Chapter 50

Sensory and Motor Mechanisms

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Sensing and Acting

- Bats use sonar to detect their prey
- Moths, a common prey for bats, can detect the bat's sonar and attempt to flee
- Both organisms have complex sensory systems that facilitate survival
- These systems include diverse mechanisms that sense stimuli and generate appropriate movement

Fig. 50-1

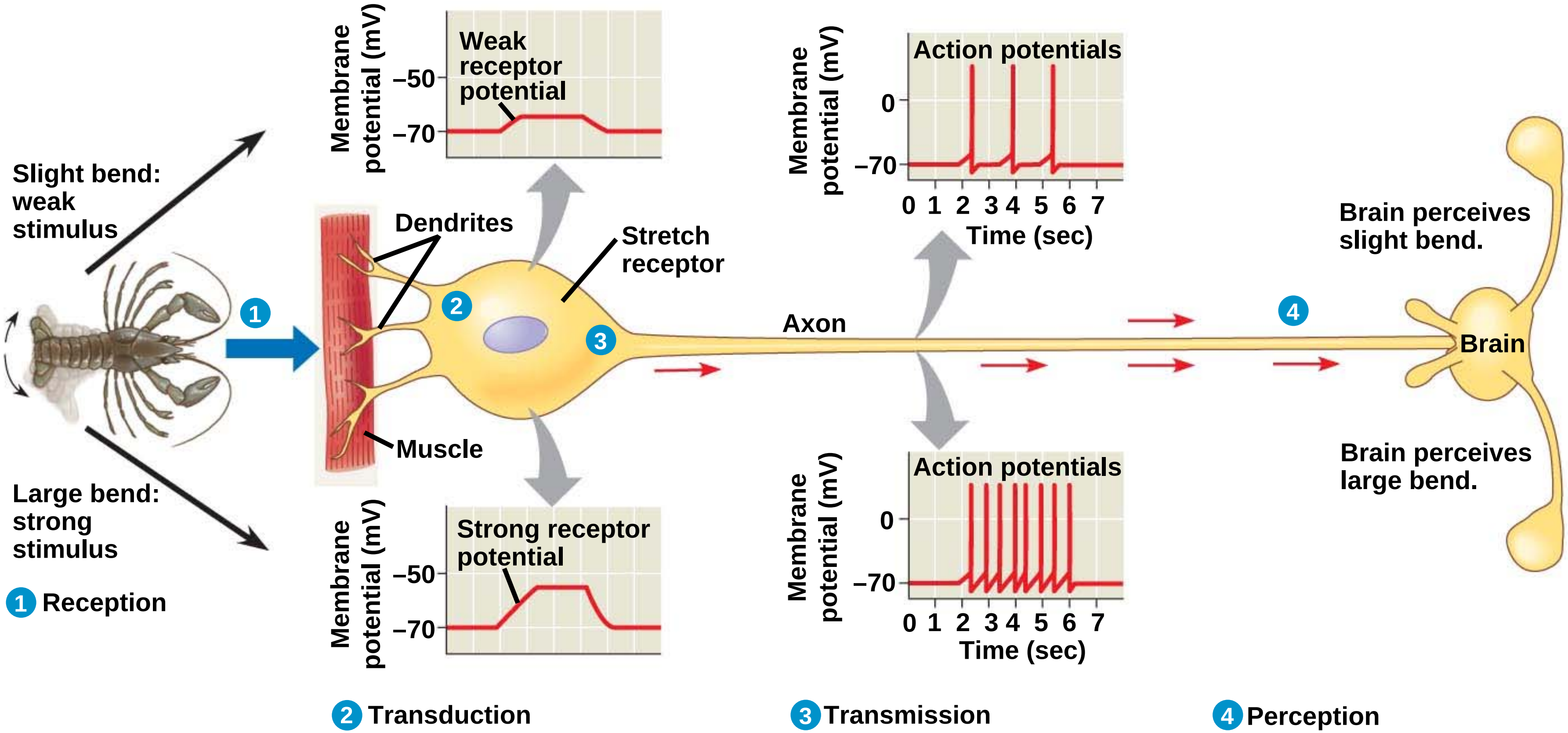
Concept 50.1: Sensory receptors transduce stimulus energy and transmit signals to the central nervous system

- All stimuli represent forms of energy
- Sensation involves converting energy into a change in the membrane potential of sensory receptors
- Sensations are action potentials that reach the brain via sensory neurons
- The brain interprets sensations, giving the perception of stimuli

Sensory Pathways

- Functions of sensory pathways: sensory reception, transduction, transmission, and integration
- For example, stimulation of a stretch receptor in a crayfish is the first step in a sensory pathway

Fig. 50-2



Slight bend: weak stimulus
Large bend: strong stimulus
1 Reception
Dendrites
Muscle
Stretch receptor
Axon
Brain
Weak receptor potential
Membrane potential (mV)
–50
–70
Strong receptor potential
Membrane potential (mV)
–50
–70
2 Transduction
Action potentials
Membrane potential (mV)
0
–70
0 1 2 3 4 5 6 7
Time (sec)
Action potentials
Membrane potential (mV)
0
–70
0 1 2 3 4 5 6 7
Time (sec)
3 Transmission
Brain perceives slight bend.
Brain perceives large bend.
4 Perception

Sensory Reception and Transduction

- Sensations and perceptions begin with **sensory reception**, detection of stimuli by sensory receptors

- **Sensory receptors** can detect stimuli outside and inside the body

- **Sensory transduction** is the conversion of stimulus energy into a change in the membrane potential of a sensory receptor
- This change in membrane potential is called a **receptor potential**
- Many sensory receptors are very sensitive: they are able to detect the smallest physical unit of stimulus
  - For example, most light receptors can detect a photon of light

Transmission

- After energy has been transduced into a receptor potential, some sensory cells generate the **transmission** of action potentials to the CNS
- Sensory cells without axons release neurotransmitters at synapses with sensory neurons
- Larger receptor potentials generate more rapid action potentials

- **Integration** of sensory information begins when information is received
- Some receptor potentials are integrated through summation

Perception

- **Perceptions** are the brain's construction of stimuli
- Stimuli from different sensory receptors travel as action potentials along different neural pathways
- The brain distinguishes stimuli from different receptors by the area in the brain where the action potentials arrive

Amplification and Adaptation

- **Amplification** is the strengthening of stimulus energy by cells in sensory pathways
- **Sensory adaptation** is a decrease in responsiveness to continued stimulation

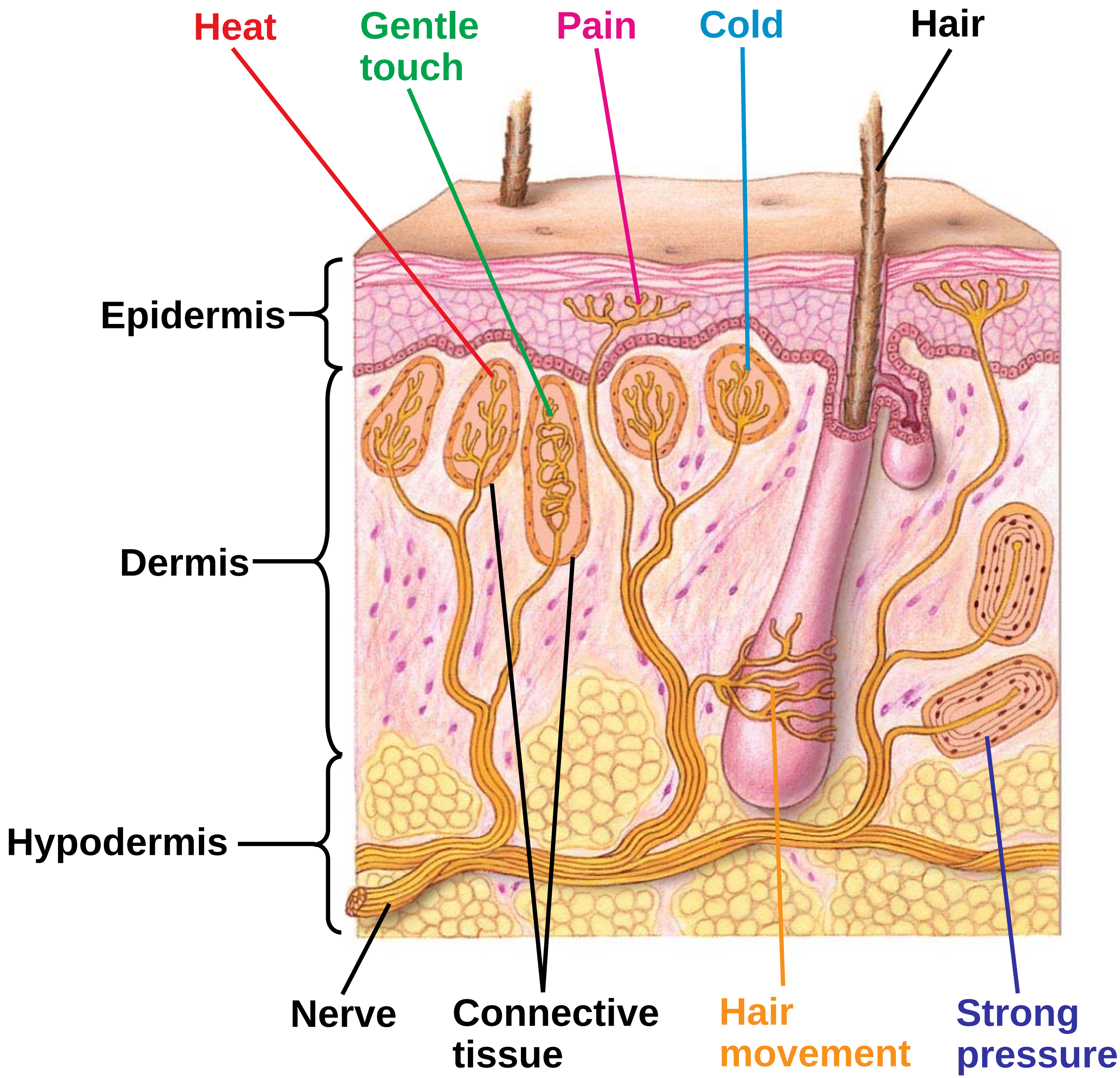
Types of Sensory Receptors

- Based on energy transduced, sensory receptors fall into five categories:
  - Mechanoreceptors
  - Chemoreceptors
  - Electromagnetic receptors
  - Thermoreceptors
  - Pain receptors

Mechanoreceptors

- **Mechanoreceptors** sense physical deformation caused by stimuli such as pressure, stretch, motion, and sound
- The sense of touch in mammals relies on mechanoreceptors that are dendrites of sensory neurons

Fig. 50-3



Heat
Gentle touch
Pain
Cold
Hair
Epidermis
Dermis
Hypodermis
Nerve
Connective tissue
Hair movement
Strong pressure

Chemoreceptors

- General **chemoreceptors** transmit information about the total solute concentration of a solution
- Specific chemoreceptors respond to individual kinds of molecules
- When a stimulus molecule binds to a chemoreceptor, the chemoreceptor becomes more or less permeable to ions
- The antennae of the male silkworm moth have very sensitive specific chemoreceptors

Fig. 50-4

Electromagnetic Receptors

- **Electromagnetic receptors** detect electromagnetic energy such as light, electricity, and magnetism
- Photoreceptors are electromagnetic receptors that detect light
- Some snakes have very sensitive infrared receptors that detect body heat of prey against a colder background

Fig. 50-5

(a) Rattlesnake

(b) Beluga whales

Fig. 50-5a

(a) Rattlesnake

- Many mammals appear to use Earth's magnetic field lines to orient themselves as they migrate

Fig. 50-5b

(b) Beluga whales

Thermoreceptors

- **Thermoreceptors**, which respond to heat or cold, help regulate body temperature by signaling both surface and body core temperature

Pain Receptors

- In humans, **pain receptors**, or **nociceptors**, are a class of naked dendrites in the epidermis
- They respond to excess heat, pressure, or chemicals released from damaged or inflamed tissues

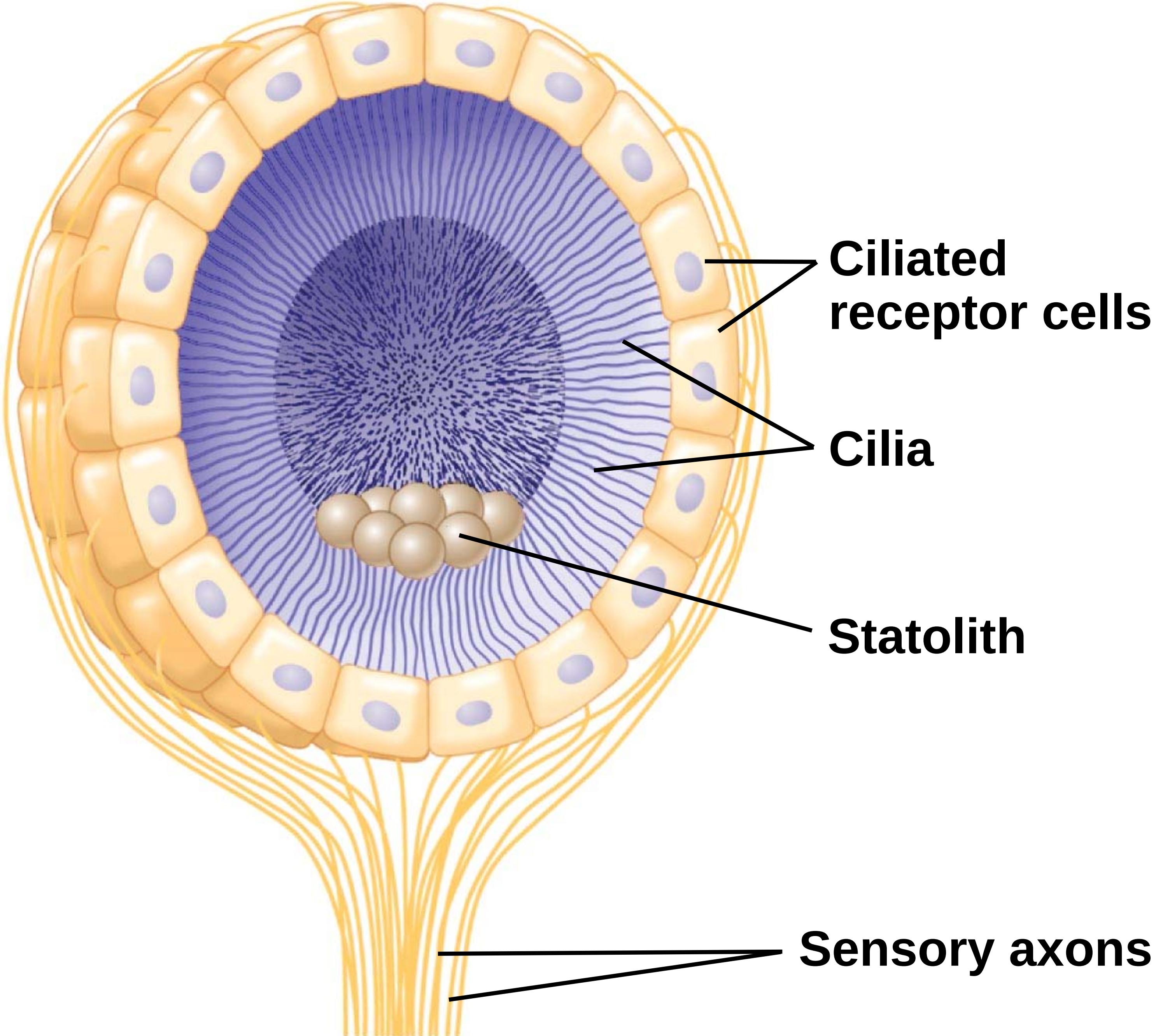
Concept 50.2: The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles

- Hearing and perception of body equilibrium are related in most animals
- Settling particles or moving fluid are detected by mechanoreceptors

Sensing Gravity and Sound in Invertebrates

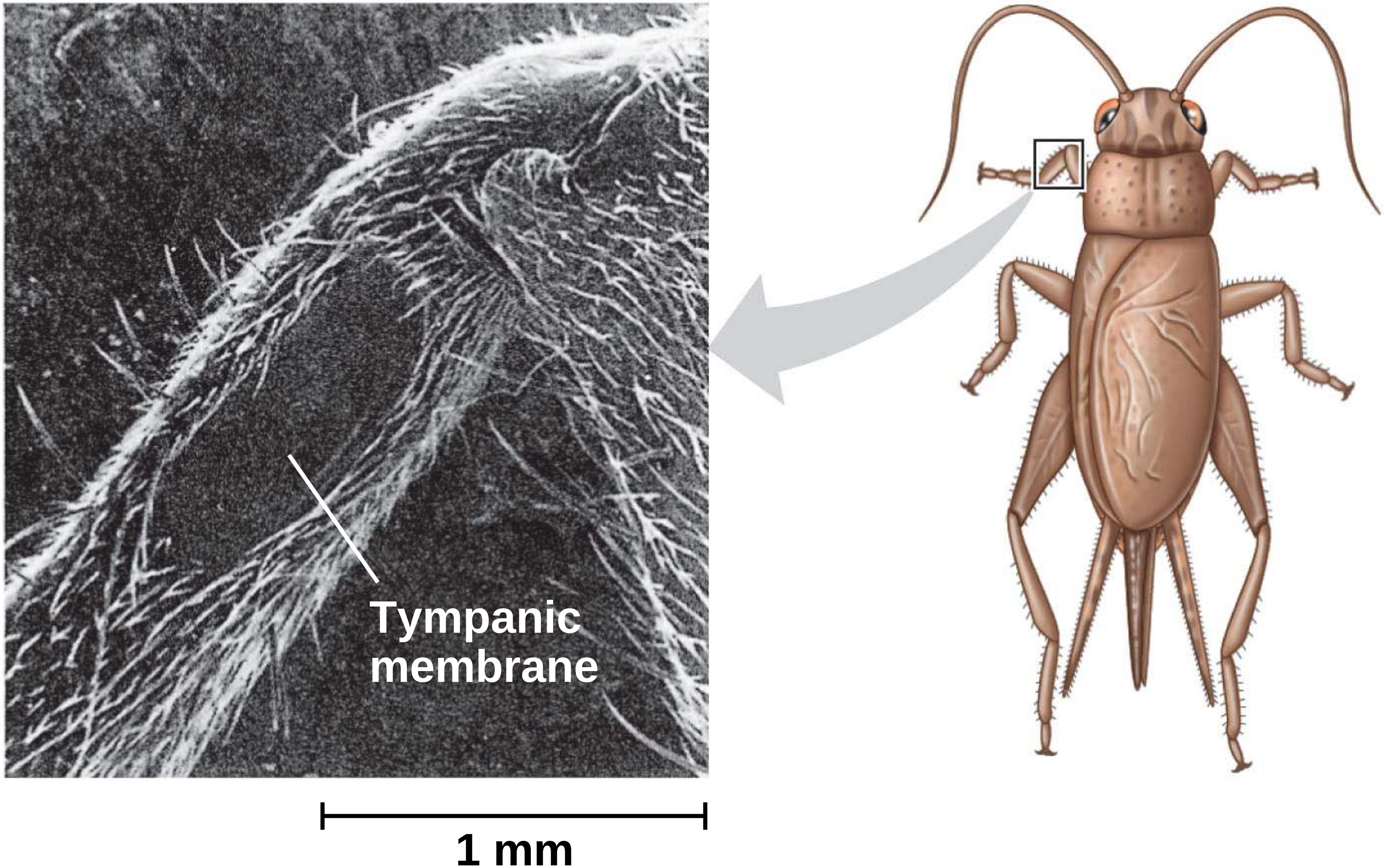
- Most invertebrates maintain equilibrium using sensory organs called **statocysts**
- Statocysts contain mechanoreceptors that detect the movement of granules called **statoliths**

Fig. 50-6



- Many arthropods sense sounds with body hairs that vibrate or with localized “ears” consisting of a tympanic membrane and receptor cells

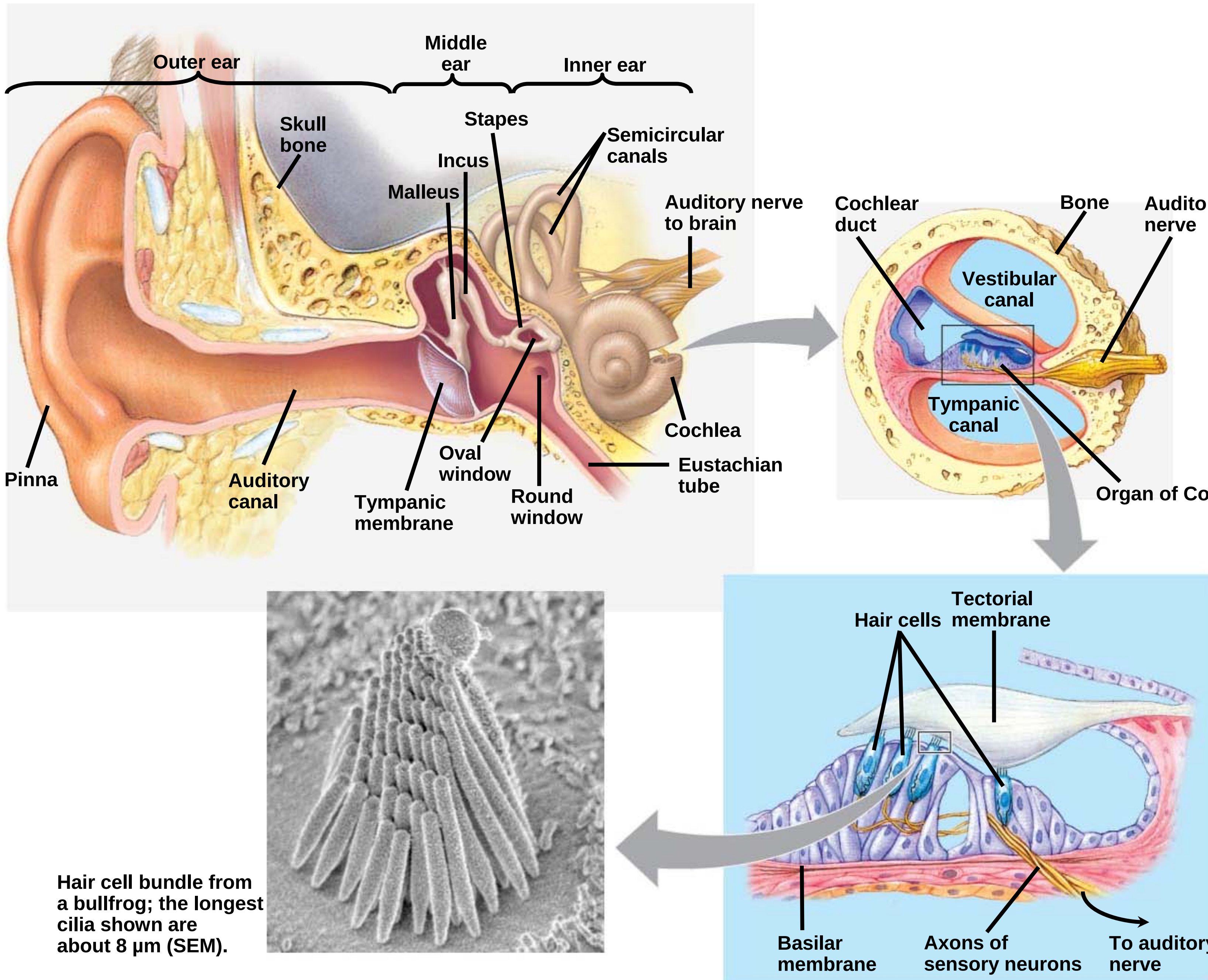
Fig. 50-7



Hearing and Equilibrium in Mammals

- In most terrestrial vertebrates, sensory organs for hearing and equilibrium are closely associated in the ear

Fig. 50-8



Outer ear
Middle ear
Inner ear
Skull bone
Stapes
Semicircular canals
Incus
Malleus
Auditory nerve to brain
Cochlear duct
Bone
Auditory nerve
Vestibular canal
Tympanic canal
Organ of Corti
Cochlea
Oval window
Eustachian tube
Pinna
Auditory canal
Tympanic membrane
Round window
Tectorial membrane
Hair cells
Basilar membrane
Axons of sensory neurons
To auditory nerve
Hair cell bundle from a bullfrog; the longest cilia shown are about 8 µm (SEM).

Fig. 50-8a

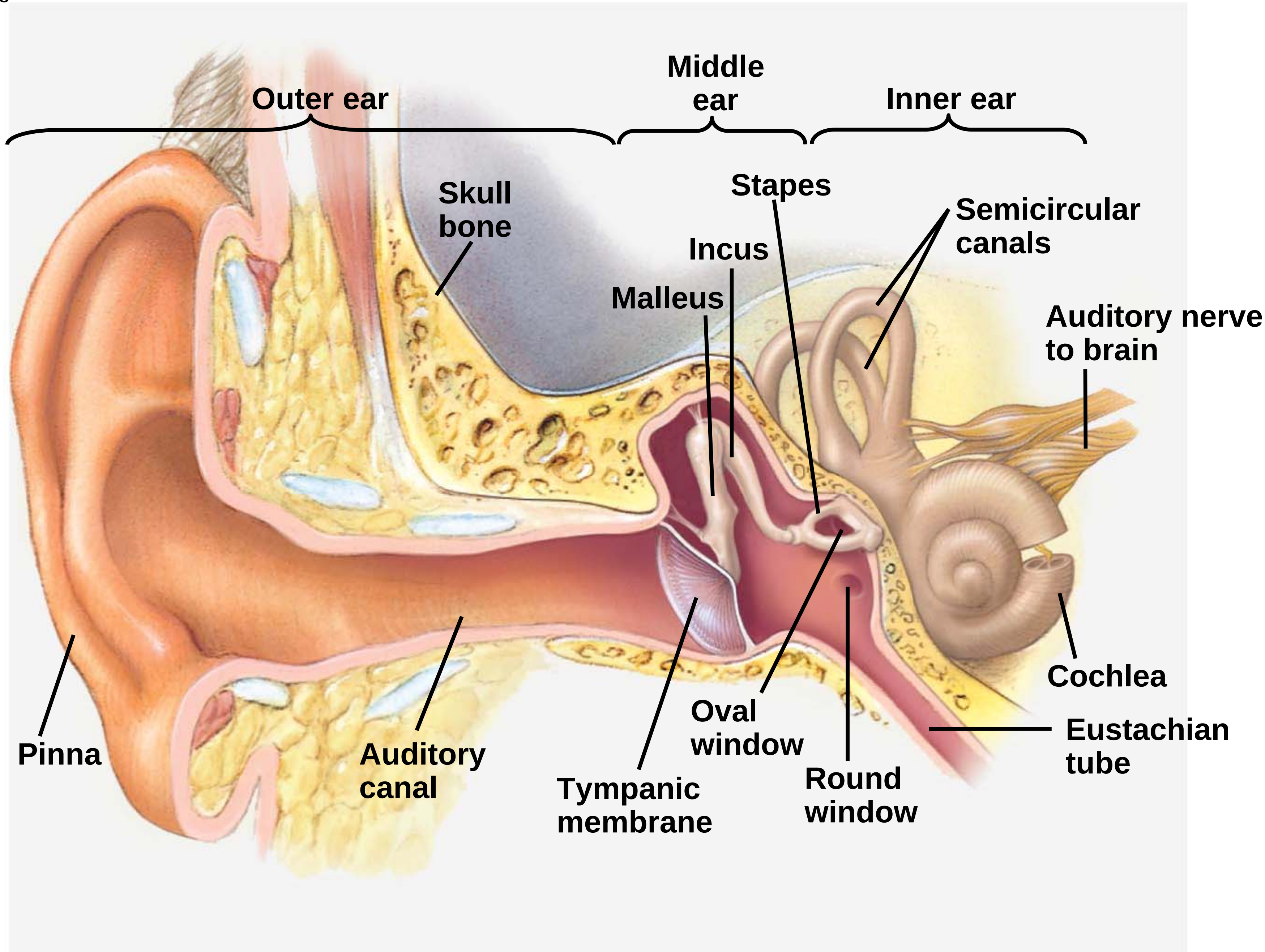

Outer ear
Middle ear
Inner ear
Skull bone
Stapes
Incus
Malleus
Semicircular canals
Auditory nerve to brain
Pinna
Auditory canal
Tympanic membrane
Oval window
Round window
Cochlea
Eustachian tube

Fig. 50-8b

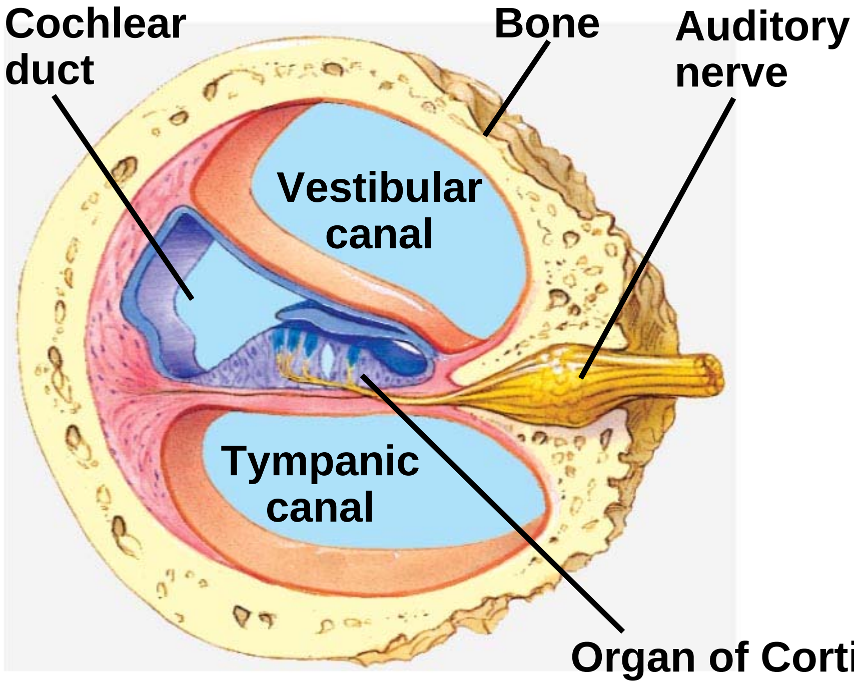
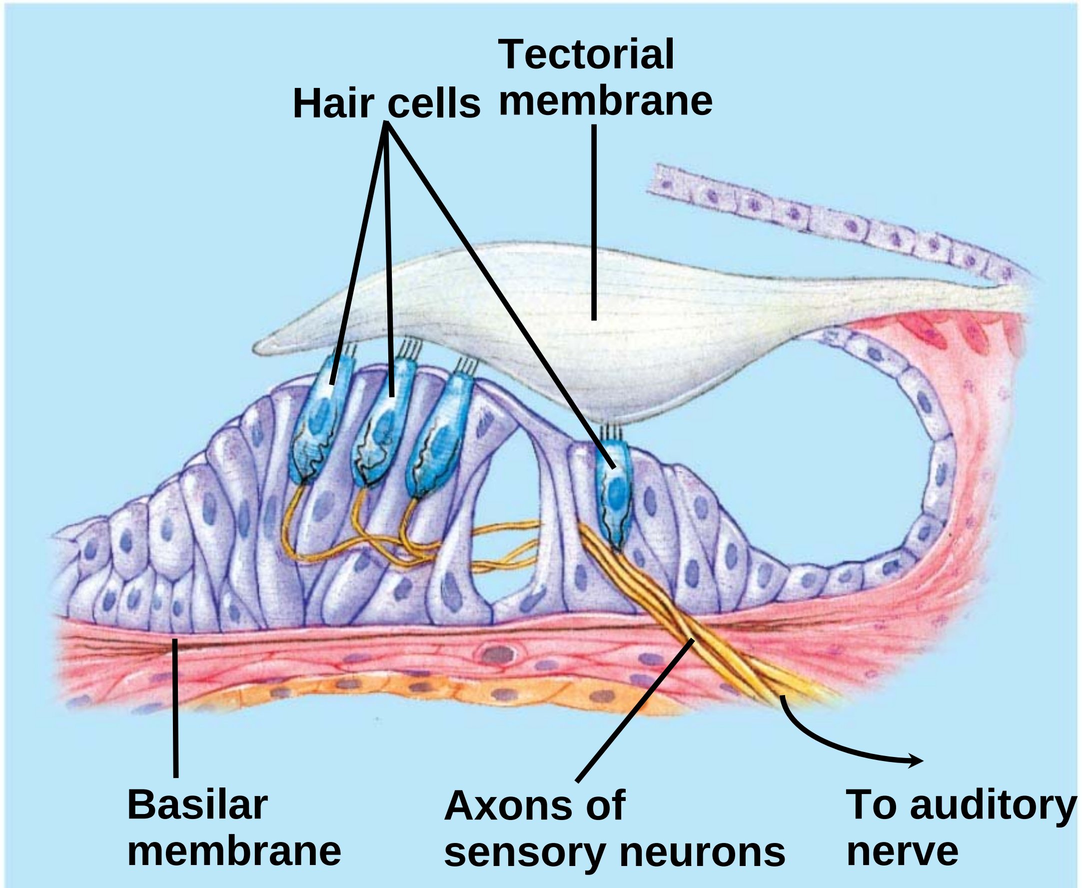
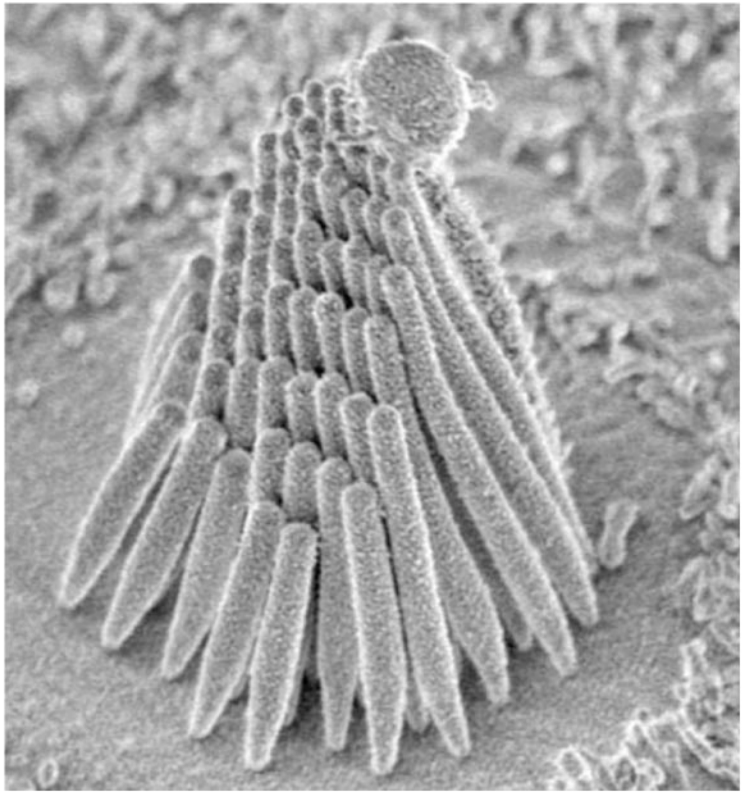

Cochlear duct
Bone
Auditory nerve
Vestibular canal
Tympanic canal
Organ of Corti

Fig. 50-8c



Tectorial membrane
Hair cells
Basilar membrane
Axons of sensory neurons
To auditory nerve

Fig. 50-8d



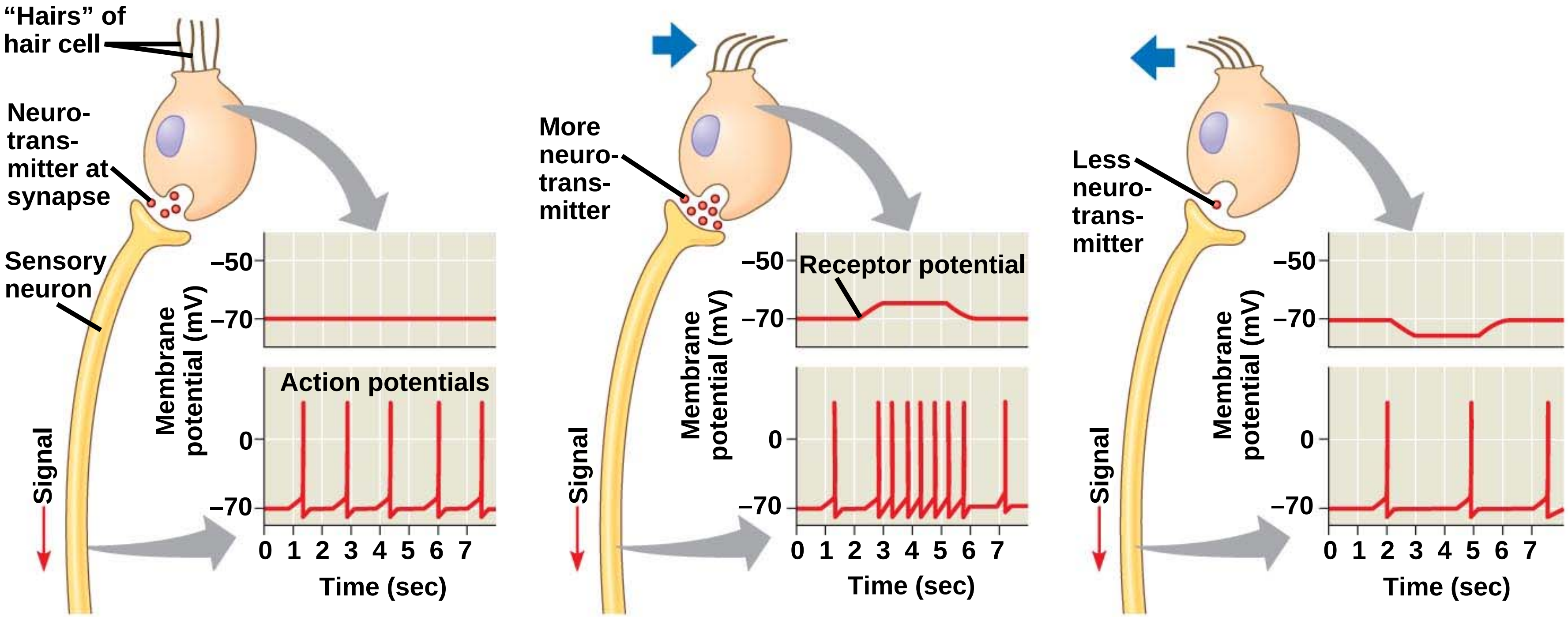
Hair cell bundle from a bullfrog; the longest cilia shown are about 8 µm (SEM).

Hearing

- Vibrating objects create percussion waves in the air that cause the tympanic membrane to vibrate
- **Hearing** is the perception of sound in the brain from the vibration of air waves
- The three bones of the middle ear transmit the vibrations of moving air to the oval window on the cochlea

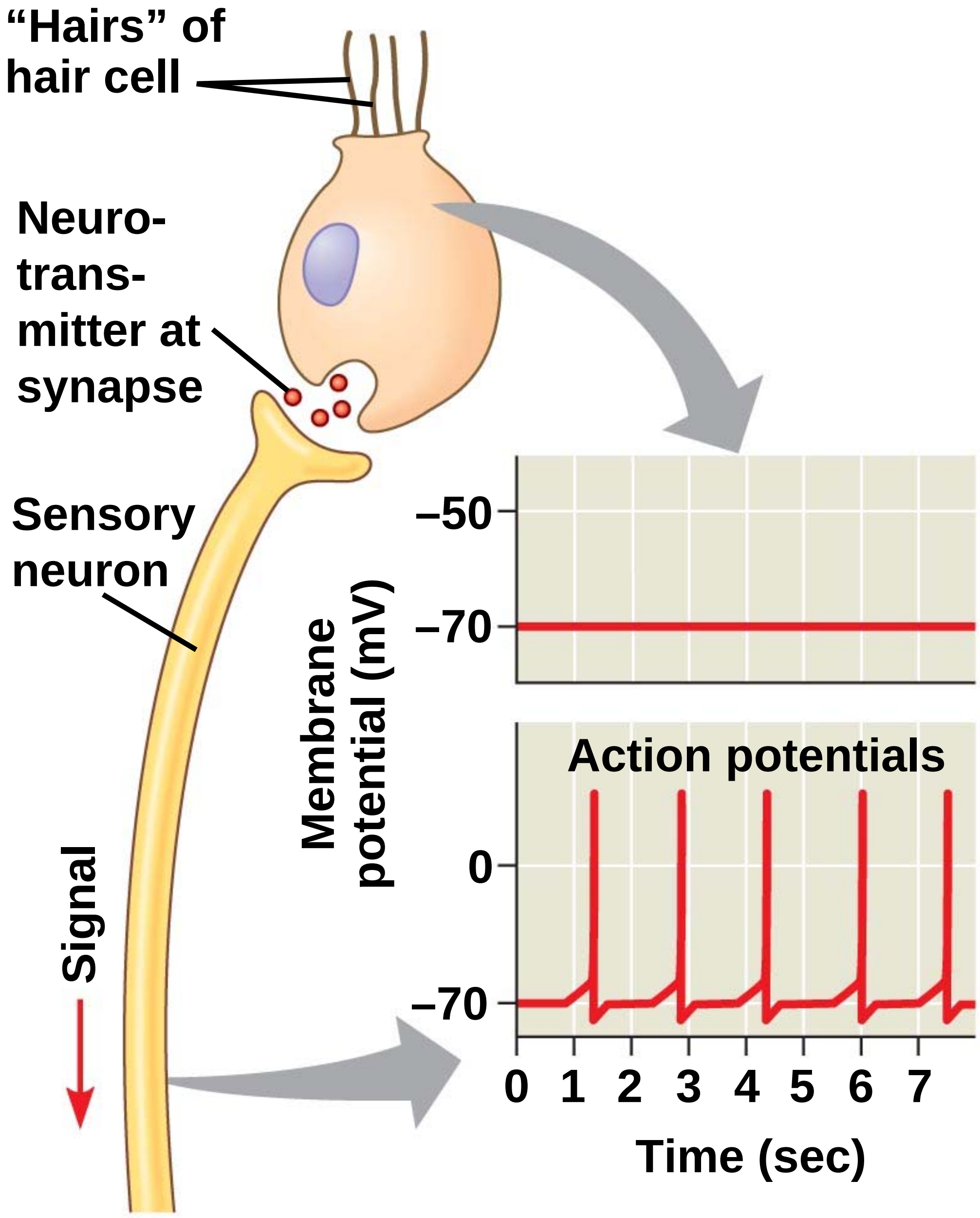
- These vibrations create pressure waves in the fluid in the cochlea that travel through the vestibular canal
- Pressure waves in the canal cause the basilar membrane to vibrate, bending its hair cells
- This bending of hair cells depolarizes the membranes of mechanoreceptors and sends action potentials to the brain via the auditory nerve

Fig. 50-9



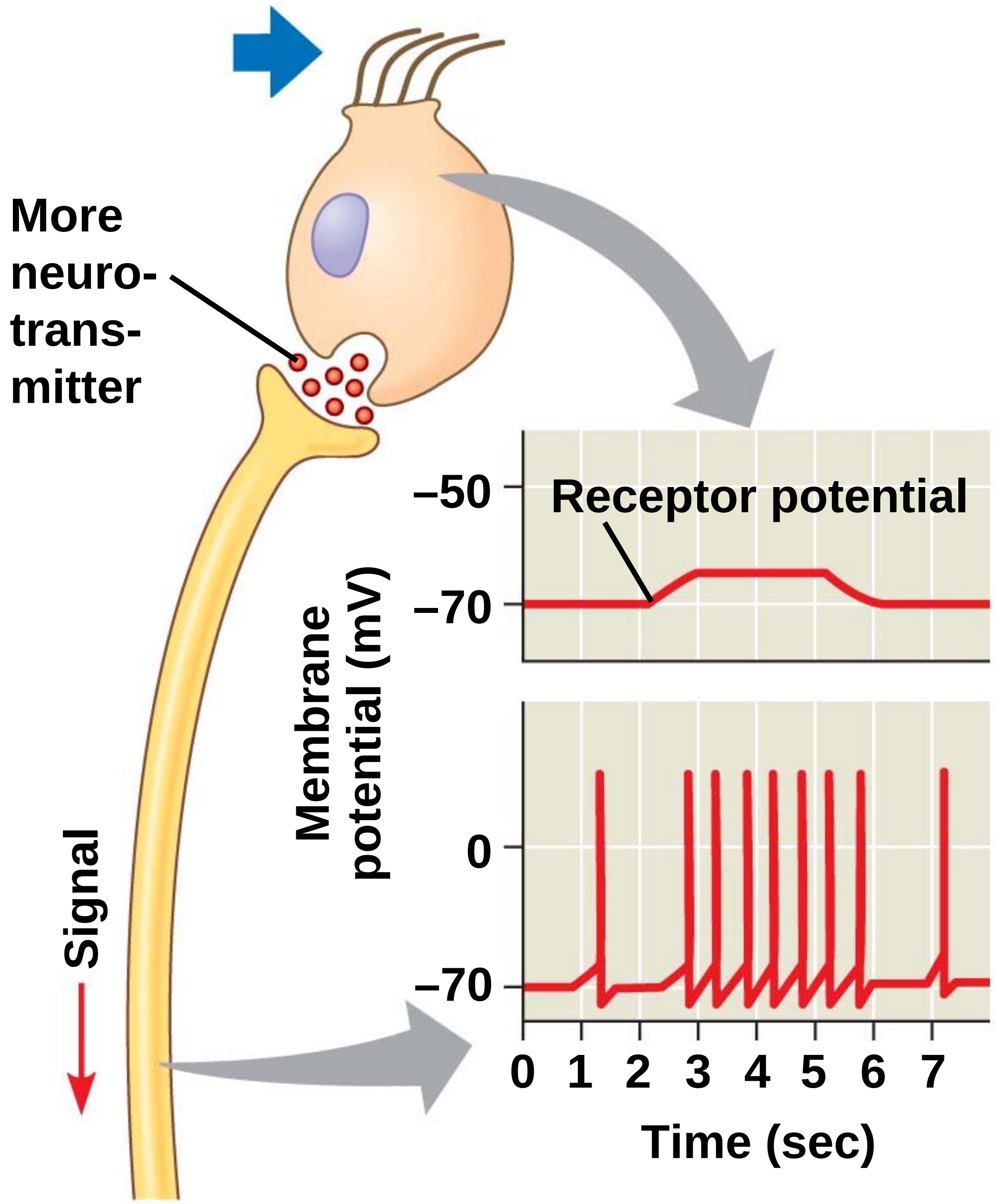
(a) No bending of hairs (b) Bending of hairs in one direction (c) Bending of hairs in other direction

Fig. 50-9a



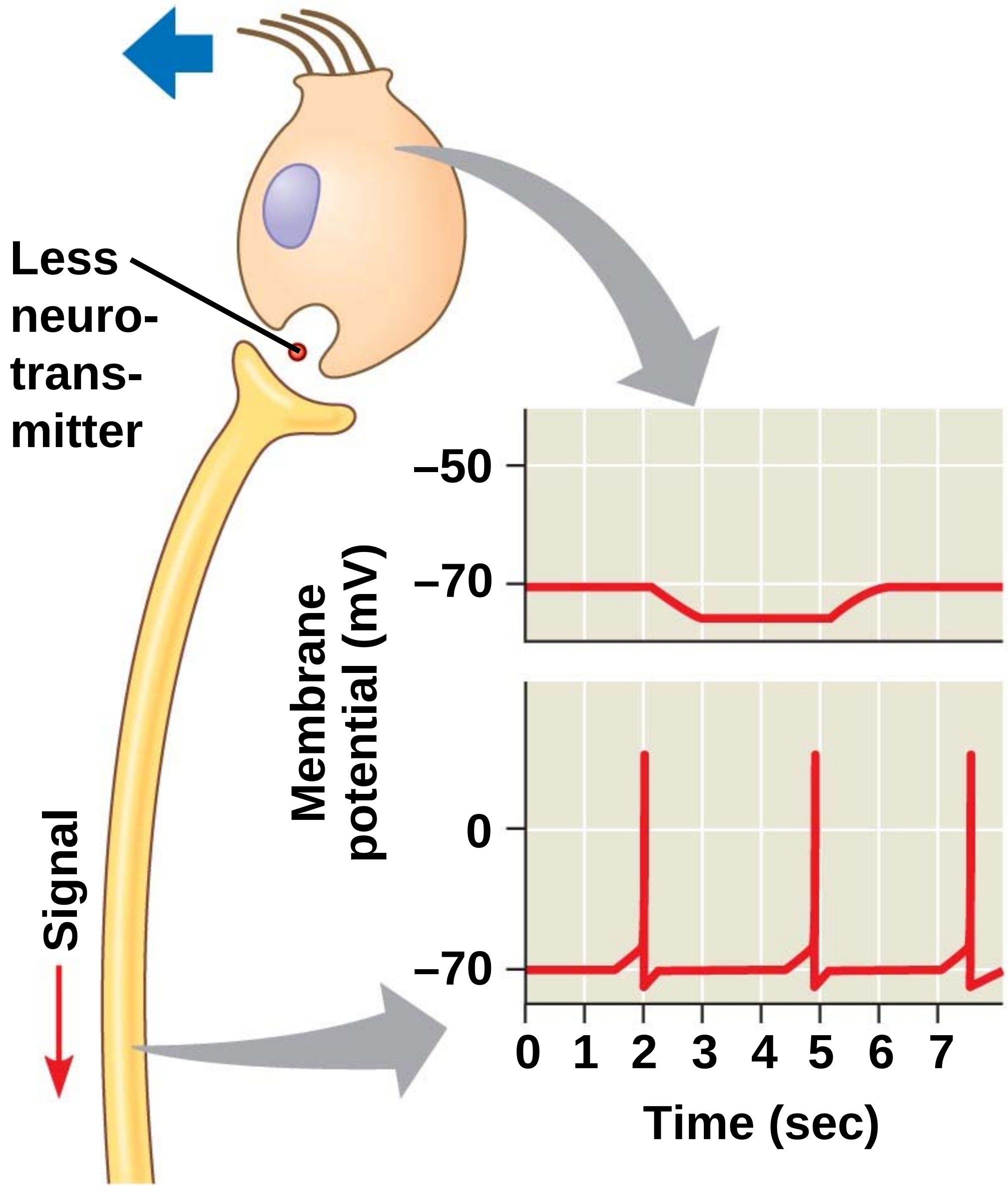
(a) No bending of hairs

Fig. 50-9b



(b) Bending of hairs in one direction

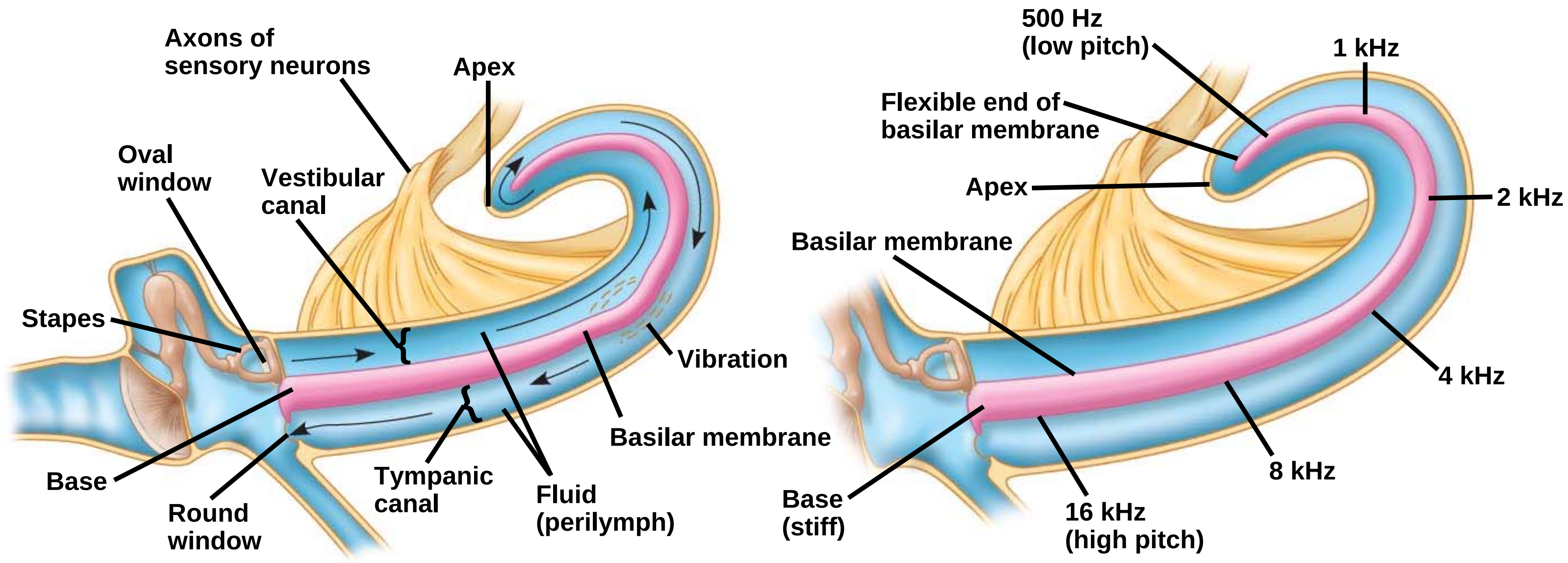
Fig. 50-9c



(c) Bending of hairs in other direction

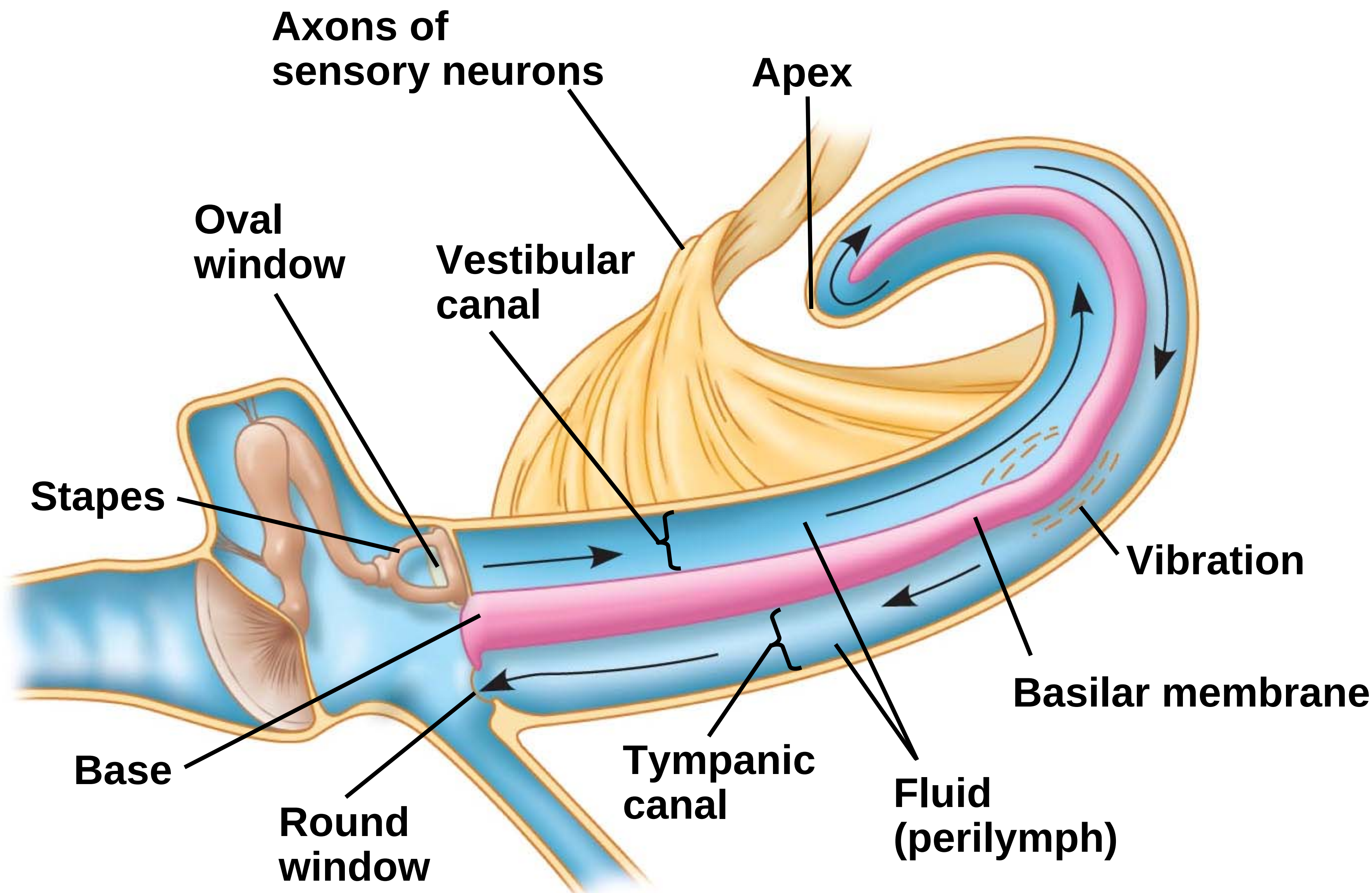
- The fluid waves dissipate when they strike the **round window** at the end of the tympanic canal

Fig. 50-10



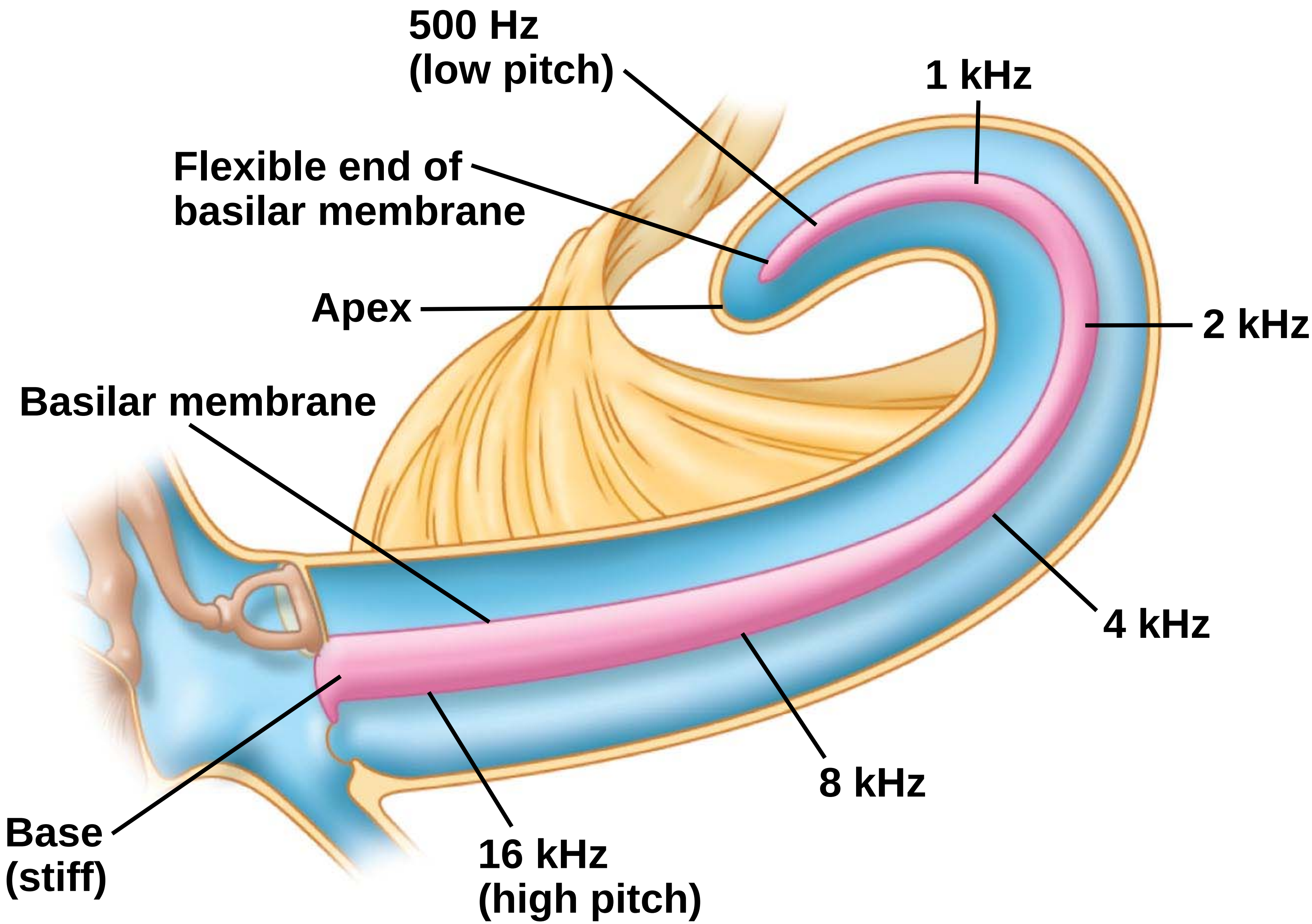
Axons of
sensory neurons
Apex
Oval
window
Vestibular
canal
Stapes
Vibration
Basilar membrane
Base
Round
window
Tympanic
canal
Fluid
(perilymph)
500 Hz
(low pitch)
1 kHz
Flexible end of
basilar membrane
Apex
2 kHz
Basilar membrane
4 kHz
8 kHz
Base
(stiff)
16 kHz
(high pitch)

Fig. 50-10a


Axons of sensory neurons
Apex
Oval window
Vestibular canal
Stapes
Vibration
Basilar membrane
Base
Round window
Tympanic canal
Fluid (perilymph)

- The ear conveys information about:
  - *Volume*, the amplitude of the sound wave
  - *Pitch*, the frequency of the sound wave
- The cochlea can distinguish pitch because the basilar membrane is not uniform along its length
- Each region vibrates most vigorously at a particular frequency and leads to excitation of a specific auditory area of the cerebral cortex

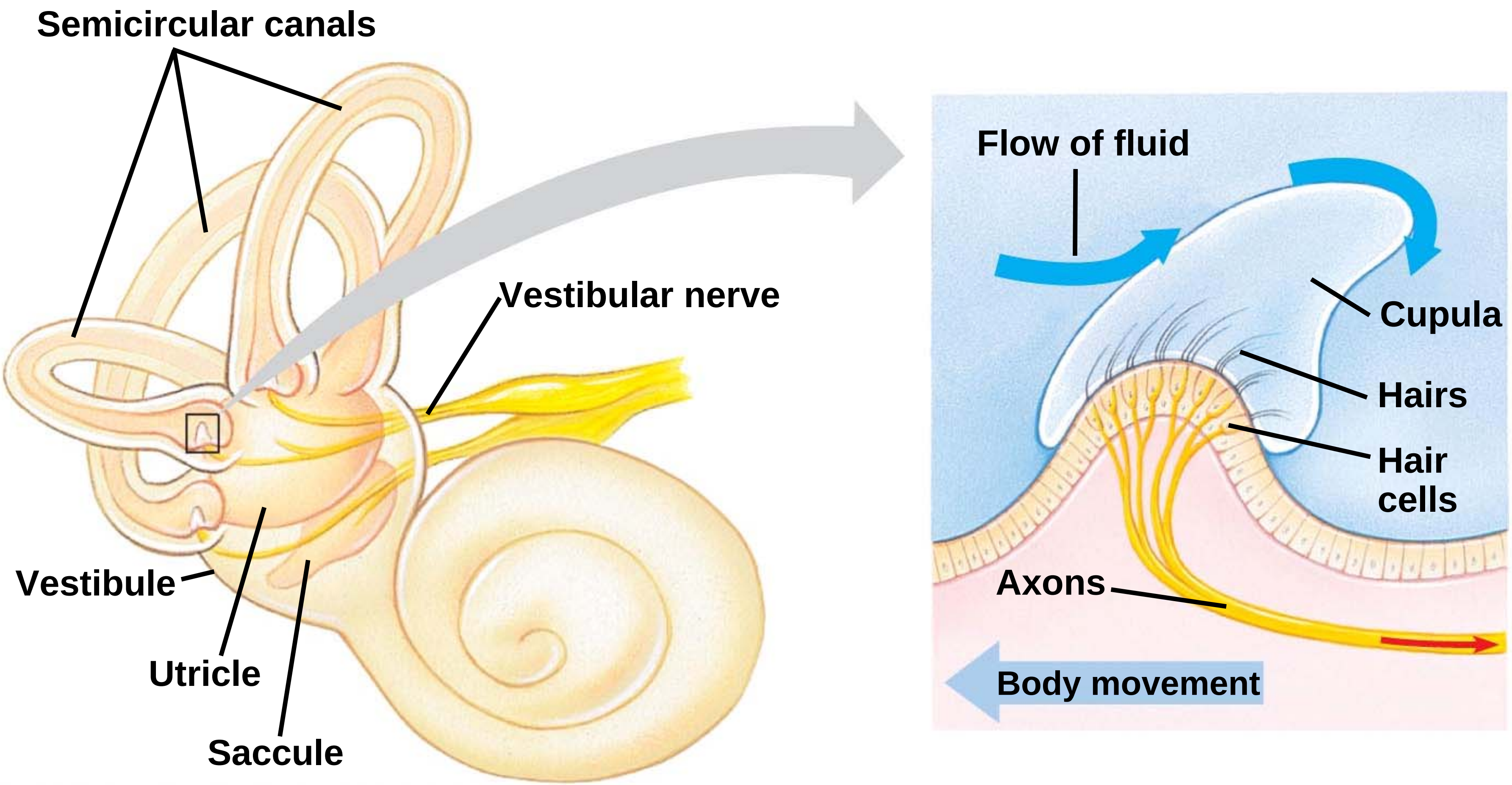
Fig. 50-10b


500 Hz
(low pitch)
1 kHz
Flexible end of
basilar membrane
Apex
2 kHz
Basilar membrane
4 kHz
8 kHz
Base
(stiff)
16 kHz
(high pitch)

Equilibrium

- Several organs of the inner ear detect body position and balance:
  - The **utricle** and **saccule** contain granules called otoliths that allow us to detect gravity and linear movement
  - Three semicircular canals contain fluid and allow us to detect angular acceleration such as the turning of the head

Fig. 50-11

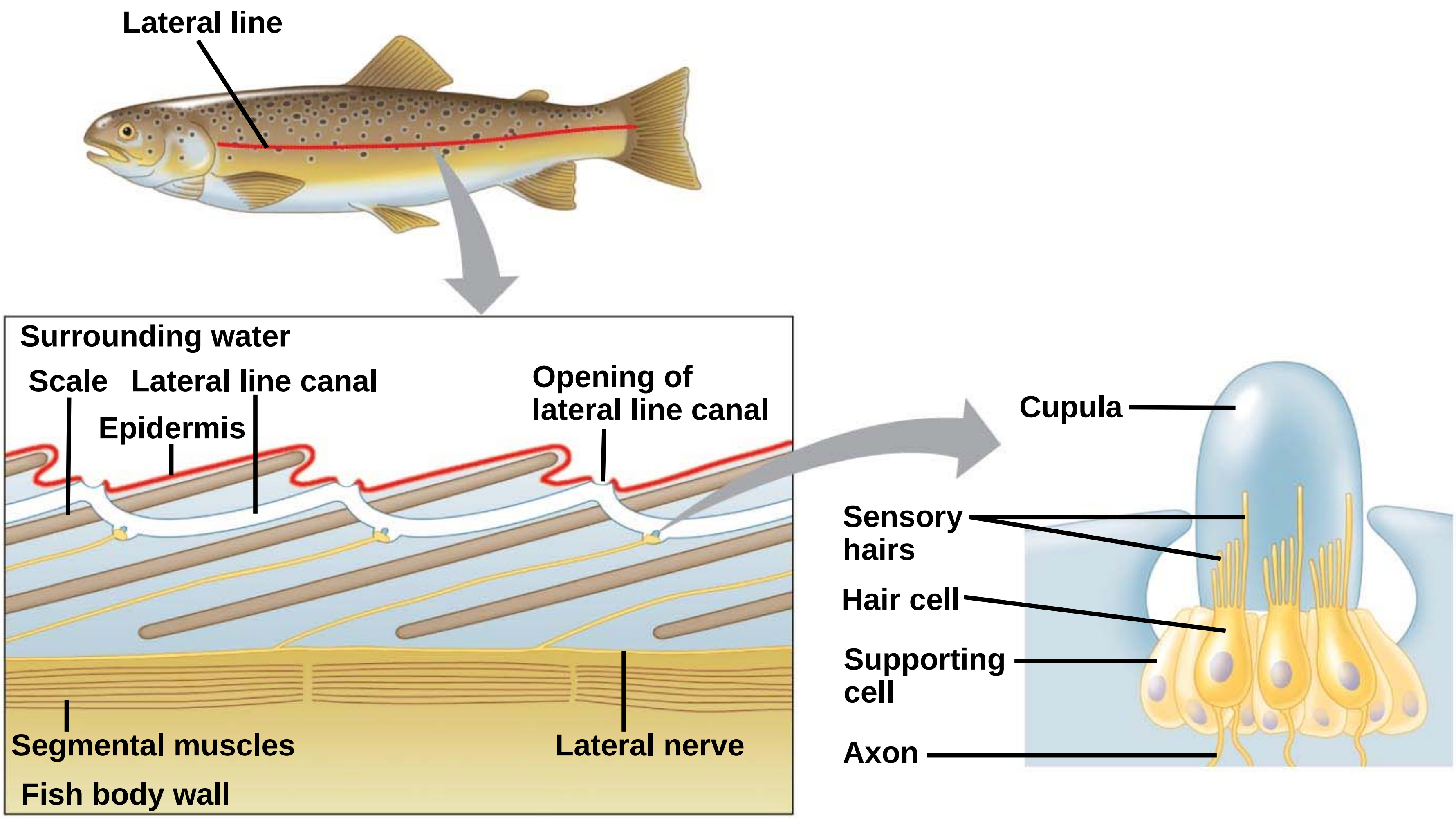


Semicircular canals
Vestibular nerve
Vestibule
Utricle
Saccule
Flow of fluid
Cupula
Hairs
Hair
cells
Axons
Body movement

Hearing and Equilibrium in Other Vertebrates

- Unlike mammals, fishes have only a pair of inner ears near the brain
- Most fishes and aquatic amphibians also have a **lateral line system** along both sides of their body
- The lateral line system contains mechanoreceptors with hair cells that detect and respond to water movement

Fig. 50-12


Lateral line
Surrounding water
Scale
Lateral line canal
Epidermis
Opening of lateral line canal
Segmental muscles
Lateral nerve
Fish body wall
Cupula
Sensory hairs
Hair cell
Supporting cell
Axon

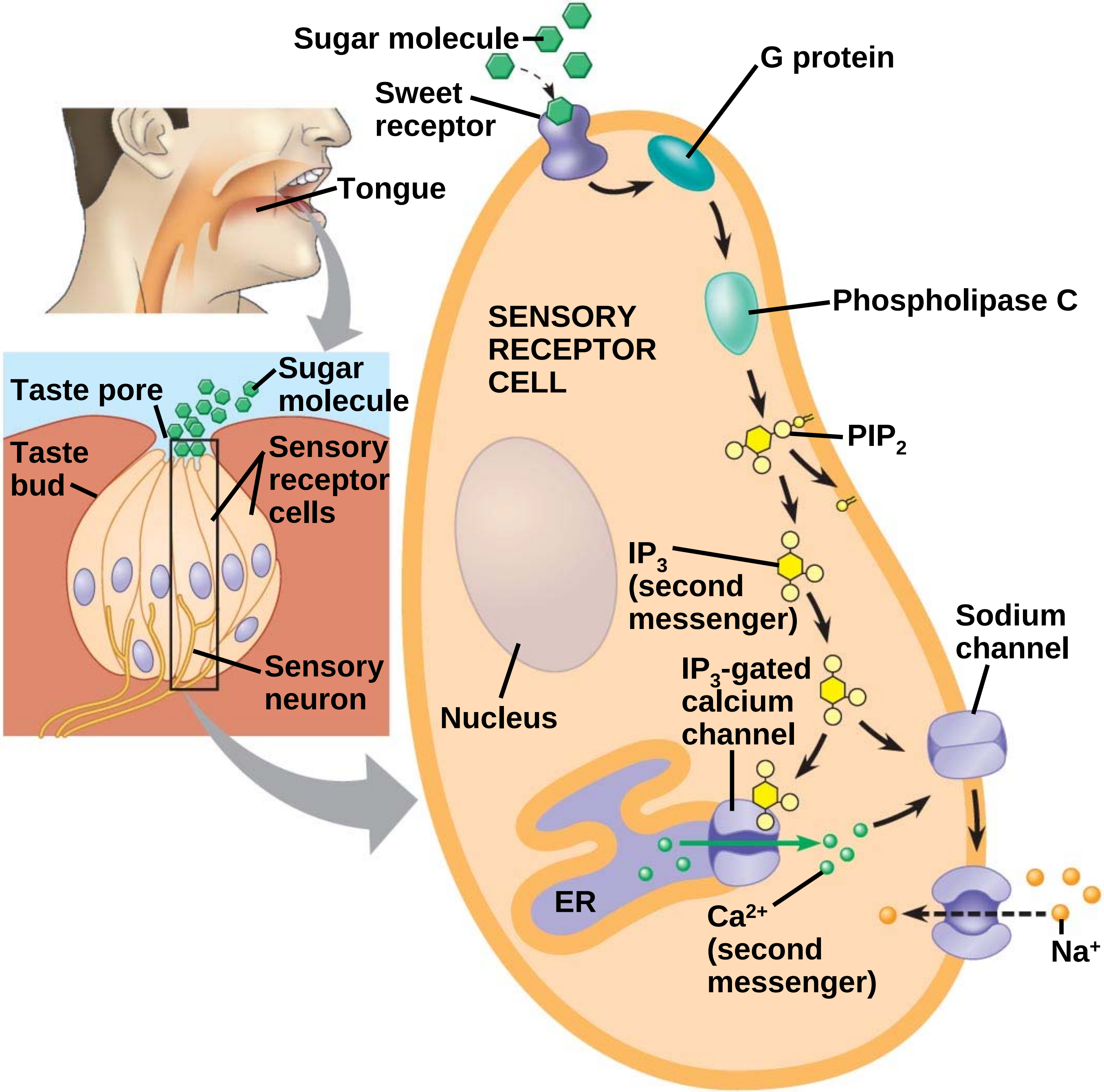
Concept 50.3: The senses of taste and smell rely on similar sets of sensory receptors

- In terrestrial animals**:**
  - **Gustation** (taste) is dependent on the detection of chemicals called **tastants**
  - **Olfaction** (smell) is dependent on the detection of **odorant** molecules
- In aquatic animals there is no distinction between taste and smell
- Taste receptors of insects are in sensory hairs called sensilla, located on feet and in mouth parts

Taste in Mammals

- In humans, receptor cells for taste are modified epithelial cells organized into **taste buds**
- There are five taste perceptions: sweet, sour, salty, bitter, and umami (elicited by glutamate)
- Each type of taste can be detected in any region of the tongue

Fig. 50-13

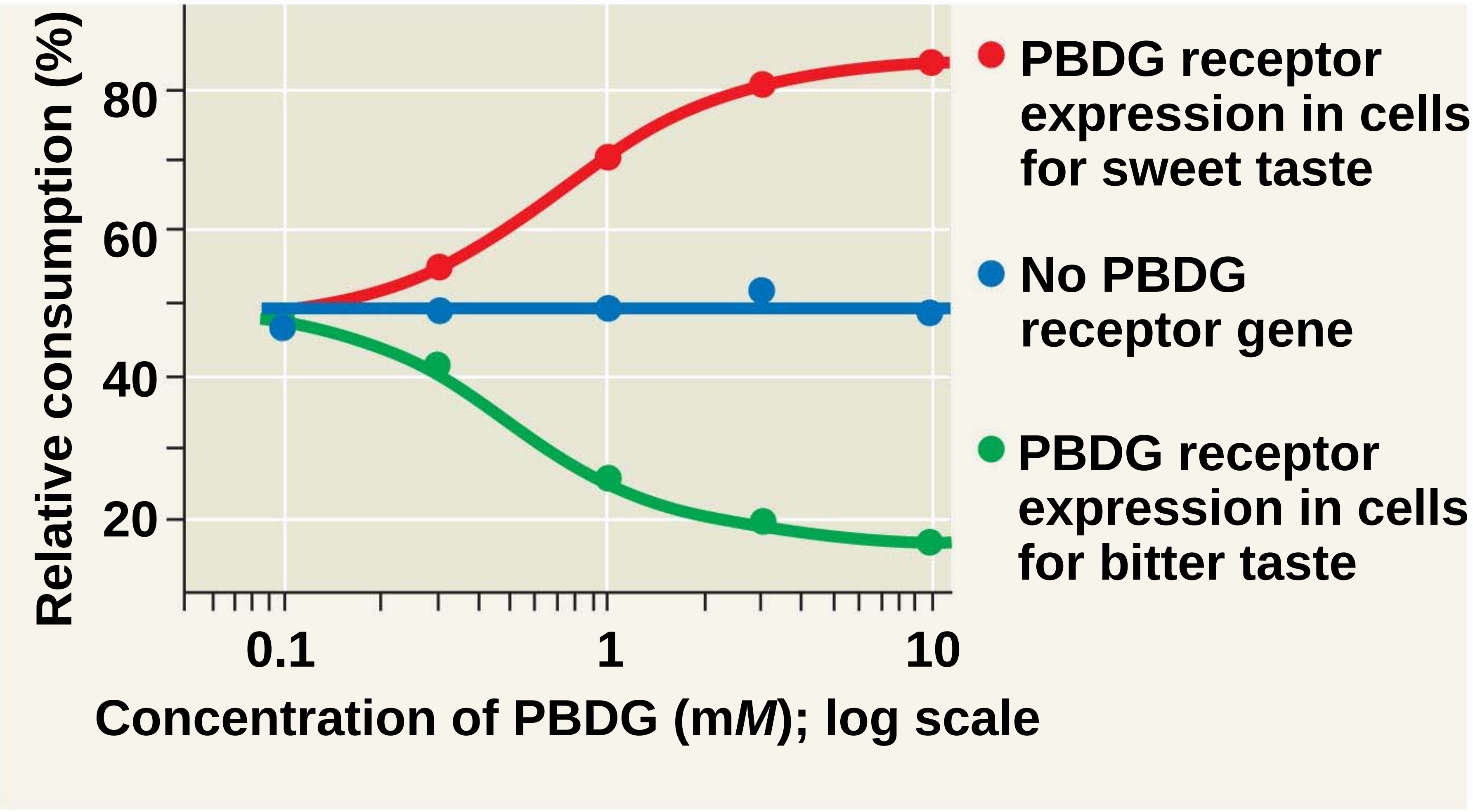


Sugar molecule
Sweet receptor
G protein
Tongue
Phospholipase C
SENSORY RECEPTOR CELL
Taste pore
Sugar molecule
PIP2
Taste bud
Sensory receptor cells
IP3 (second messenger)
Sodium channel
Sensory neuron
IP3-gated calcium channel
Nucleus
ER
Ca2+ (second messenger)
Na+

- When a taste receptor is stimulated, the signal is transduced to a sensory neuron
- Each taste cell has only one type of receptor

Fig. 50-14

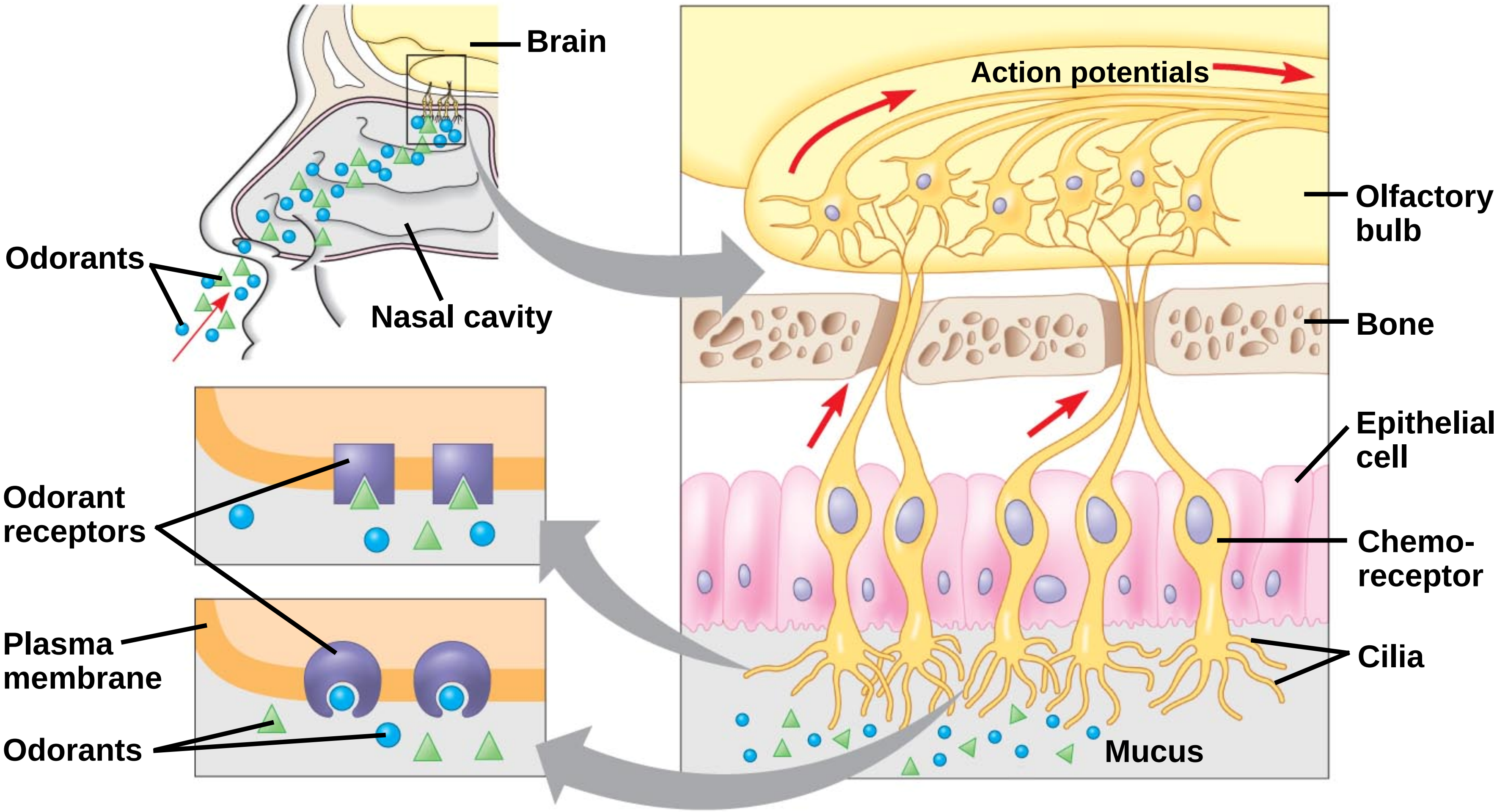
RESULTS



Smell in Humans

- Olfactory receptor cells are neurons that line the upper portion of the nasal cavity
- Binding of odorant molecules to receptors triggers a signal transduction pathway, sending action potentials to the brain

Fig. 50-15



Brain
Odorants
Nasal cavity
Action potentials
Olfactory bulb
Bone
Epithelial cell
Chemo-receptor
Cilia
Mucus
Odorant receptors
Plasma membrane
Odorants

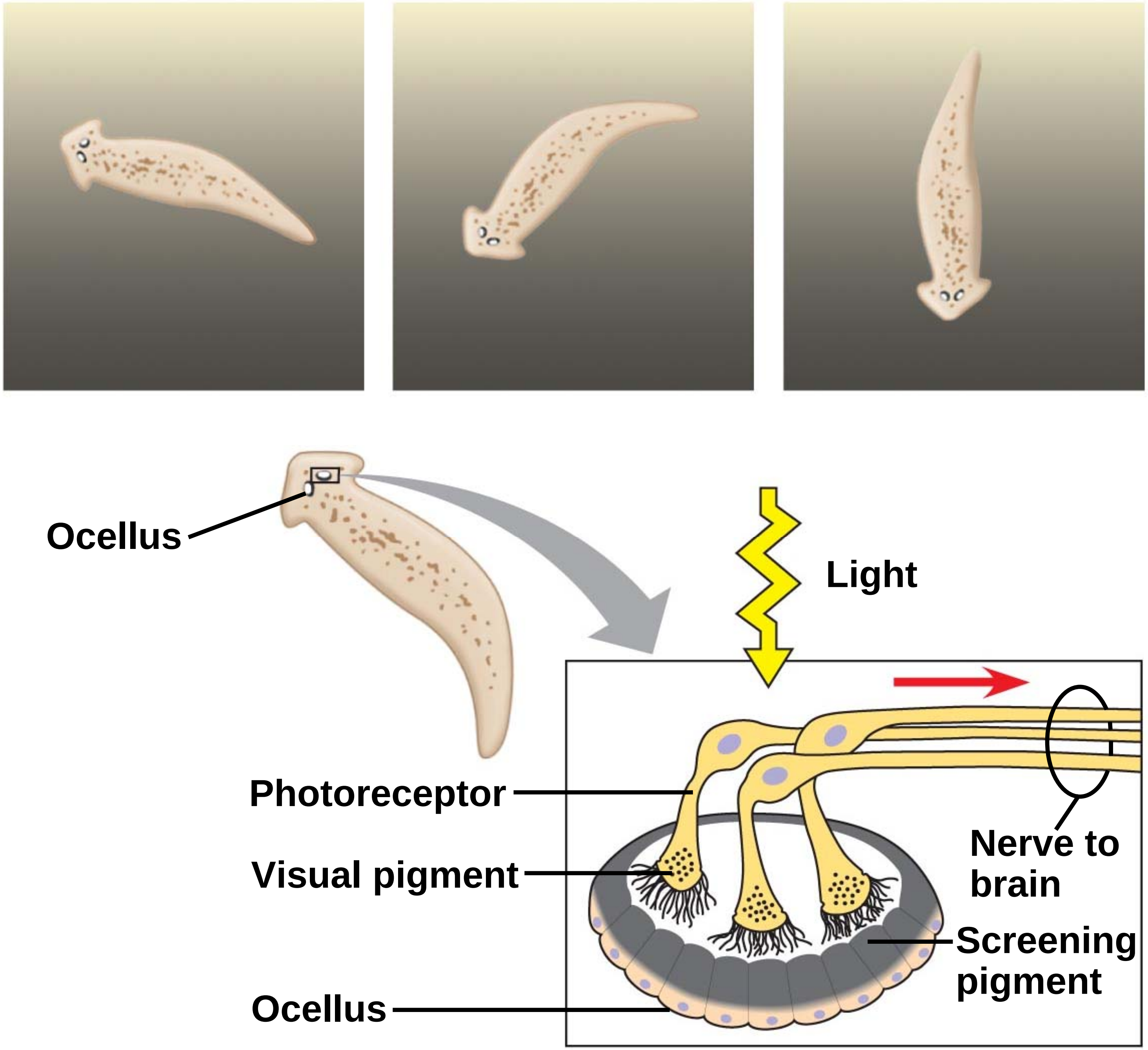
Concept 50.4: Similar mechanisms underlie vision throughout the animal kingdom

- Many types of light detectors have evolved in the animal kingdom

Vision in Invertebrates

- Most invertebrates have a light-detecting organ
- One of the simplest is the eye cup of planarians, which provides information about light intensity and direction but does not form images

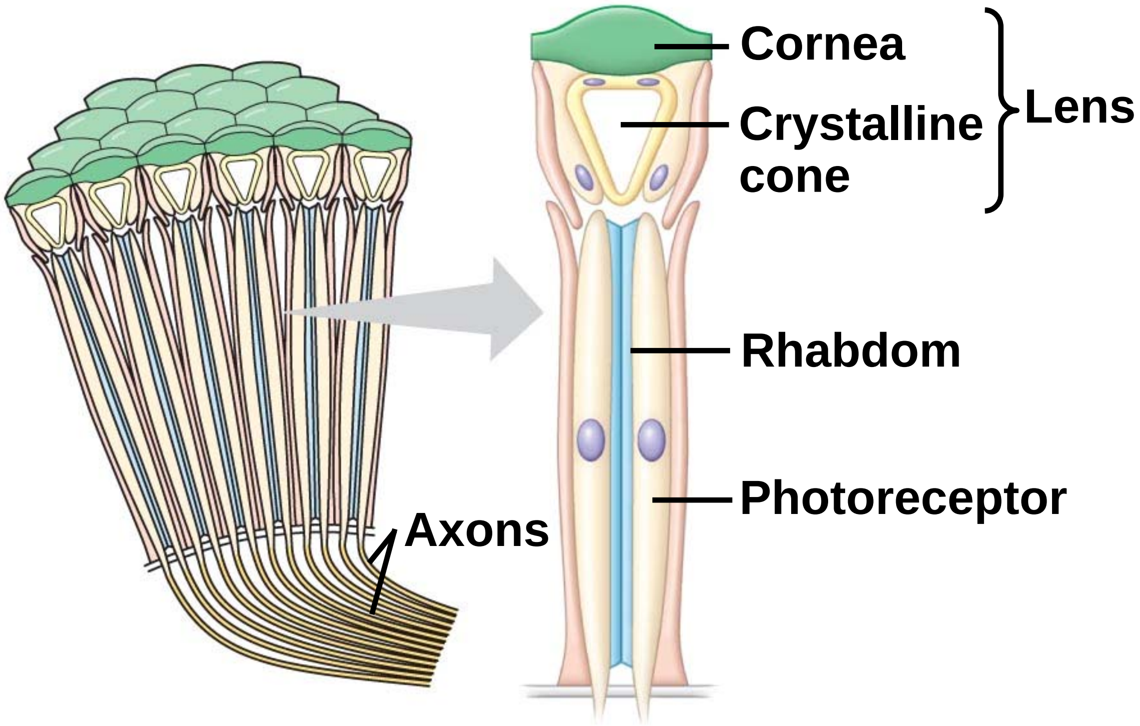
Fig. 50-16


Ocellus
Light
Photoreceptor
Visual pigment
Ocellus
Nerve to brain
Screening pigment

- Two major types of image-forming eyes have evolved in invertebrates: the compound eye and the single-lens eye
- **Compound eyes** are found in insects and crustaceans and consist of up to several thousand light detectors called **ommatidia**
- Compound eyes are very effective at detecting movement

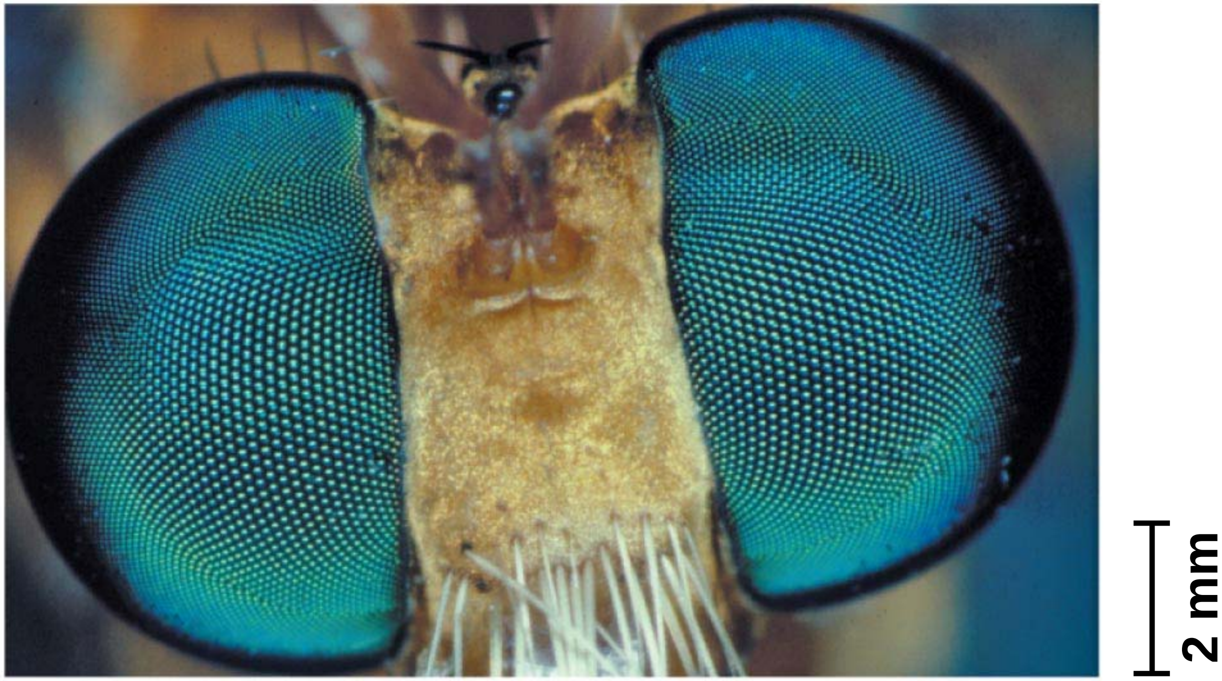
Fig. 50-17

(a) Fly eyes



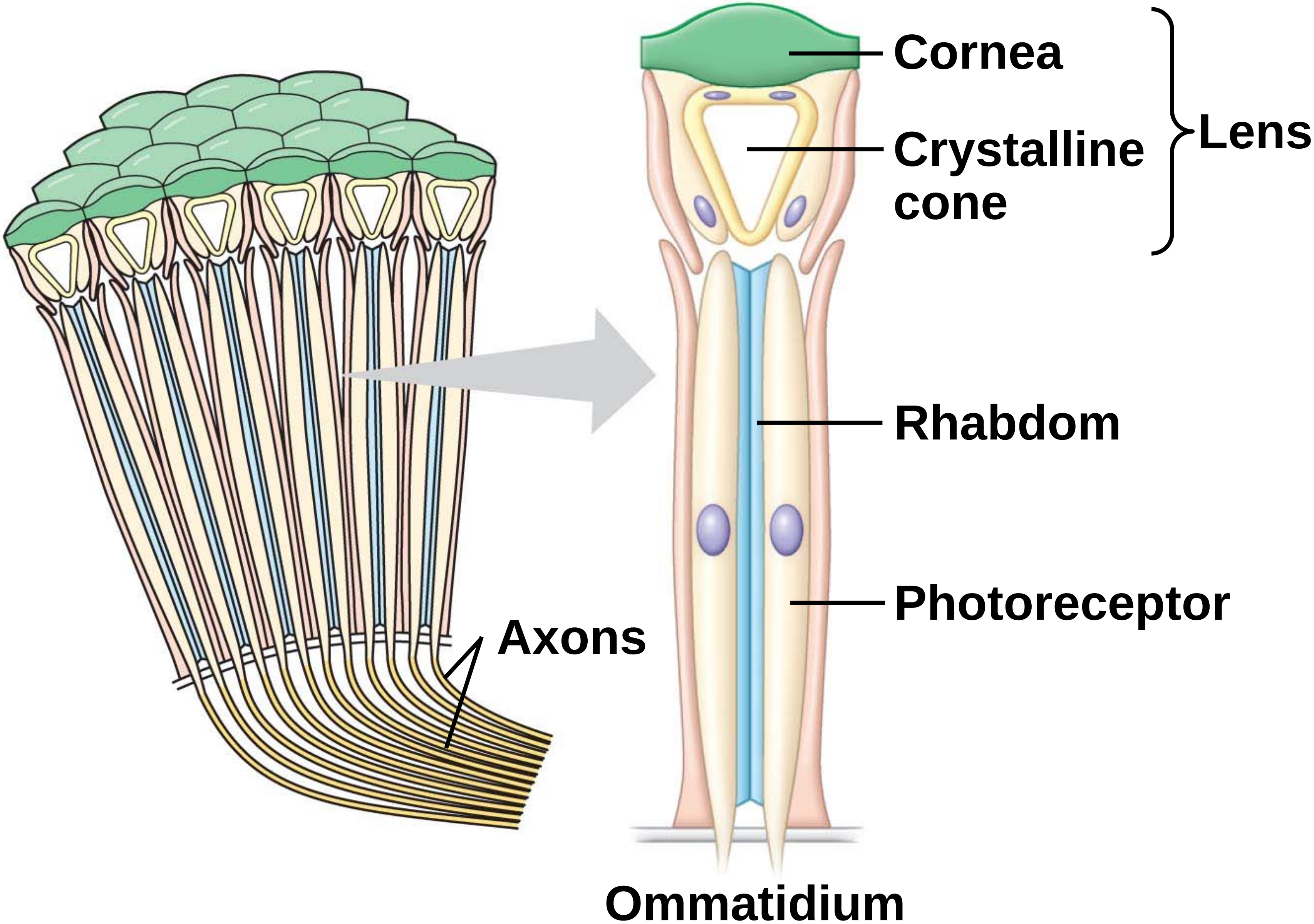
(b) Ommatidia

Fig. 50-17a



(a) Fly eyes

Fig. 50-17b



(b) Ommatidia

- **Single-lens eyes** are found in some jellies, polychaetes, spiders, and many molluscs
- They work on a camera-like principle: the **iris** changes the diameter of the **pupil** to control how much light enters

The Vertebrate Visual System

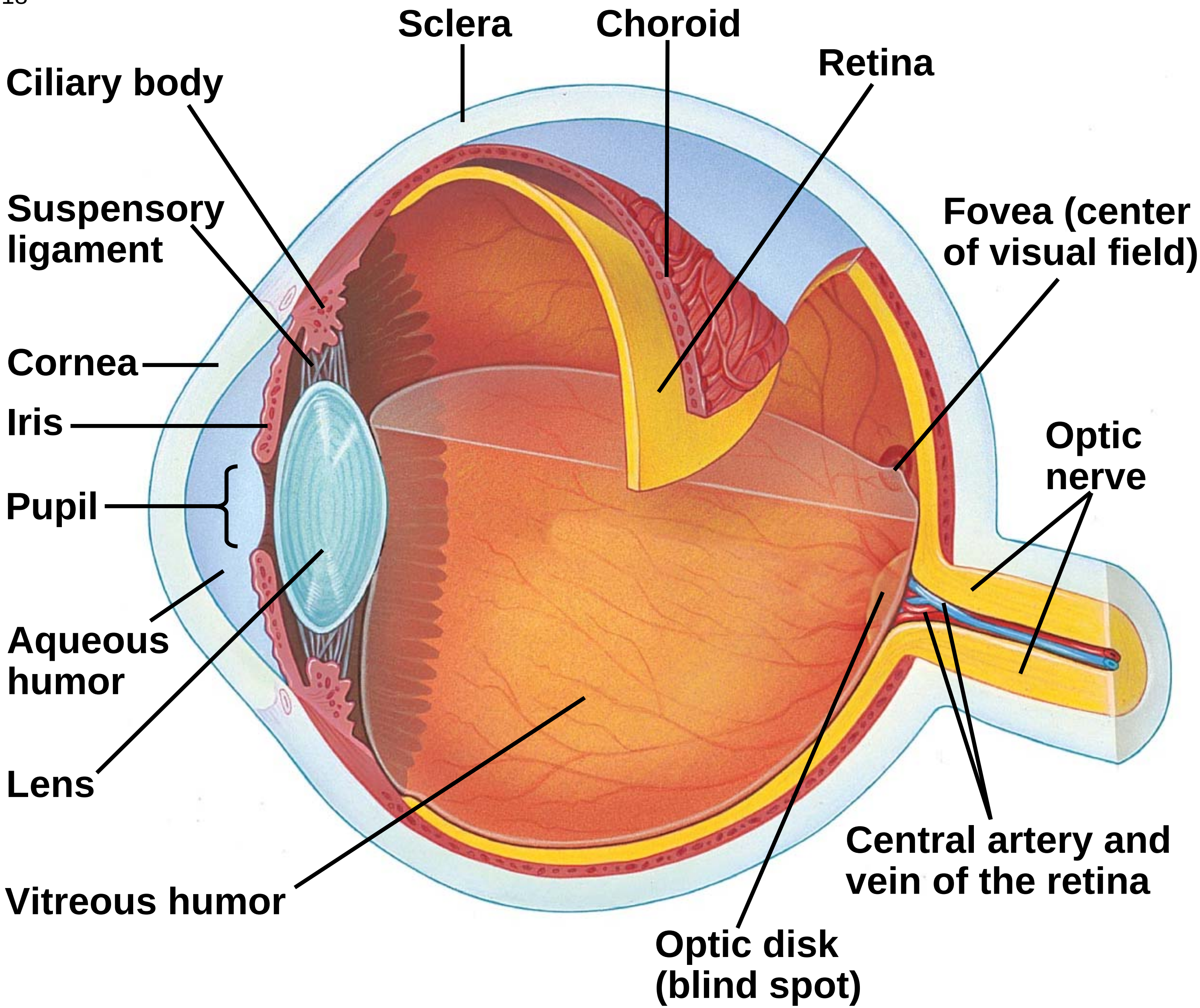
- In vertebrates the eye detects color and light, but the brain assembles the information and perceives the image

Structure of the Eye

- Main parts of the vertebrate eye:
  - The **sclera**: white outer layer, including **cornea**
  - The **choroid**: pigmented layer
  - The iris: regulates the size of the pupil
  - The **retina**: contains photoreceptors
  - The **lens**: focuses light on the retina
  - The optic disk: a blind spot in the retina where the optic nerve attaches to the eye

- The eye is divided into two cavities separated by the lens and **ciliary body**:
  - The anterior cavity is filled with watery **aqueous humor**
  - The posterior cavity is filled with jellylike **vitreous humor**
- The ciliary body produces the aqueous humor

Fig. 50-18

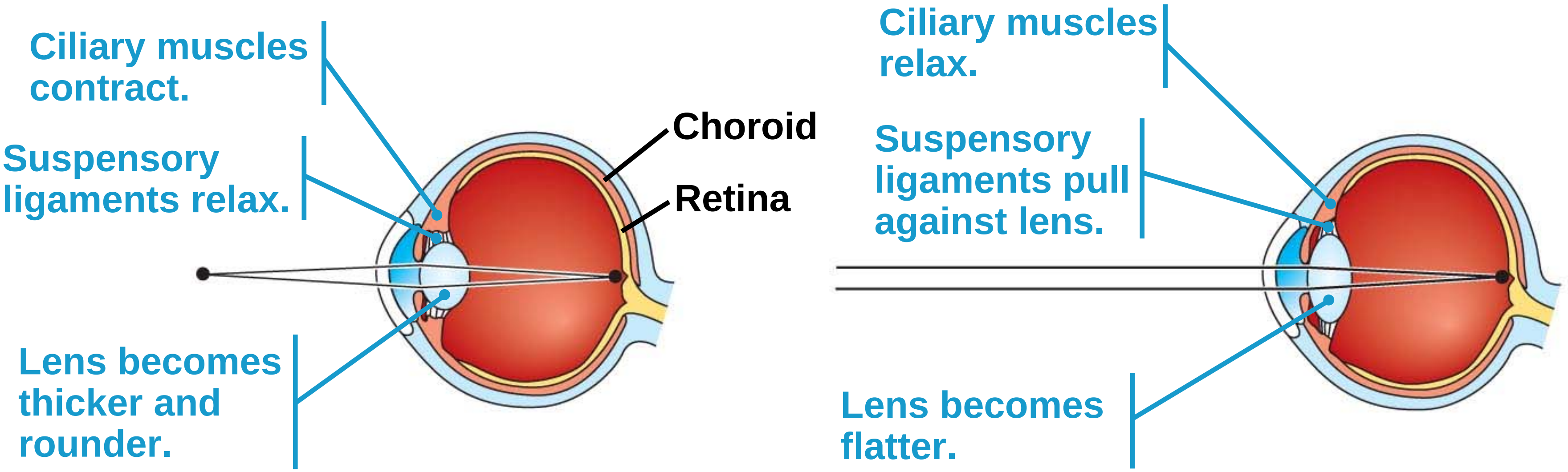

Sclera
Choroid
Retina
Ciliary body
Suspensory ligament
Cornea
Iris
Pupil
Aqueous humor
Lens
Vitreous humor
Fovea (center of visual field)
Optic nerve
Central artery and vein of the retina
Optic disk (blind spot)

- Humans and other mammals focus light by changing the shape of the lens

PLAY

Animation: Near and Distance Vision

Fig. 50-19



(a) Near vision (accommodation)

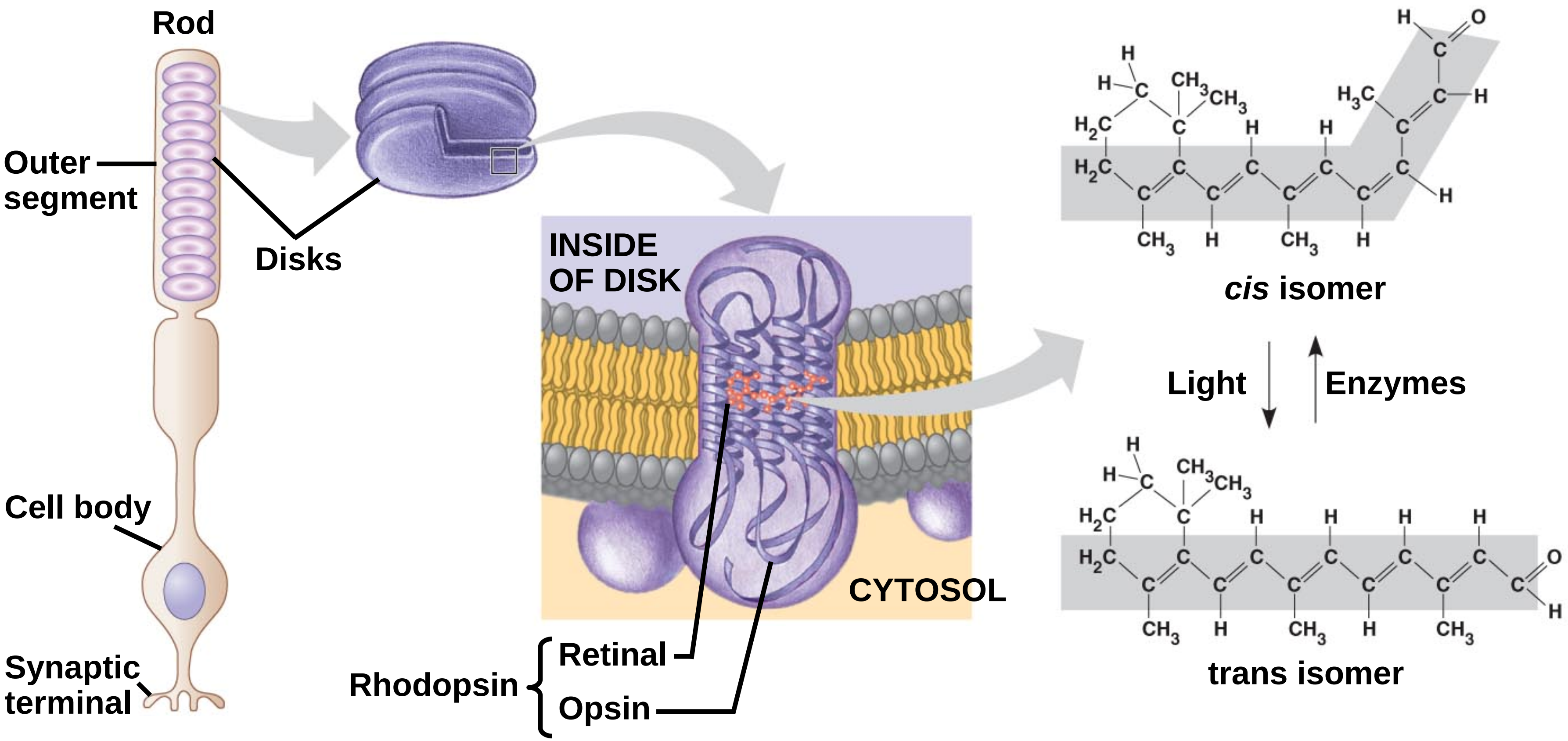
(b) Distance vision

- The human retina contains two types of photoreceptors: rods and cones
- **Rods** are light-sensitive but don’t distinguish colors
- **Cones** distinguish colors but are not as sensitive to light
- In humans, cones are concentrated in the **fovea**, the center of the visual field, and rods are more concentrated around the periphery of the retina

Sensory Transduction in the Eye

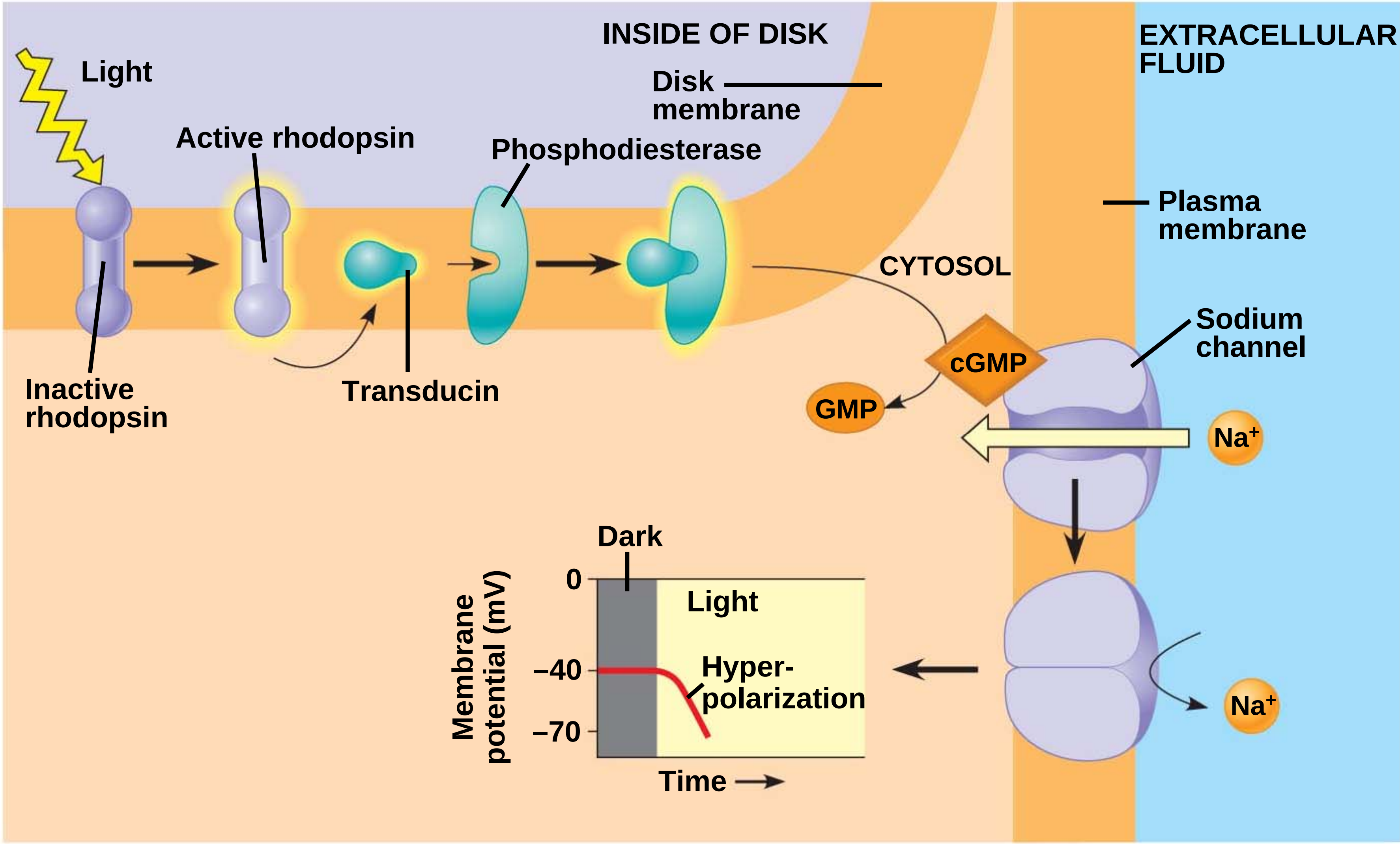
- Each rod or cone contains visual pigments consisting of a light-absorbing molecule called **retinal** bonded to a protein called an **opsin**
- Rods contain the pigment **rhodopsin** (retinal combined with a specific opsin), which changes shape when absorbing light

Fig. 50-20


Rod
Outer segment
Disks
Cell body
Synaptic terminal
INSIDE OF DISK
CYTOSOL
Rhodopsin
Retinal
Opsin
cis isomer
Light
Enzymes
trans isomer

- Once light activates rhodopsin, cyclic GMP breaks down, and Na^{+} channels close
- This hyperpolarizes the cell

Fig. 50-21



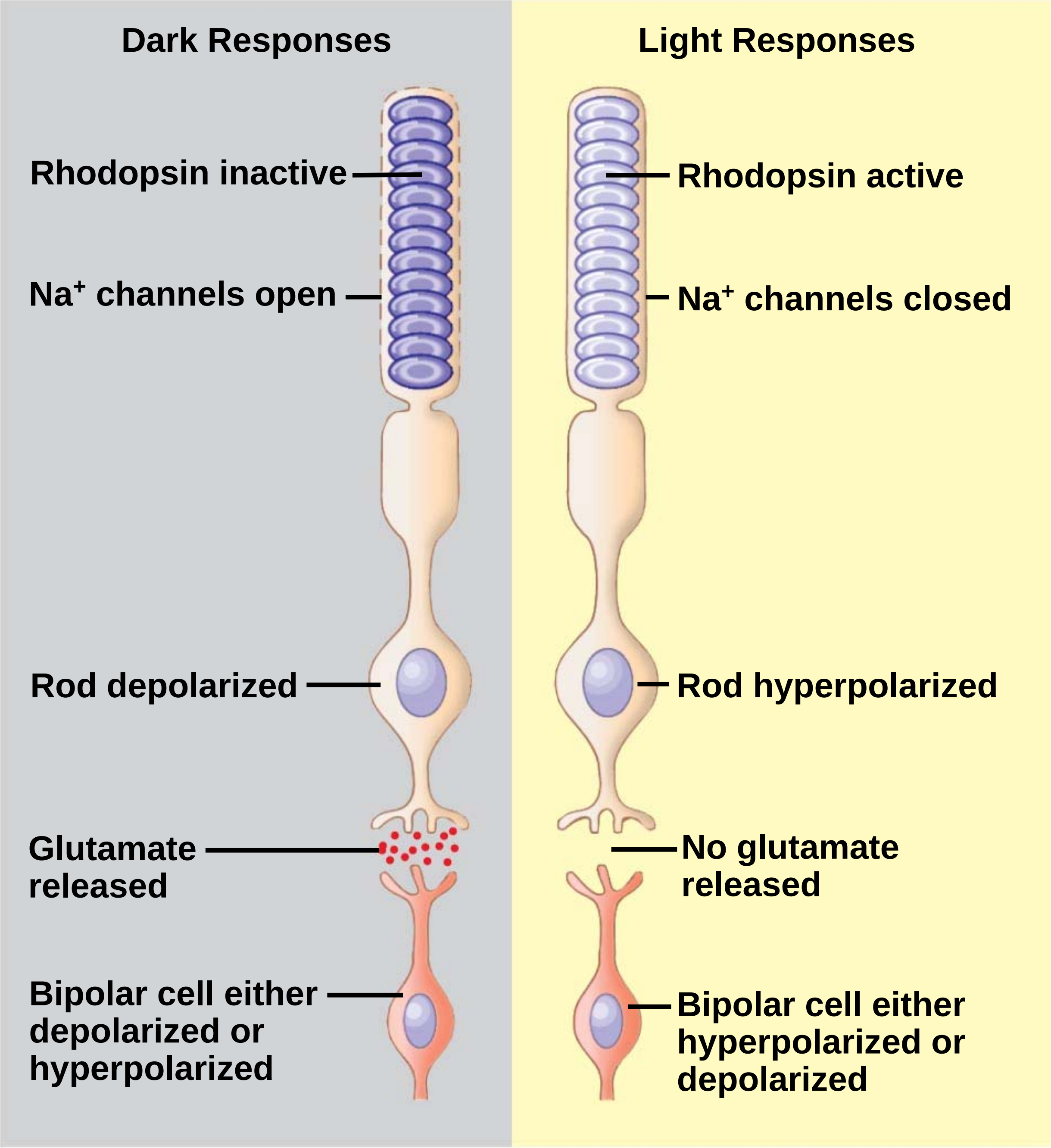
INSIDE OF DISK
EXTRACELLULAR FLUID
Light
Disk membrane
Active rhodopsin
Phosphodiesterase
Plasma membrane
CYTOSOL
Sodium channel
cGMP
GMP
Inactive rhodopsin
Transducin
Na+
Dark
0
Light
Membrane potential (mV)
–40
Hyper-polarization
–70
Na+
Time

- In humans, three pigments called photopsins detect light of different wave lengths: red, green, or blue

Processing of Visual Information

- Processing of visual information begins in the retina
- Absorption of light by retinal triggers a signal transduction pathway

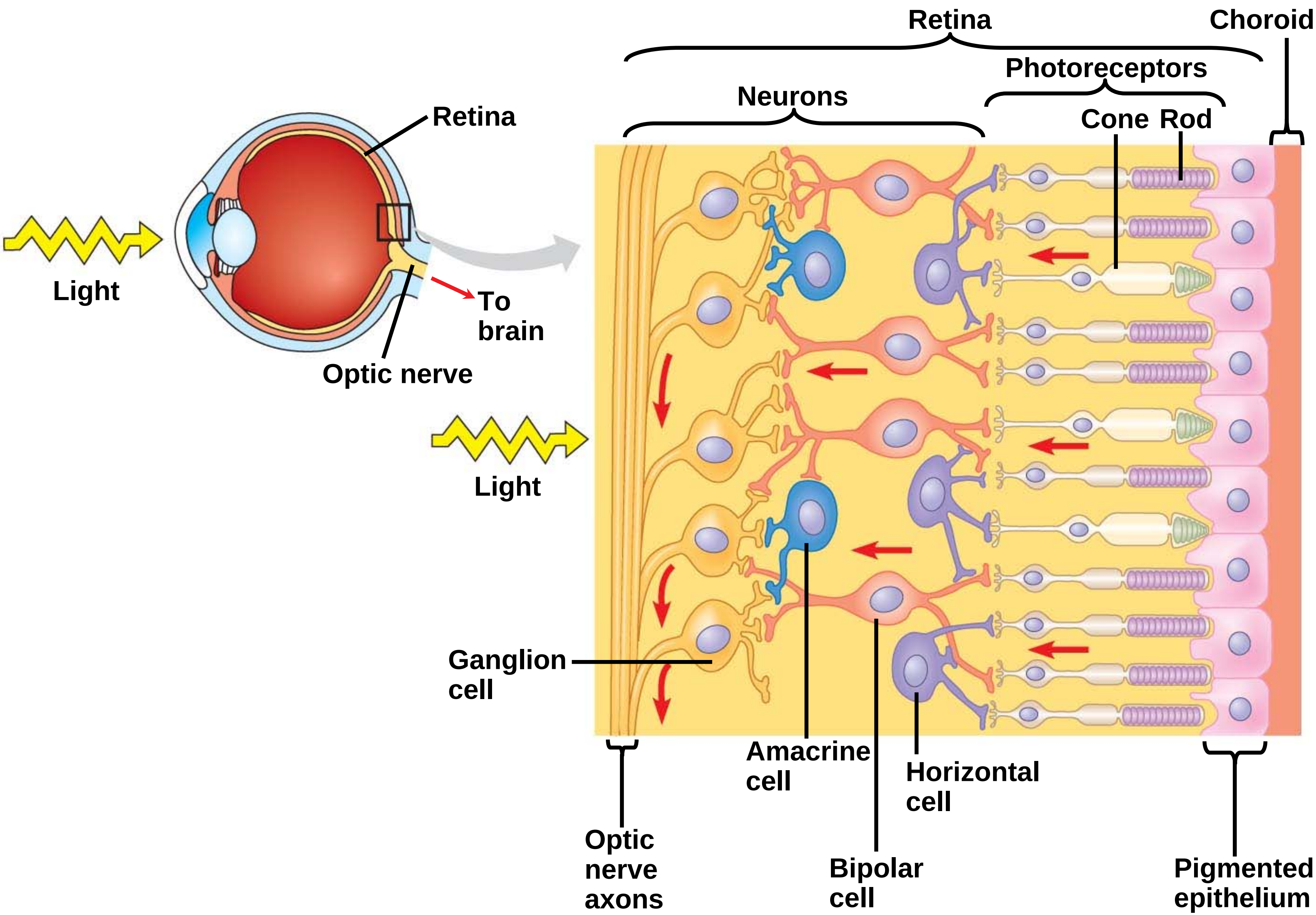
Fig. 50-22


Dark Responses
Light Responses
Rhodopsin inactive
Na+ channels open
Rod depolarized
Glutamate released
Bipolar cell either depolarized or hyperpolarized
Rhodopsin active
Na+ channels closed
Rod hyperpolarized
No glutamate released
Bipolar cell either hyperpolarized or depolarized

- In the dark, rods and cones release the neurotransmitter glutamate into synapses with neurons called **bipolar cells**
- Bipolar cells are either hyperpolarized or depolarized in response to glutamate
- In the light, rods and cones hyperpolarize, shutting off release of glutamate
- The bipolar cells are then either depolarized or hyperpolarized

- Three other types of neurons contribute to information processing in the retina
  - **Ganglion cells** transmit signals from bipolar cells to the brain; these signals travel along the optic nerves, which are made of ganglion cell axons
  - **Horizontal cells** and **amacrine cells** help integrate visual information before it is sent to the brain
- Interaction among different cells results in **lateral inhibition**, a greater contrast in image

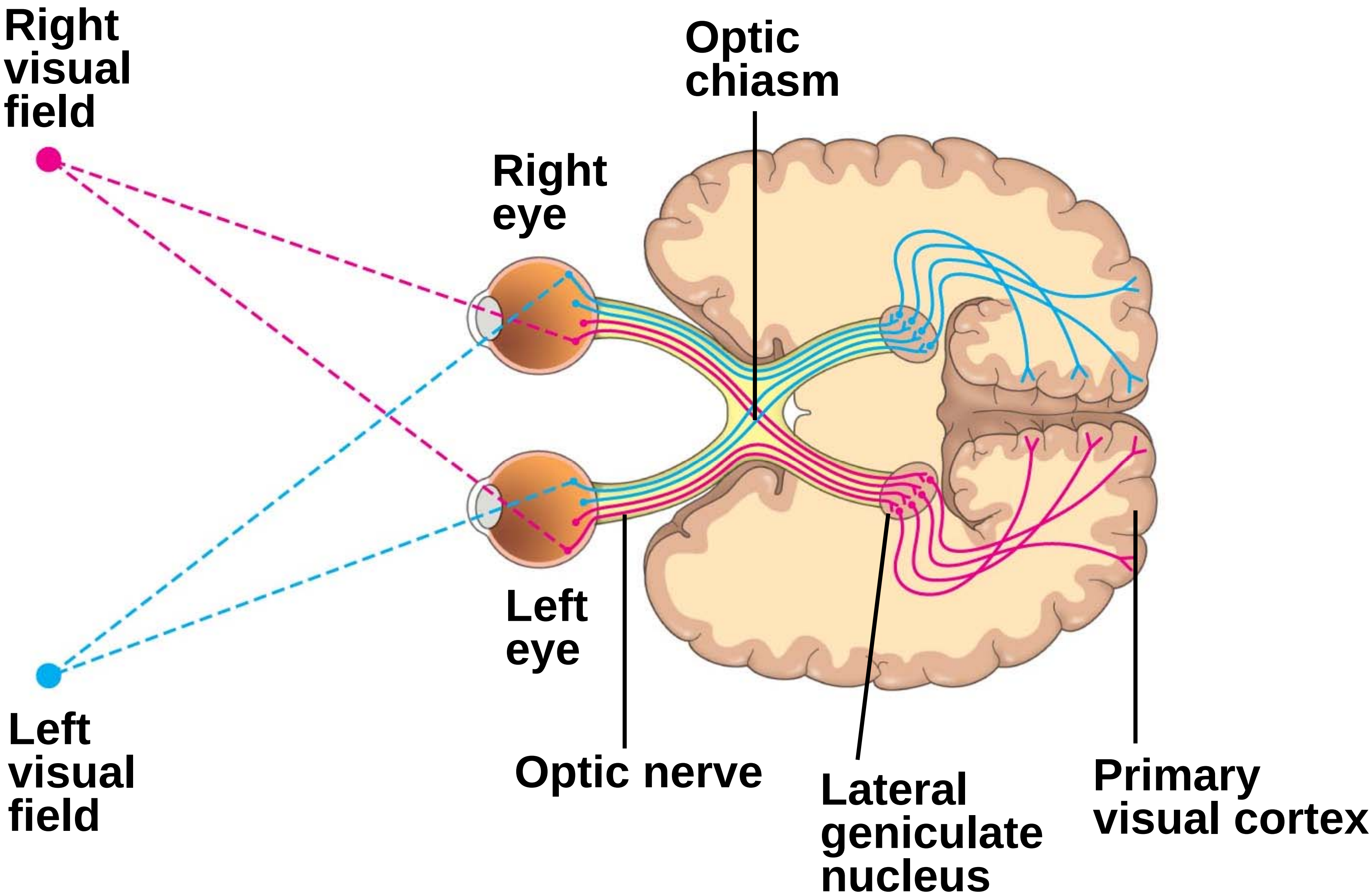
Fig. 50-23


Retina
Choroid
Photoreceptors
Neurons
Cone
Rod
Retina
Light
To brain
Optic nerve
Light
Ganglion cell
Amacrine cell
Horizontal cell
Optic nerve axons
Bipolar cell
Pigmented epithelium

- The optic nerves meet at the **optic chiasm** near the cerebral cortex
- Here, axons from the left visual field (from both the left and right eye) converge and travel to the right side of the brain
- Likewise, axons from the right visual field travel to the left side of the brain

- Most ganglion cell axons lead to the **lateral geniculate nuclei**
- The lateral geniculate nuclei relay information to the **primary visual cortex** in the cerebrum
- Several integrating centers in the cerebral cortex are active in creating visual perceptions

Fig. 50-24


Right visual field
Optic chiasm
Right eye
Left eye
Left visual field
Optic nerve
Lateral geniculate nucleus
Primary visual cortex

Evolution of Visual Perception

- Photoreceptors in diverse animals likely originated in the earliest bilateral animals
- Melanopsin, a pigment in ganglion cells, may play a role in circadian rhythms in humans

Concept 50.5: The physical interaction of protein filaments is required for muscle function

- Muscle activity is a response to input from the nervous system
- The action of a muscle is always to contract

Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** is characterized by a hierarchy of smaller and smaller units
- A skeletal muscle consists of a bundle of long fibers, each a single cell, running parallel to the length of the muscle
- Each muscle fiber is itself a bundle of smaller **myofibrils** arranged longitudinally

- The myofibrils are composed to two kinds of myofilaments:
  - **Thin filaments** consist of two strands of actin and one strand of regulatory protein
  - **Thick filaments** are staggered arrays of myosin molecules

- Skeletal muscle is also called **striated muscle** because the regular arrangement of myofilaments creates a pattern of light and dark bands
- The functional unit of a muscle is called a **sarcomere**, and is bordered by Z lines

Fig. 50-25

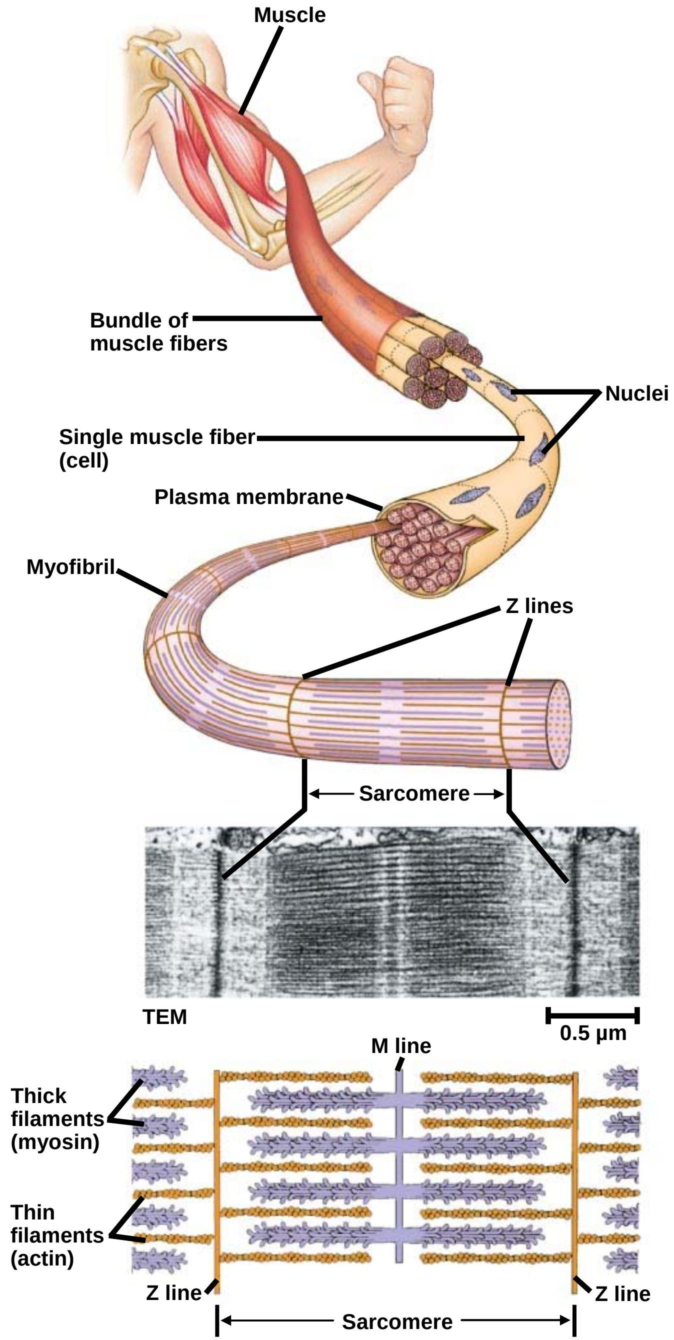

Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere
TEM
0.5 µm
M line
Thick filaments (myosin)
Thin filaments (actin)
Z line
Z line
Sarcomere

Fig. 50-25a

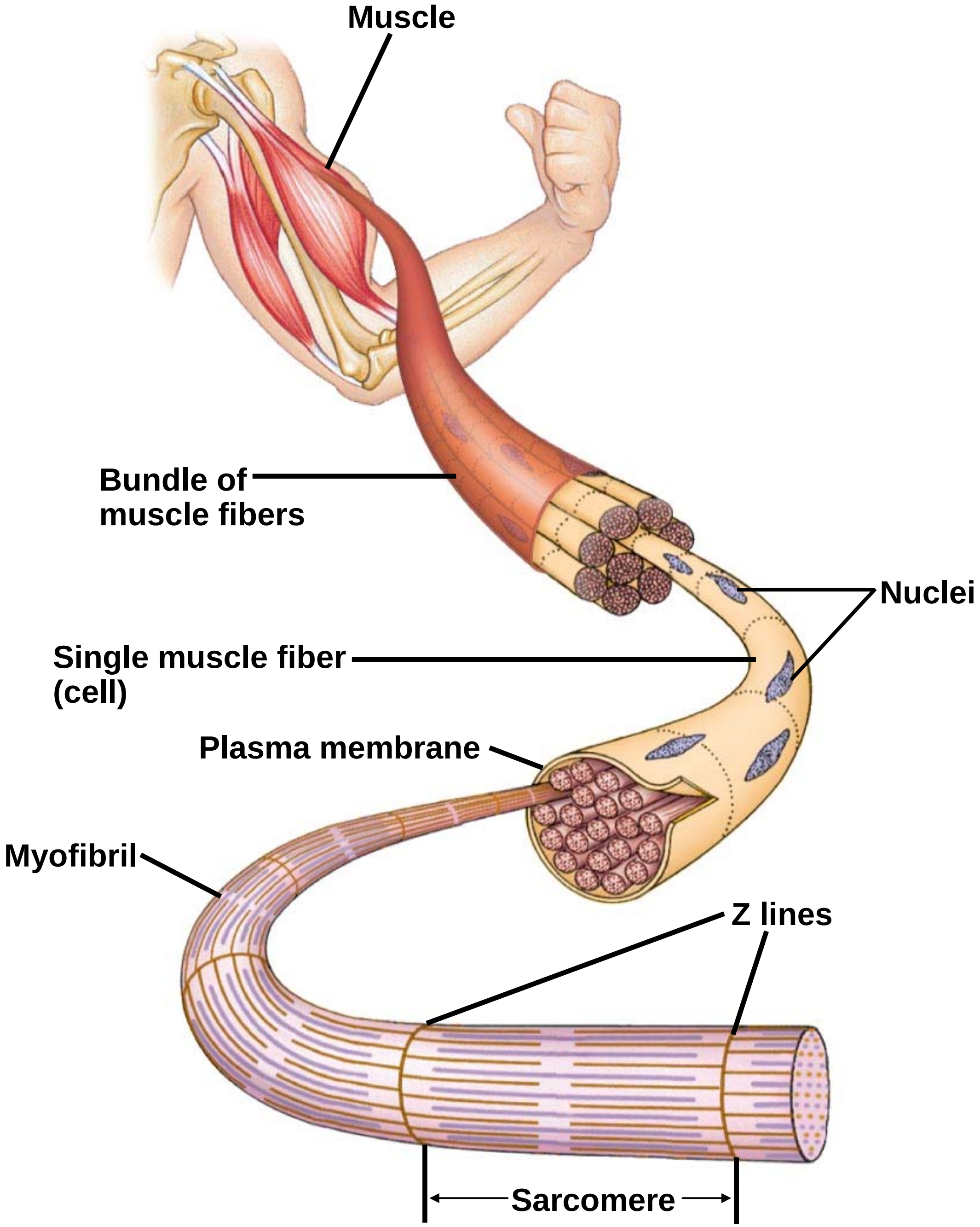
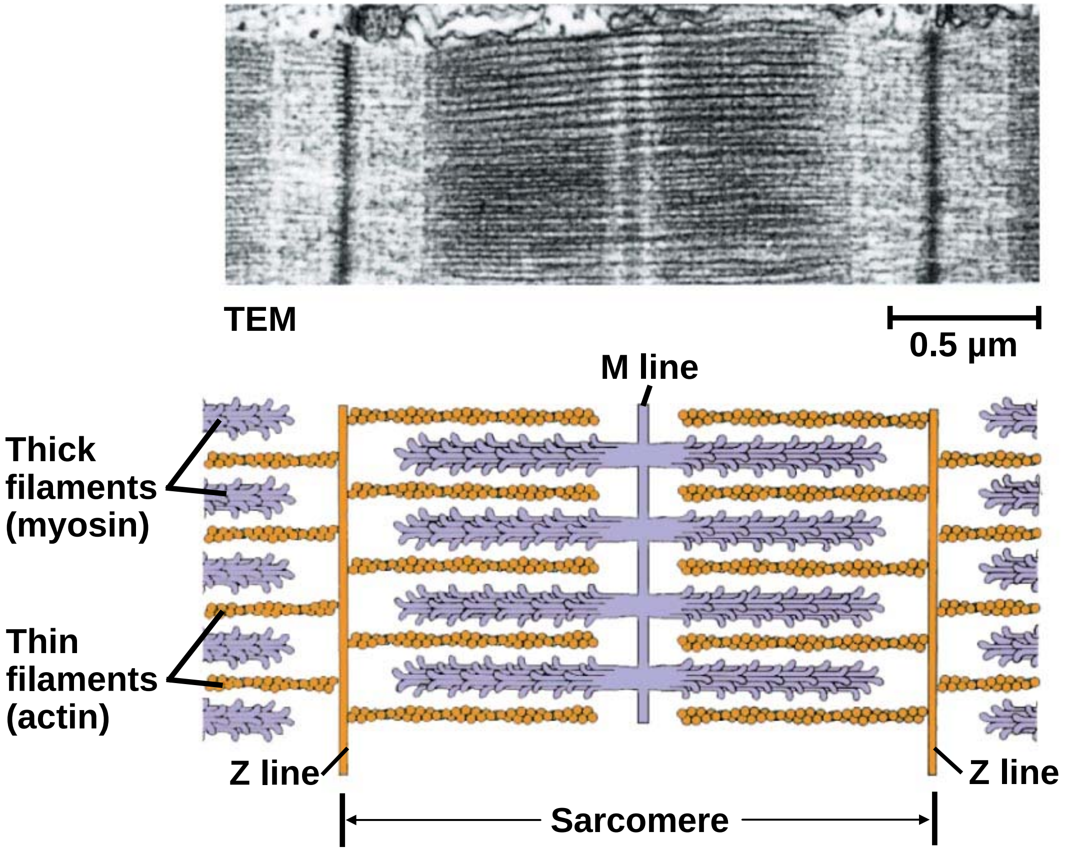

Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere

Fig. 50-25b

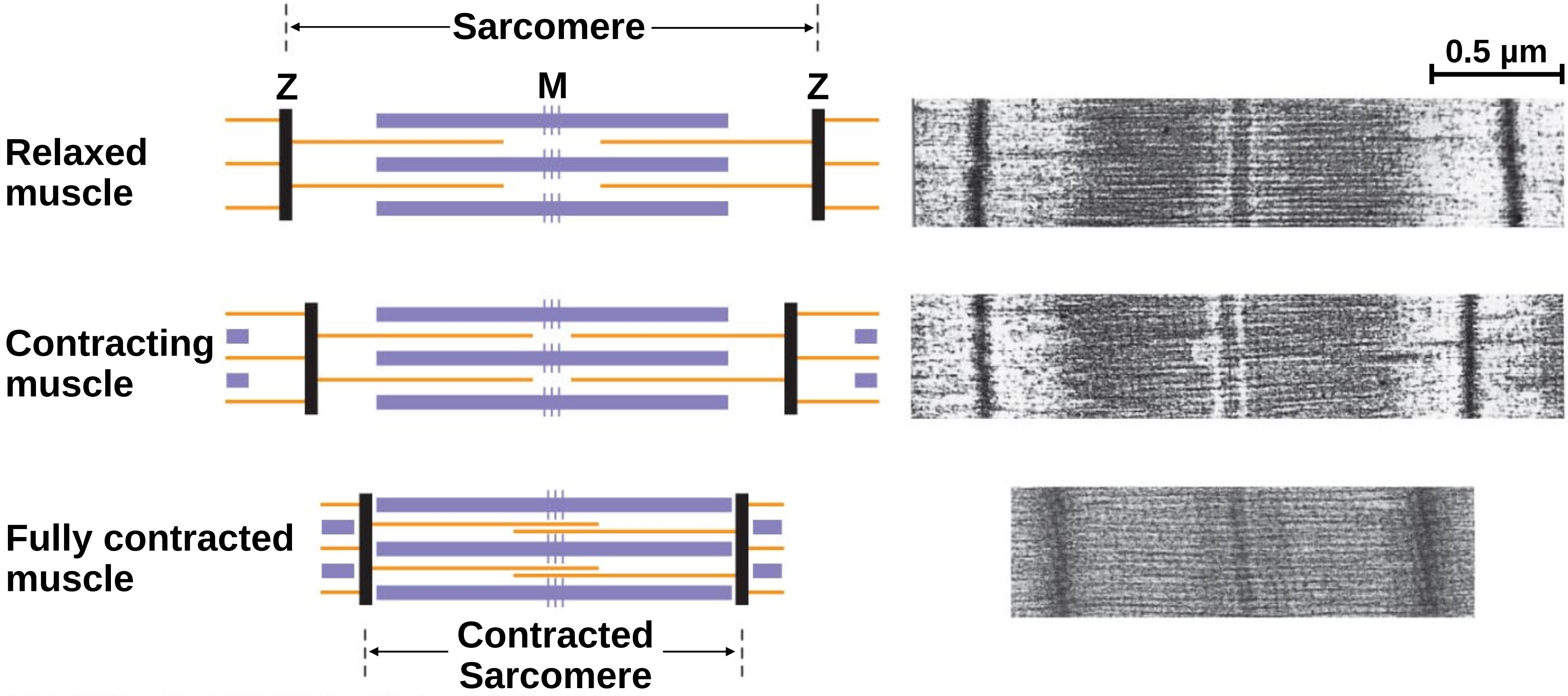


TEM
0.5 µm
M line
Thick filaments (myosin)
Thin filaments (actin)
Z line
Z line
Sarcomere

The Sliding-Filament Model of Muscle Contraction

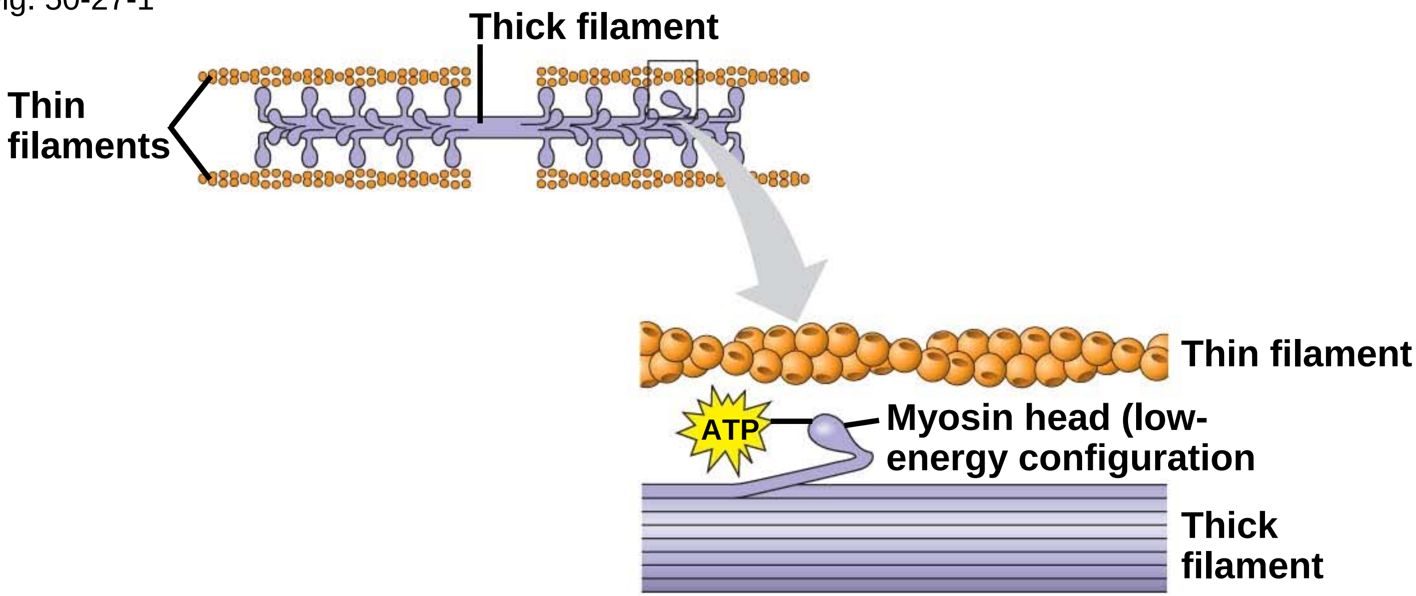
- According to the **sliding-filament model**, filaments slide past each other longitudinally, producing more overlap between thin and thick filaments

Fig. 50-26


Sarcomere
Z
M
Z
0.5 µm
Relaxed muscle
Contracting muscle
Fully contracted muscle
Contracted Sarcomere

- The sliding of filaments is based on interaction between actin of the thin filaments and myosin of the thick filaments
- The “head” of a myosin molecule binds to an actin filament, forming a cross-bridge and pulling the thin filament toward the center of the sarcomere
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction

Fig. 50-27-1



Thick filament
Thin
filaments
Thin filament
ATP
Myosin head (low-
energy configuration
Thick
filament

Fig. 50-27-2

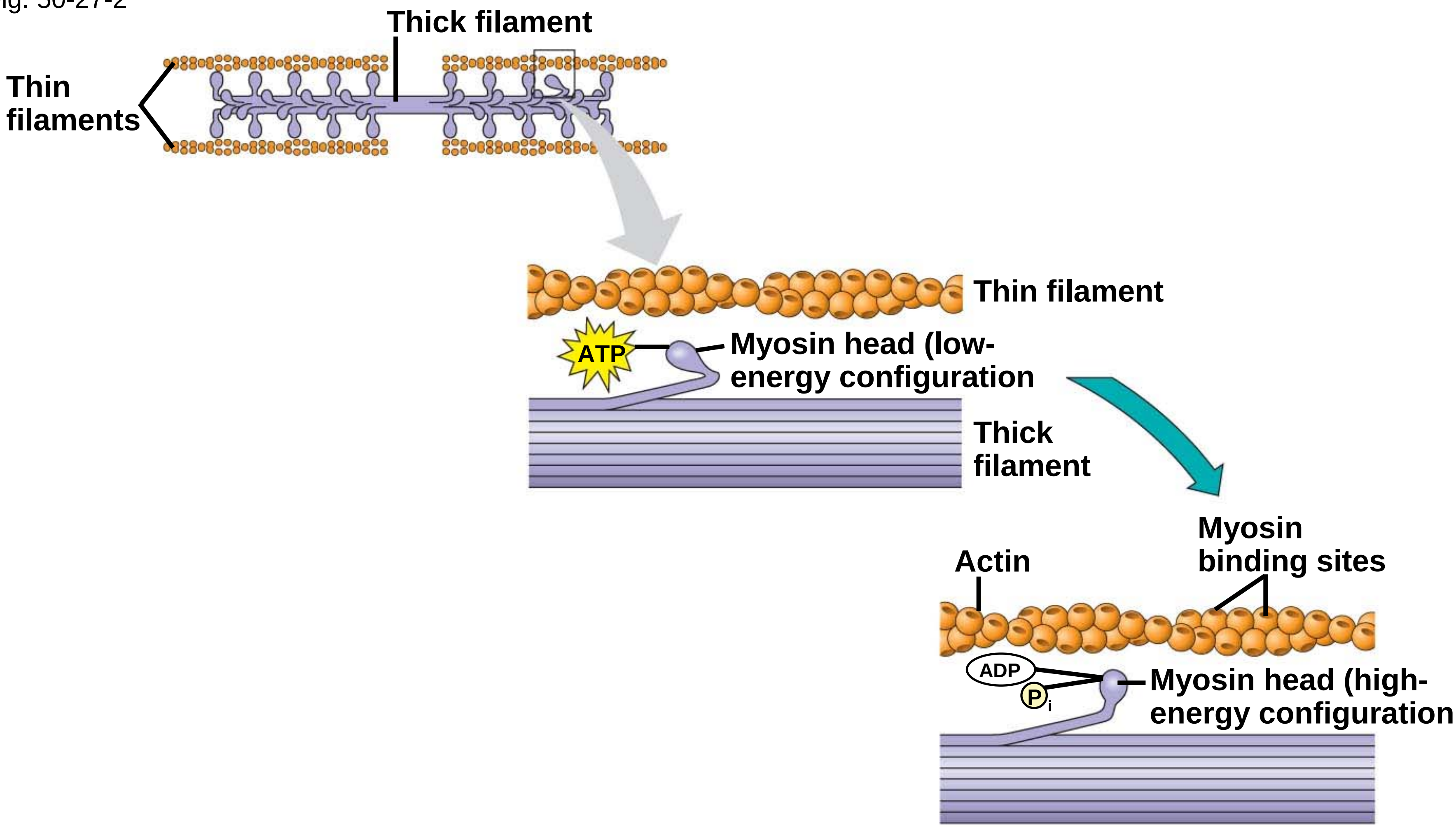

Thick filament
Thin filaments
Thin filament
ATP
Myosin head (low-energy configuration
Thick filament
Actin
Myosin binding sites
ADP
P i
Myosin head (high-energy configuration

Fig. 50-27-3

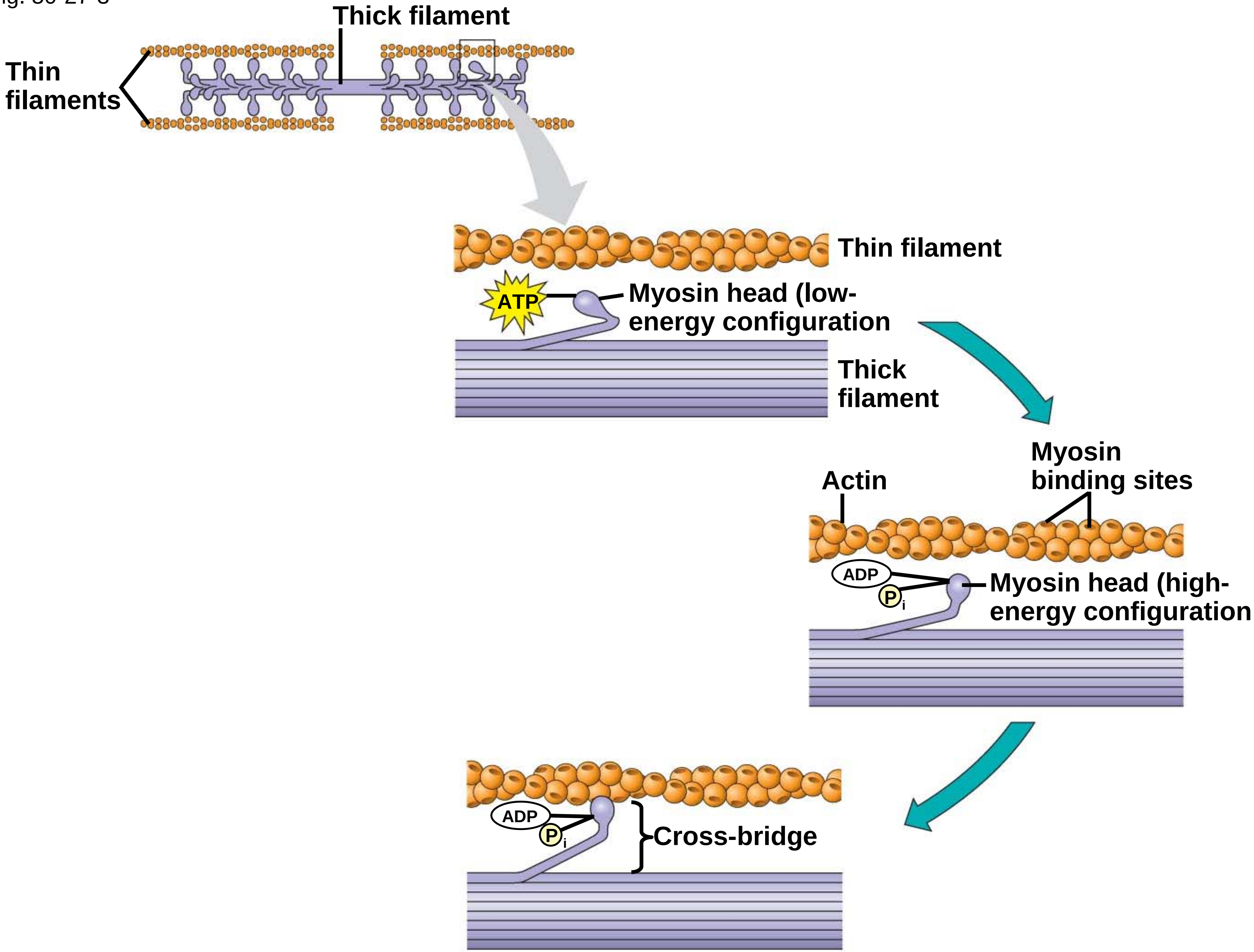
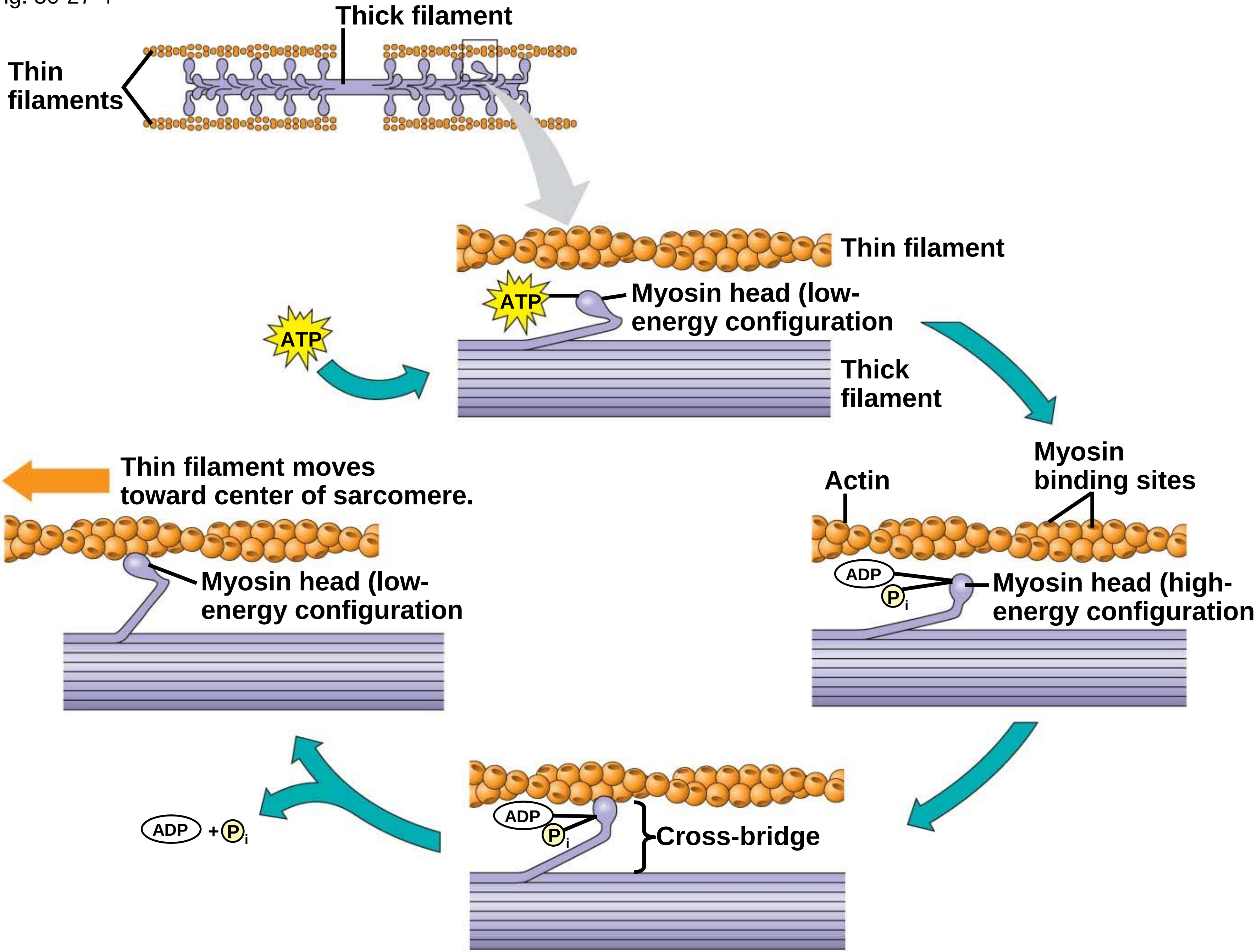

Thick filament
Thin filaments
Thin filament
ATP
Myosin head (low-energy configuration
Thick filament
Actin
Myosin binding sites
ADP
P i
Myosin head (high-energy configuration
ADP
P i
Cross-bridge

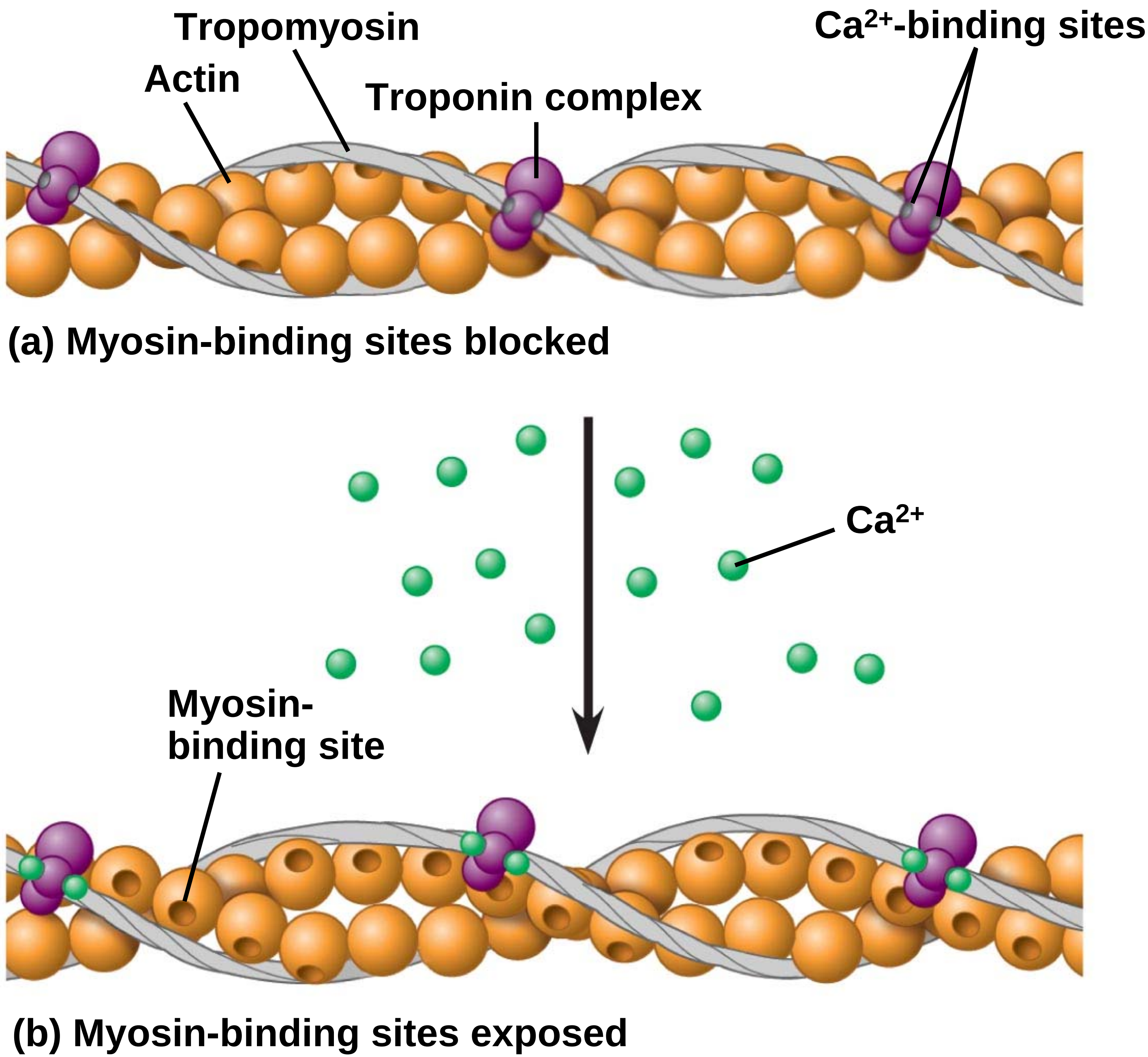
Fig. 50-27-4


Thick filament
Thin
filaments
Thin filament
ATP
ATP
Myosin head (low-
energy configuration
Thick
filament
Actin
Myosin
binding sites
ADP
P i
Myosin head (high-
energy configuration
ADP
P i
Cross-bridge
ADP + P i
Thin filament moves
toward center of sarcomere.
Myosin head (low-
energy configuration

The Role of Calcium and Regulatory Proteins

- A skeletal muscle fiber contracts only when stimulated by a motor neuron
- When a muscle is at rest, myosin-binding sites on the thin filament are blocked by the regulatory protein **tropomyosin**

Fig. 50-28

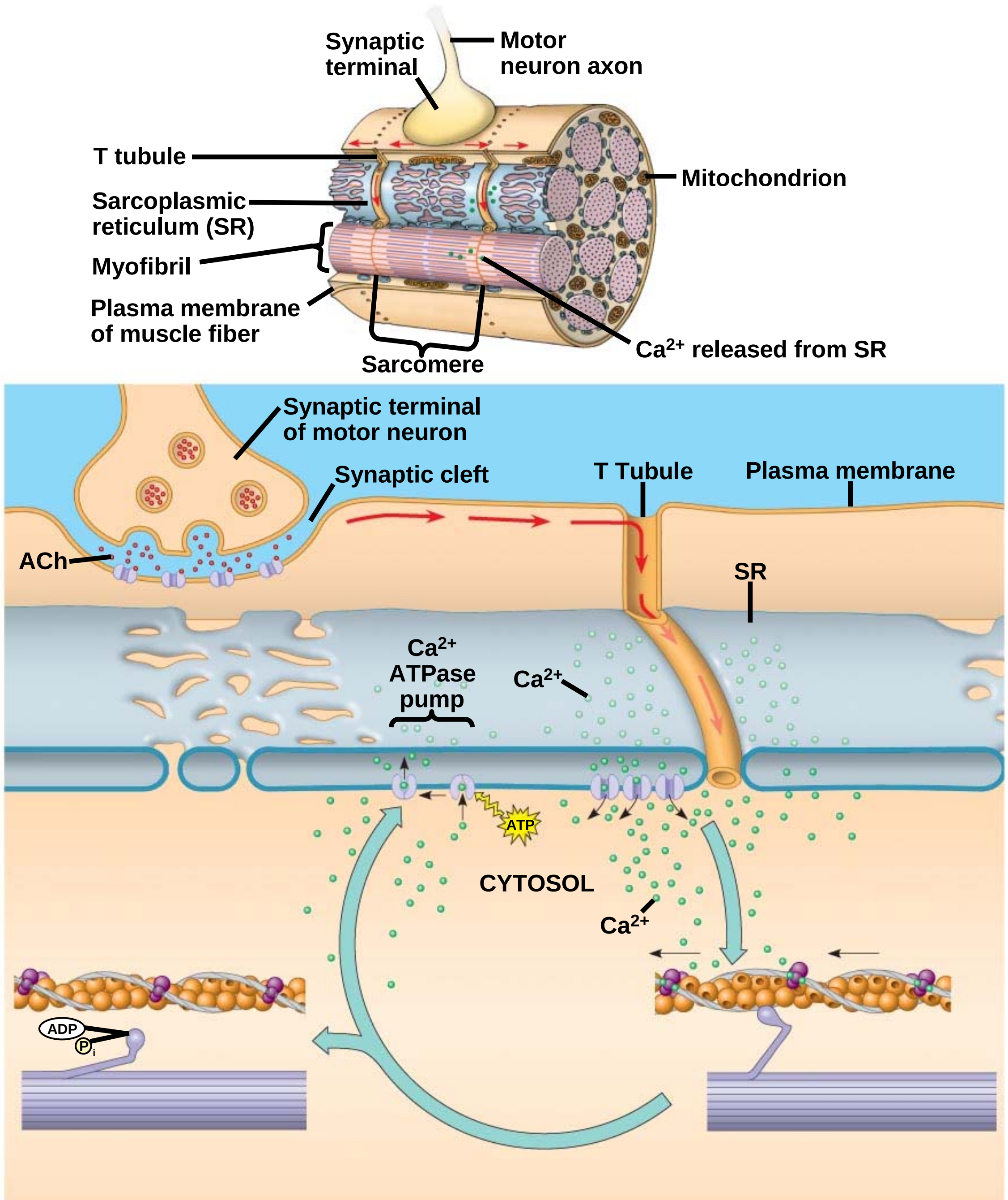


Tropomyosin
Actin
Troponin complex
Ca2+-binding sites
(a) Myosin-binding sites blocked
Ca2+
Myosin-
binding site
(b) Myosin-binding sites exposed

- For a muscle fiber to contract, myosin-binding sites must be uncovered
- This occurs when calcium ions (Ca^{2+}) bind to a set of regulatory proteins, the **troponin complex**
- Muscle fiber contracts when the concentration of Ca^{2+} is high; muscle fiber contraction stops when the concentration of Ca^{2+} is low

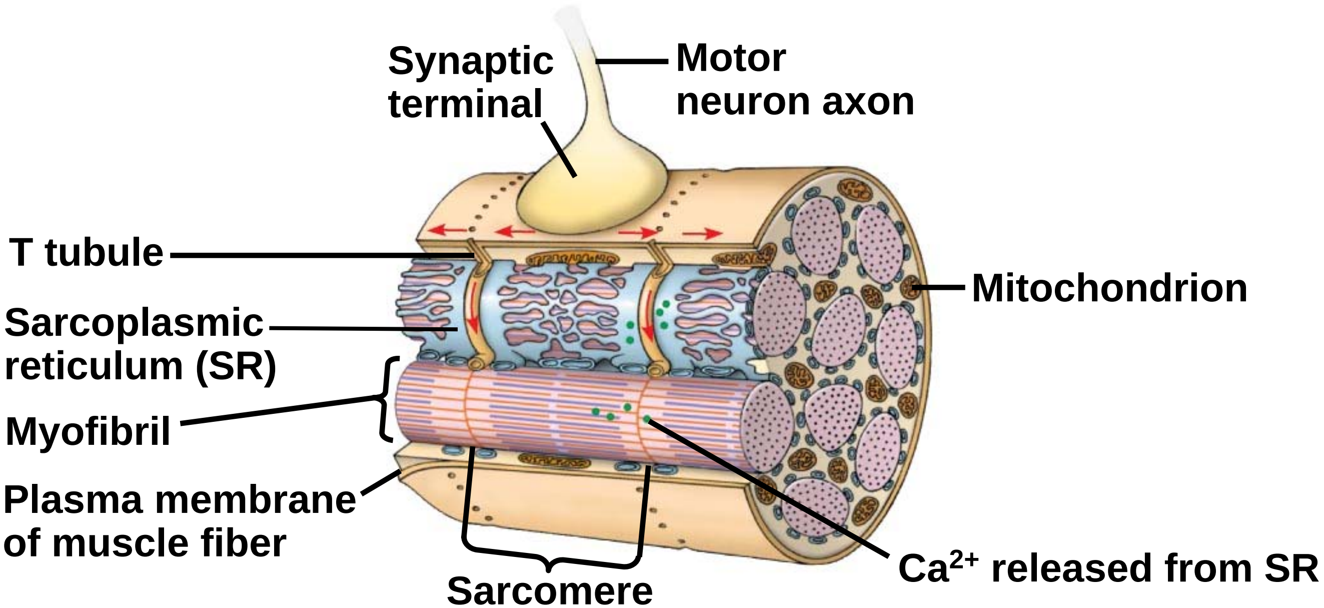
- The stimulus leading to contraction of a muscle fiber is an action potential in a motor neuron that makes a synapse with the muscle fiber

Fig. 50-29



Synaptic terminal
Motor neuron axon
T tubule
Sarcoplasmic reticulum (SR)
Myofibril
Plasma membrane of muscle fiber
Sarcomere
Mitochondrion
Ca2+ released from SR
Synaptic terminal of motor neuron
Synaptic cleft
T Tubule
Plasma membrane
ACh
SR
Ca2+ ATPase pump
Ca2+
ATP
CYTOSOL
Ca2+
ADP
P i

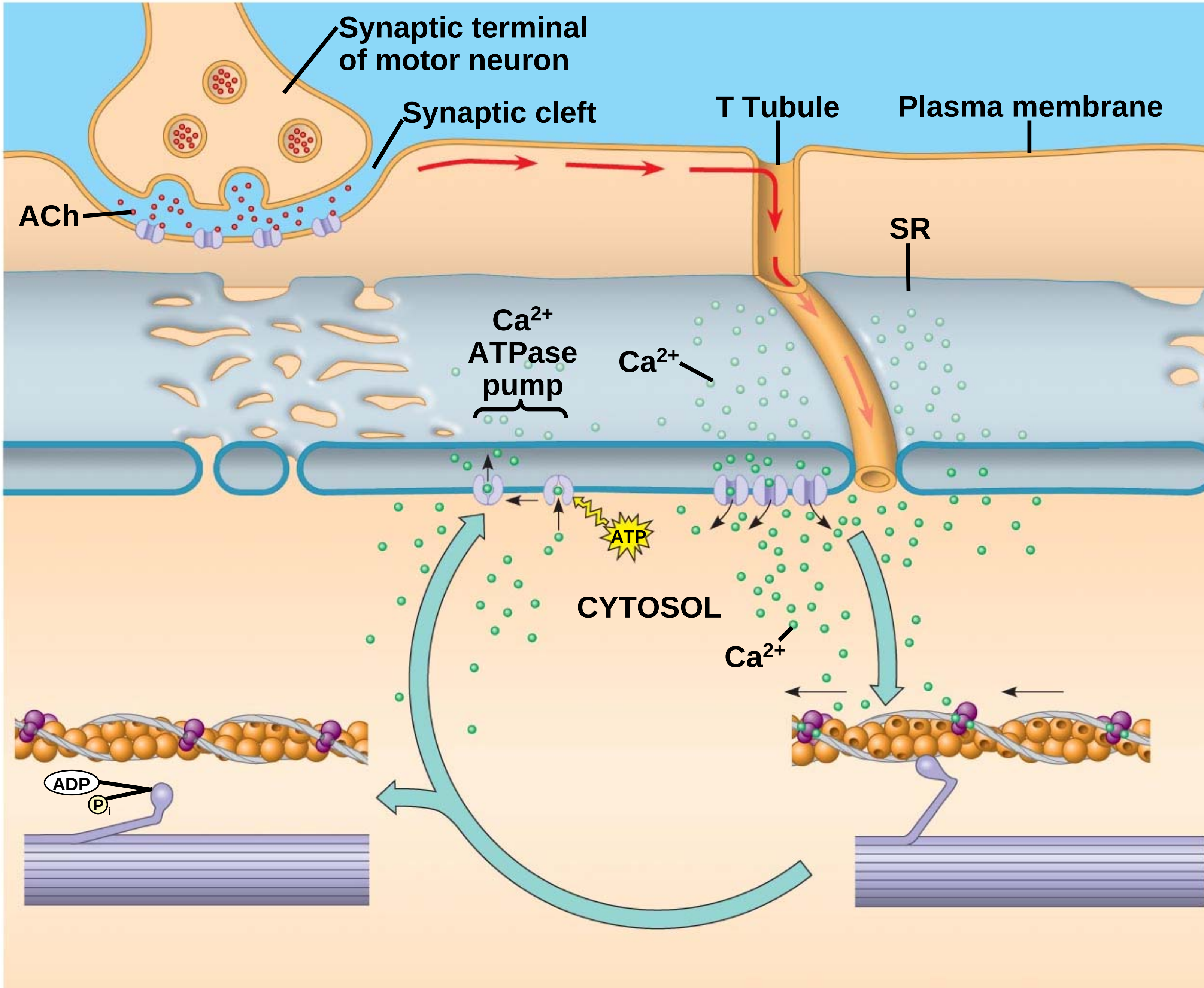
Fig. 50-29a



Synaptic terminal
Motor neuron axon
T tubule
Sarcoplasmic reticulum (SR)
Myofibril
Plasma membrane of muscle fiber
Sarcomere
Mitochondrion
Ca^{2+} released from SR

- The synaptic terminal of the motor neuron releases the neurotransmitter acetylcholine
- Acetylcholine depolarizes the muscle, causing it to produce an action potential

Fig. 50-29b



Synaptic terminal of motor neuron
Synaptic cleft
T Tubule
Plasma membrane
ACh
SR
Ca2+ ATPase pump
Ca2+
ATP
CYTOSOL
Ca2+
ADP
Pi

- Action potentials travel to the interior of the muscle fiber along **transverse (T) tubules**
- The action potential along T tubules causes the **sarcoplasmic reticulum (SR)** to release Ca^{2+}
- The Ca^{2+} binds to the troponin complex on the thin filaments
- This binding exposes myosin-binding sites and allows the cross-bridge cycle to proceed

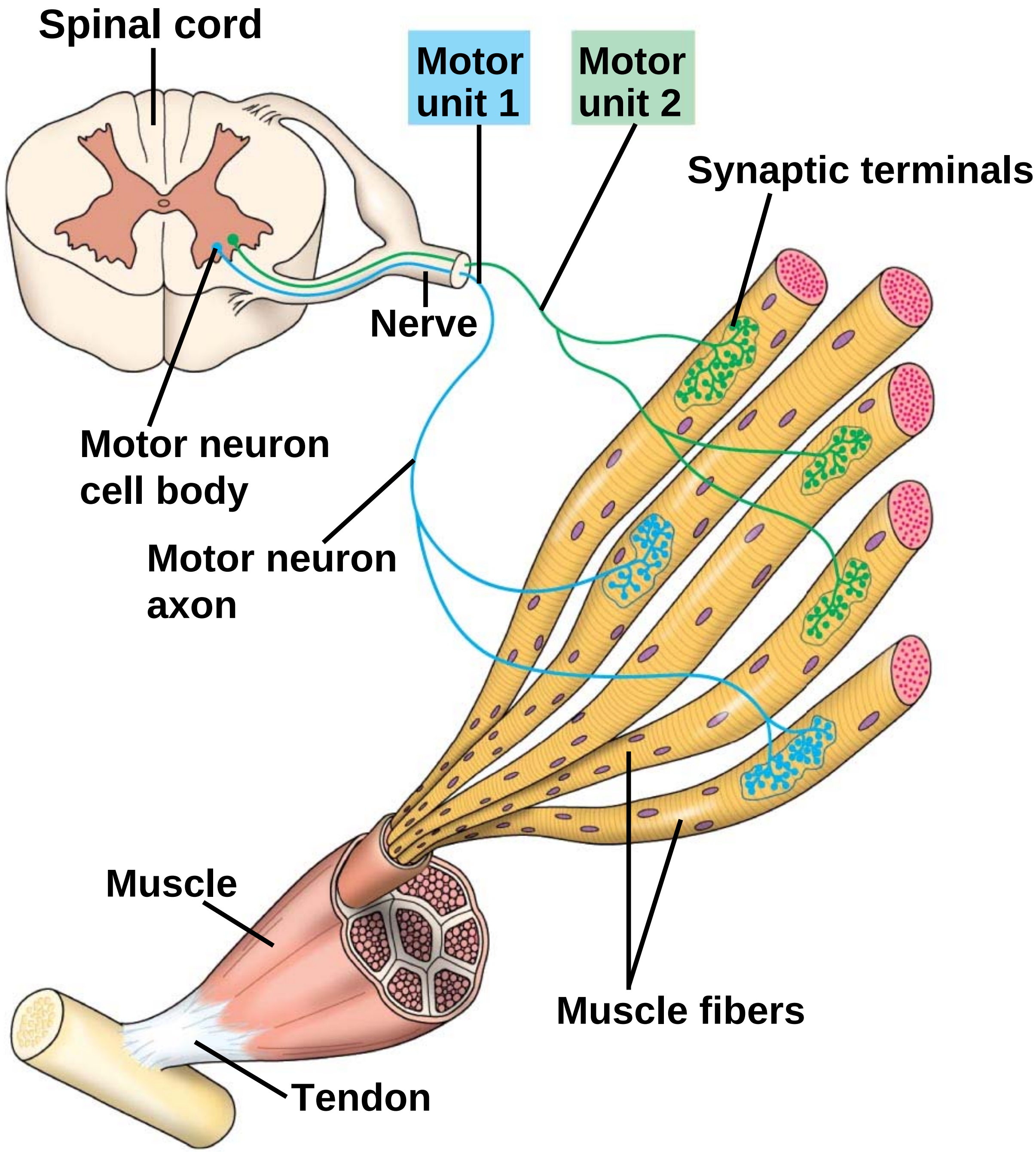
- Amyotrophic lateral sclerosis (ALS), formerly called Lou Gehrig’s disease, interferes with the excitation of skeletal muscle fibers; this disease is usually fatal
- Myasthenia gravis is an autoimmune disease that attacks acetylcholine receptors on muscle fibers; treatments exist for this disease

Nervous Control of Muscle Tension

- Contraction of a whole muscle is graded, which means that the extent and strength of its contraction can be voluntarily altered
- There are two basic mechanisms by which the nervous system produces graded contractions:
  - Varying the number of fibers that contract
  - Varying the rate at which fibers are stimulated

- In a vertebrate skeletal muscle, each branched muscle fiber is innervated by one motor neuron
- Each motor neuron may synapse with multiple muscle fibers
- A **motor unit** consists of a single motor neuron and all the muscle fibers it controls

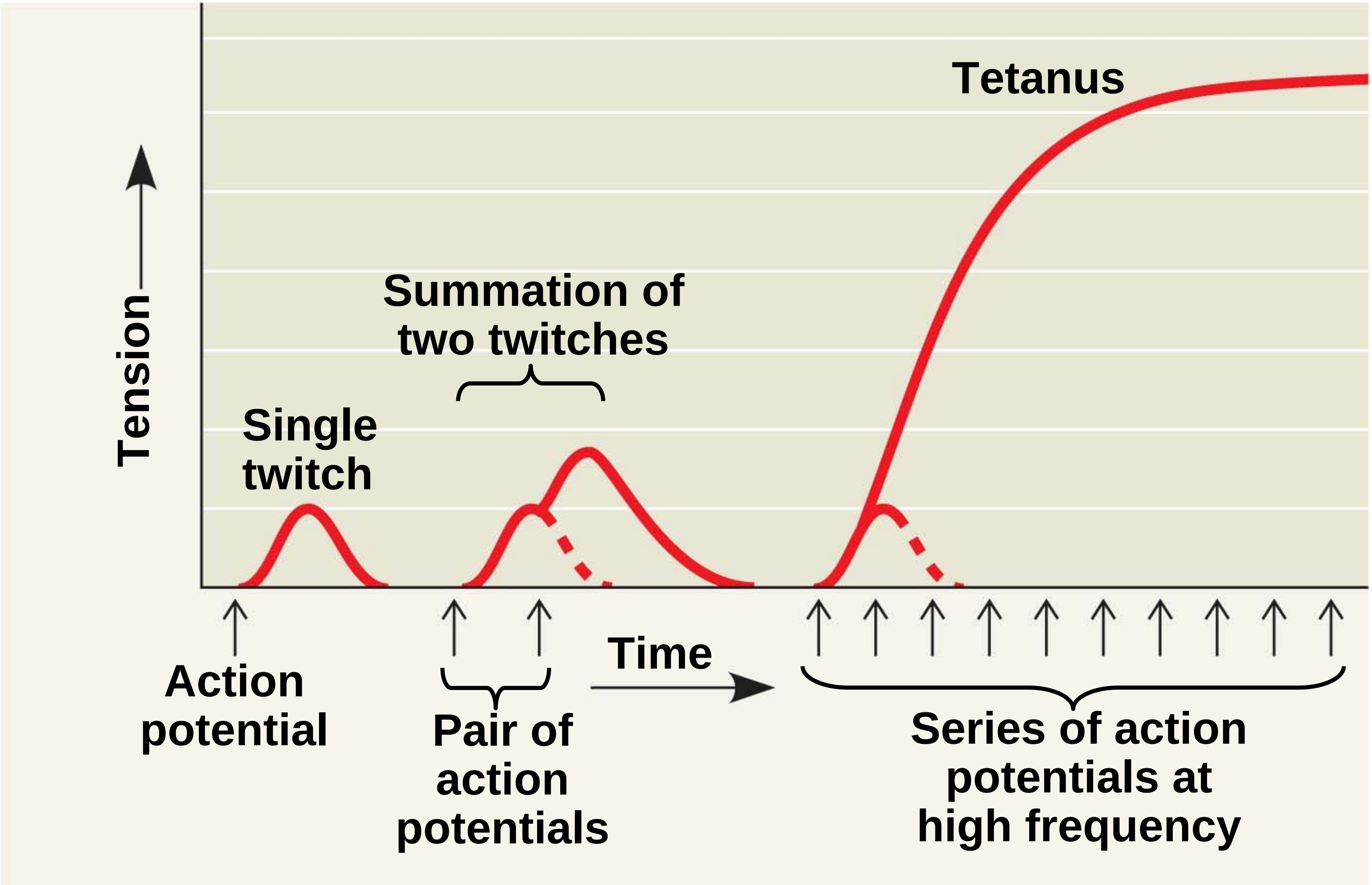
Fig. 50-30



Spinal cord
Motor unit 1
Motor unit 2
Synaptic terminals
Nerve
Motor neuron cell body
Motor neuron axon
Muscle
Tendon
Muscle fibers

- **Recruitment** of multiple motor neurons results in stronger contractions
- A twitch results from a single action potential in a motor neuron
- More rapidly delivered action potentials produce a graded contraction by summation

Fig. 50-31


Tetanus
Summation of two twitches
Single twitch
Tension
Action potential
Pair of action potentials
Time
Series of action potentials at high frequency

- **Tetanus** is a state of smooth and sustained contraction produced when motor neurons deliver a volley of action potentials

Types of Skeletal Muscle Fibers

- Skeletal muscle fibers can be classified
  - As oxidative or glycolytic fibers, by the source of ATP
  - As fast-twitch or slow-twitch fibers, by the speed of muscle contraction

Oxidative and Glycolytic Fibers

- Oxidative fibers rely on aerobic respiration to generate ATP
- These fibers have many mitochondria, a rich blood supply, and much myoglobin
- **Myoglobin** is a protein that binds oxygen more tightly than hemoglobin does

- Glycolytic fibers use glycolysis as their primary source of ATP
- Glycolytic fibers have less myoglobin than oxidative fibers, and tire more easily
- In poultry and fish, light meat is composed of glycolytic fibers, while dark meat is composed of oxidative fibers

Fast-Twitch and Slow-Twitch Fibers

- **Slow-twitch fibers** contract more slowly, but sustain longer contractions
- All slow twitch fibers are oxidative
- **Fast-twitch fibers** contract more rapidly, but sustain shorter contractions
- Fast-twitch fibers can be either glycolytic or oxidative

- Most skeletal muscles contain both slow-twitch and fast-twitch muscles in varying ratios

Other Types of Muscle

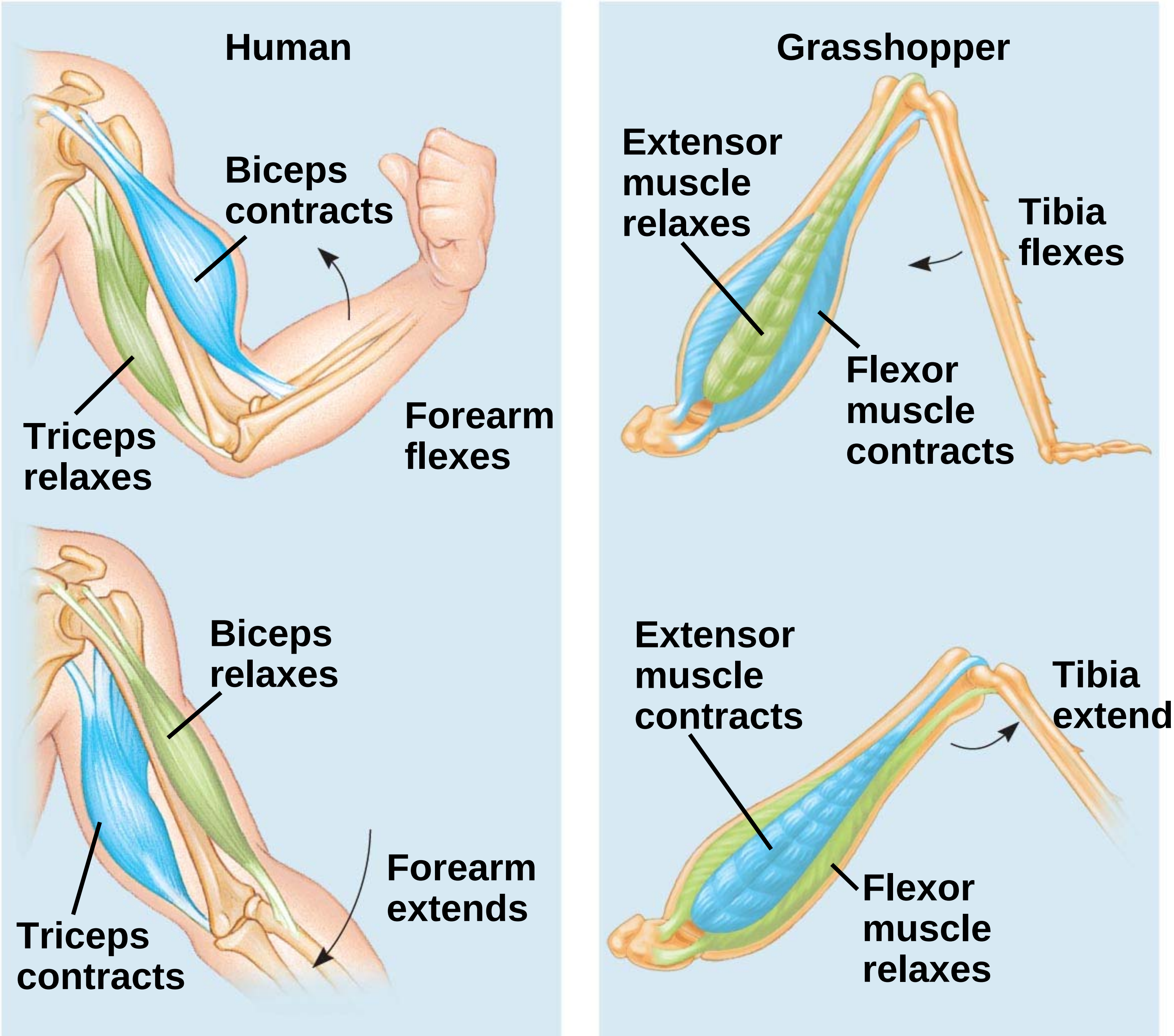
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
- **Cardiac muscle**, found only in the heart, consists of striated cells electrically connected by **intercalated disks**
- Cardiac muscle can generate action potentials without neural input

- In **smooth muscle**, found mainly in walls of hollow organs, contractions are relatively slow and may be initiated by the muscles themselves
- Contractions may also be caused by stimulation from neurons in the autonomic nervous system

Concept 50.6: Skeletal systems transform muscle contraction into locomotion

- Skeletal muscles are attached in antagonistic pairs, with each member of the pair working against the other
- The skeleton provides a rigid structure to which muscles attach
- Skeletons function in support, protection, and movement

Fig. 50-32


Human
Biceps contracts
Triceps relaxes
Forearm flexes
Biceps relaxes
Triceps contracts
Forearm extends
Grasshopper
Extensor muscle relaxes
Tibia flexes
Flexor muscle contracts
Extensor muscle contracts
Tibia extends
Flexor muscle relaxes

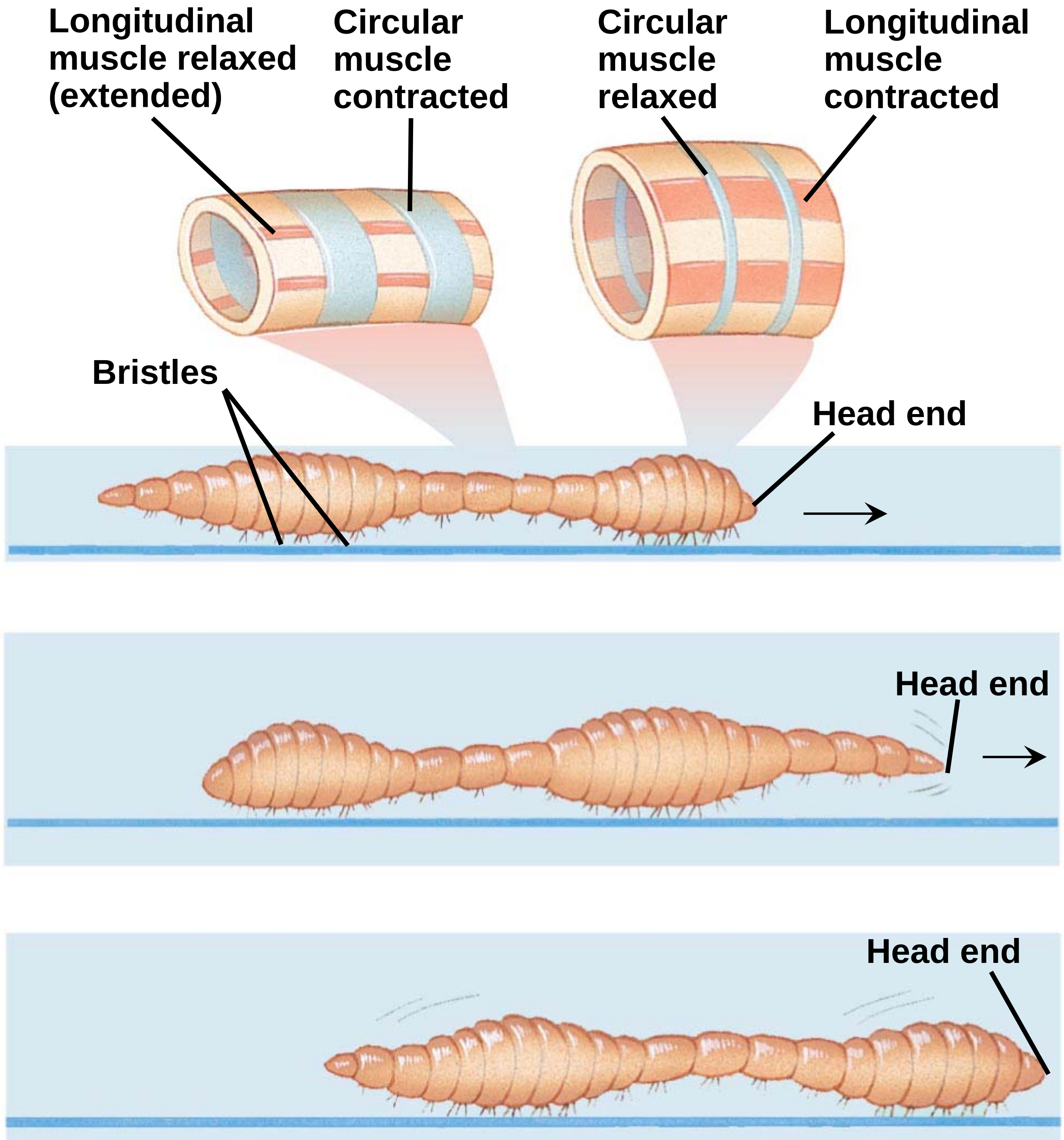
Types of Skeletal Systems

- The three main types of skeletons are:
  - Hydrostatic skeletons (lack hard parts)
  - Exoskeletons (external hard parts)
  - Endoskeletons (internal hard parts)

Hydrostatic Skeletons

- A **hydrostatic skeleton** consists of fluid held under pressure in a closed body compartment
- This is the main type of skeleton in most cnidarians, flatworms, nematodes, and annelids
- Annelids use their hydrostatic skeleton for **peristalsis**, a type of movement on land produced by rhythmic waves of muscle contractions

Fig. 50-33



Longitudinal muscle relaxed (extended)
Circular muscle contracted
Circular muscle relaxed
Longitudinal muscle contracted
Bristles
Head end
Head end
Head end

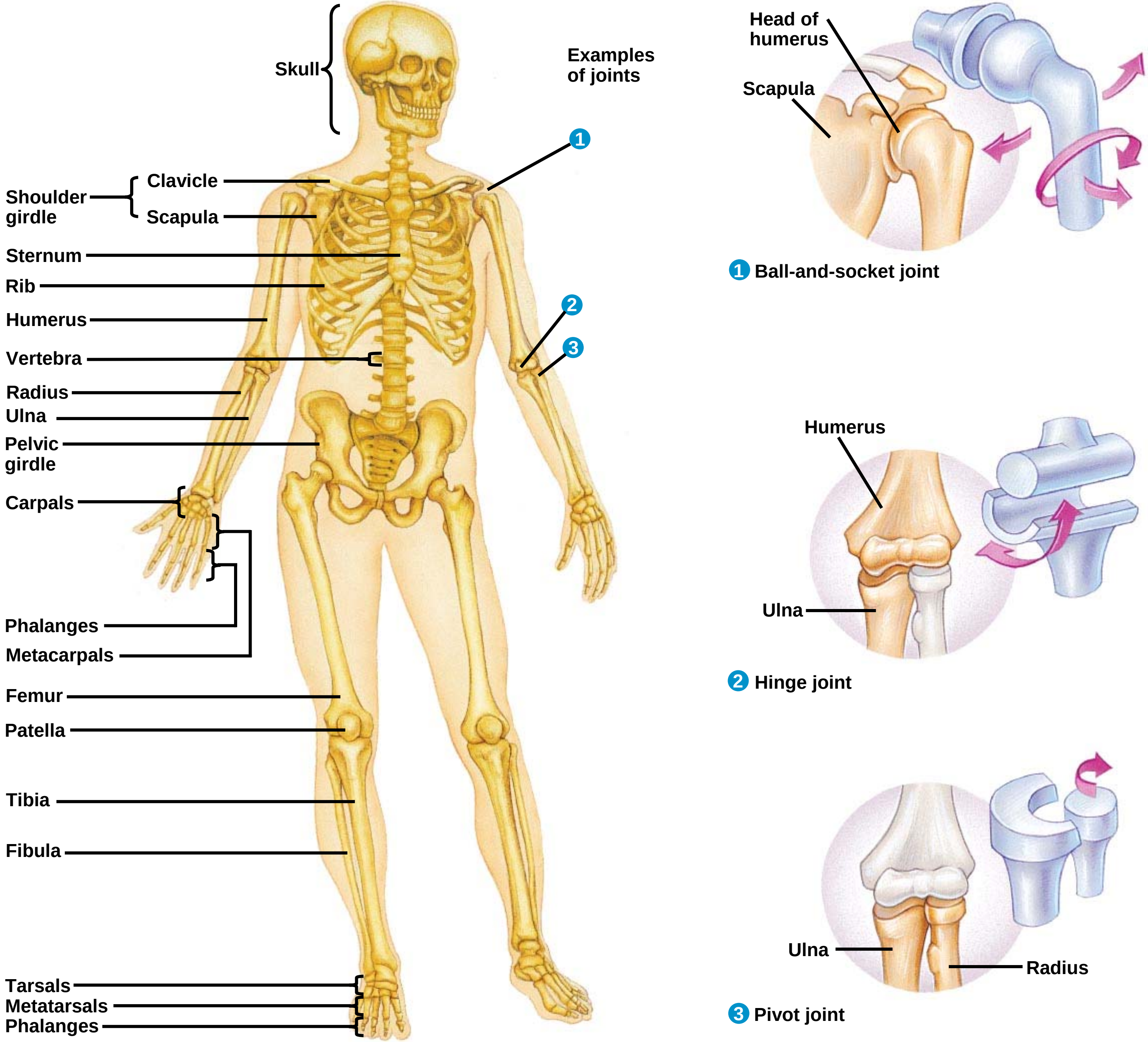
Exoskeletons

- An **exoskeleton** is a hard encasement deposited on the surface of an animal
- Exoskeletons are found in most molluscs and arthropods
- Arthropod exoskeletons are made of cuticle and can be both strong and flexible
- The polysaccharide **chitin** is often found in arthropod cuticle

Endoskeletons

- An **endoskeleton** consists of hard supporting elements, such as bones, buried in soft tissue
- Endoskeletons are found in sponges, echinoderms, and chordates
- A mammalian skeleton has more than 200 bones
- Some bones are fused; others are connected at joints by ligaments that allow freedom of movement

Fig. 50-34



Skull
Examples of joints
Shoulder girdle
Clavicle
Scapula
Sternum
Rib
Humerus
Vertebra
Radius
Ulna
Pelvic girdle
Carpals
Phalanges
Metacarpals
Femur
Patella
Tibia
Fibula
Tarsals
Metatarsals
Phalanges
1
2
3
Head of humerus
Scapula
1 Ball-and-socket joint
Humerus
Ulna
2 Hinge joint
Ulna
Radius
3 Pivot joint

Fig. 50-34a

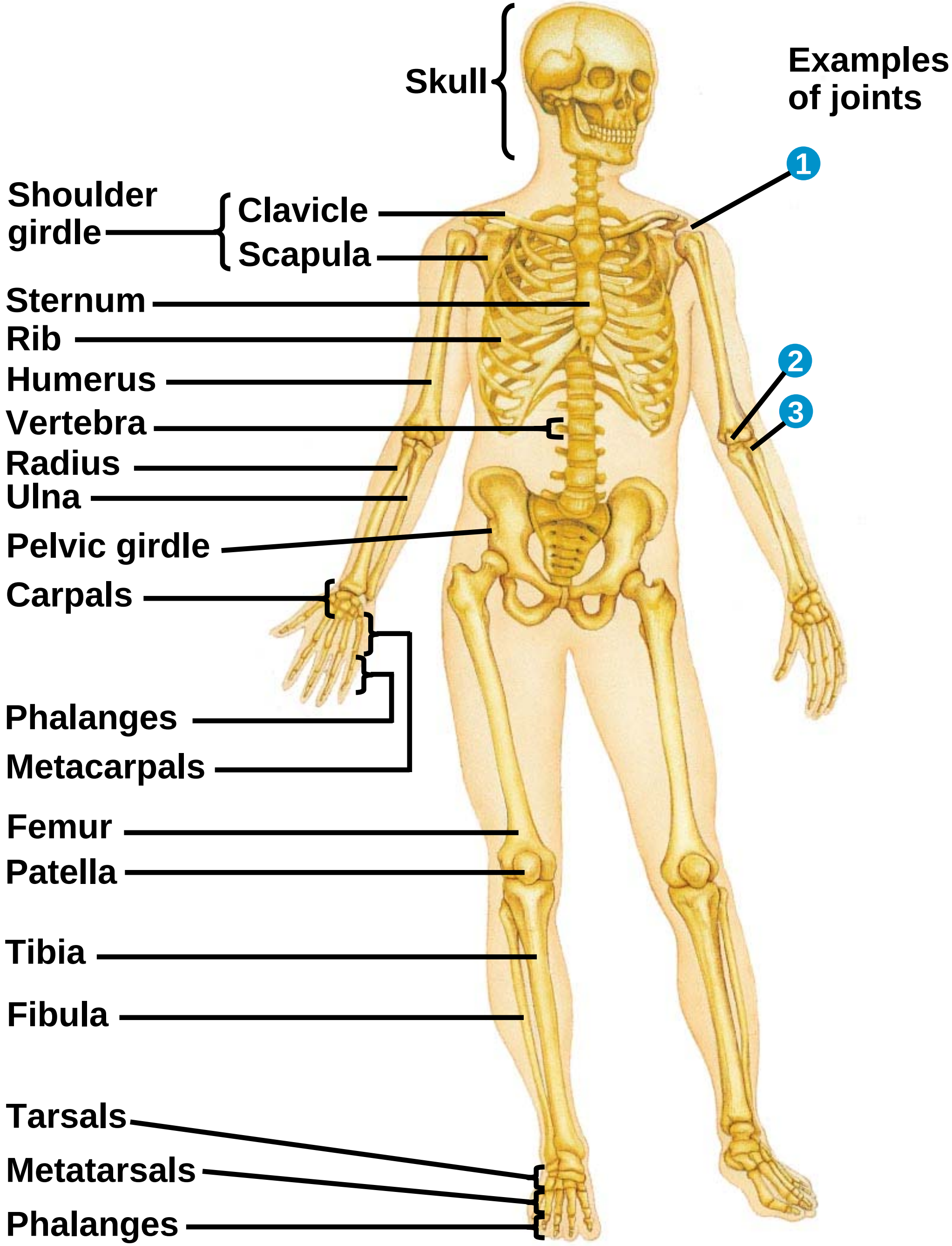
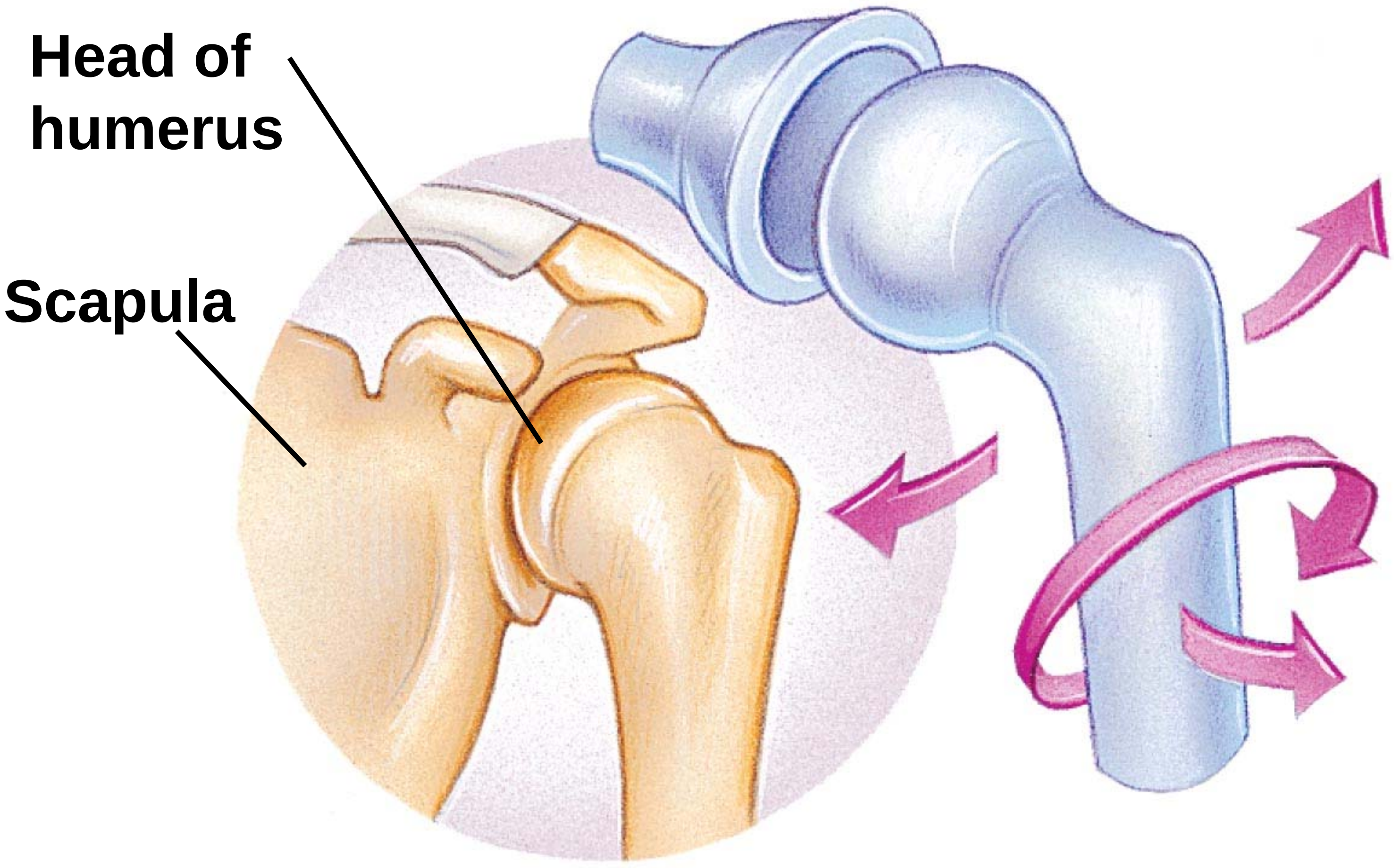
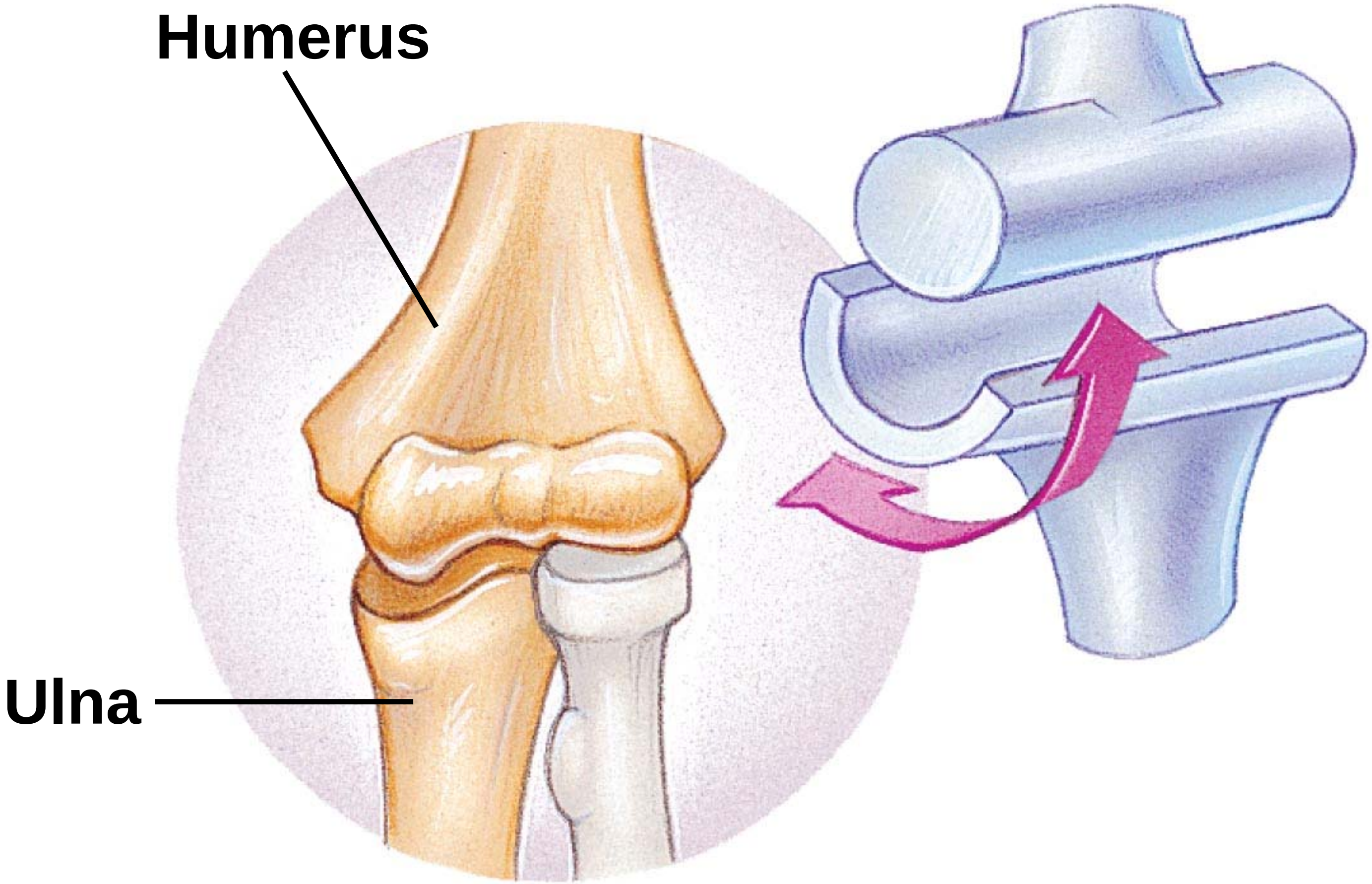

Skull
Examples of joints
1
2
3
Shoulder girdle
Clavicle
Scapula
Sternum
Rib
Humerus
Vertebra
Radius
Ulna
Pelvic girdle
Carpals
Phalanges
Metacarpals
Femur
Patella
Tibia
Fibula
Tarsals
Metatarsals
Phalanges

Fig. 50-34b



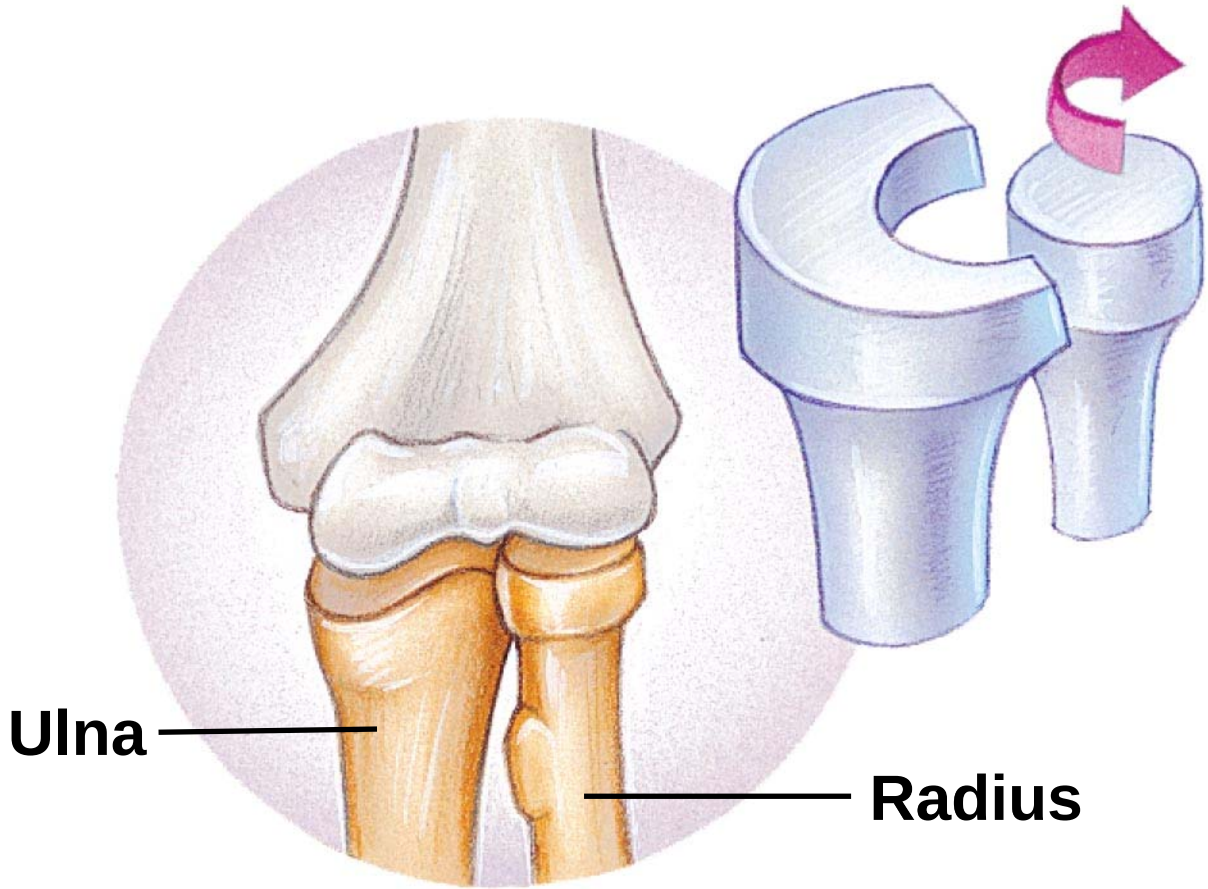
1 **Ball-and-socket joint**

Fig. 50-34c



2 Hinge joint

Fig. 50-34d



3 **Pivot joint**

Size and Scale of Skeletons

- An animal's body structure must support its size
- The size of an animal's body scales with volume (a function of n^3), while the support for that body scales with cross-sectional area of the legs (a function of n^2)
- As objects get larger, size (n^3) increases faster than cross-sectional area (n^2); this is the principle of scaling

- The skeletons of small and large animals have different proportions because of the principle of scaling
- In mammals and birds, the position of legs relative to the body is very important in determining how much weight the legs can bear

Types of Locomotion

- Most animals are capable of **locomotion**, or active travel from place to place
- In locomotion, energy is expended to overcome friction and gravity

Swimming

- In water, friction is a bigger problem than gravity
- Fast swimmers usually have a streamlined shape to minimize friction
- Animals swim in diverse ways
  - Paddling with their legs as oars
  - Jet propulsion
  - Undulating their body and tail from side to side, or up and down

Locomotion on Land

- Walking, running, hopping, or crawling on land requires an animal to support itself and move against gravity
- Diverse adaptations for locomotion on land have evolved in vertebrates

Fig. 50-35

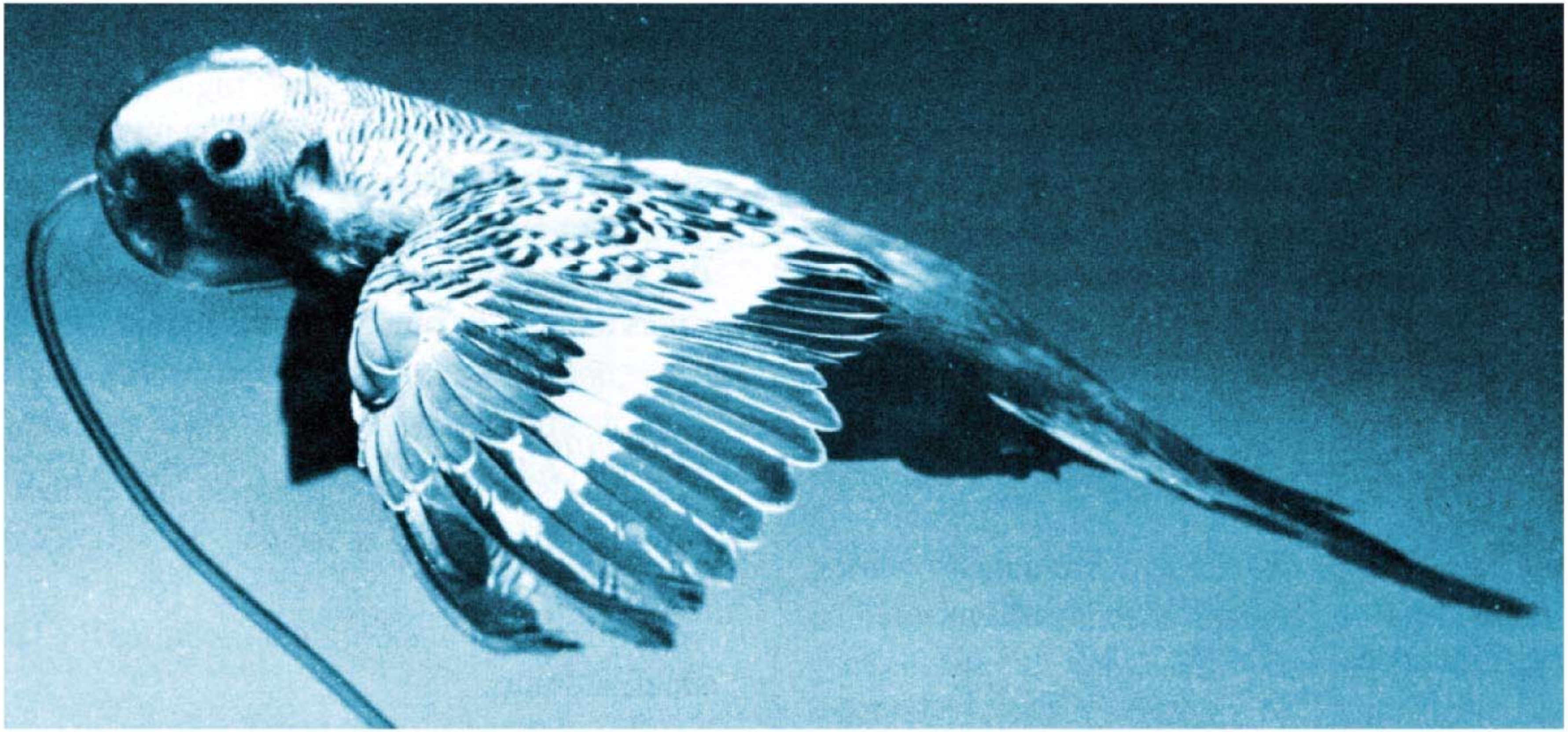
Flying

- Flight requires that wings develop enough lift to overcome the downward force of gravity
- Many flying animals have adaptations that reduce body mass
  - For example, birds lack teeth and a urinary bladder

Energy Costs of Locomotion

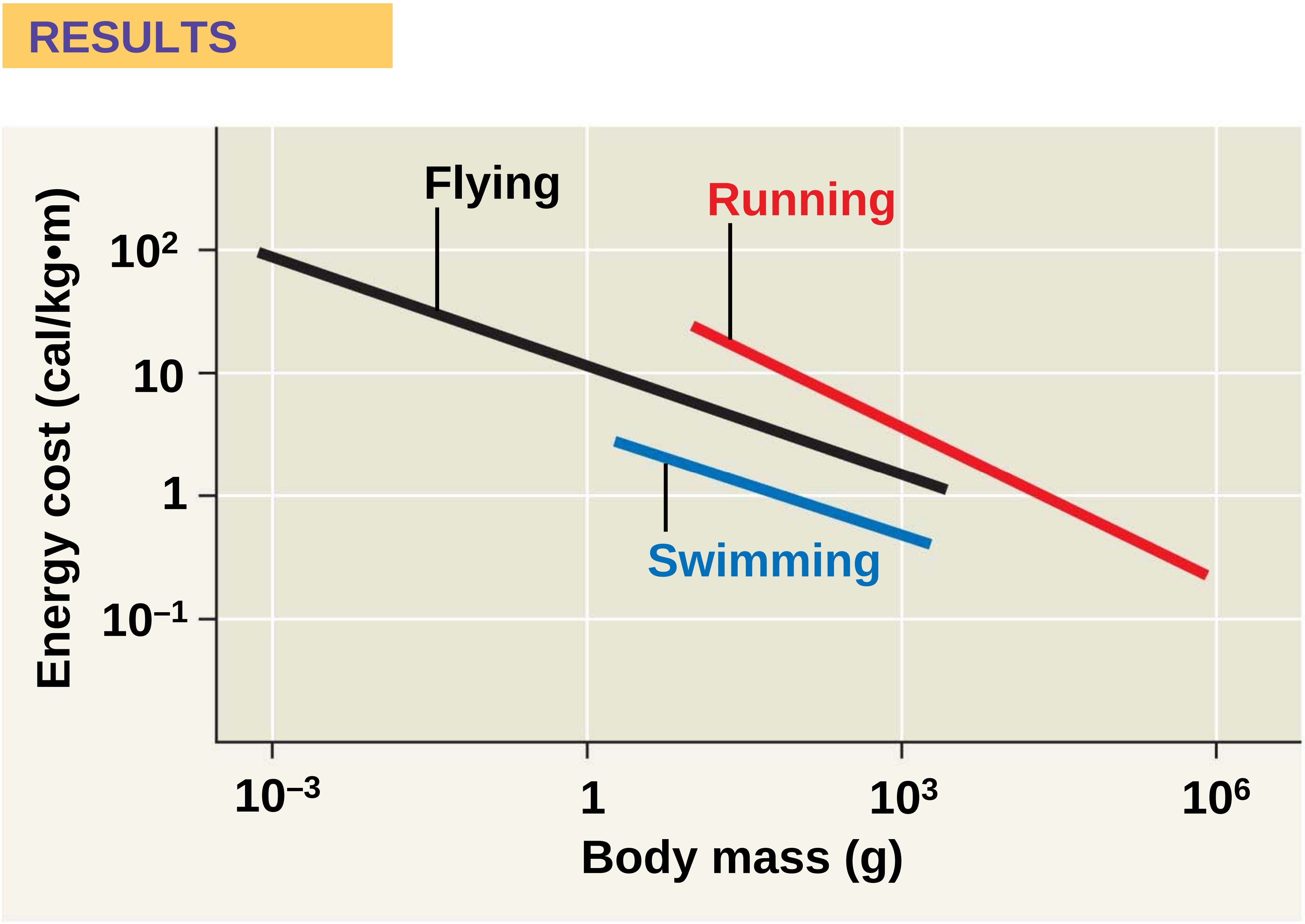
- The energy cost of locomotion
  - Depends on the mode of locomotion and the environment
  - Can be estimated by the rate of oxygen consumption or carbon dioxide production

Fig. 50-36



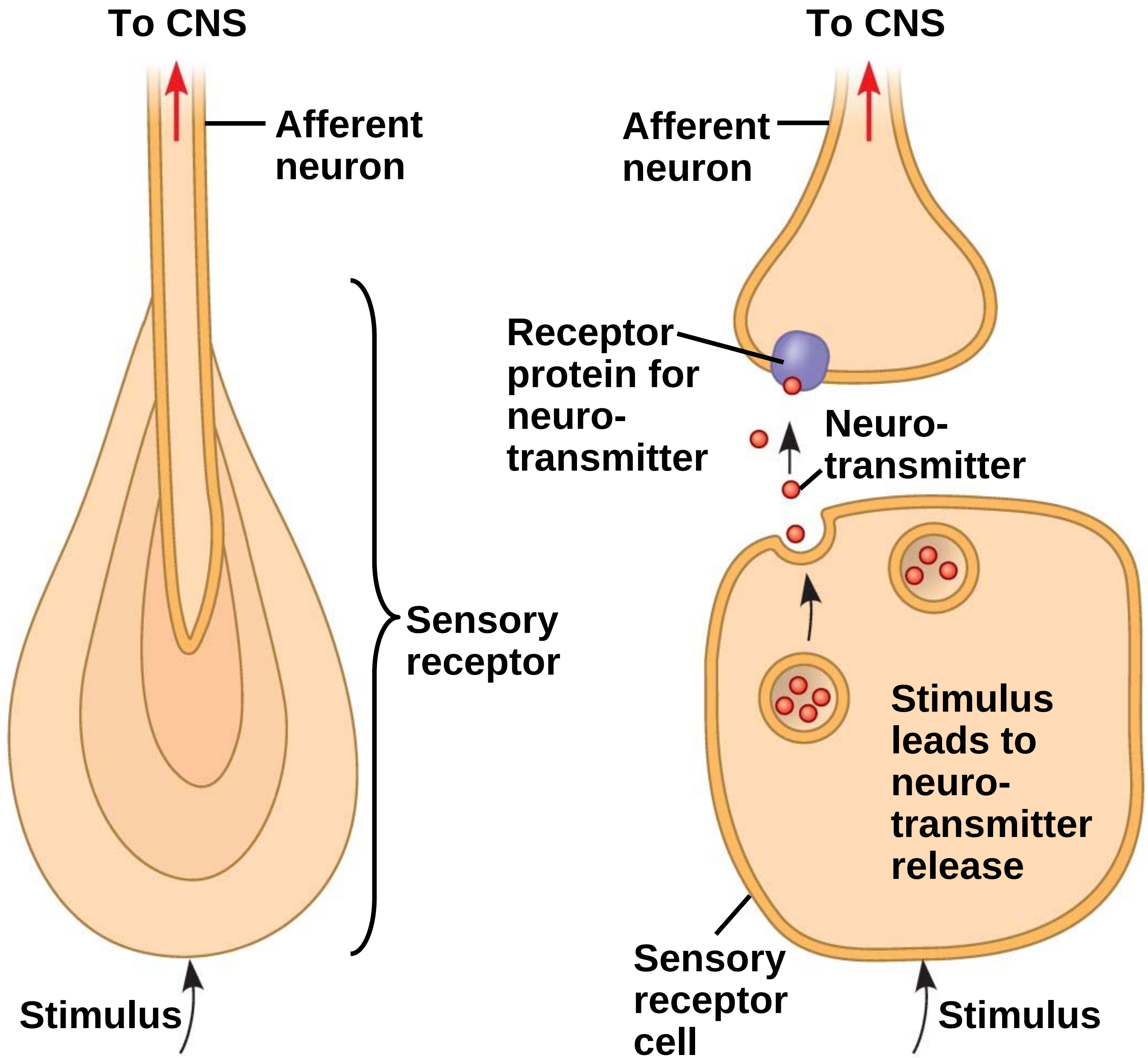
- Animals specialized for swimming expend less energy per meter traveled than equivalently sized animals specialized for flying or running

Fig. 50-37



RESULTS
Flying
Running
Swimming
Energy cost (cal/kg•m)
10²
10
1
10⁻¹
10⁻³
1
10³
10⁶
Body mass (g)

Fig. 50-UN1



(a) Receptor *is* afferent neuron. (b) Receptor *regulates* afferent neuron.

Fig. 50-UN2

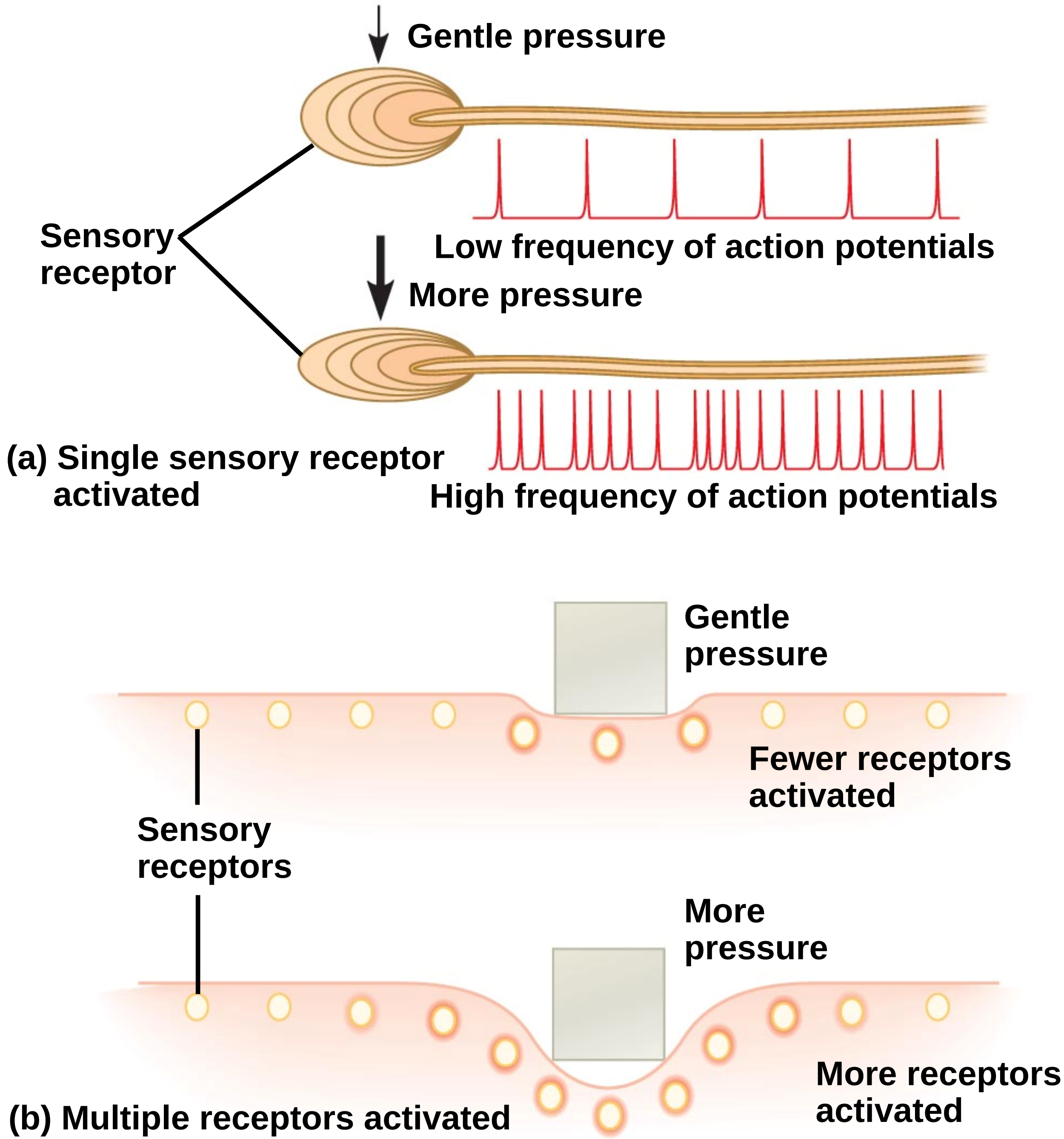

Gentle pressure
Sensory receptor
Low frequency of action potentials
More pressure
(a) Single sensory receptor activated
High frequency of action potentials
Gentle pressure
Fewer receptors activated
Sensory receptors
More pressure
More receptors activated
(b) Multiple receptors activated

Fig. 50-UN3

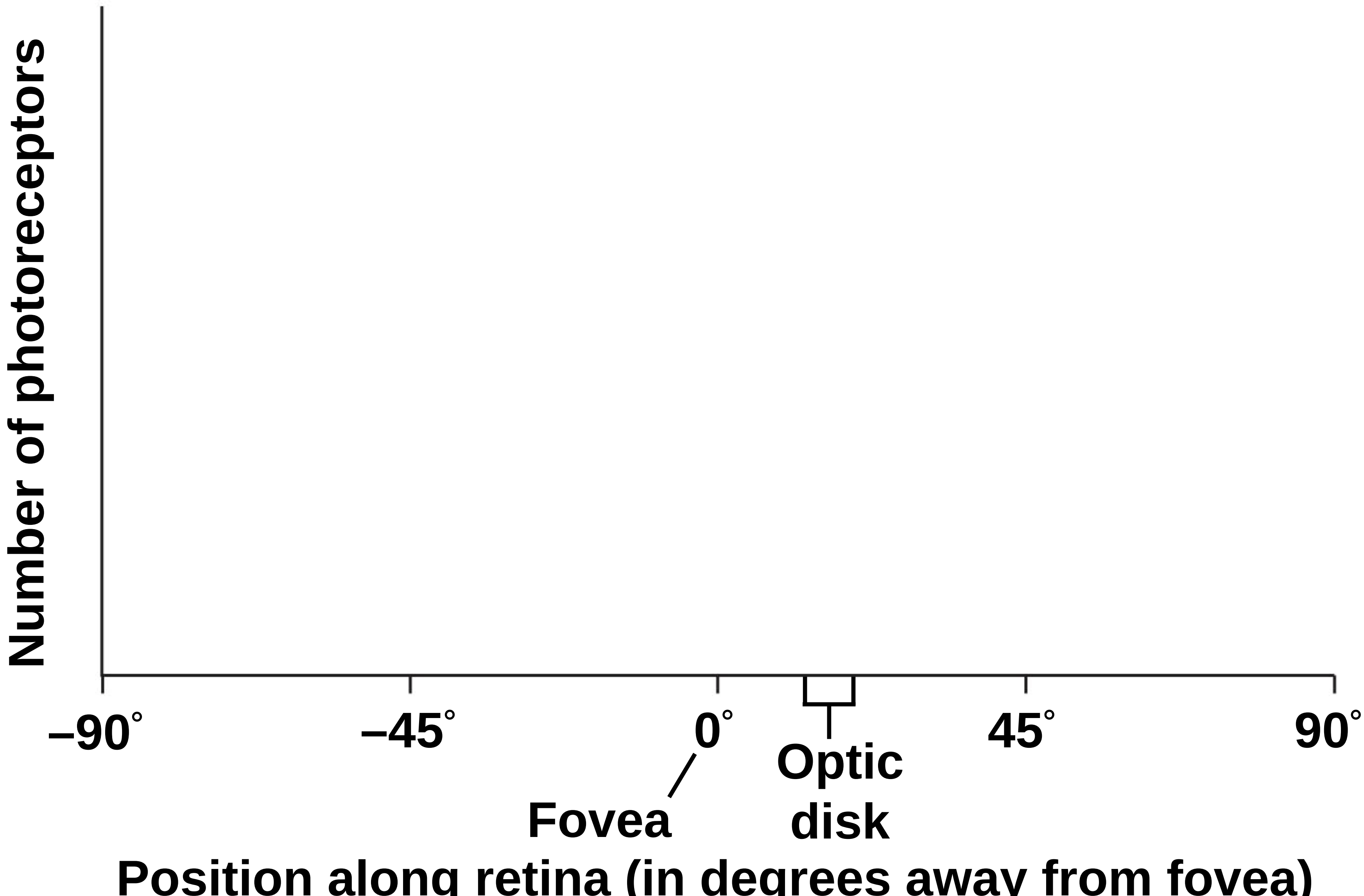
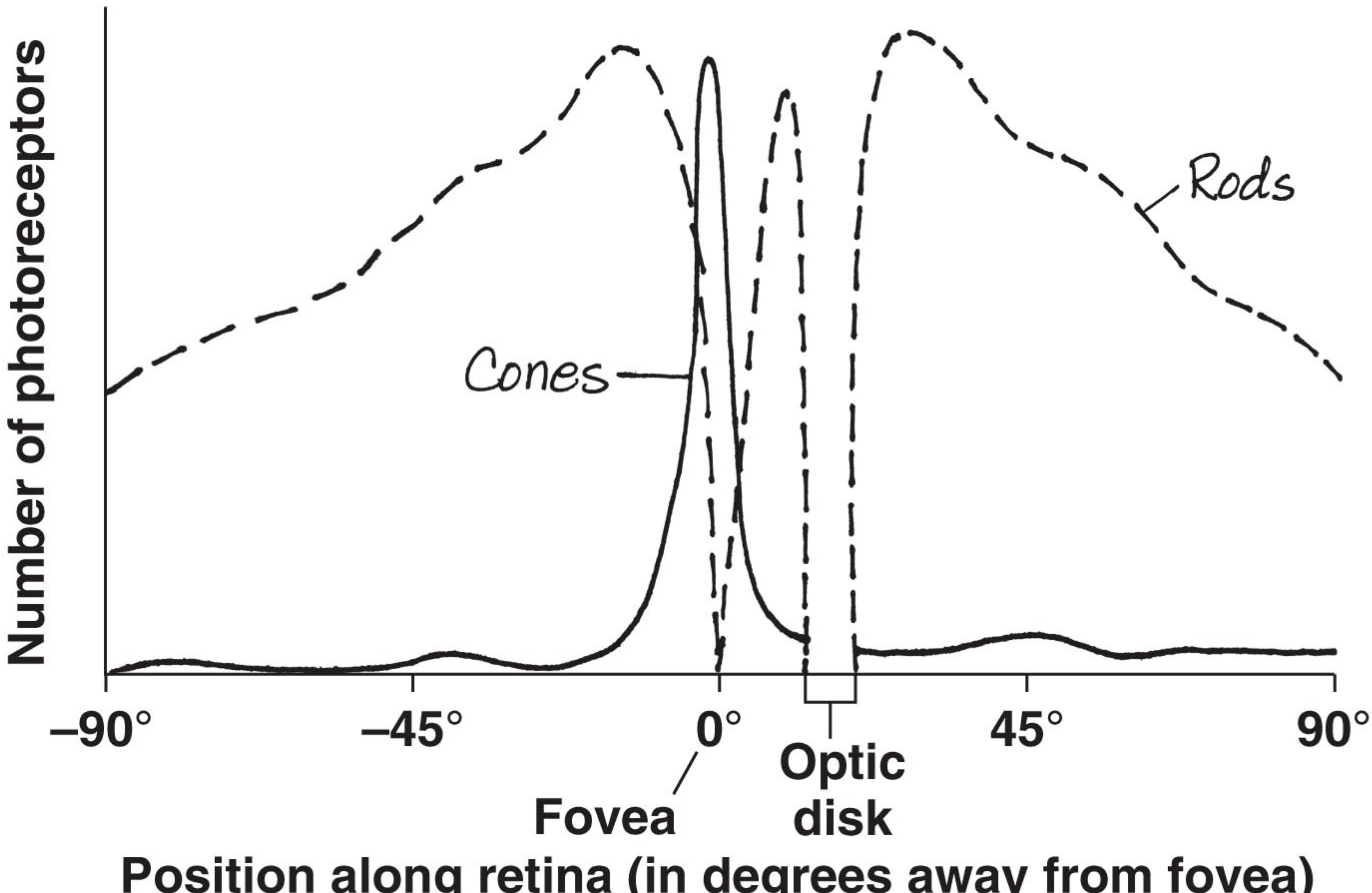

Number of photoreceptors
–90°
–45°
0°
45°
90°
Optic
disk
Fovea
Position along retina (in degrees away from fovea)

Fig. 50-UN4



Number of photoreceptors
Rods
Cones
–90°
–45°
0°
45°
90°
Fovea
Optic disk
Position along retina (in degrees away from fovea)

You should now be able to:

1. Distinguish between the following pairs of terms: sensation and perception; sensory transduction and receptor potential; tastants and odorants; rod and cone cells; oxidative and glycolytic muscle fibers; slow-twitch and fast-twitch muscle fibers; endoskeleton and exoskeleton

2. List the five categories of sensory receptors and explain the energy transduced by each type

3. Explain the role of mechanoreceptors in hearing and balance
4. Give the function of each structure using a diagram of the human ear
5. Explain the basis of the sensory discrimination of human smell
6. Identify and give the function of each structure using a diagram of the vertebrate eye

7. Identify the components of a skeletal muscle cell using a diagram
8. Explain the sliding-filament model of muscle contraction
9. Explain how a skeleton combines with an antagonistic muscle arrangement to provide a mechanism for movement