalamus
Reticular formation
Cerebellum
Vestibular nuclei of medulla
Somatic motor neurons controlling eye movements

Figure 10-29

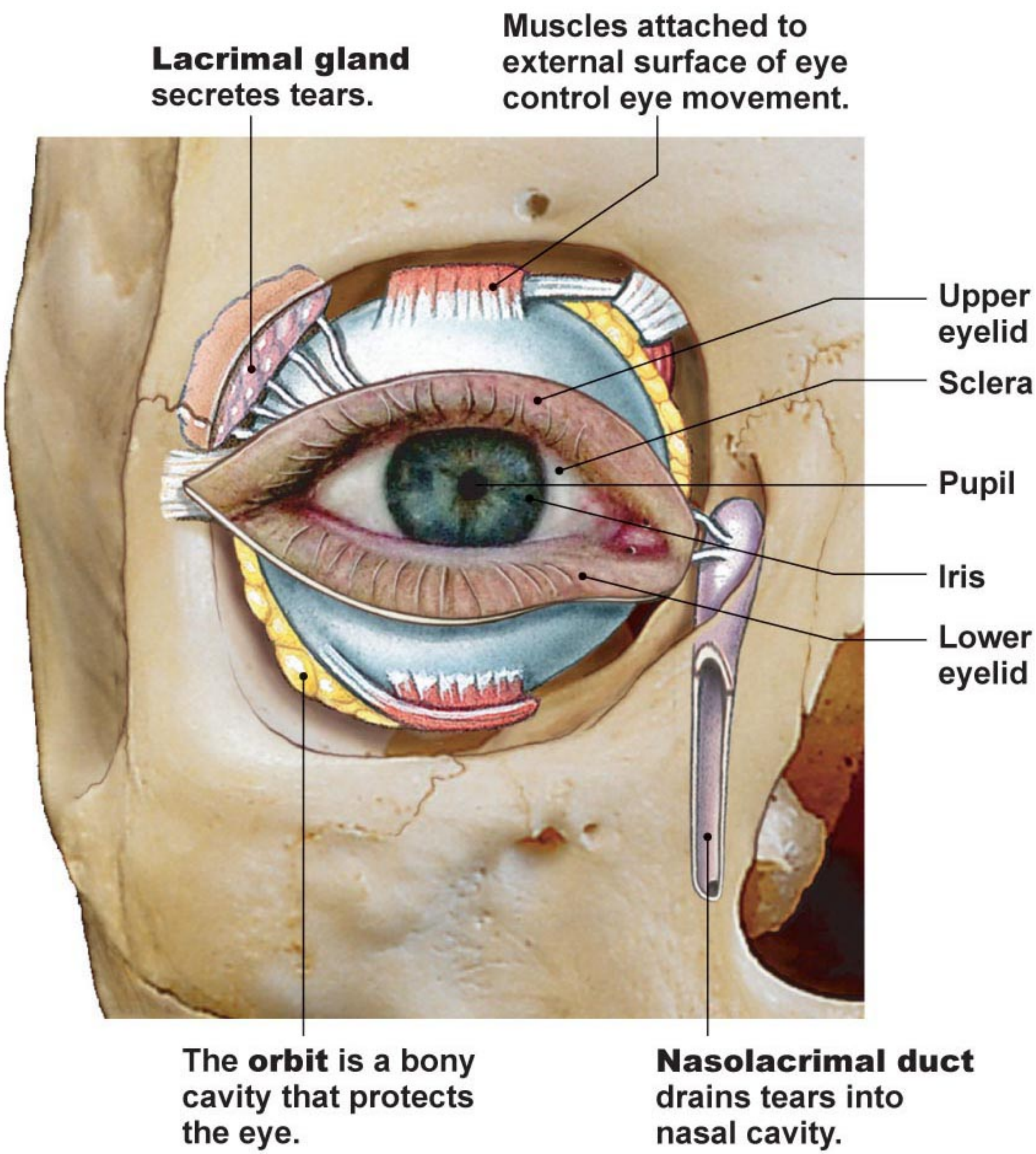
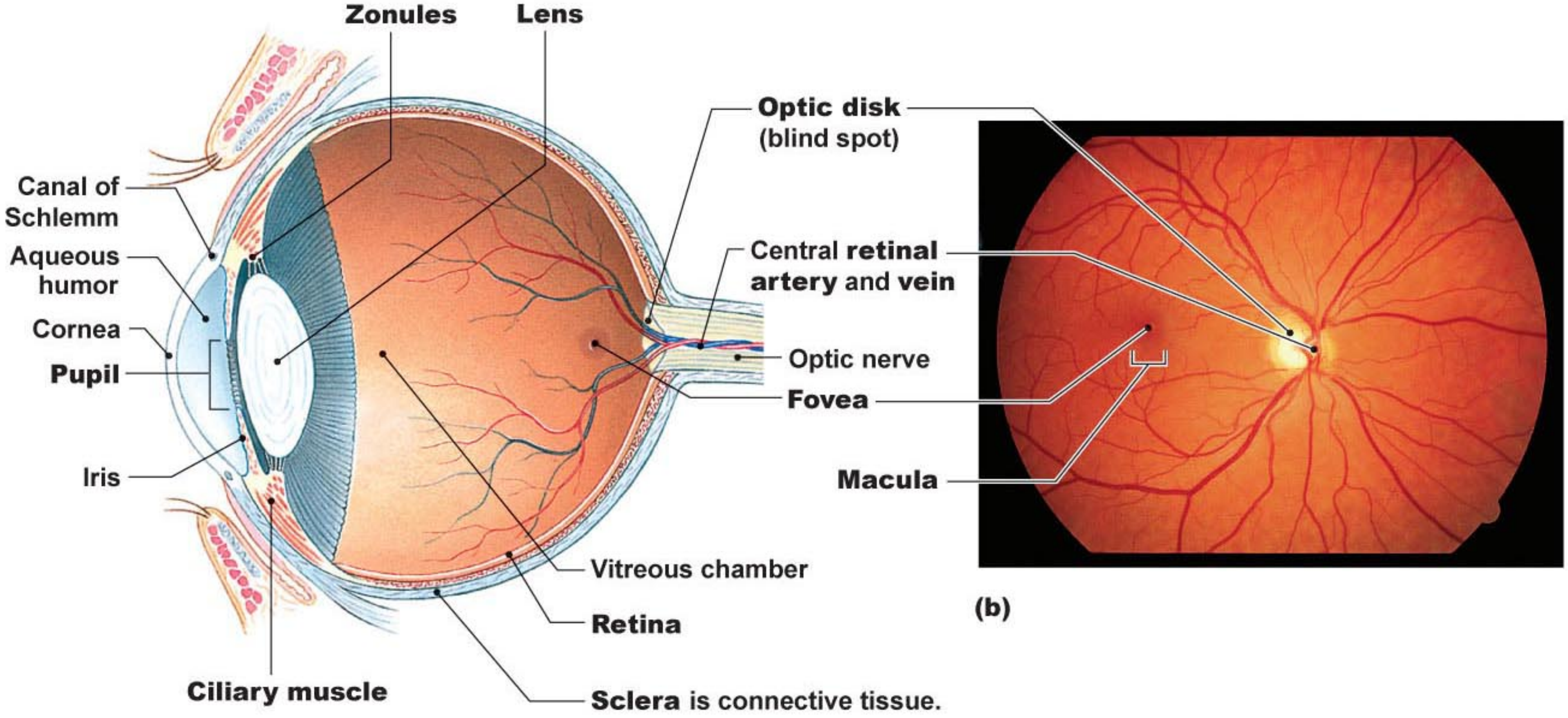
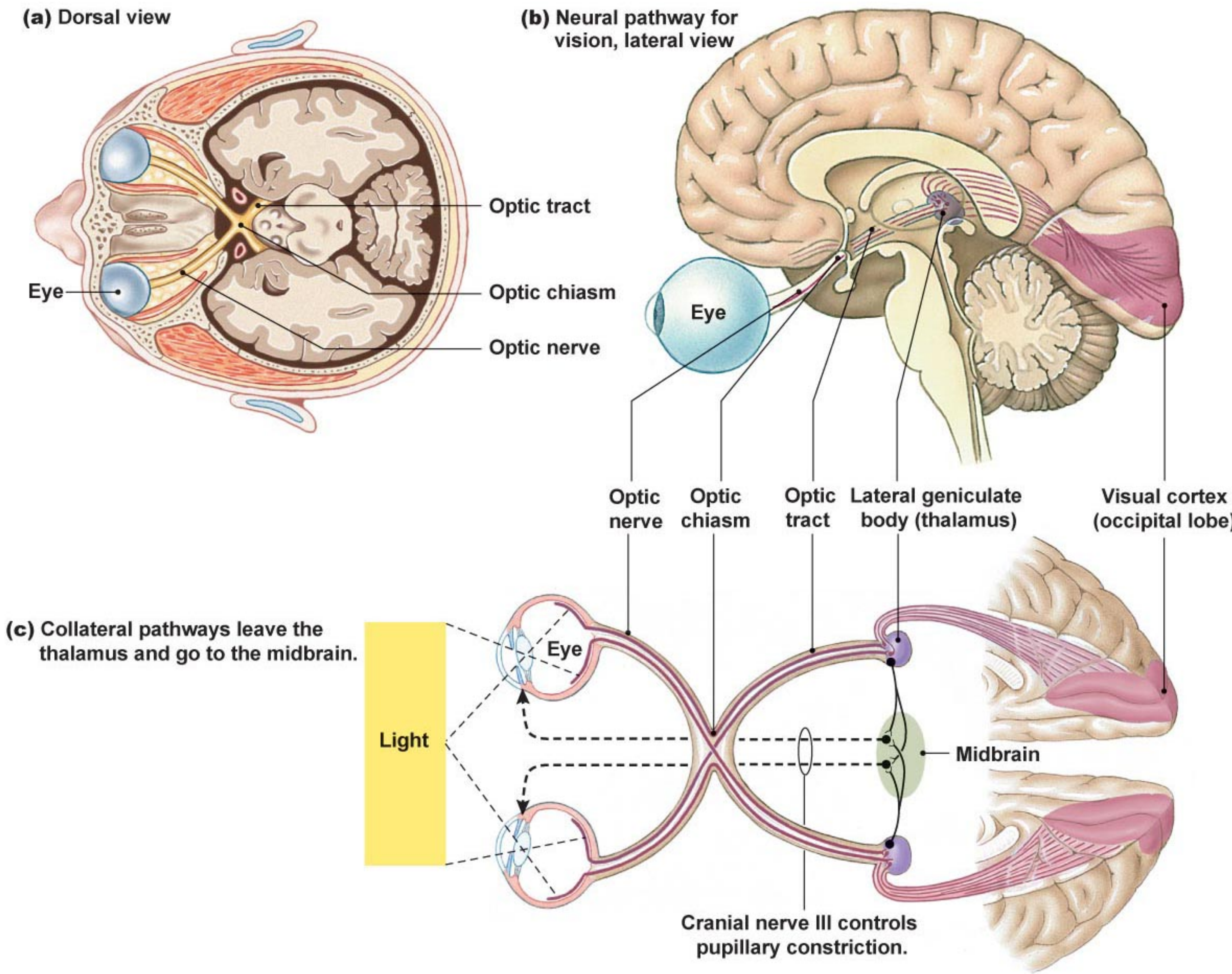

Lacrimal gland secretes tears.
Muscles attached to external surface of eye control eye movement.
Upper eyelid
Sclera
Pupil
Iris
Lower eyelid
The **orbit** is a bony cavity that protects the eye.
Nasolacrimal duct drains tears into nasal cavity.

Figure 10-30



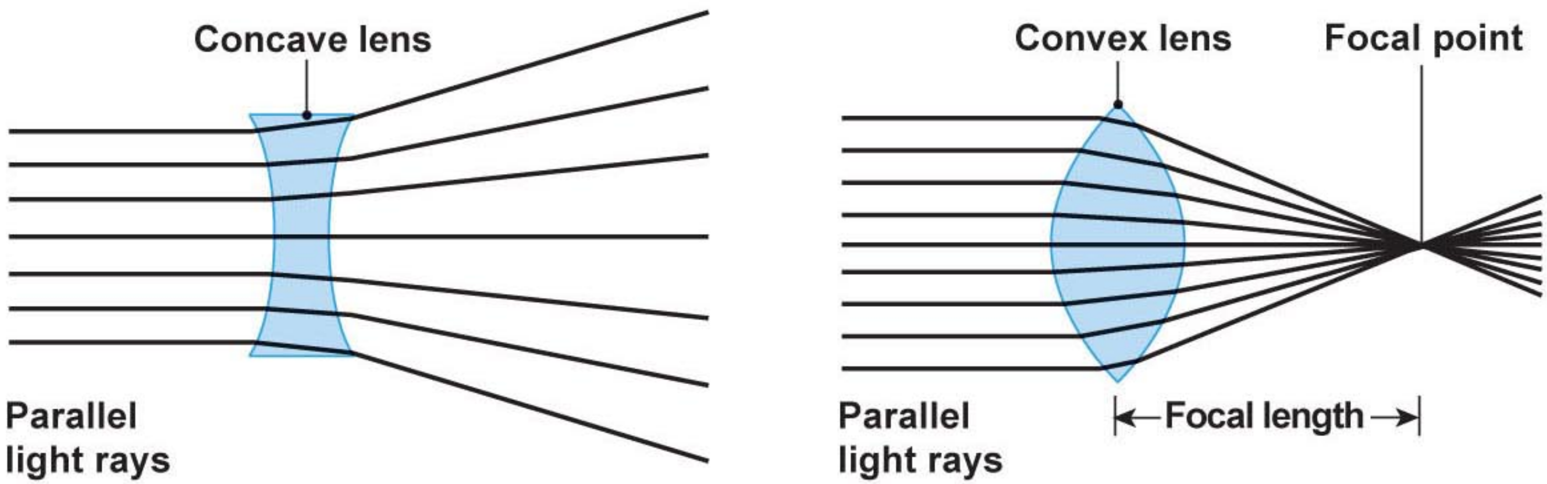
(a) Sagittal section of the eye

Figure 10-31



(a) Dorsal view
Optic tract
Eye
Optic chiasm
Optic nerve
(b) Neural pathway for vision, lateral view
Eye
Optic nerve
Optic chiasm
Optic tract
Lateral geniculate body (thalamus)
Visual cortex (occipital lobe)
(c) Collateral pathways leave the thalamus and go to the midbrain.
Light
Eye
Midbrain
Cranial nerve III controls pupillary constriction.

Figure 10-32



The focal length of the lens is the distance from the center of the lens to the focal point.

(a) A **concave lens** scatters light rays.

(b) A **convex lens** causes light rays to converge.

Figure 10-33

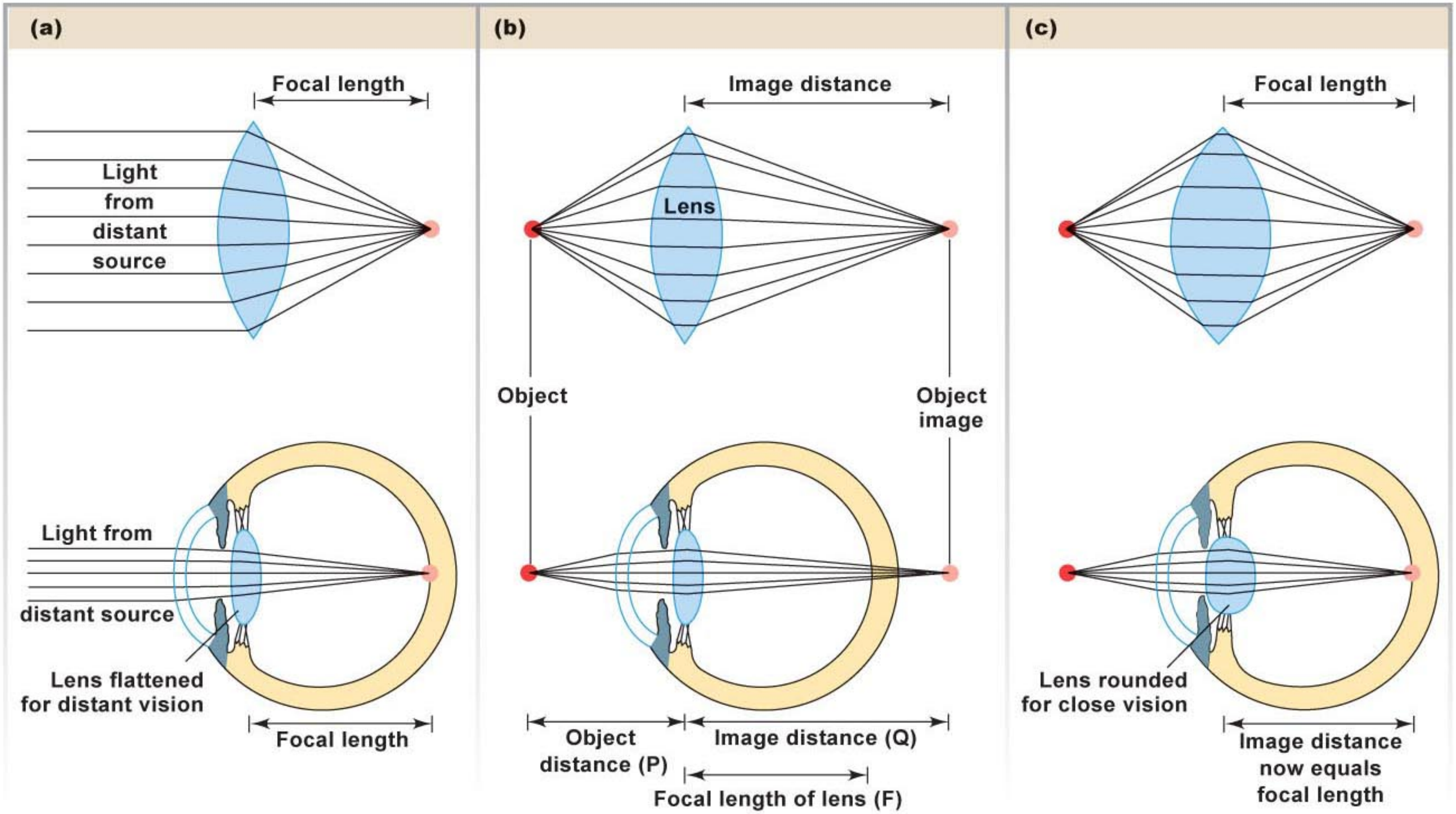

(a)
Focal length
Light
from
distant
source
Light from
distant source
Lens flattened
for distant vision
Focal length
(b)
Image distance
Lens
Object
Object
image
Object
distance (P)
Image distance (Q)
Focal length of lens (F)
(c)
Focal length
Lens rounded
for close vision
Image distance
now equals
focal length

Figure 10-34

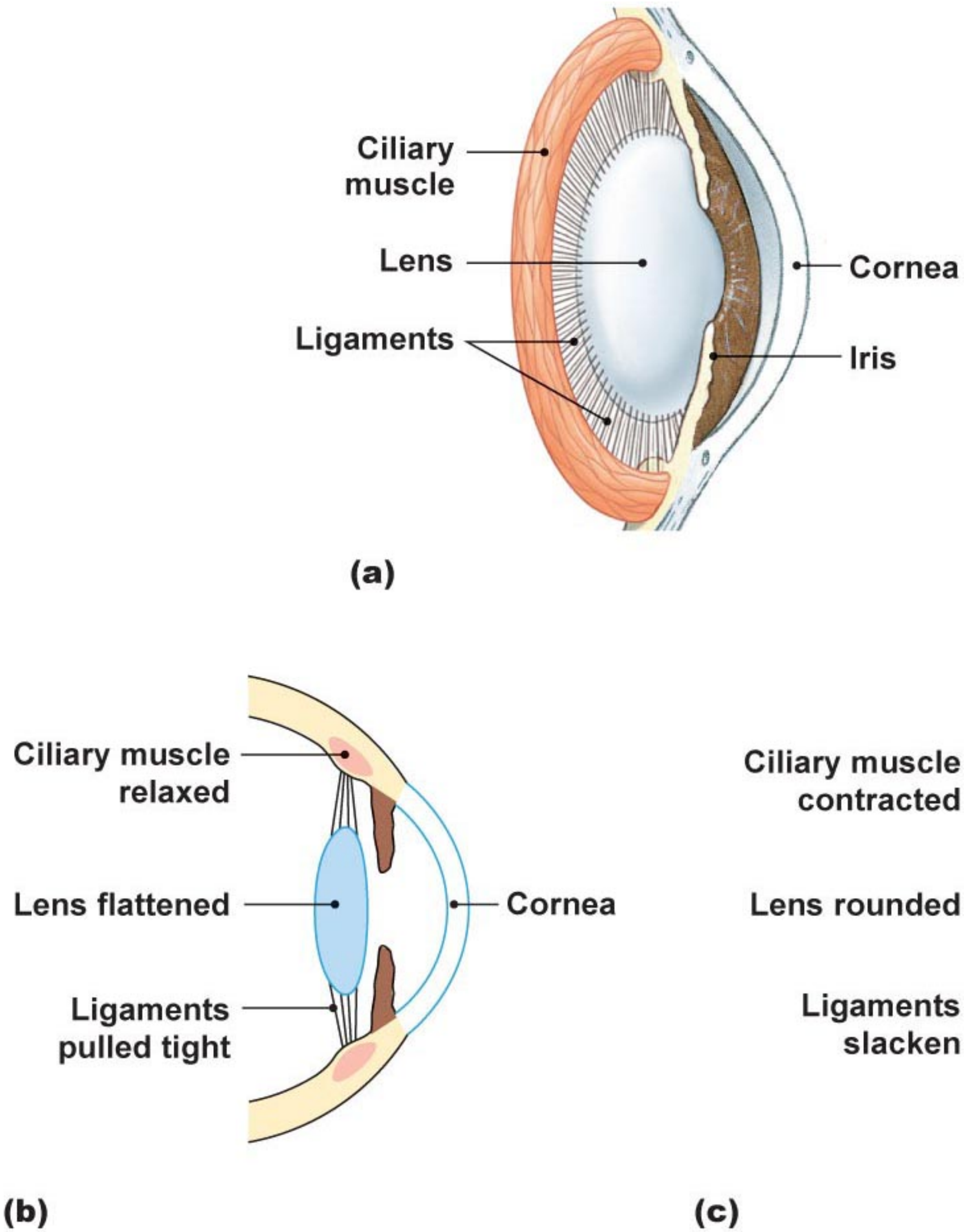
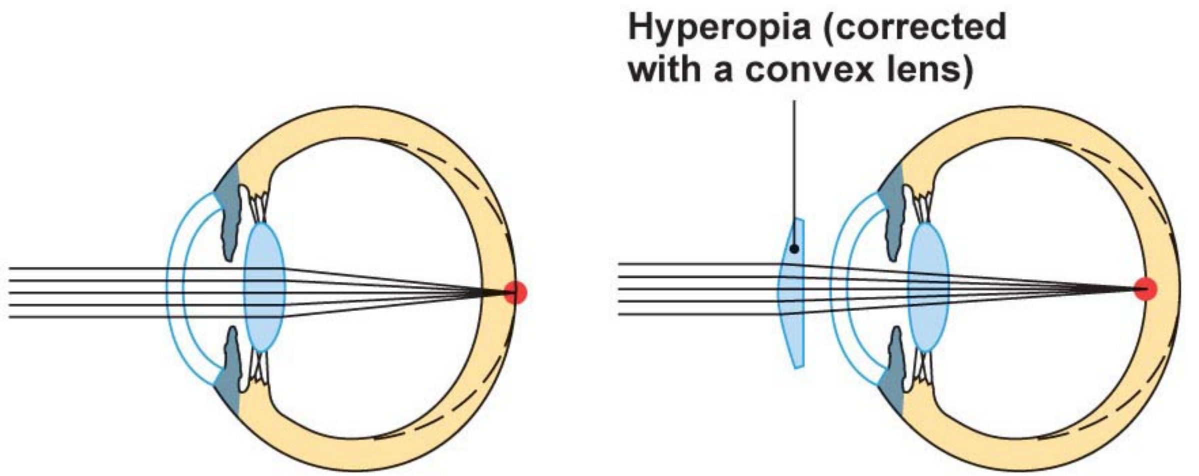
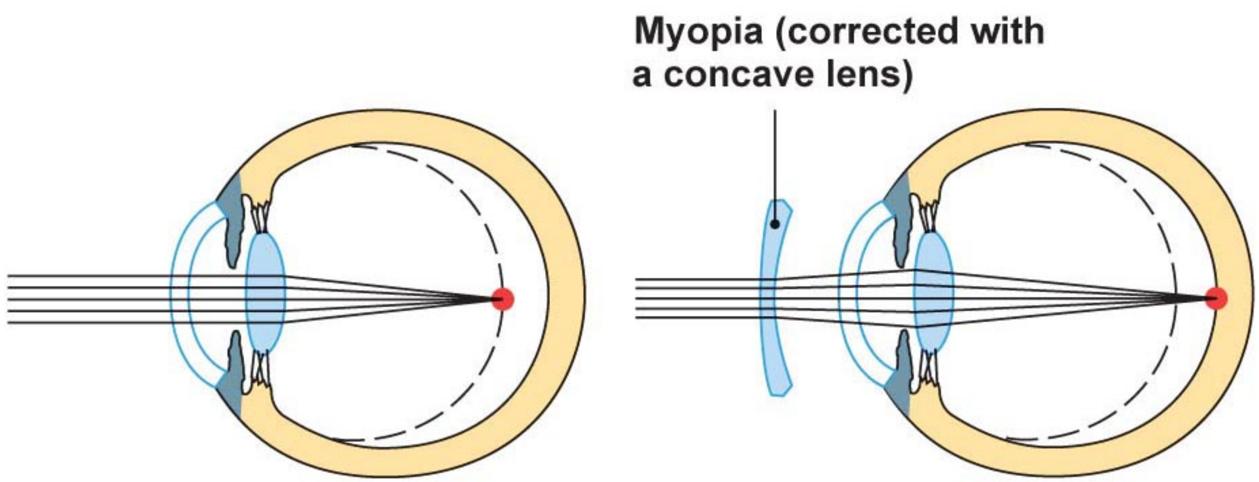

Ciliary muscle
Lens
Ligaments
Cornea
Iris
(a)
Ciliary muscle relaxed
Lens flattened
Ligaments pulled tight
Cornea
(b)
Ciliary muscle contracted
Lens rounded
Ligaments slacken
(c)

Figure 10-35



(a) Hyperopia, or far-sightedness, occurs when the focal point falls behind the retina.



(b) Myopia, or near-sightedness, occurs when the focal point falls in front of the retina.

Figure 10-36

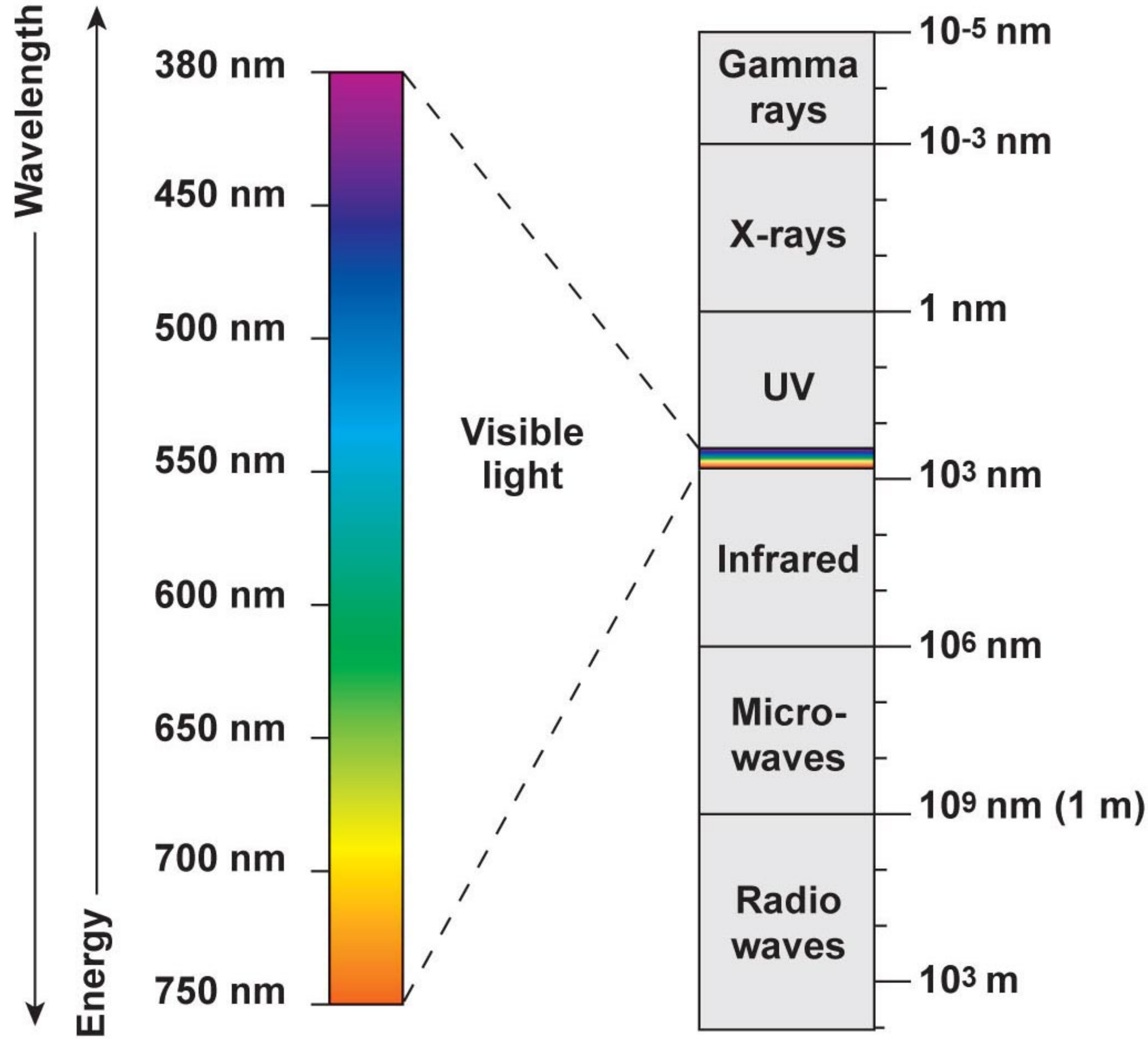
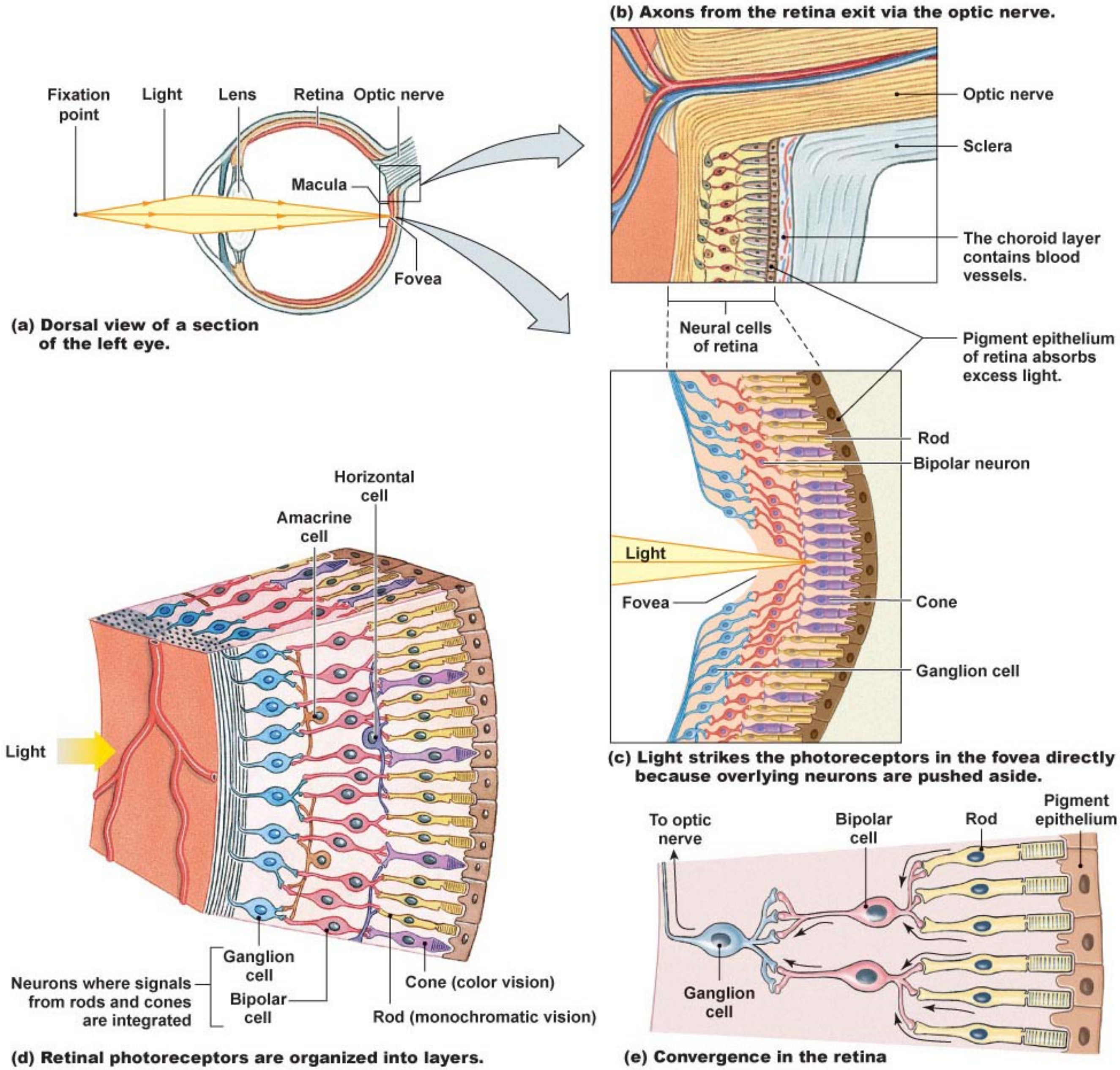
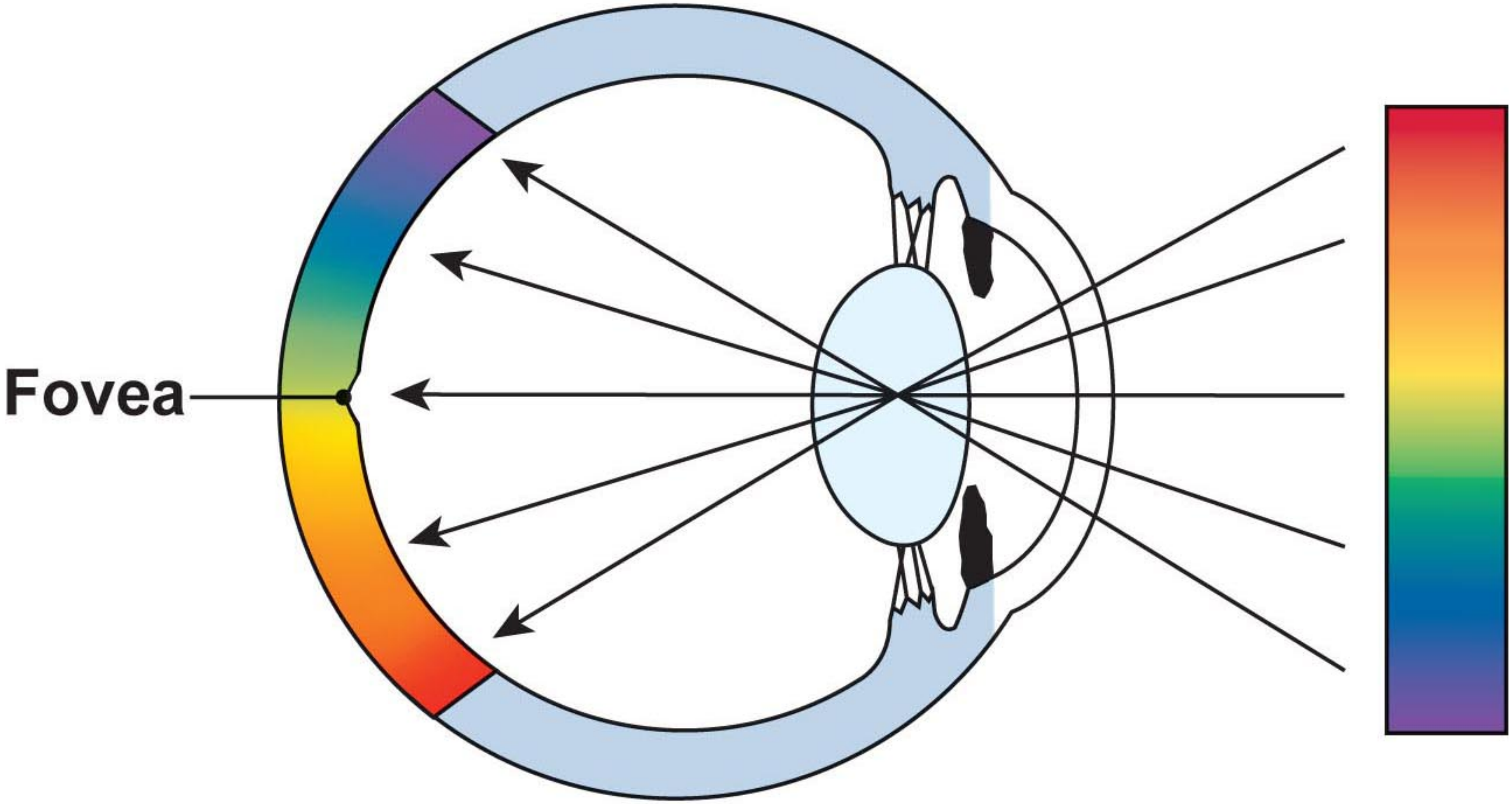

Wavelength
Energy
380 nm
450 nm
500 nm
550 nm
600 nm
650 nm
700 nm
750 nm
Visible light
Gamma rays
X-rays
UV
Infrared
Micro-waves
Radio waves
10-5 nm
10-3 nm
1 nm
103 nm
106 nm
109 nm (1 m)
103 m

Figure 10-37



Fixation point
Light
Lens
Retina
Optic nerve
Macula
Fovea
(a) Dorsal view of a section of the left eye.
(b) Axons from the retina exit via the optic nerve.
Optic nerve
Sclera
The choroid layer contains blood vessels.
Neural cells of retina
Pigment epithelium of retina absorbs excess light.
Rod
Bipolar neuron
Light
Fovea
Cone
Ganglion cell
(c) Light strikes the photoreceptors in the fovea directly because overlying neurons are pushed aside.
Horizontal cell
Amacrine cell
Light
Neurons where signals from rods and cones are integrated
Ganglion cell
Bipolar cell
Cone (color vision)
Rod (monochromatic vision)
(d) Retinal photoreceptors are organized into layers.
To optic nerve
Bipolar cell
Rod
Pigment epithelium
Ganglion cell
(e) Convergence in the retina

Figure 10-38



The projected image is upside down on the retina. Visual processing in the brain reverses the image.

Figure 10-39, overview

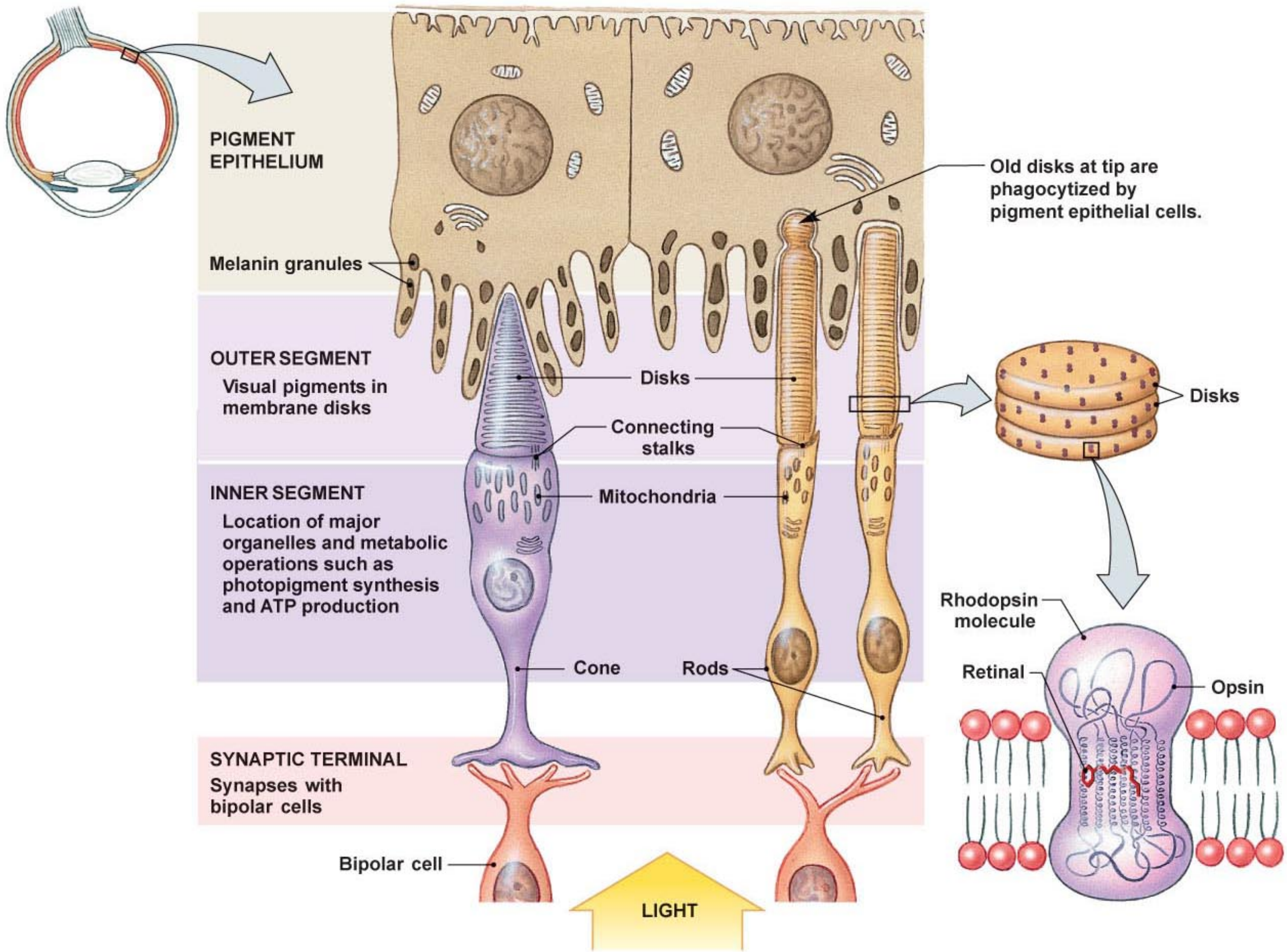


Figure 10-40

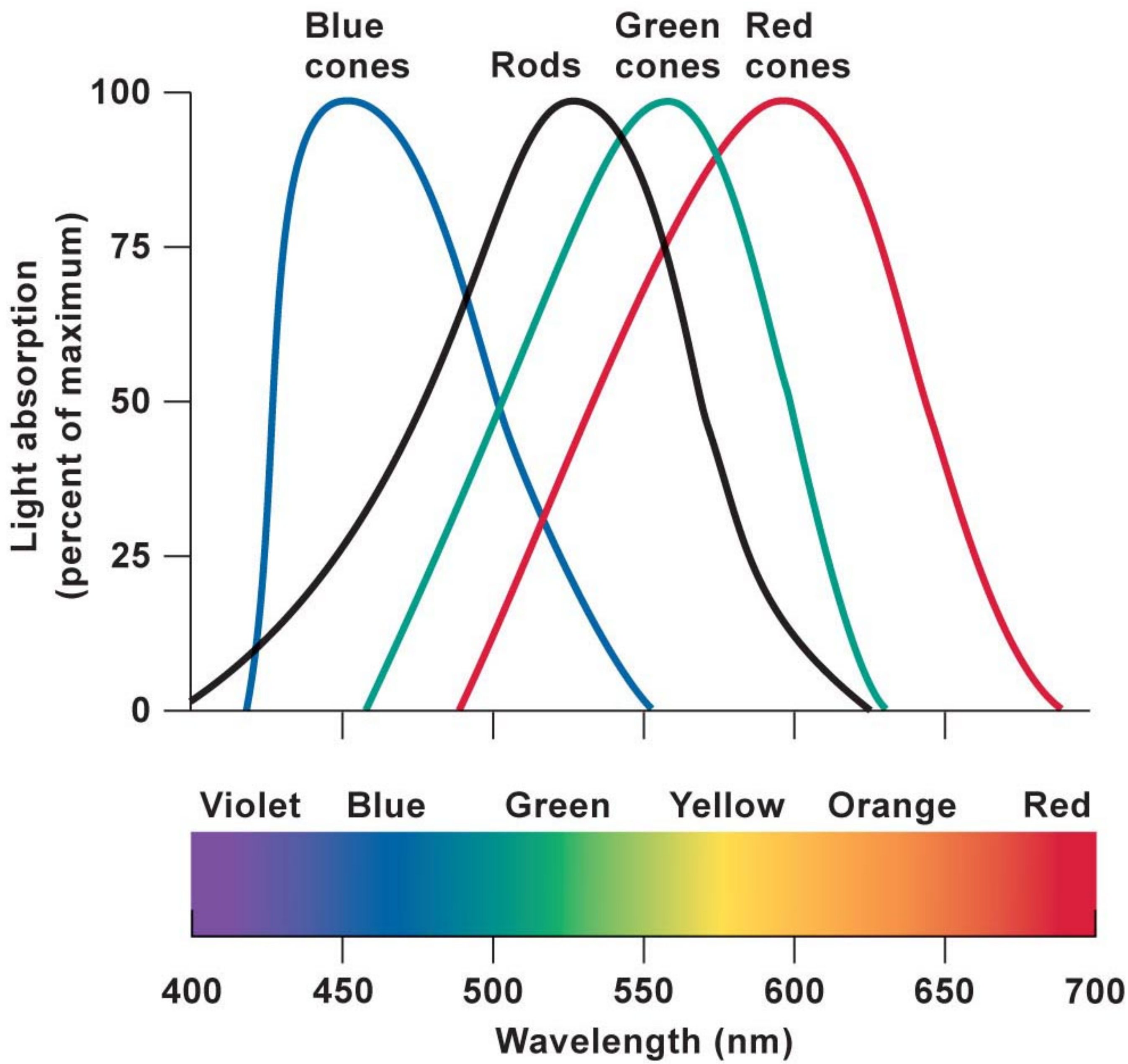
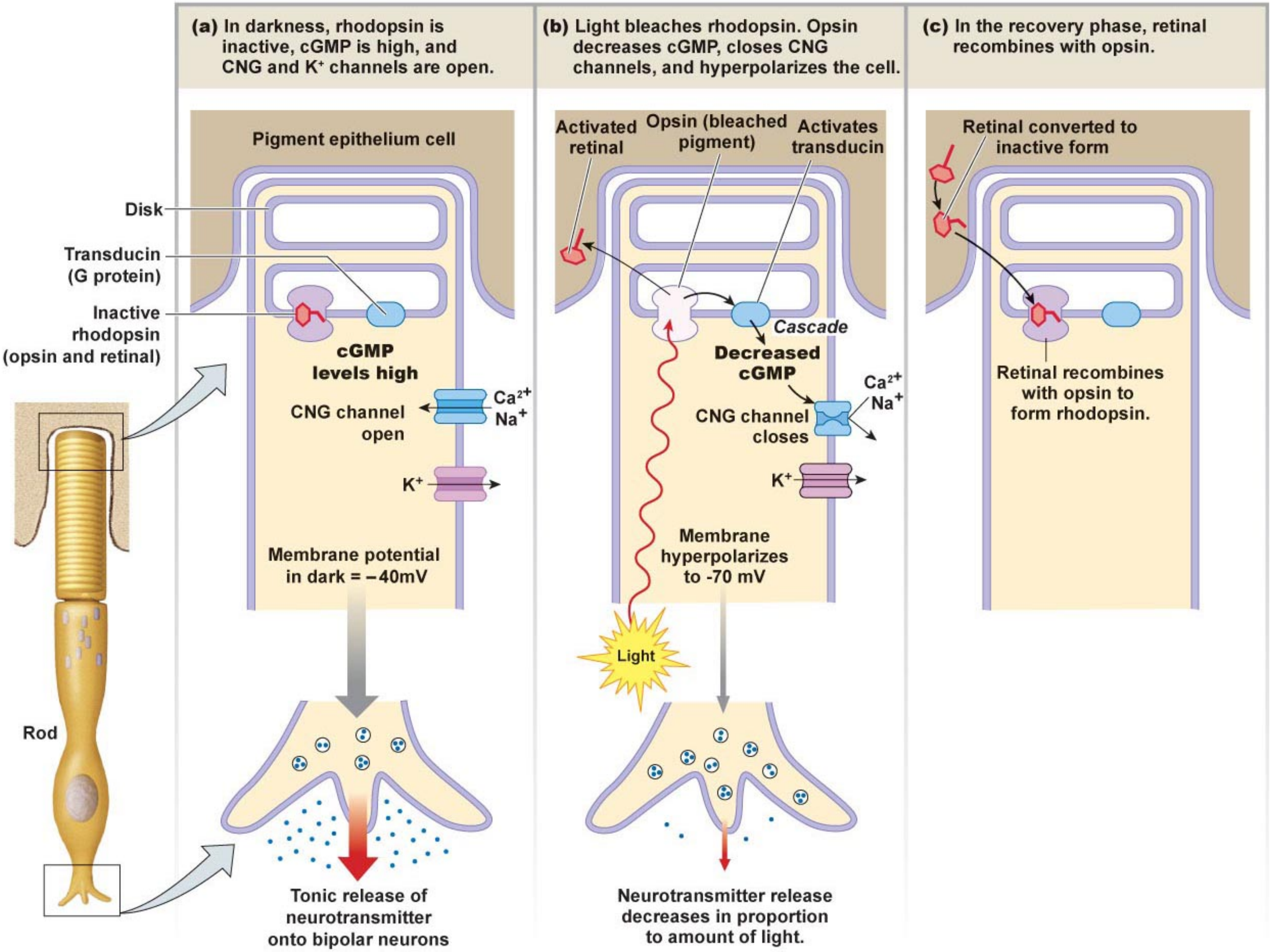
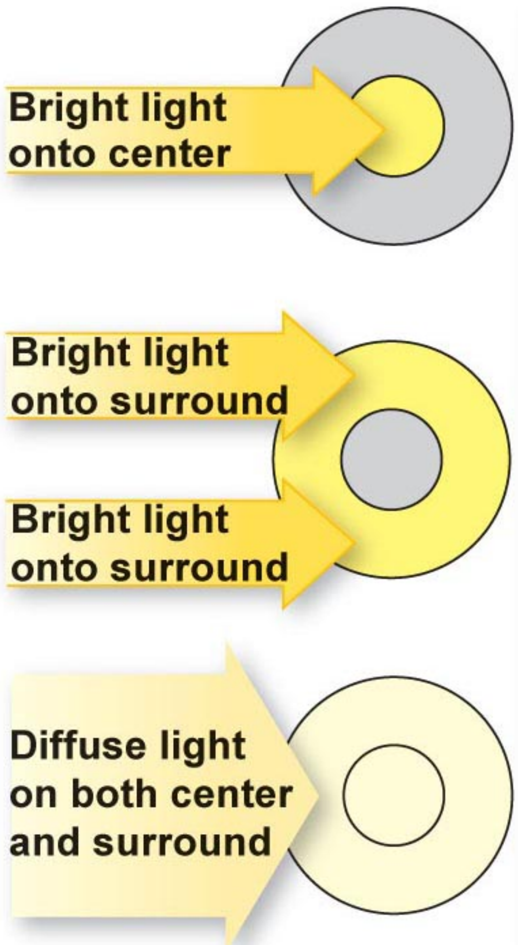

Blue cones
Rods
Green cones
Red cones
Light absorption (percent of maximum)
100
75
50
25
0
Violet
Blue
Green
Yellow
Orange
Red
400
450
500
550
600
650
700
Wavelength (nm)

Figure 10-41



(a) In darkness, rhodopsin is inactive, cGMP is high, and CNG and K+ channels are open.
(b) Light bleaches rhodopsin. Opsin decreases cGMP, closes CNG channels, and hyperpolarizes the cell.
(c) In the recovery phase, retinal recombines with opsin.
Disk
Transducin (G protein)
Inactive rhodopsin (opsin and retinal)
Rod
Pigment epithelium cell
cGMP levels high
CNG channel open
Ca2+
Na+
K+
Membrane potential in dark = –40mV
Tonic release of neurotransmitter onto bipolar neurons
Activated retinal
Opsin (bleached pigment)
Activates transducin
Cascade
Decreased cGMP
CNG channel closes
Ca2+
Na+
K+
Membrane hyperpolarizes to -70 mV
Light
Neurotransmitter release decreases in proportion to amount of light.
Retinal converted to inactive form
Retinal recombines with opsin to form rhodopsin.

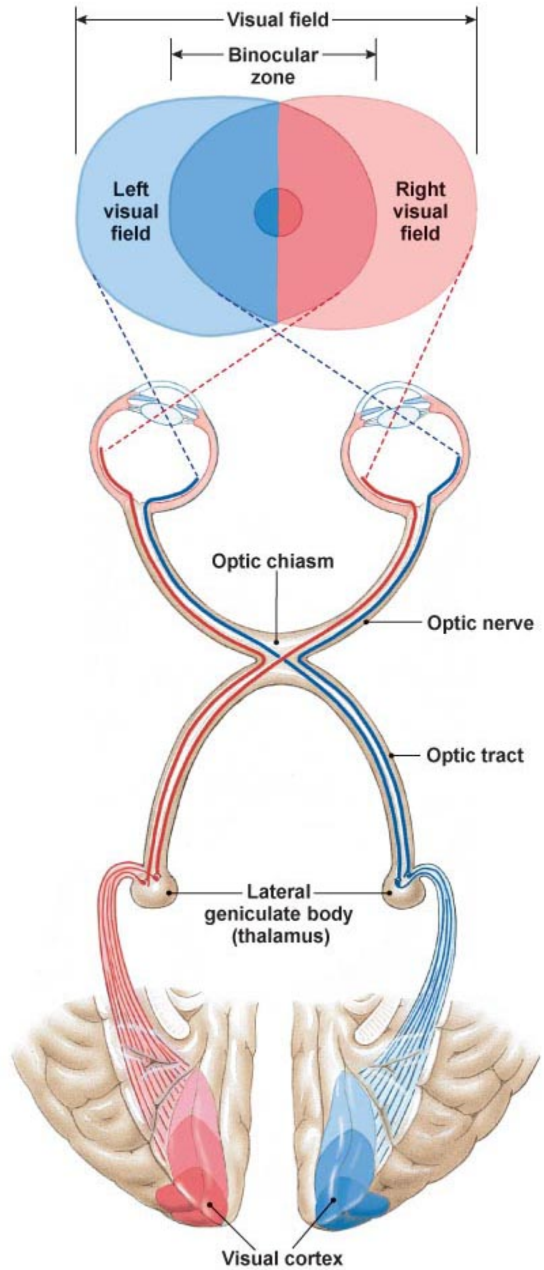
Figure 10-42



On-center/ off-surround field	Off-center/ on-surround field
Excites ganglion cell	Inhibits ganglion cell
Inhibits ganglion cell	Excites ganglion cell
Weak response from ganglion cell	Weak response from ganglion cell

The retina uses contrast rather than absolute light intensity for better detection of weak stimuli.

Figure 10-43


Visual field
Binocular zone
Left visual field
Right visual field
Optic chiasm
Optic nerve
Optic tract
Lateral geniculate body (thalamus)
Visual cortex