LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

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Chapter 50

Sensory and Motor Mechanisms

Lectures by
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Overview: Sensing and Acting

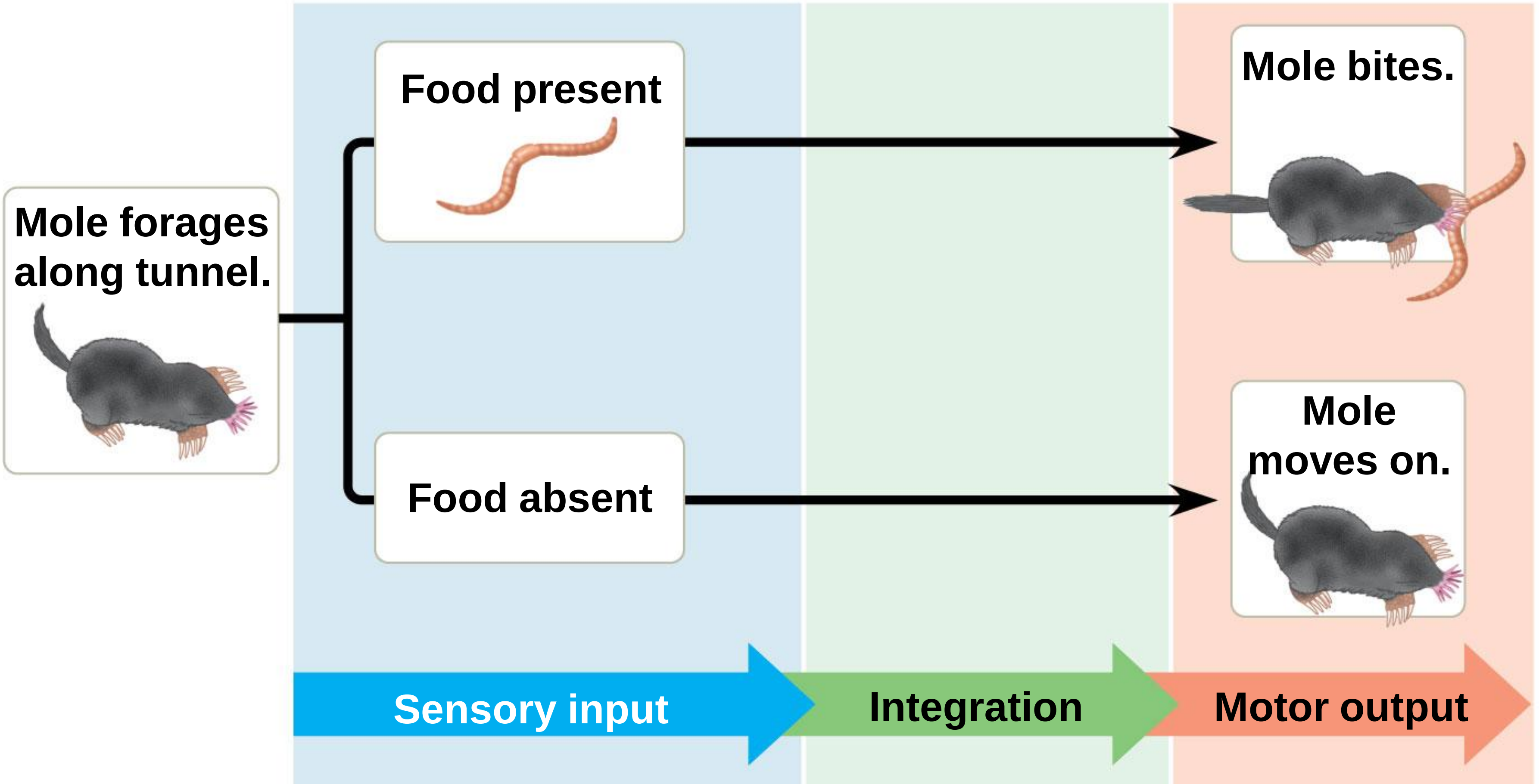
- The star-nosed mole can catch insect prey in near total darkness in as little as 120 milliseconds
- It uses the 11 appendages protruding from its nose to locate and capture prey
- Sensory processes convey information about an animal's environment to its brain, and muscles and skeletons carry out movements as instructed by the brain

Figure 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
- When a stimulus's input to the nervous system is processed a motor response may be generated
- This may involve a simple reflex or more elaborate processing

Figure 50.2


Mole forages along tunnel.
Food present
Food absent
Mole bites.
Mole moves on.
Sensory input
Integration
Motor output

Sensory Pathways

- Sensory pathways have four basic functions in common
  - Sensory reception
  - Tranduction
  - Transmission
  - Integration

Sensory Reception and Transduction

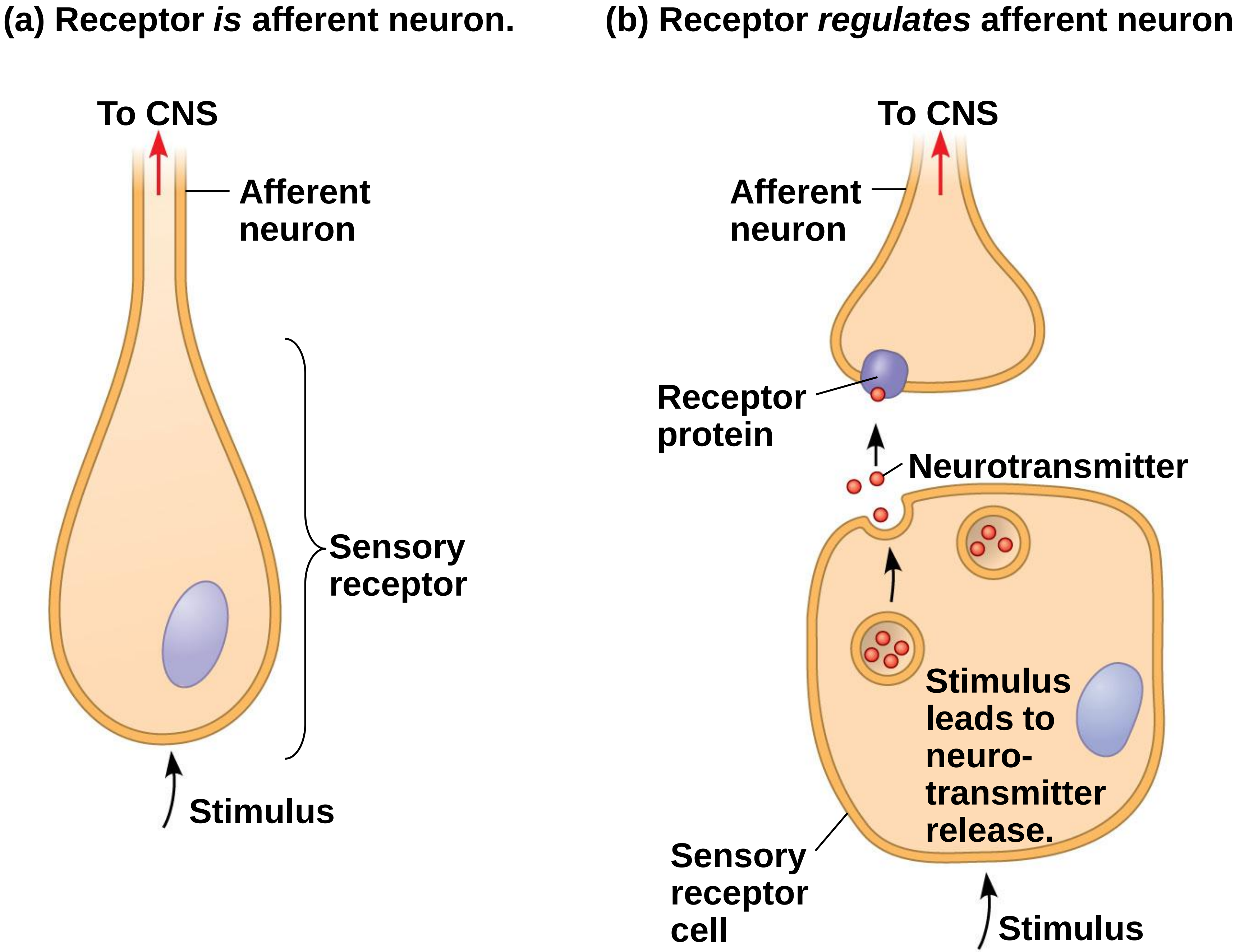
- Sensations and perceptions begin with **sensory reception**, detection of stimuli by sensory receptors
- **Sensory receptors** interact directly with stimuli, both inside and outside the body

- **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**
- Receptor potentials are graded potentials; their magnitude varies with the strength of the stimulus

Transmission

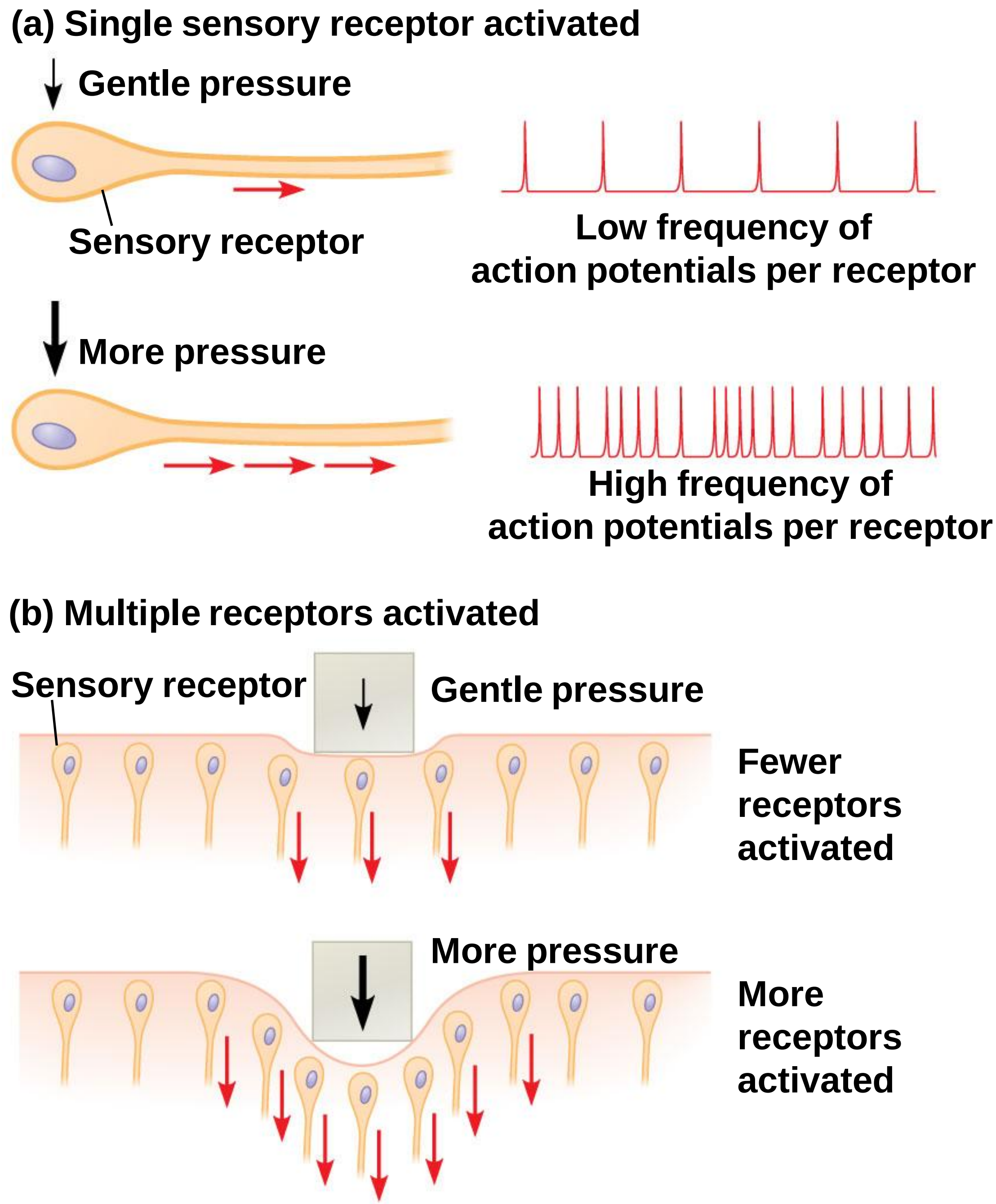
- After energy has been transduced into a receptor potential, some sensory cells generate the **transmission** of action potentials to the CNS
- Some sensory receptors are specialized neurons while others are specialized cells that regulate neurons
- Sensory neurons produce action potentials and their axons extend into the CNA

Figure 50.3


(a) Receptor *is* afferent neuron.
To CNS
Afferent neuron
Sensory receptor
Stimulus
(b) Receptor *regulates* afferent neuron.
To CNS
Afferent neuron
Receptor protein
Neurotransmitter
Stimulus leads to neuro-transmitter release.
Sensory receptor cell
Stimulus

- The response of a sensory receptor varies with intensity of stimuli
- If the receptor is a neuron, a larger receptor potential results in more frequent action potentials
- If the receptor is not a neuron, a larger receptor potential causes more neurotransmitters to be released

Figure 50.4



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

Figure 50.4a

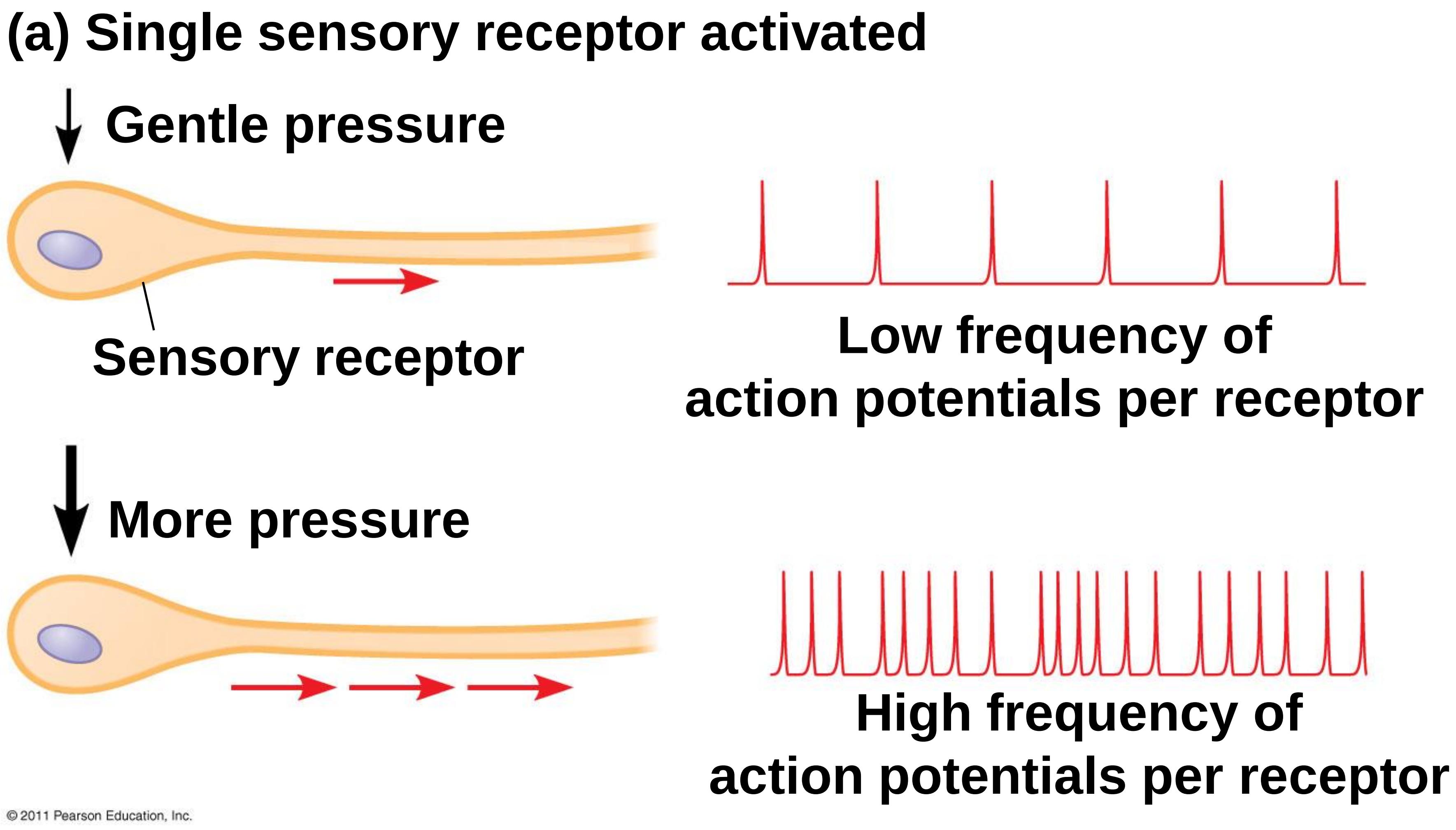

(a) Single sensory receptor activated
Gentle pressure
Sensory receptor
Low frequency of
action potentials per receptor
More pressure
High frequency of
action potentials per receptor
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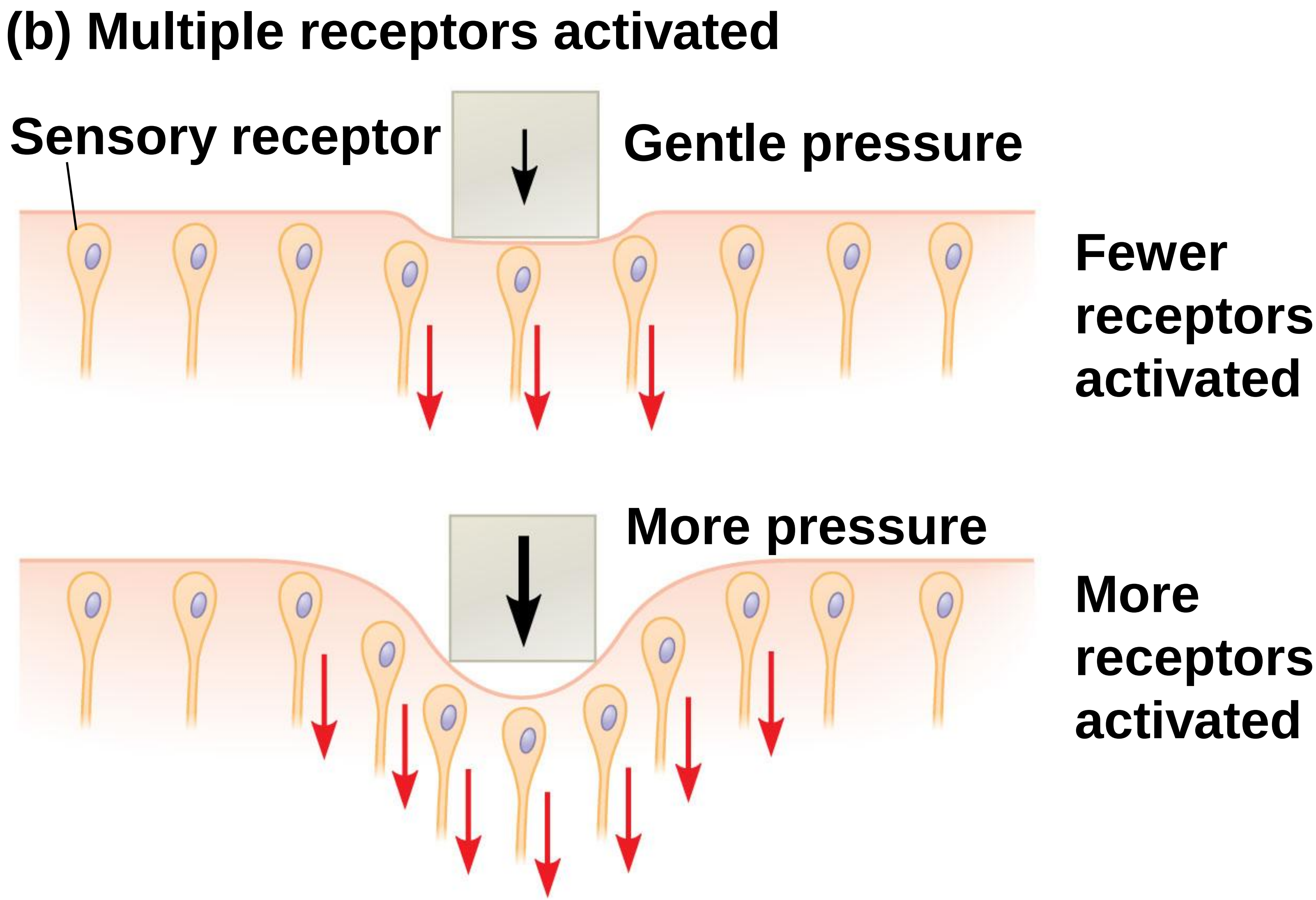
Figure 50.4b



(b) Multiple receptors activated
Sensory receptor
Gentle pressure
Fewer receptors activated
More pressure
More receptors activated

Perception

- **Perceptions** are the brain's construction of stimuli
- Stimuli from different sensory receptors travel as action potentials along dedicated neural pathways
- The brain distinguishes stimuli from different receptors based on 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

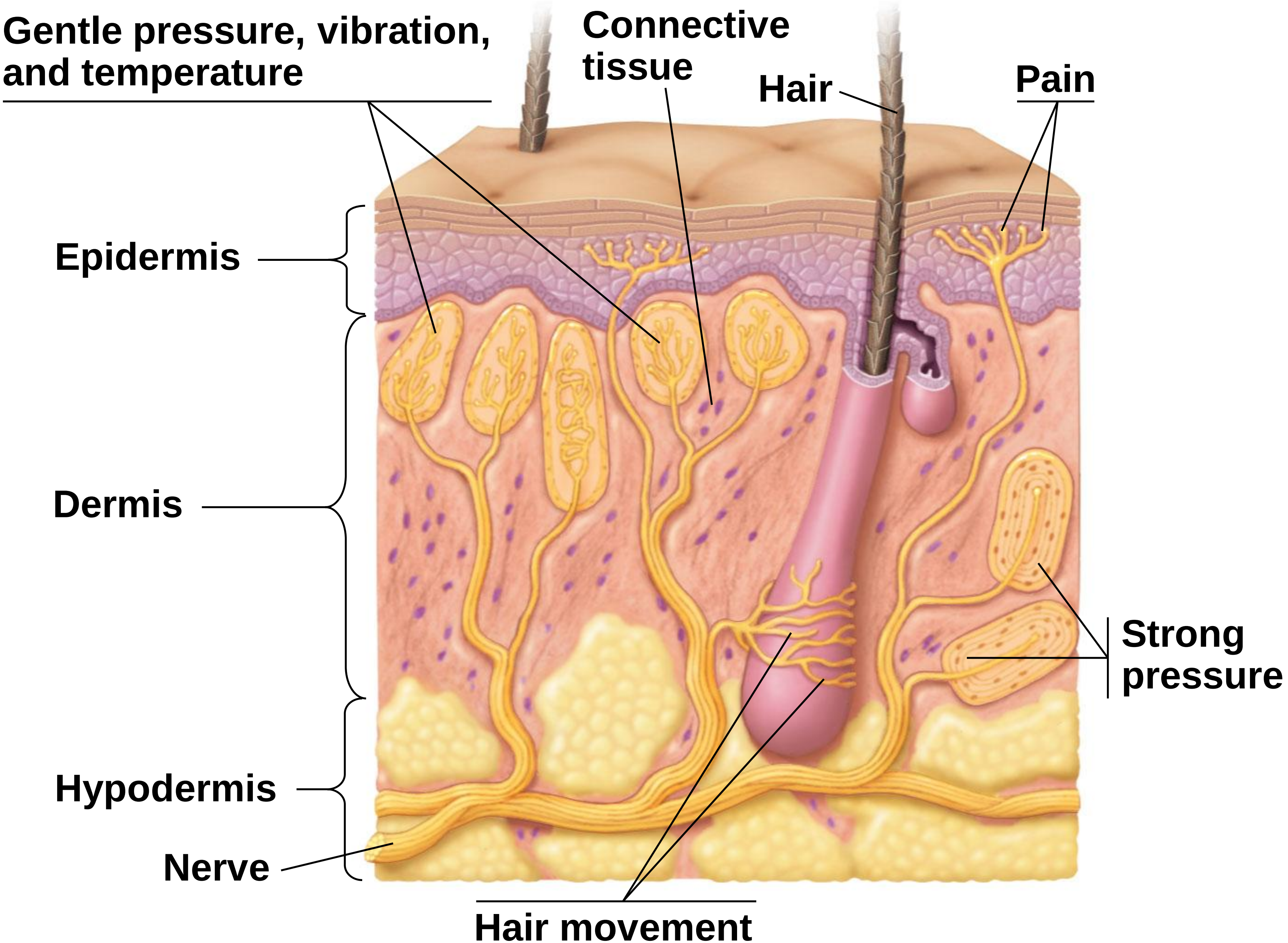
Types of Sensory Receptors

- 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 knee-jerk response is triggered by the vertebrate stretch receptor, a mechanoreceptor that detects muscle movement
- The mammalian sense of touch relies on mechanoreceptors that are dendrites of sensory neurons

Figure 50.5



Gentle pressure, vibration, and temperature
Connective tissue
Hair
Pain
Epidermis
Dermis
Hypodermis
Nerve
Strong pressure
Hair movement

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

Figure 50.6

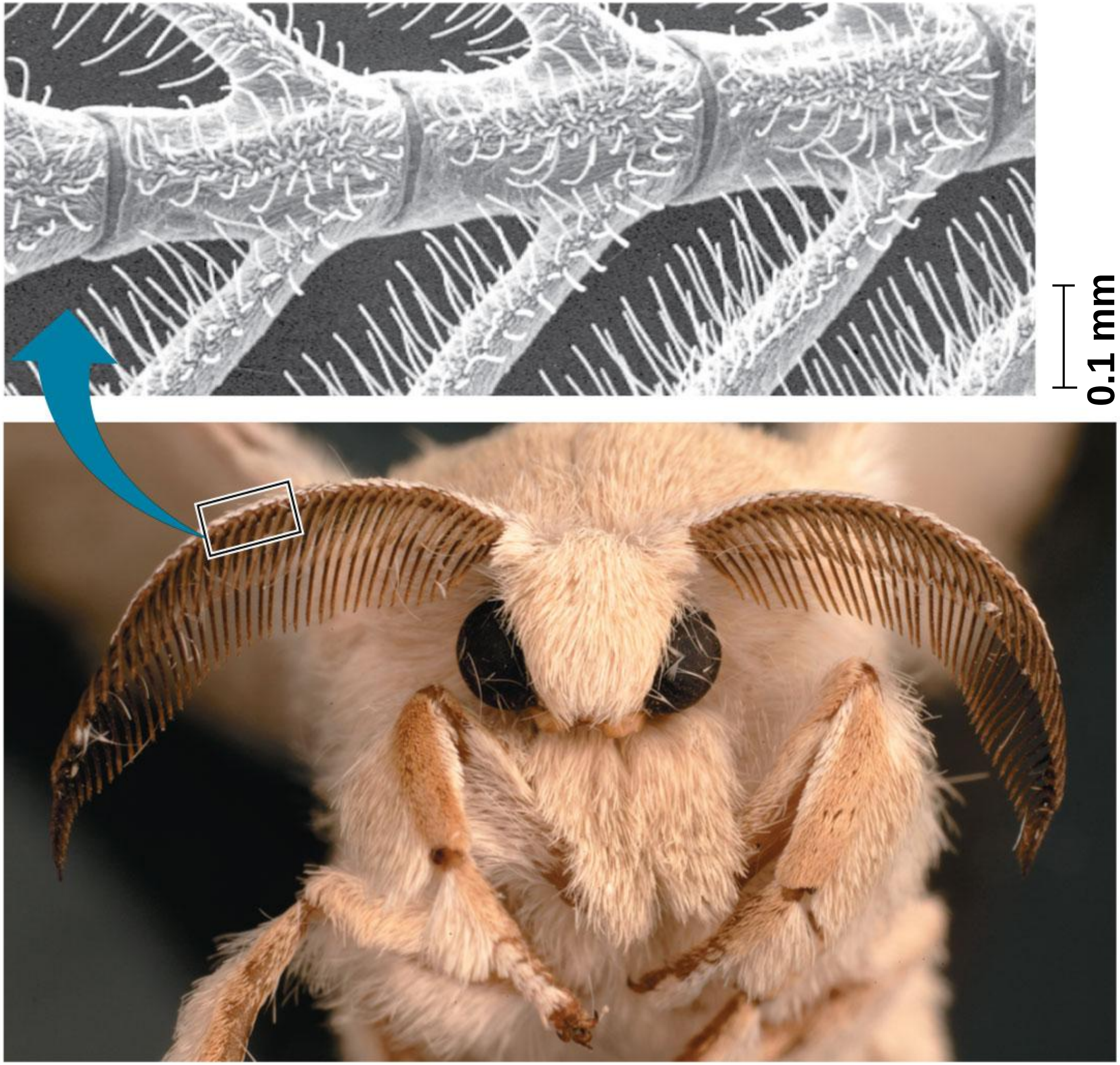
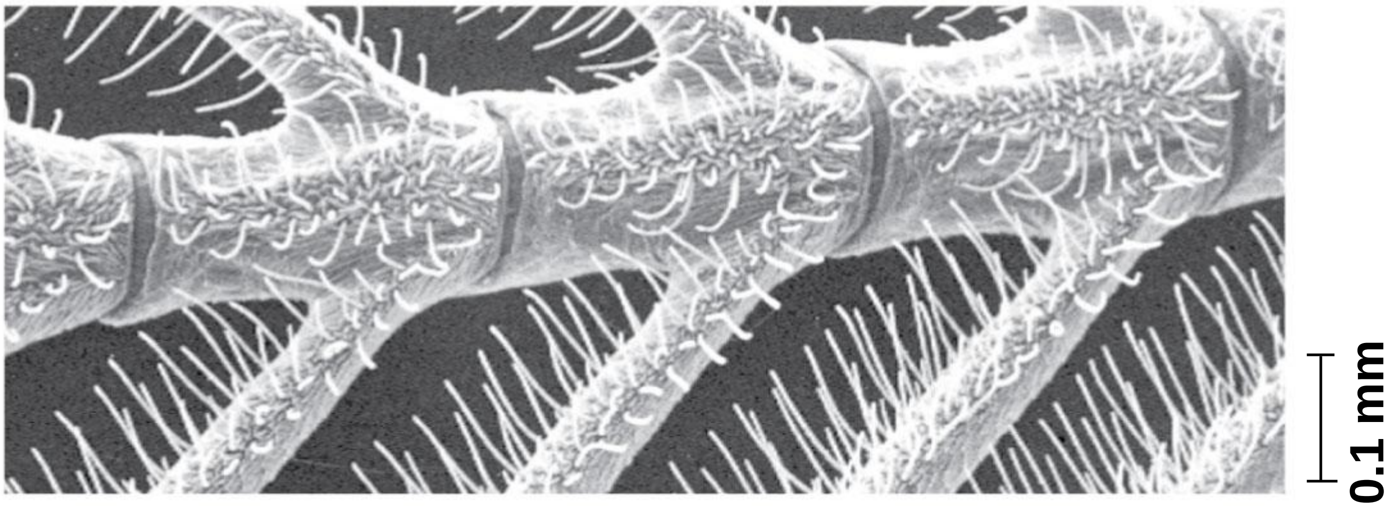


Figure 50.6a

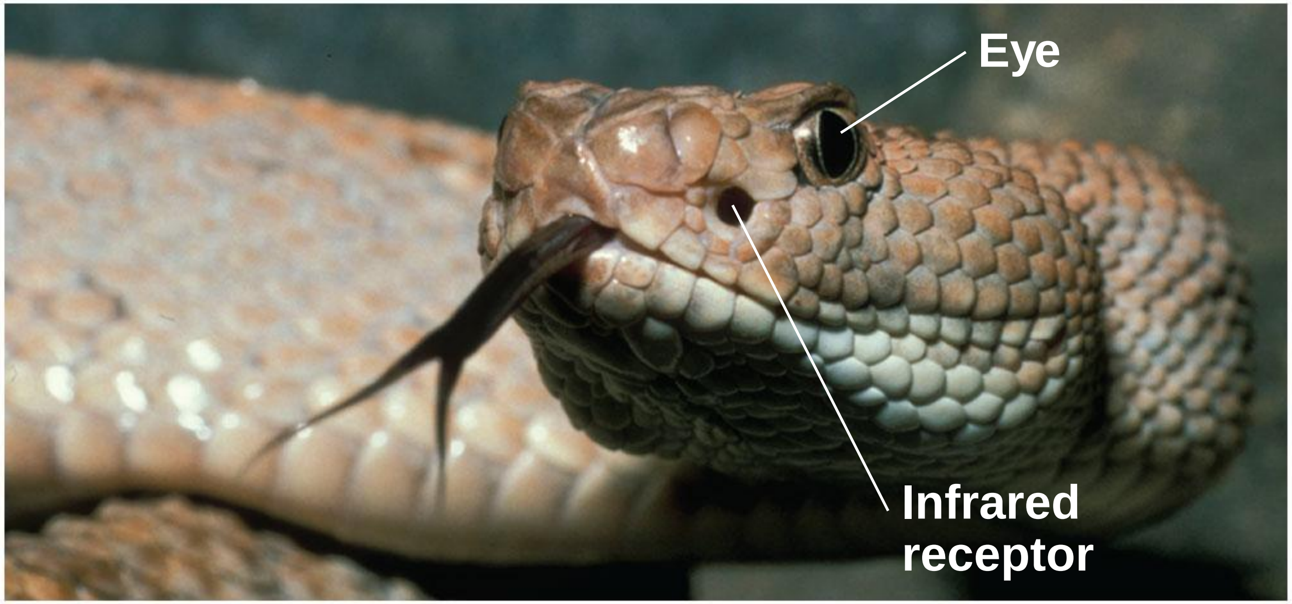
Figure 50.6b



Electromagnetic Receptors

- **Electromagnetic receptors** detect electromagnetic energy such as light, electricity, and magnetism
- Some snakes have very sensitive infrared receptors that detect body heat of prey against a colder background
- Many animals apparently migrate using the Earth's magnetic field to orient themselves

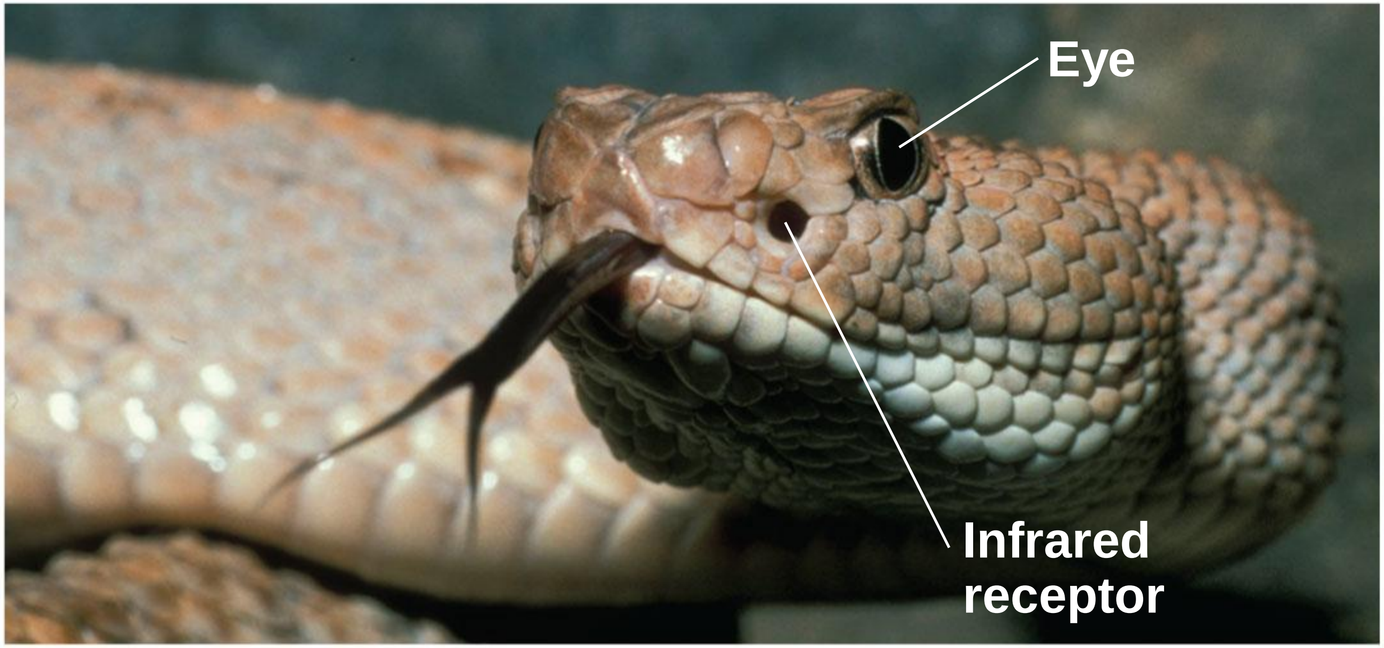
Figure 50.7



(a) Rattlesnake

(b) Beluga whales

Figure 50.7a



(a) Rattlesnake

Figure 50.7b

(b) Beluga whales

Thermoreceptors

- **Thermoreceptors**, which respond to heat or cold, help regulate body temperature by signaling both surface and body core temperature
- Mammals have a number of kinds of thermoreceptors, each specific for a particular temperature range

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

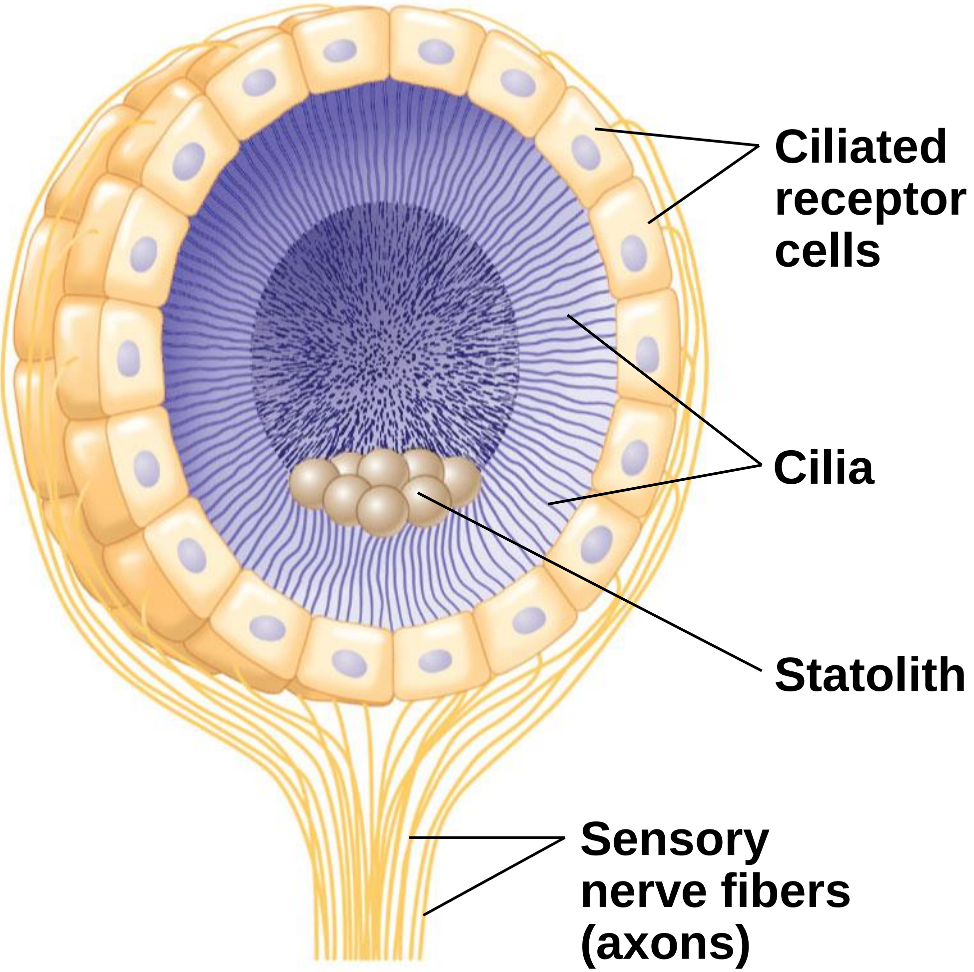
Concept 50.2: The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles

- Hearing and perception of body equilibrium are related in most animals
- For both senses, settling particles or moving fluid are detected by mechanoreceptors

Sensing Gravity and Sound in Invertebrates

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

Figure 50.8


Ciliated receptor cells
Cilia
Statolith
Sensory nerve fibers (axons)

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

Figure 50.9

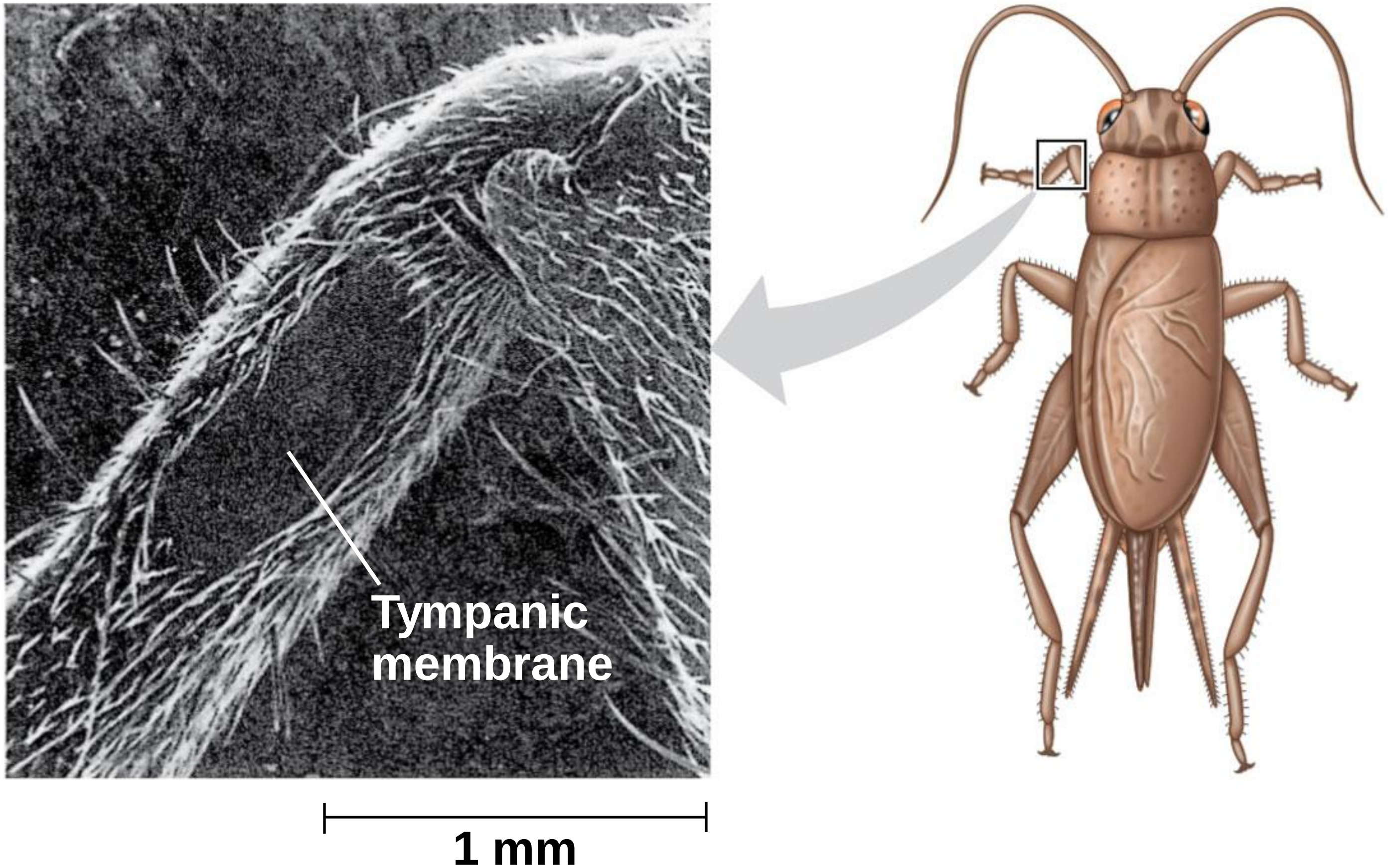
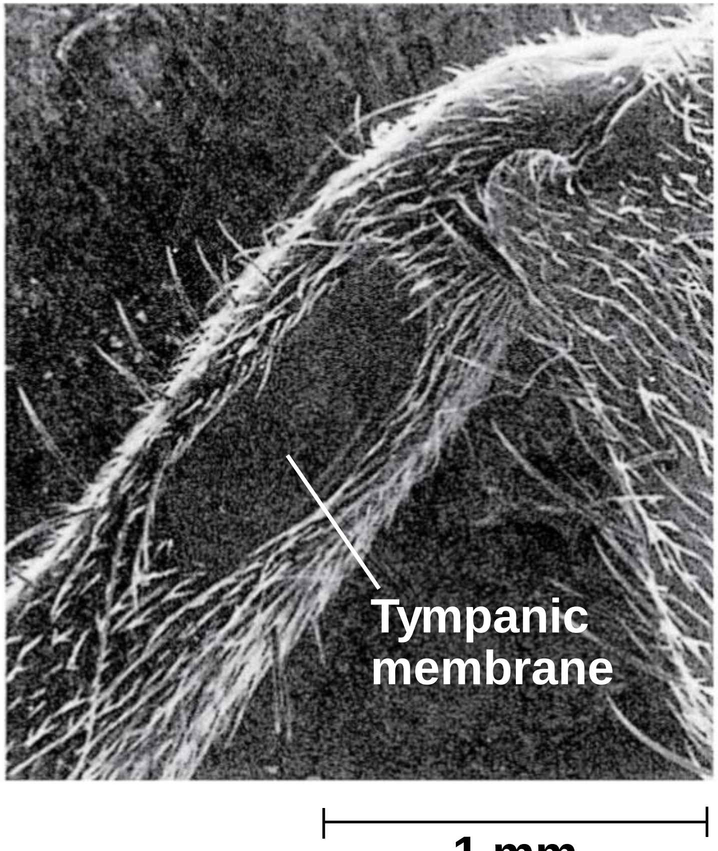


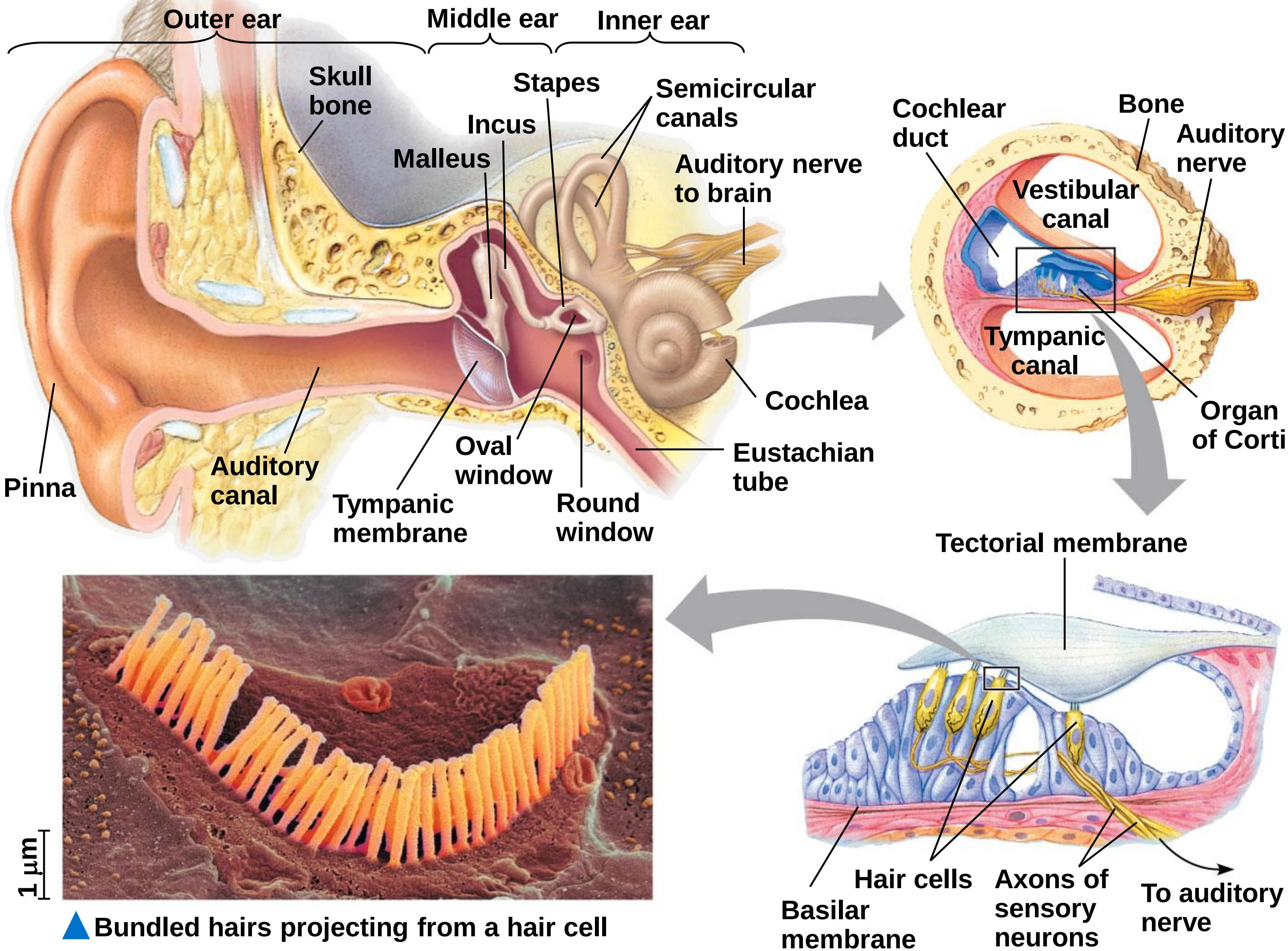
Figure 50.9a



Hearing and Equilibrium in Mammals

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

Figure 50.10



Bundled hairs projecting from a hair cell

Figure 50.10a

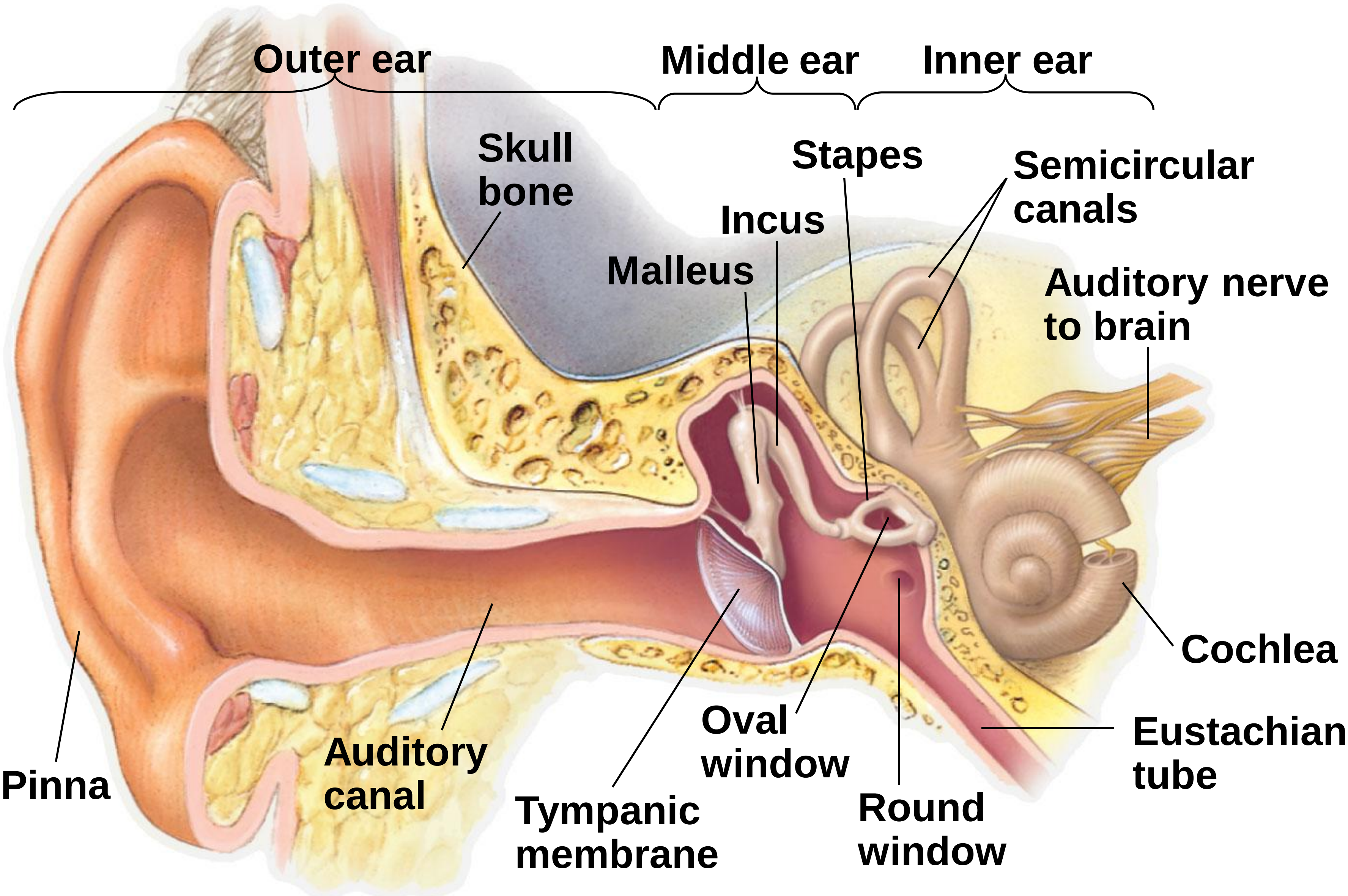


Figure 50.10b

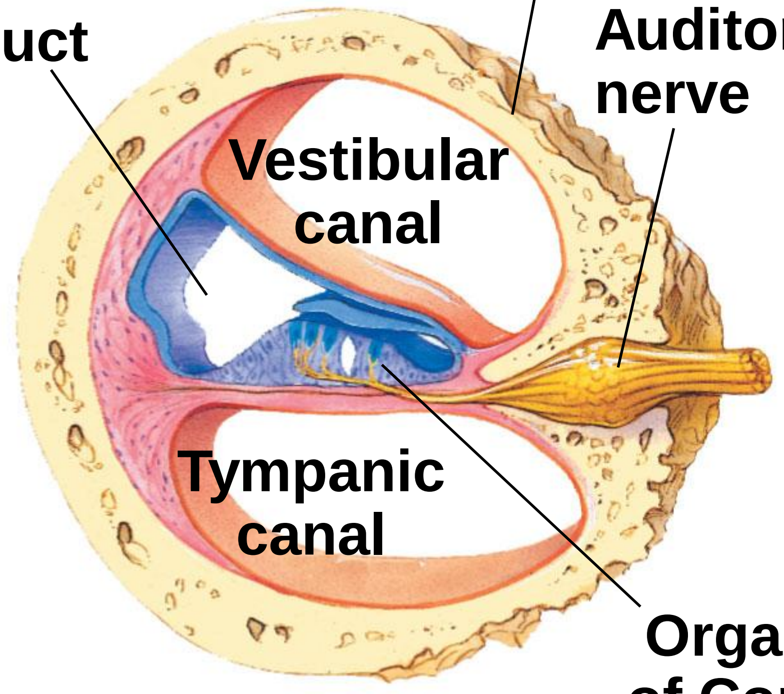


Figure 50.10c

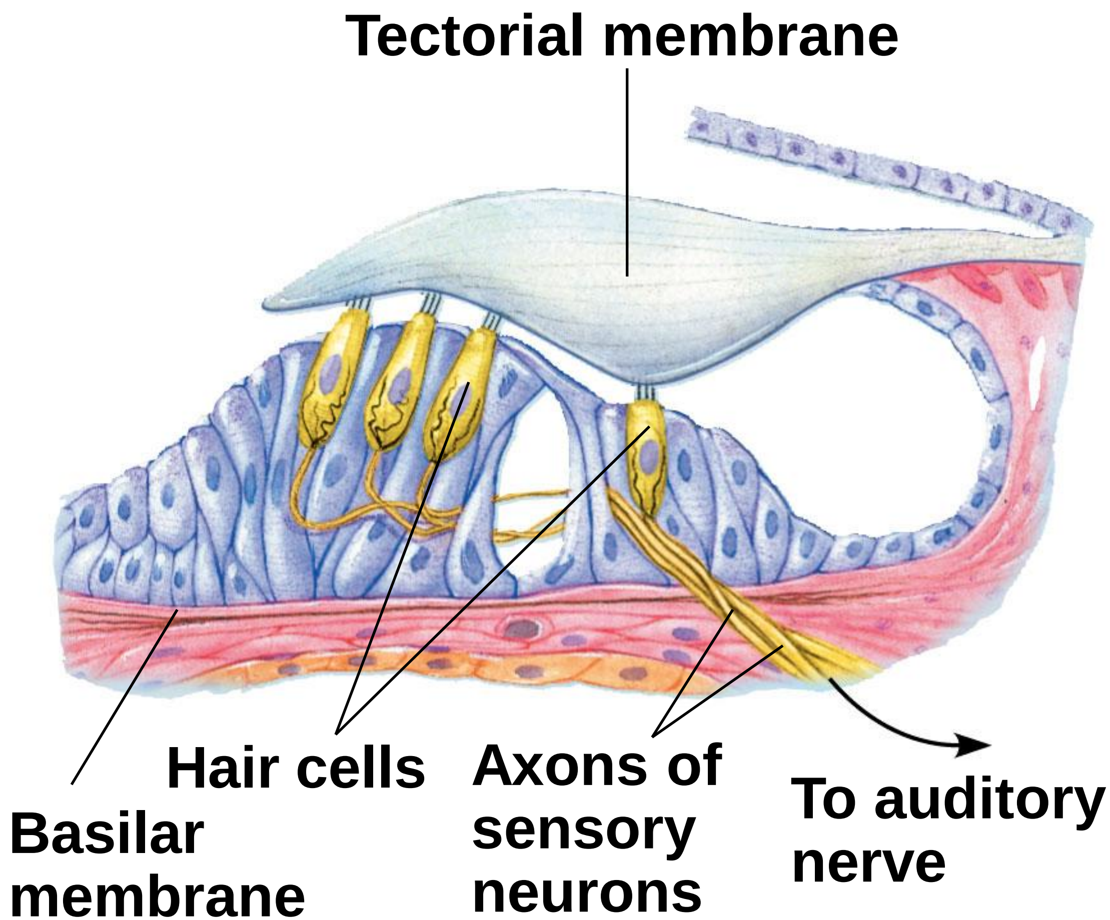


Figure 50.10d

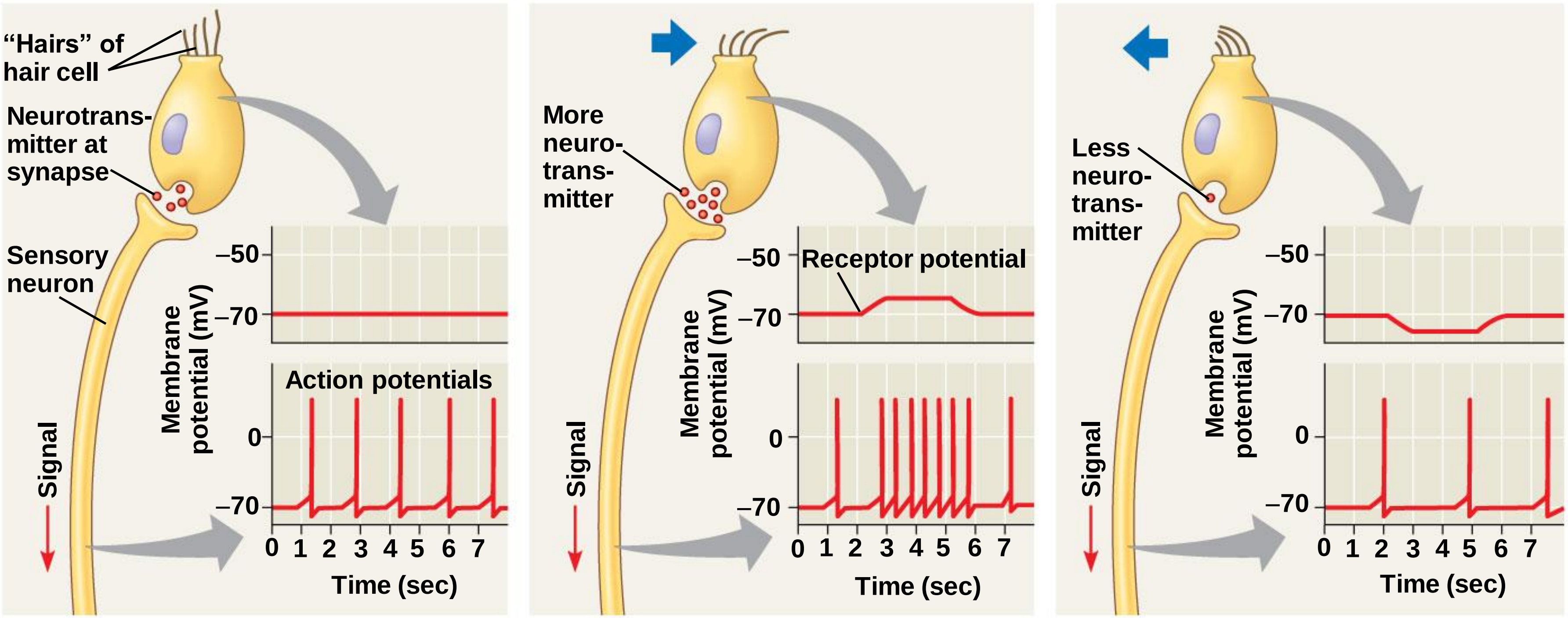
▲ **Bundled hairs projecting from a hair cell**

Hearing

- Vibrating objects create percussion waves in the air that cause the tympanic membrane to vibrate
- 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

Figure 50.11

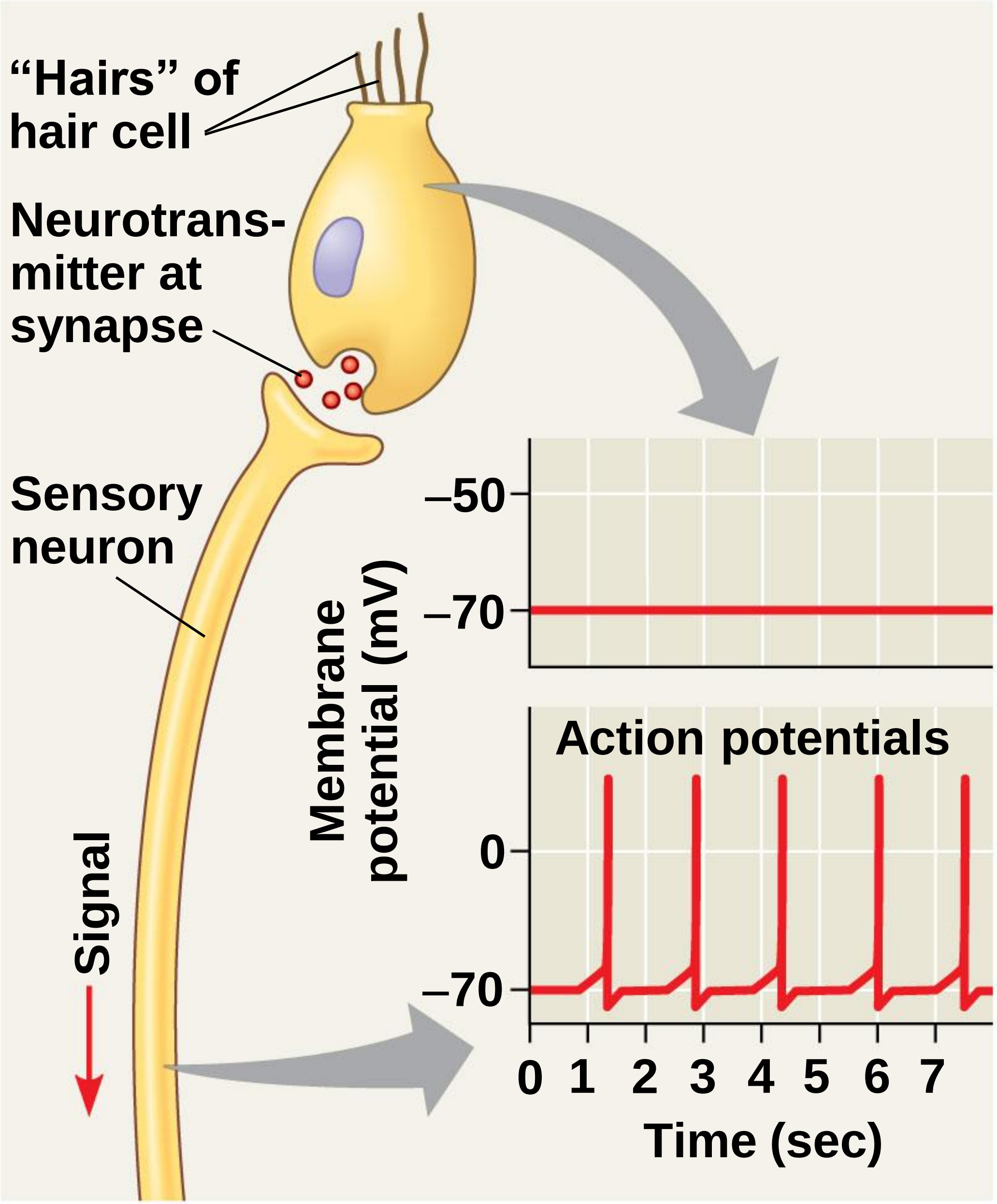


(a) No bending of hairs

(b) Bending of hairs in one direction

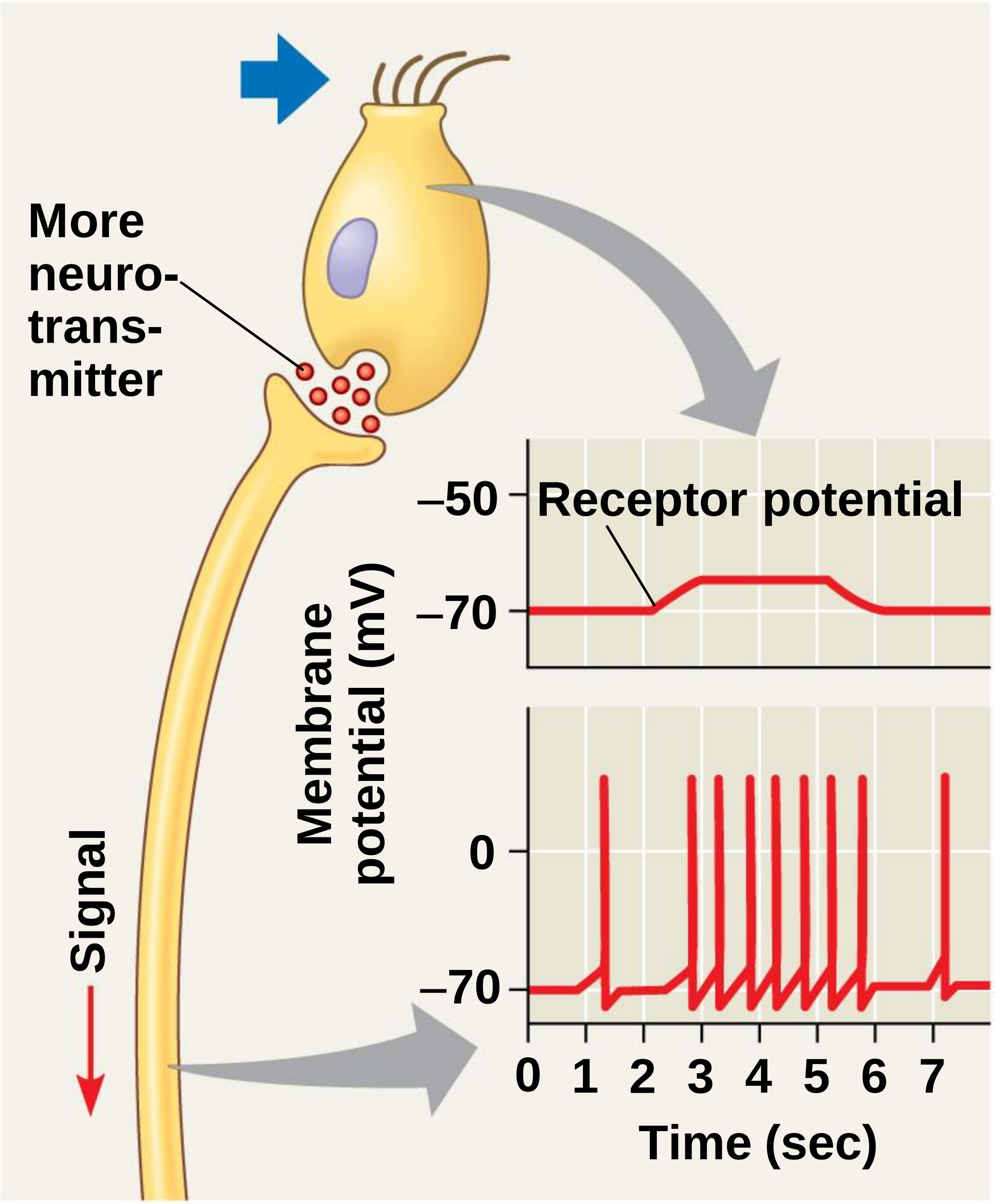
(c) Bending of hairs in other direction

Figure 50.11a



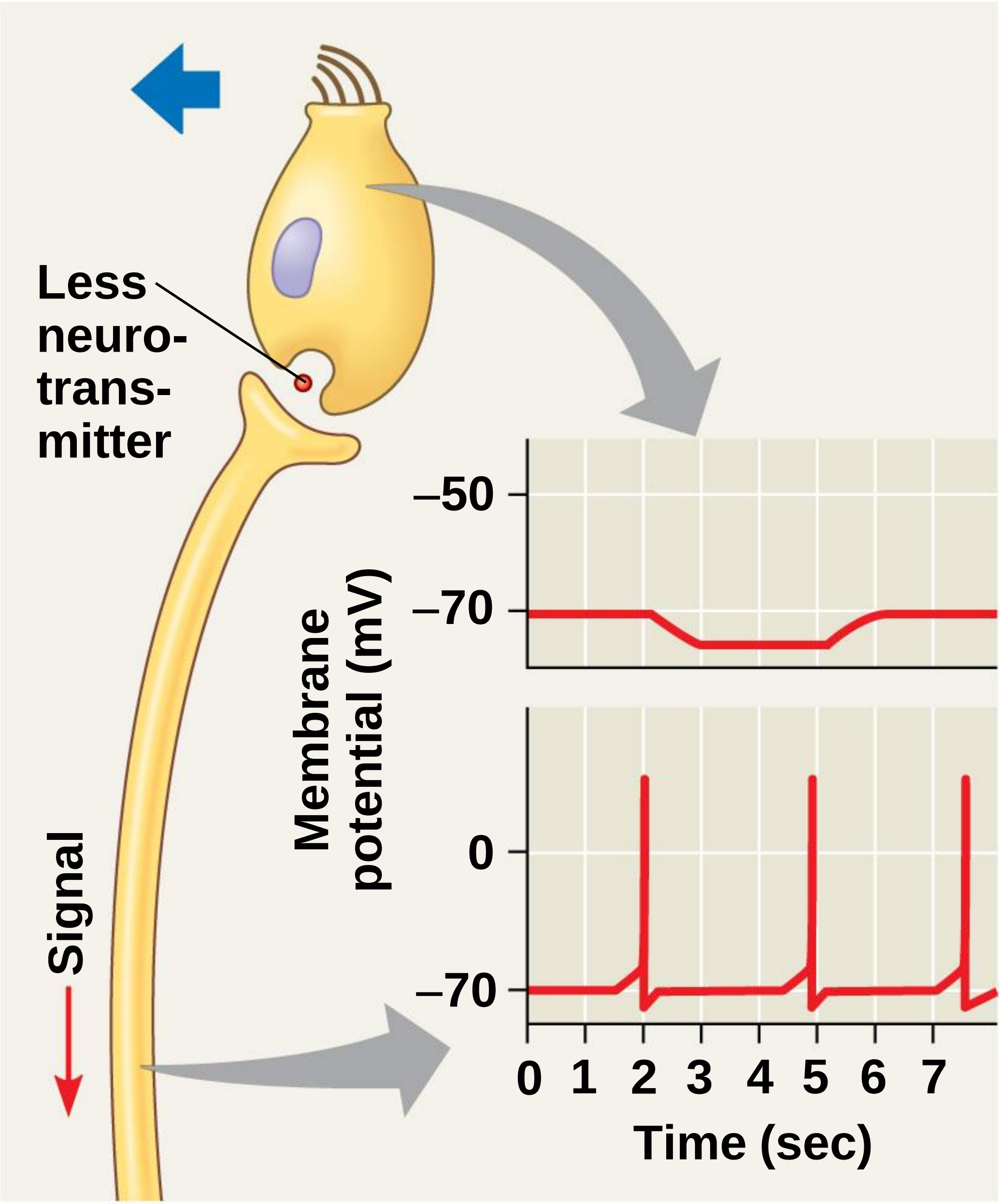
(a) No bending of hairs

Figure 50.11b



(b) Bending of hairs in one direction

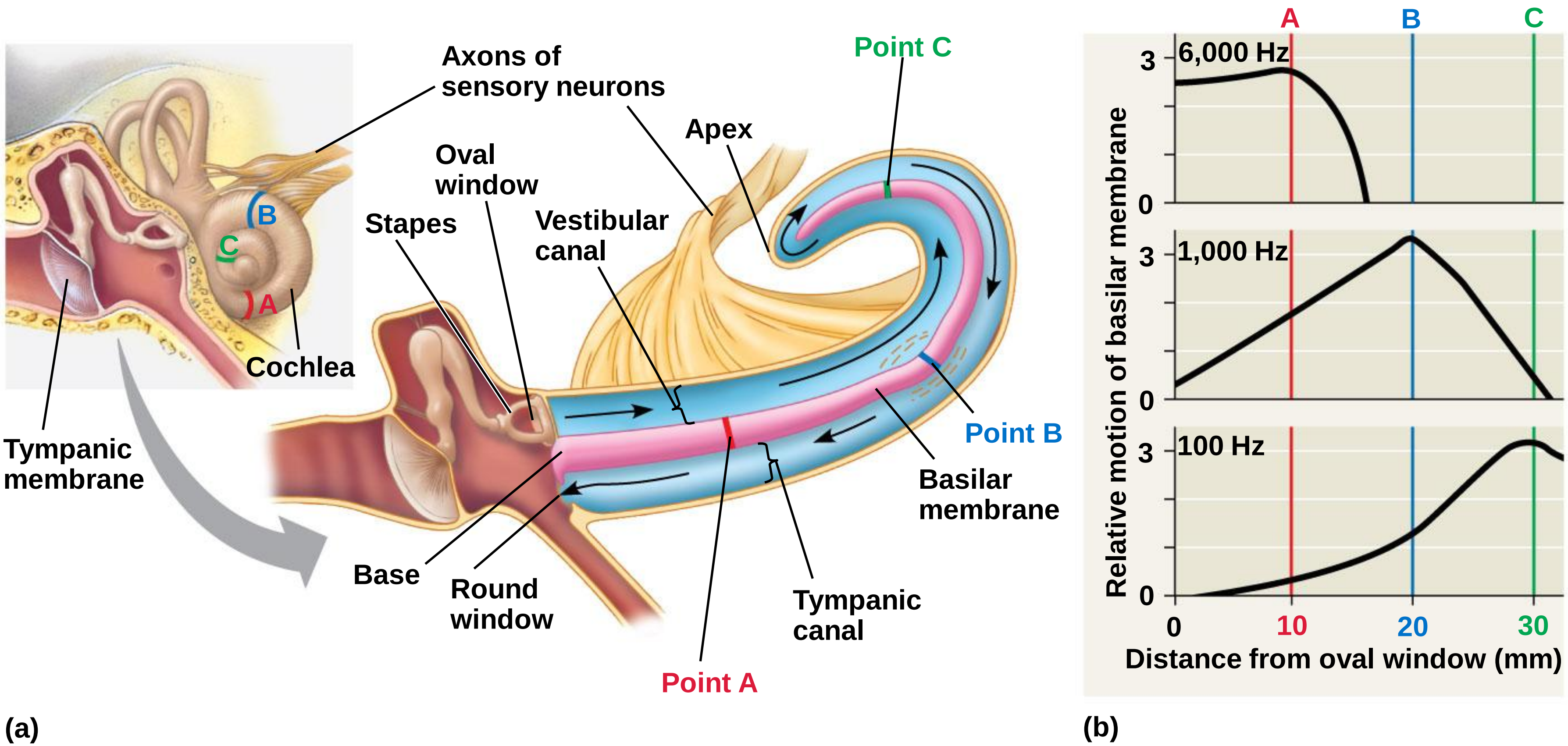
Figure 50.11c



(c) Bending of hairs in other direction

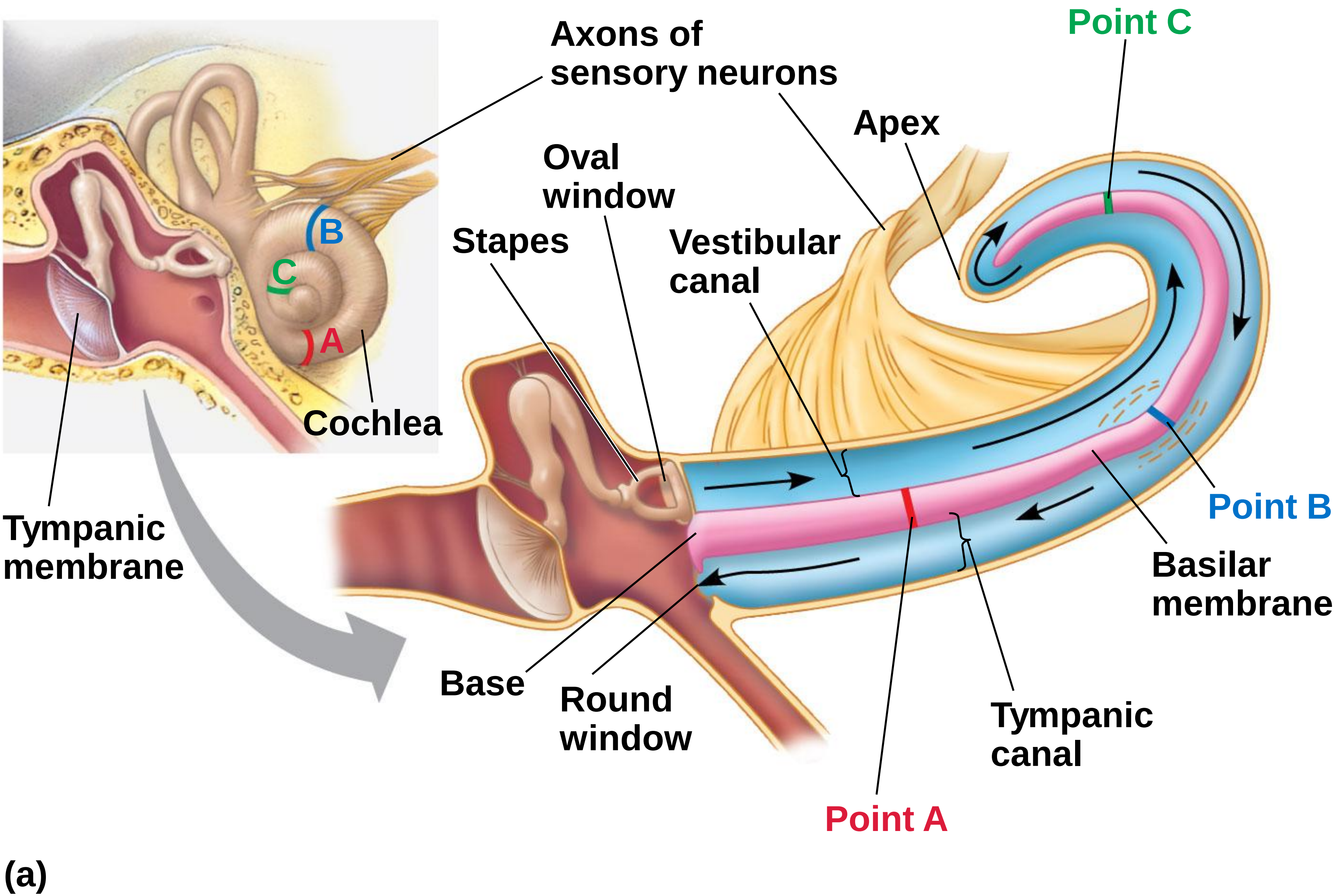
- The fluid waves dissipate when they strike the **round window** at the end of the tympanic canal

Figure 50.12



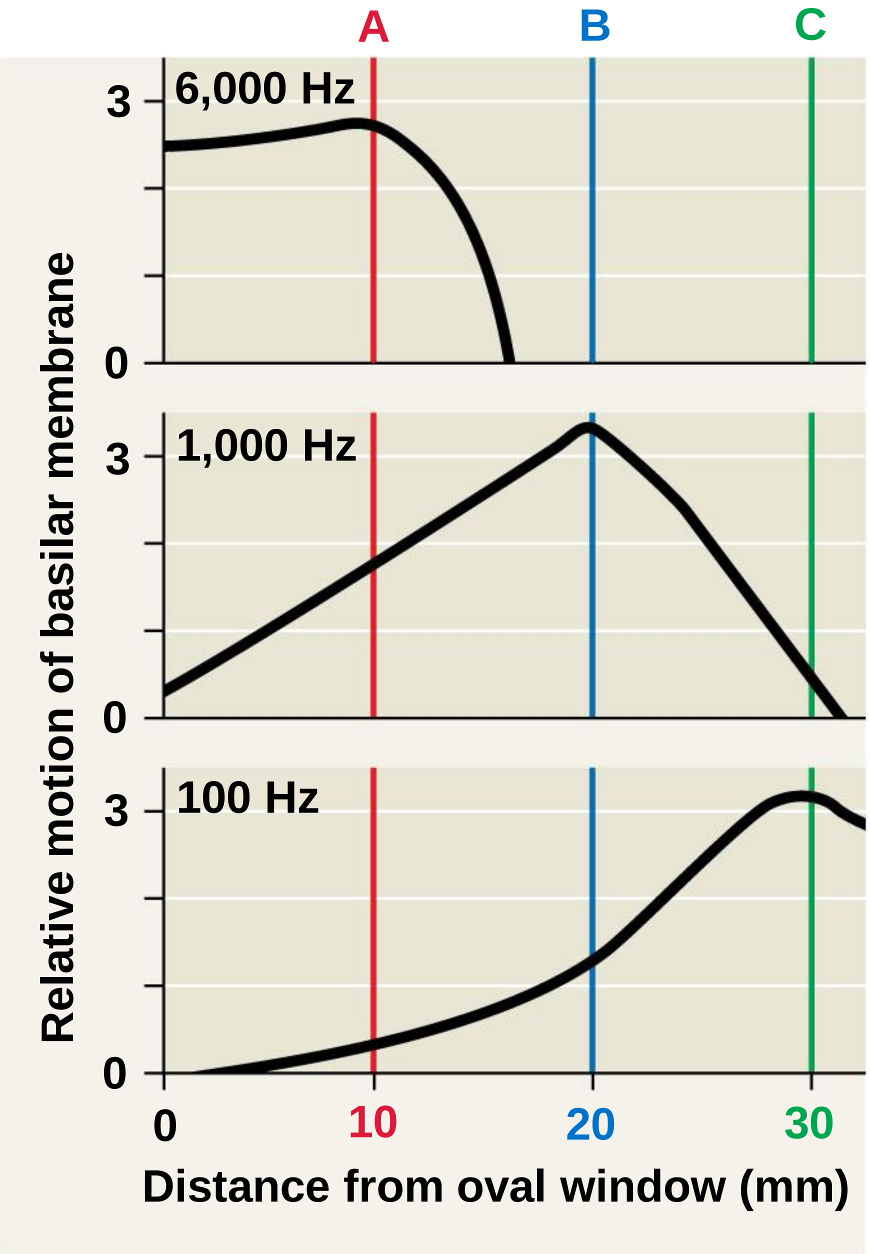
Axons of sensory neurons
Point C
Apex
Oval window
Stapes
Vestibular canal
B
C
A
Cochlea
Tympanic membrane
Point B
Basilar membrane
Base
Round window
Tympanic canal
Point A
(a)
A
B
C
6,000 Hz
1,000 Hz
100 Hz
3
0
Relative motion of basilar membrane
0
10
20
30
Distance from oval window (mm)
(b)

Figure 50.12a



- 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 of the basilar membrane is tuned to a particular vibration frequency

Figure 50.12b

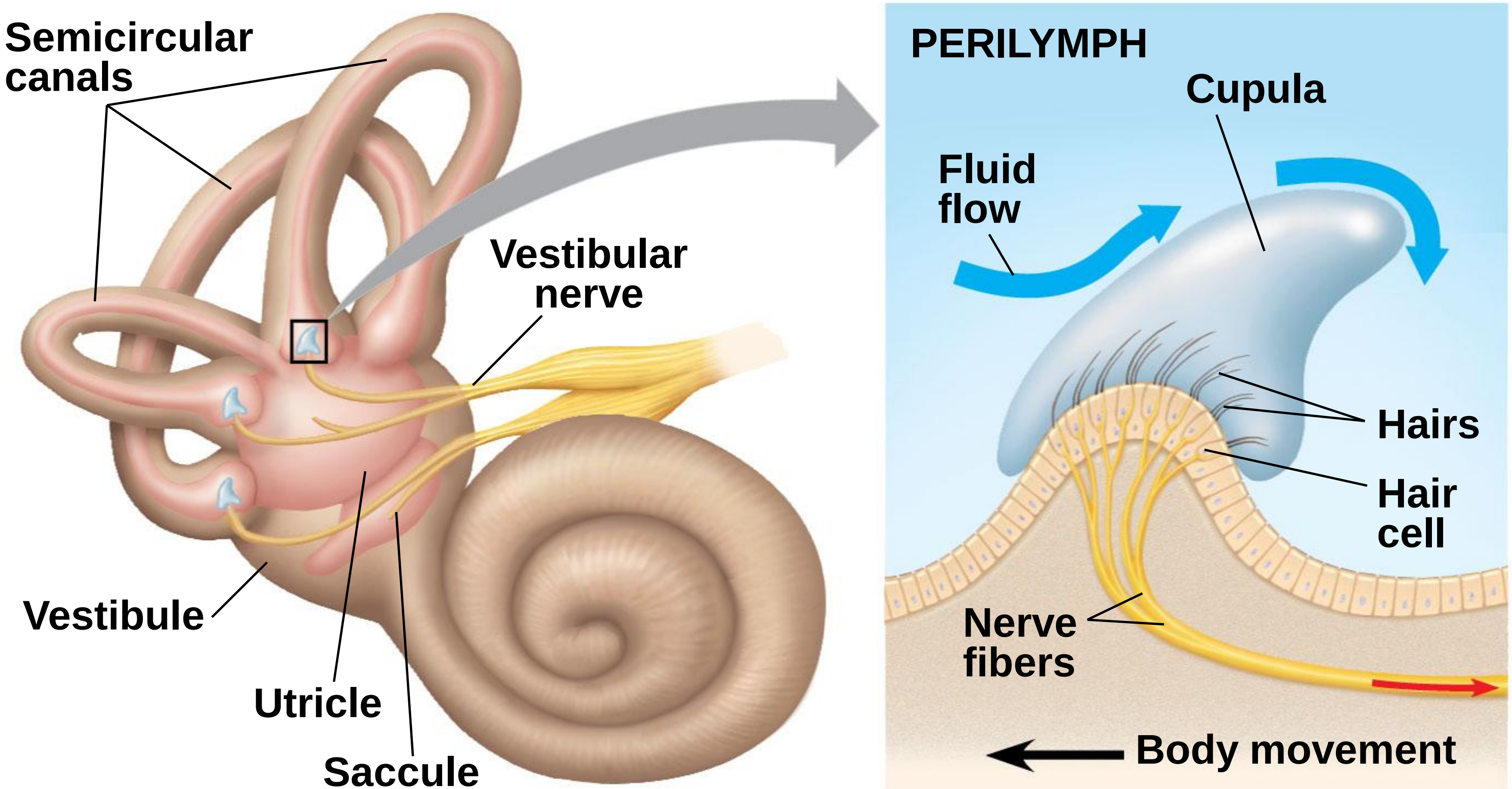


(b)

Equilibrium

- Several organs of the inner ear detect body movement, position, and balance
  - The **utricle** and **saccule** contain granules called otoliths that allow us to perceive position relative to gravity or linear movement
  - Three semicircular canals contain fluid and can detect angular movement in any direction

Figure 50.13

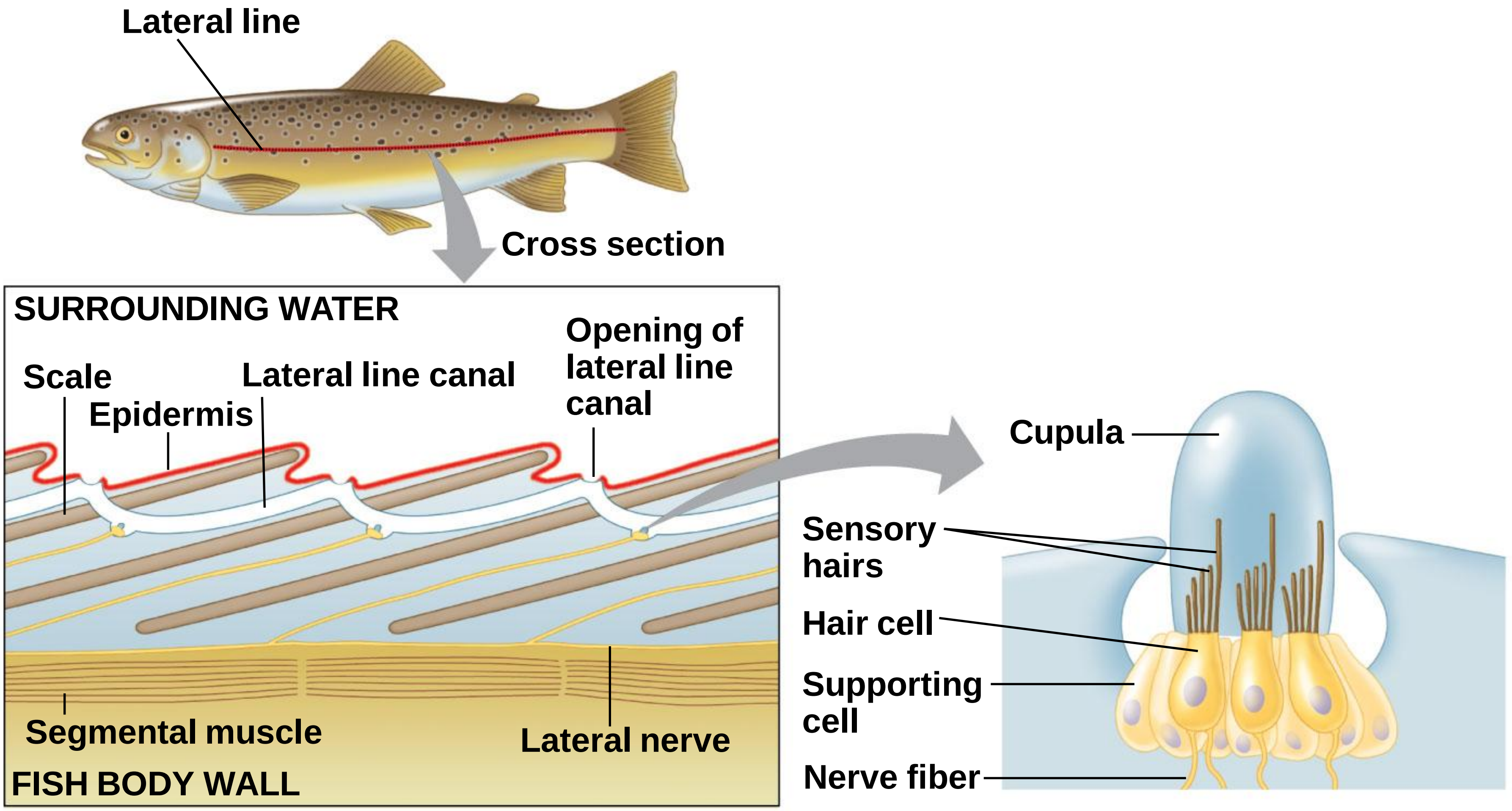


Semicircular canals
Vestibular nerve
Vestibule
Utricle
Saccule
PERILYMPH
Cupula
Fluid flow
Hairs
Hair cell
Nerve fibers
Body movement

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

Figure 50.14



Lateral line
Cross section
SURROUNDING WATER
Scale
Epidermis
Lateral line canal
Opening of lateral line canal
Segmental muscle
Lateral nerve
FISH BODY WALL
Cupula
Sensory hairs
Hair cell
Supporting cell
Nerve fiber

Figure 50.14a

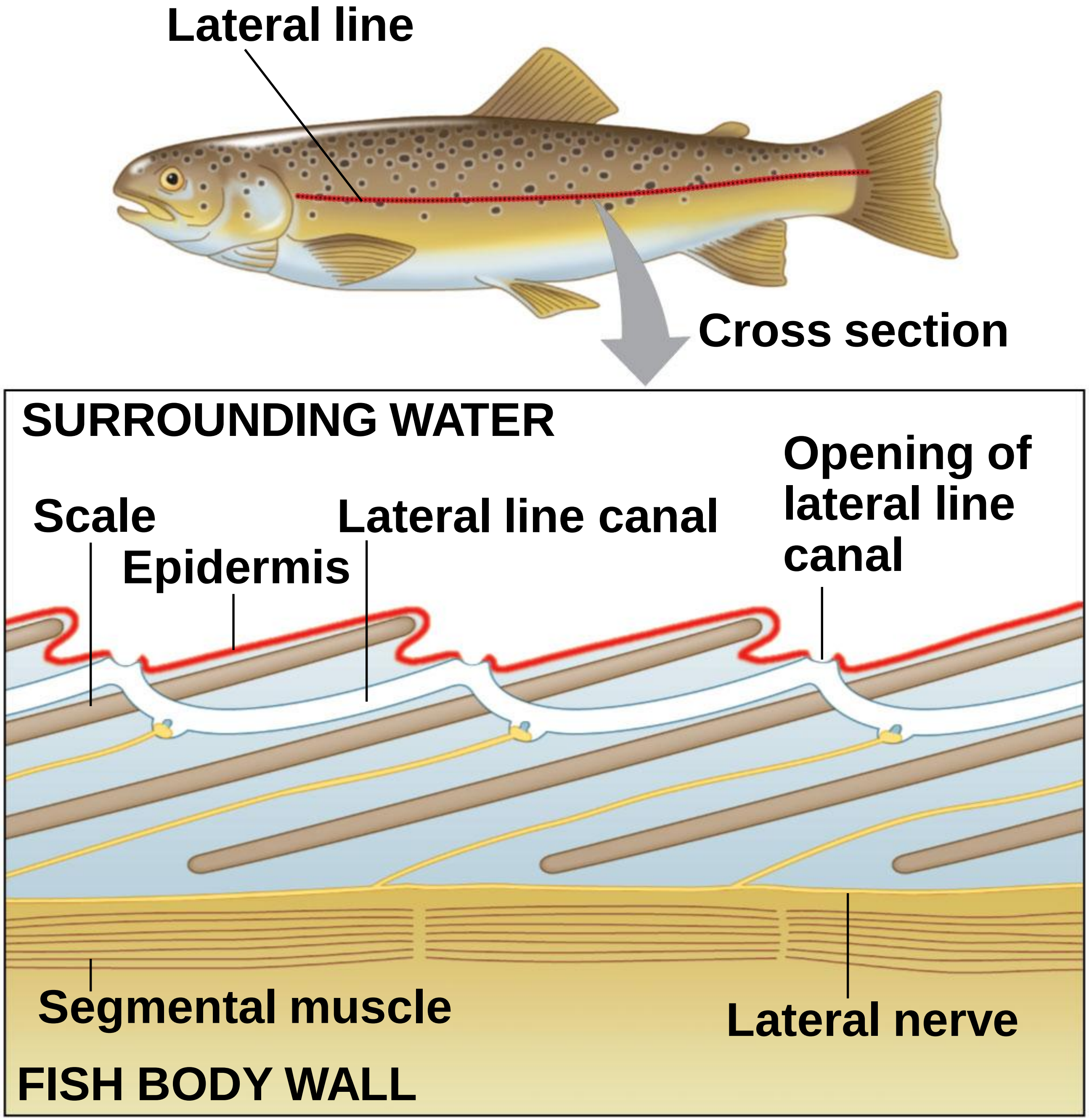
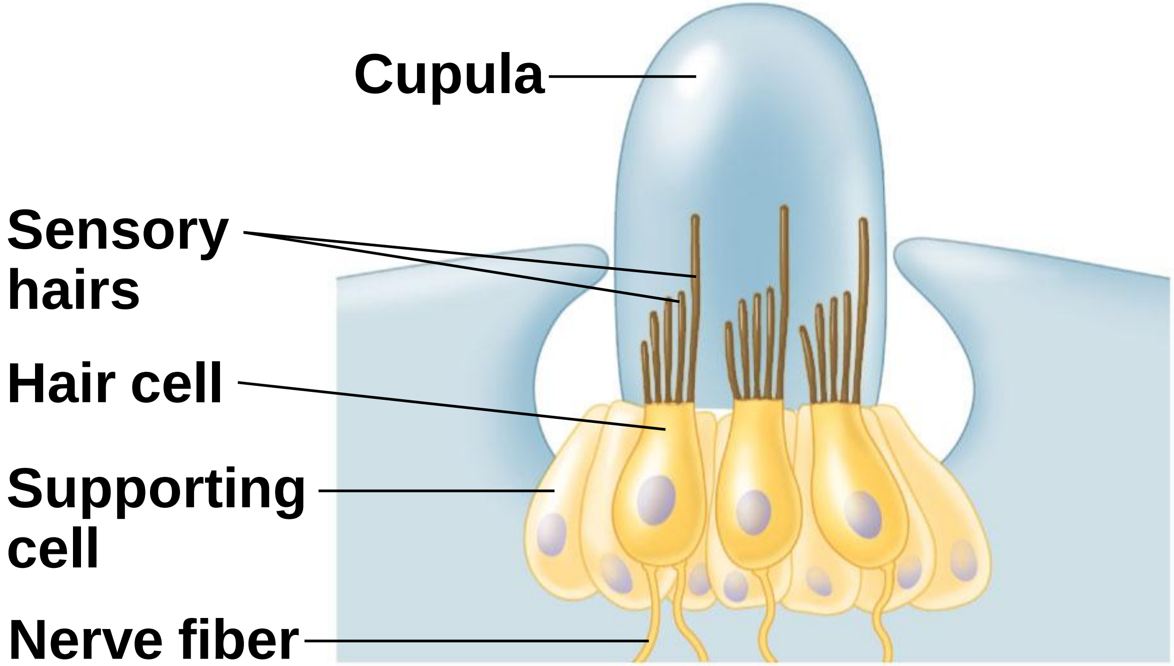


Figure 50.14b



Concept 50.3: Visual receptors on diverse animals depend on light-absorbing pigments

- Animals use a diverse set of organs for vision, but the underlying mechanism for capturing light is the same, suggesting a common evolutionary origin

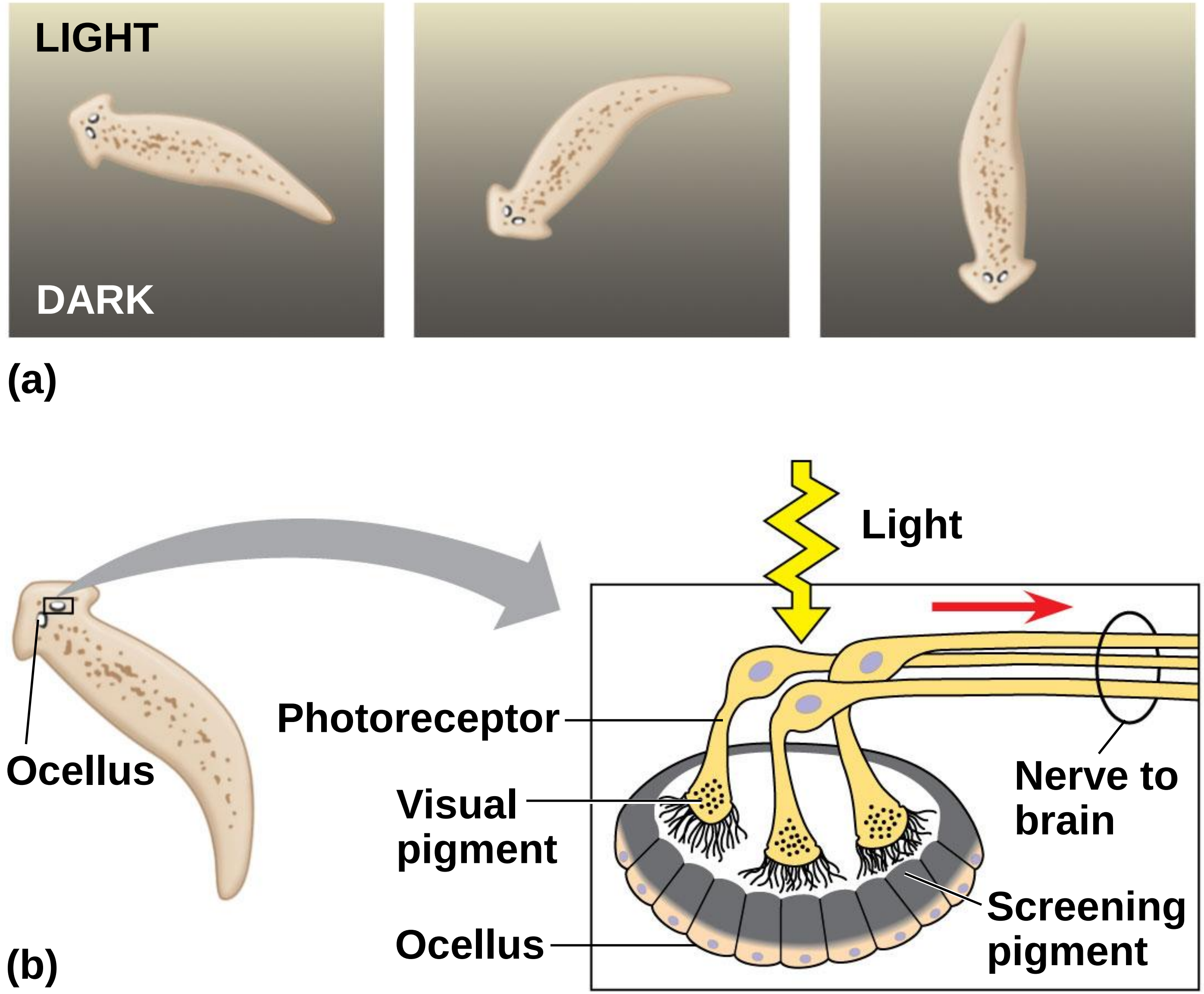
Evolution of Visual Perception

- Light detectors in the animal kingdom range from simple clusters of cells that detect direction and intensity of light to complex organs that form images
- Light detectors all contain **photoreceptors**, cells that contain light-absorbing pigment molecules

Light-Detecting Organs

- Most invertebrates have a light-detecting organ
- One of the simplest light-detecting organs is that of planarians
- A pair of ocelli called eyespots are located near the head
- These allow planarians to move away from light and seek shaded locations

Figure 50.15



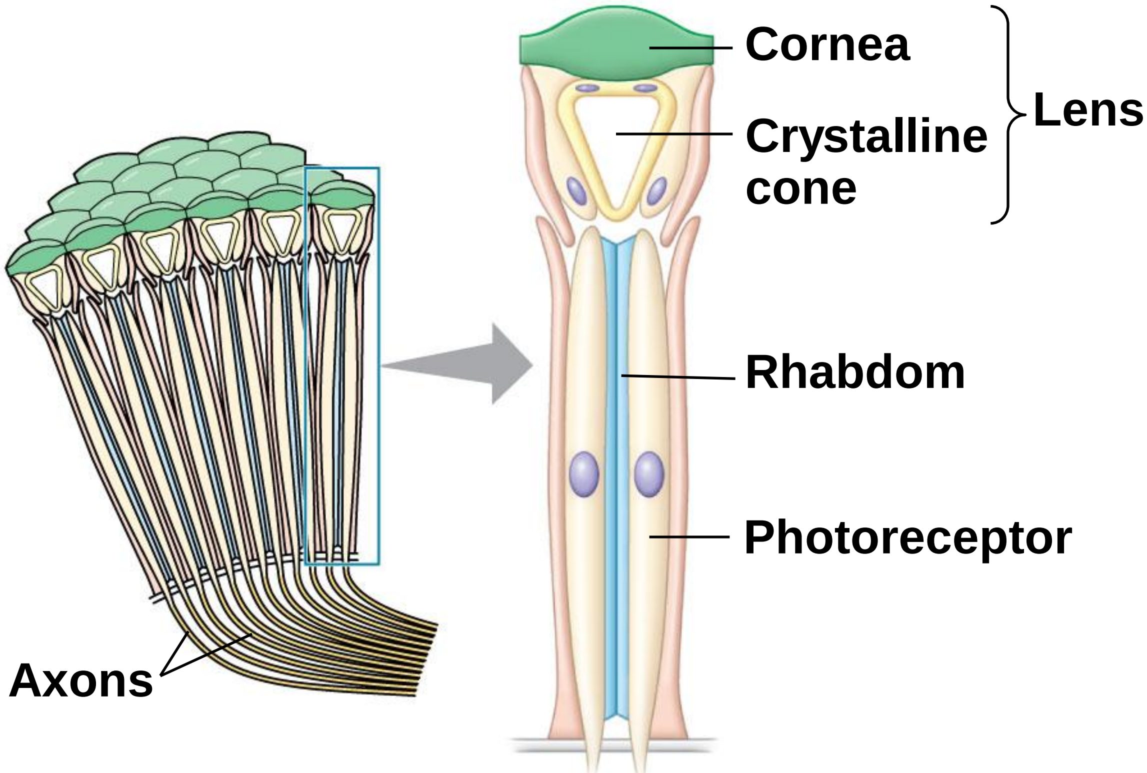
LIGHT
DARK
(a)
Light
Photoreceptor
Ocellus
Visual pigment
Ocellus
Nerve to brain
Screening pigment
(b)

Compound Eyes

- Insects and crustaceans have **compound eyes**, which consist of up to several thousand light detectors called **ommatidia**
- Compound eyes are very effective at detecting movement

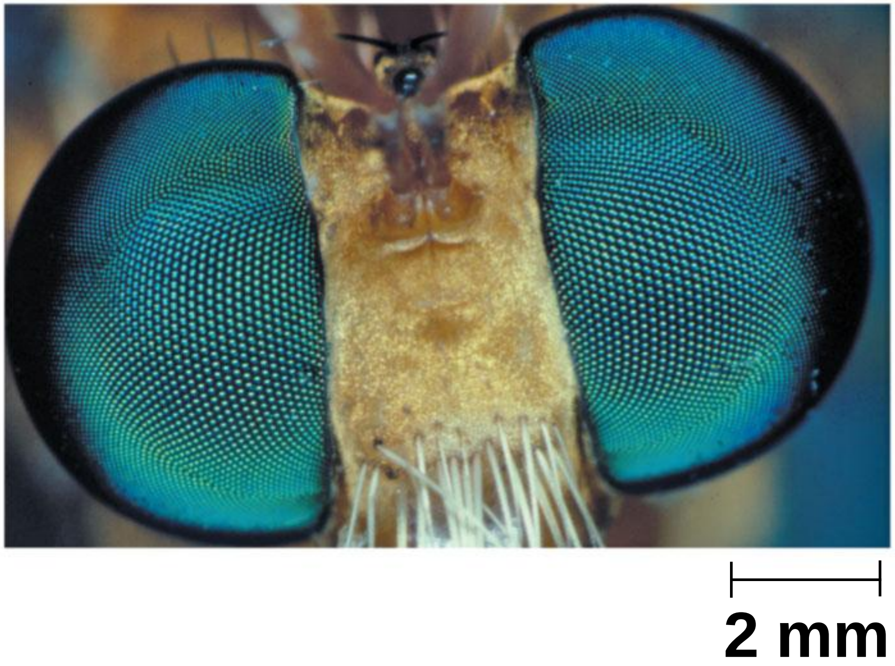
Figure 50.16

(a) Fly eyes



(b) Ommatidia

Figure 50.16a



Single-Lens Eyes

- **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 eyes of all vertebrates hae a single lens

The Vertebrate Visual System

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

Figure 50.17a

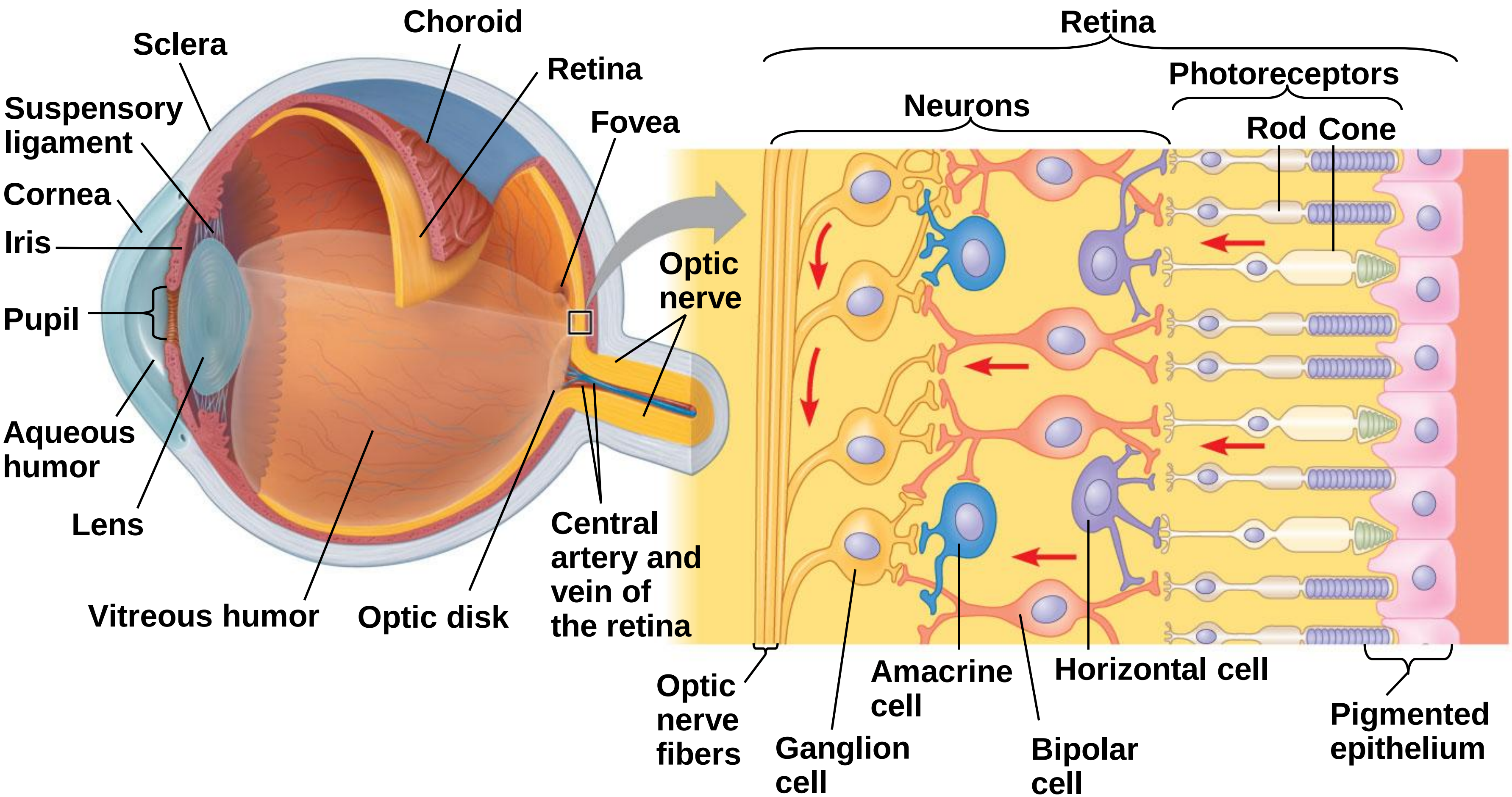


Figure 50.17aa

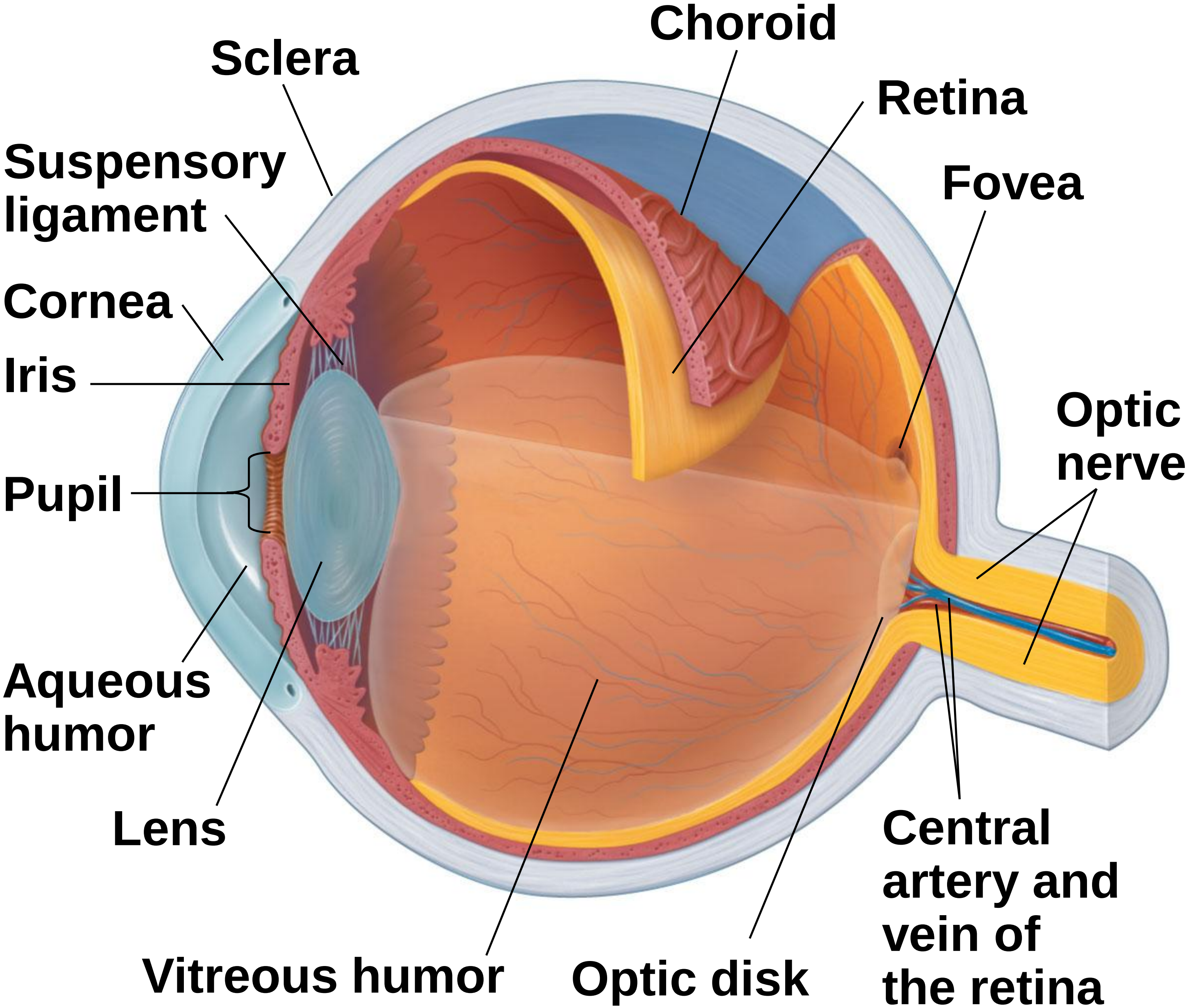


Figure 50.17ab

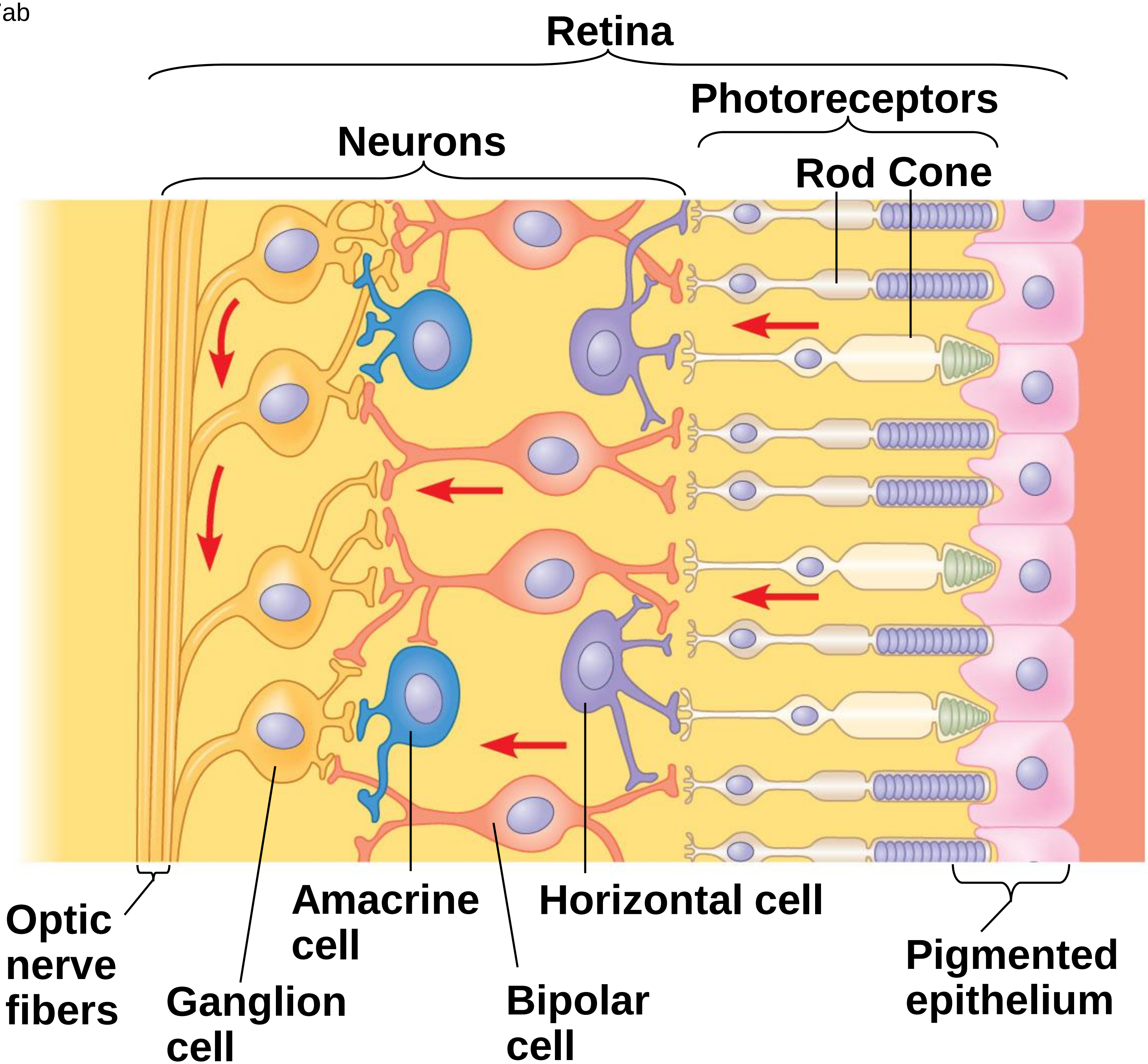


Figure 50.17b

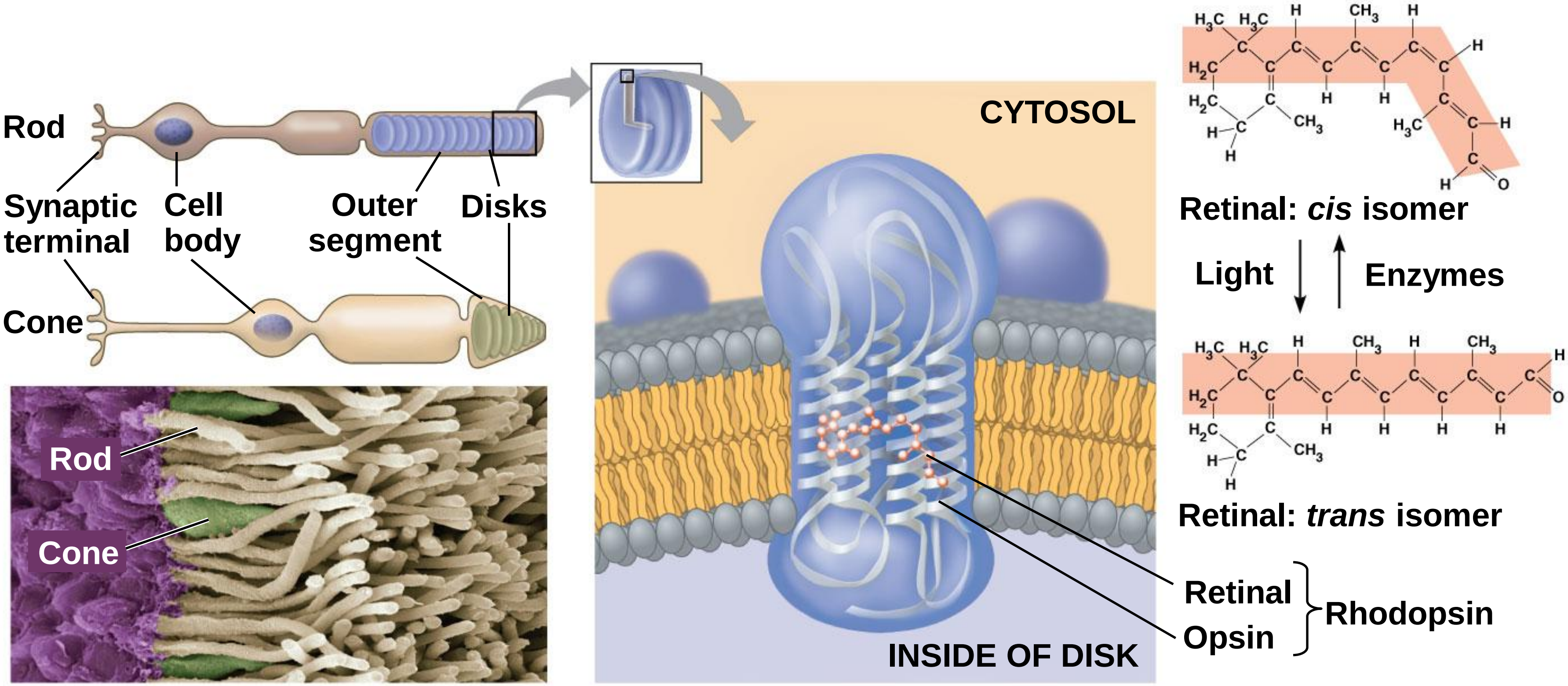


Figure 50.17ba

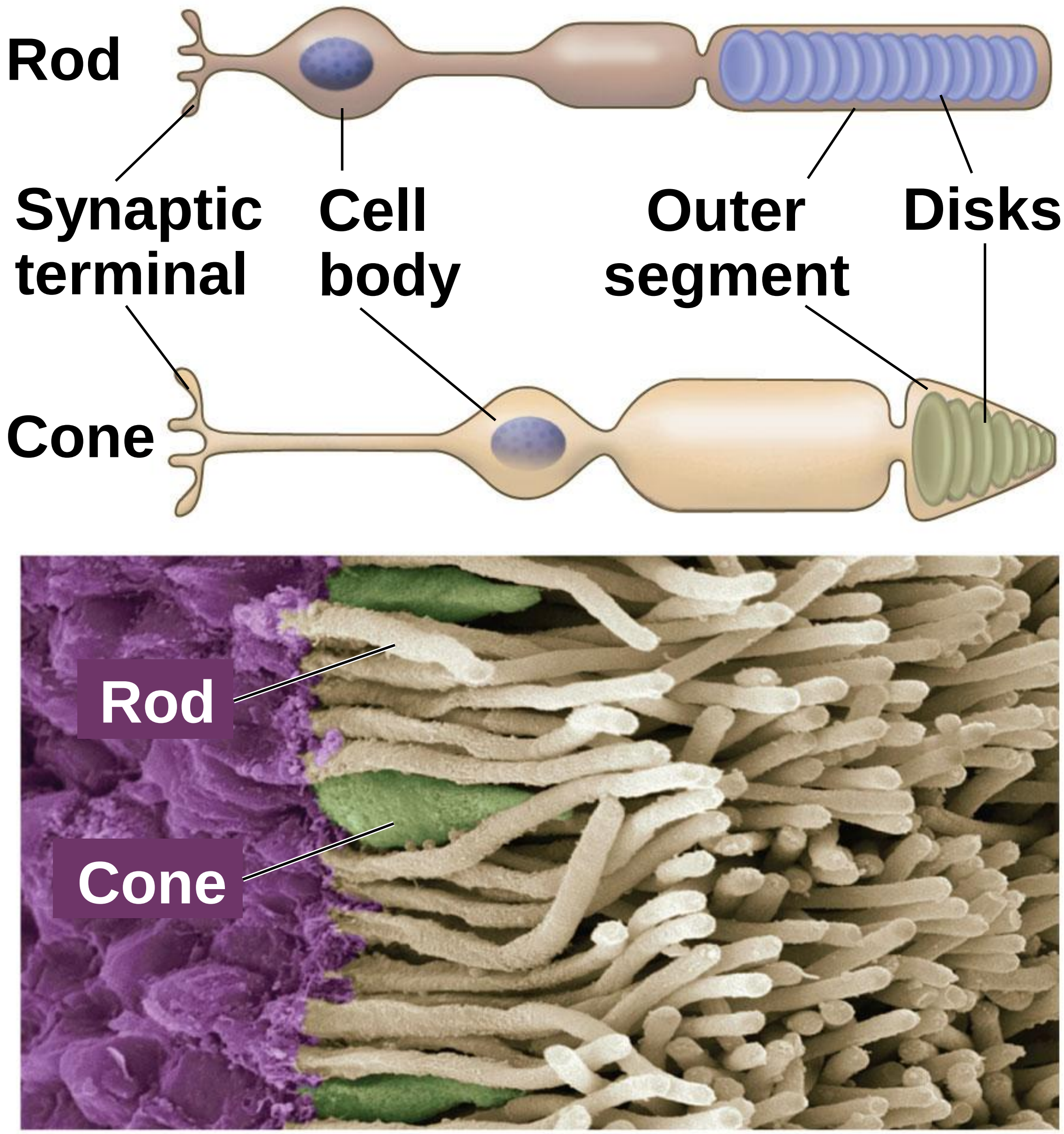


Figure 50.17bb

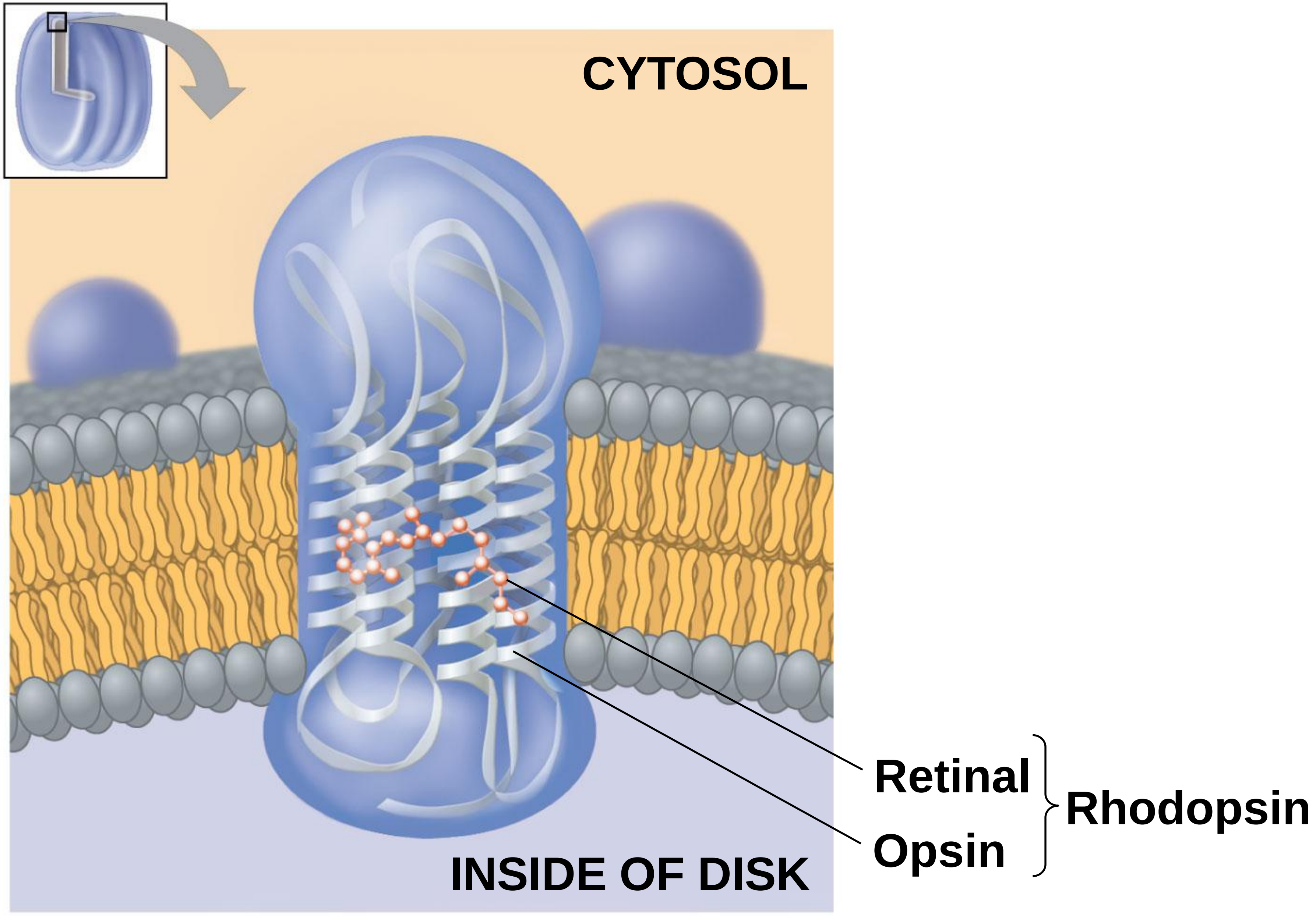


Figure 50.17bc

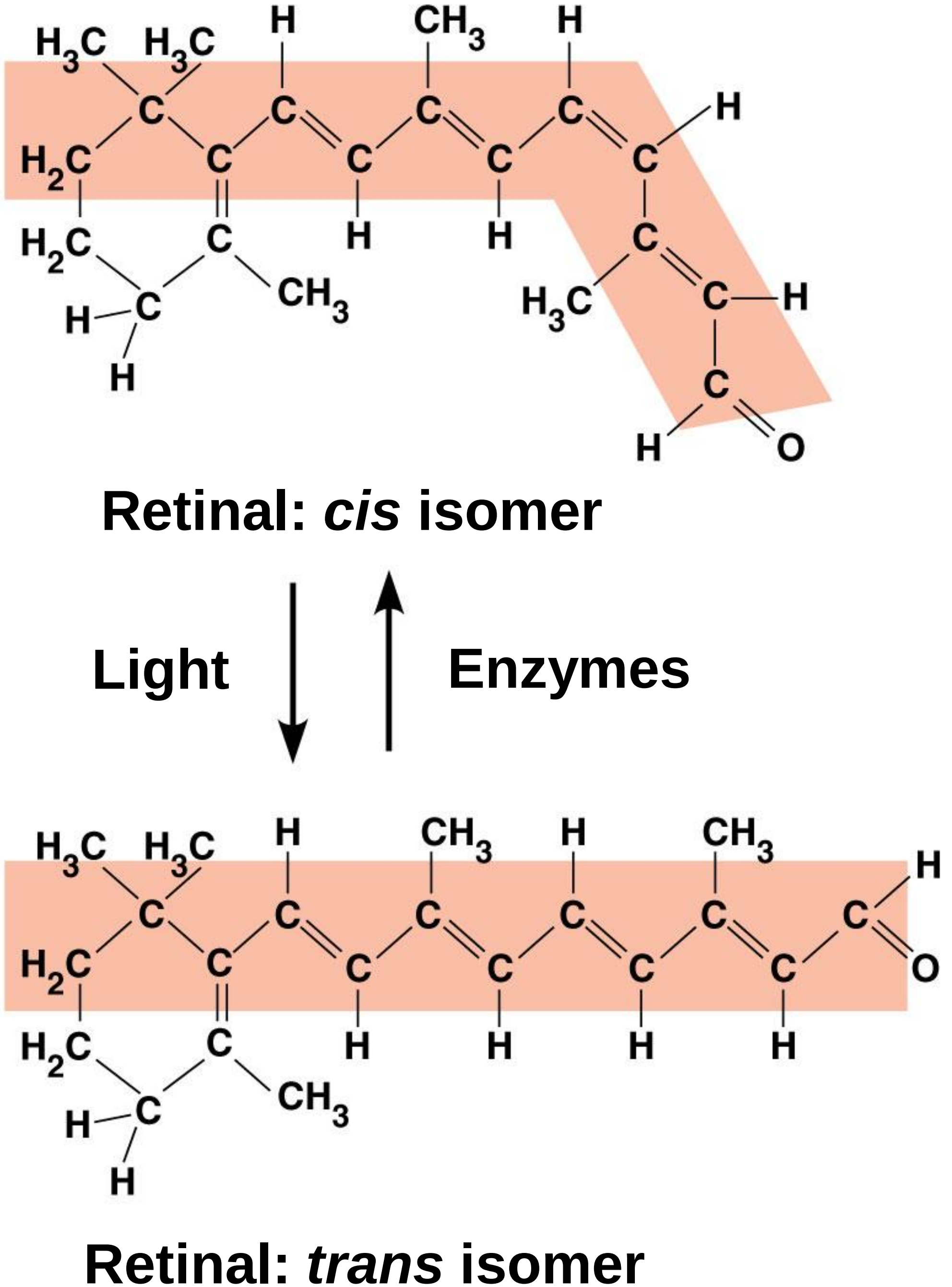
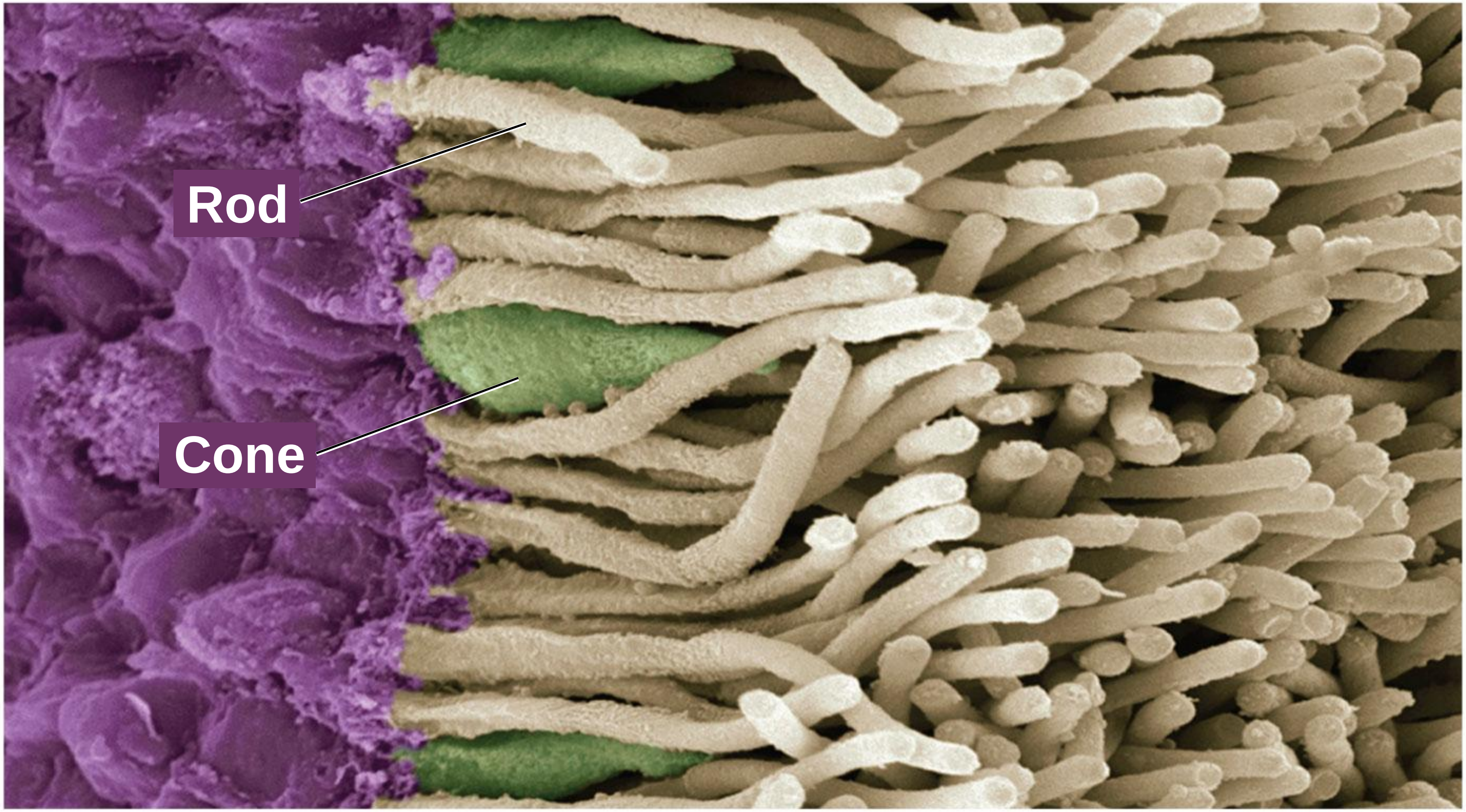


Figure 50.17bd

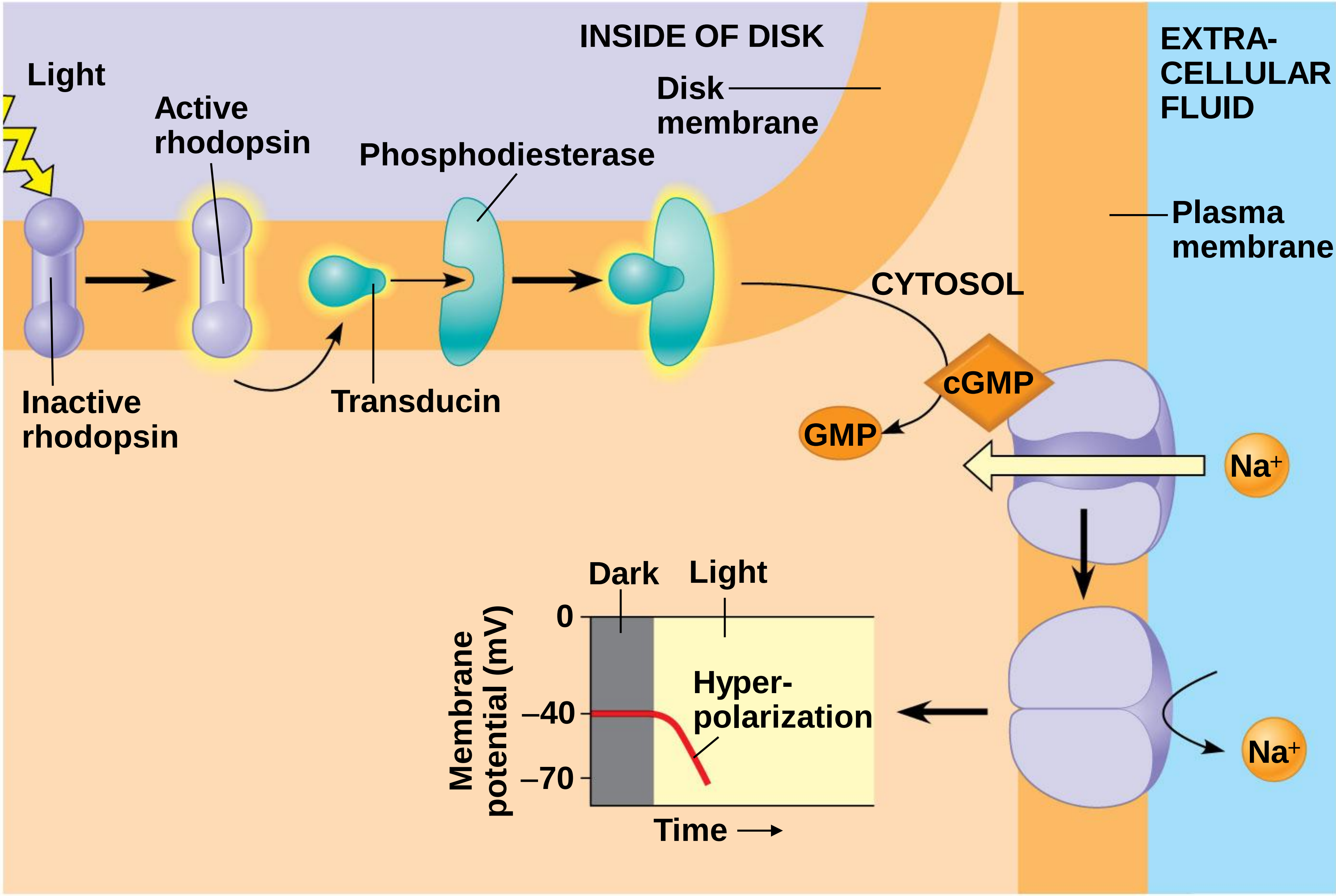


Sensory Transduction in the Eye

- Transduction of visual information to the nervous system begins when light induces the conversion of *cis*-retinal to *trans*-retinal
- *trans*-retinal activates rhodopsin, which activates a G protein, eventually leading to hydrolysis of cyclic GMP

- When cyclic GMP breaks down, Na^+ channels close
- This hyperpolarizes the cell
- The signal transduction pathway usually shuts off again as enzymes convert retinal back to the *cis* form

Figure 50.18



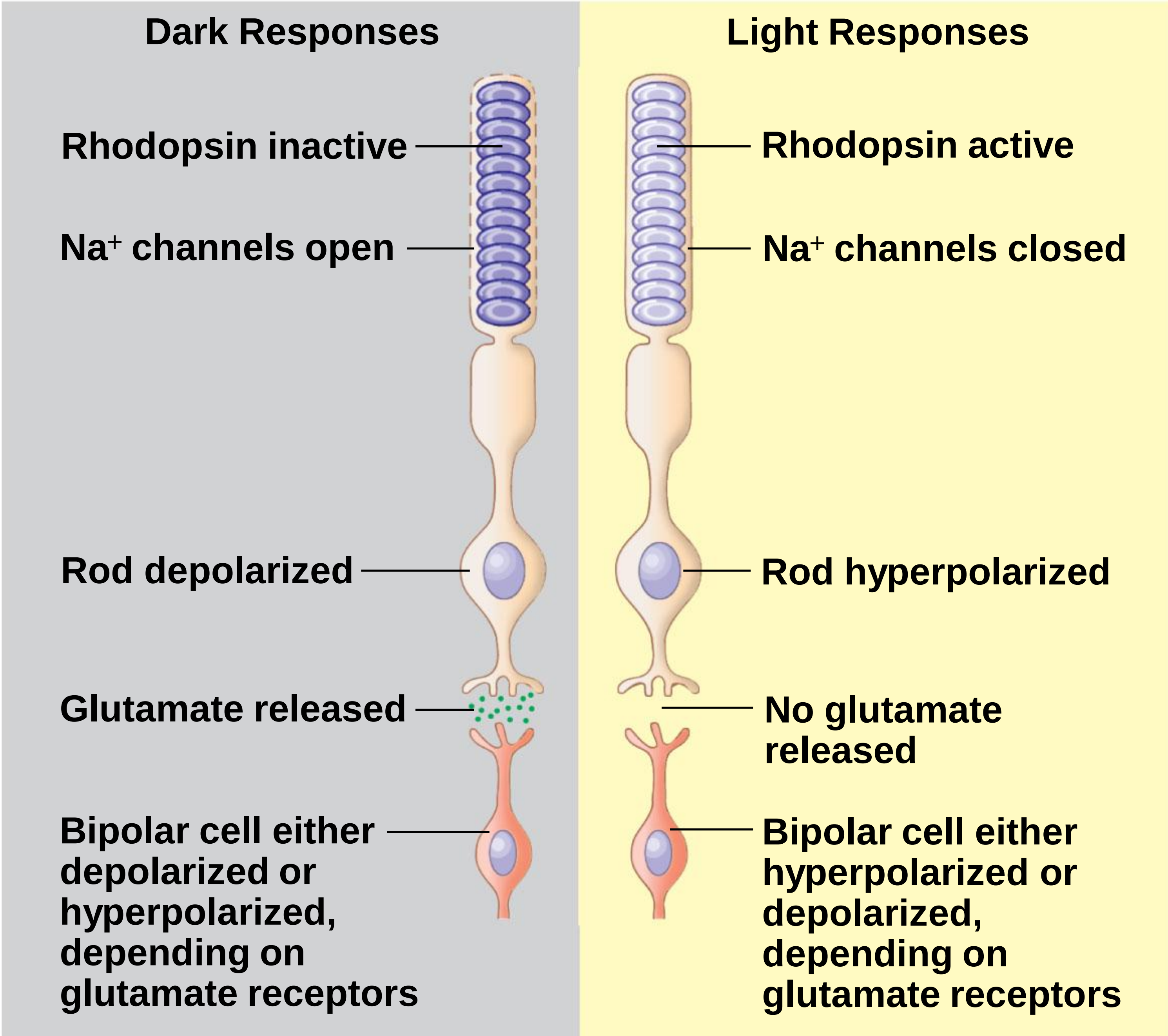
INSIDE OF DISK
Light
Active rhodopsin
Phosphodiesterase
Disk membrane
EXTRA-CELLULAR FLUID
Plasma membrane
CYTOSOL
cGMP
GMP
Inactive rhodopsin
Transducin
Na+
Dark
Light
0
–40
–70
Membrane potential (mV)
Hyper-polarization
Time
Na+

Processing of Visual Information in the Retina

- Processing of visual information begins in the retina
- 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

Figure 50.19



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

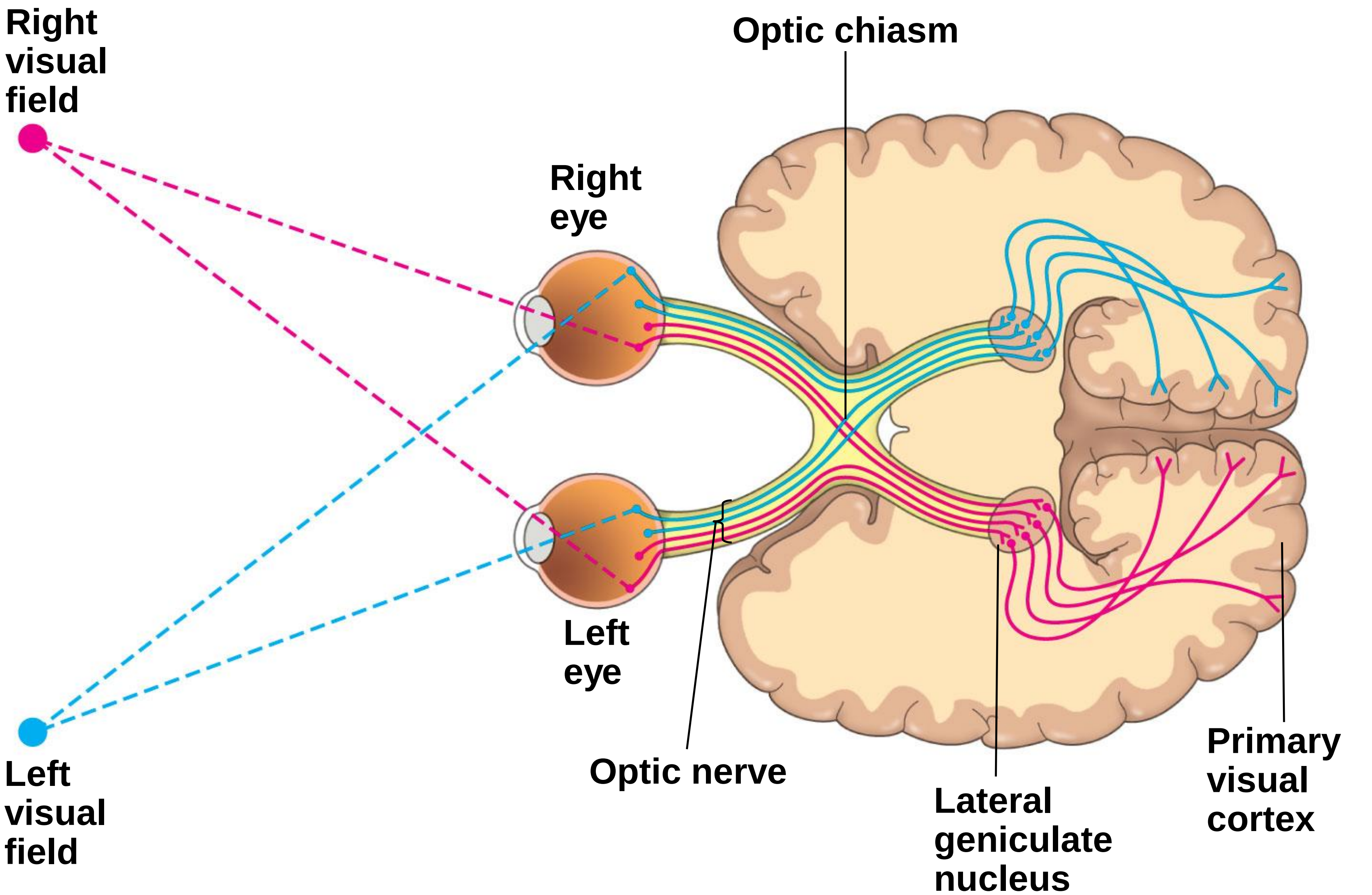
- Three other types of neurons contribute to information processing in the retina
  - Ganglion cells transmit signals from bipolar cells to the brain
  - Horizontal and amacrine cells help integrate visual information before it is sent to the brain
- Interaction among different cells results in **lateral inhibition**, enhanced contrast in the image

Processing of Visual Information in the Brain

- The optic nerves meet at the **optic chiasm** near the cerebral cortex
- Sensations from the left visual field of both eyes are transmitted to the right side of the brain
- Sensations from the right visual field are transmitted 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
- At least 30% of the cerebral cortex, in dozens of integrating centers, are active in creating visual perceptions

Figure 50.20


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

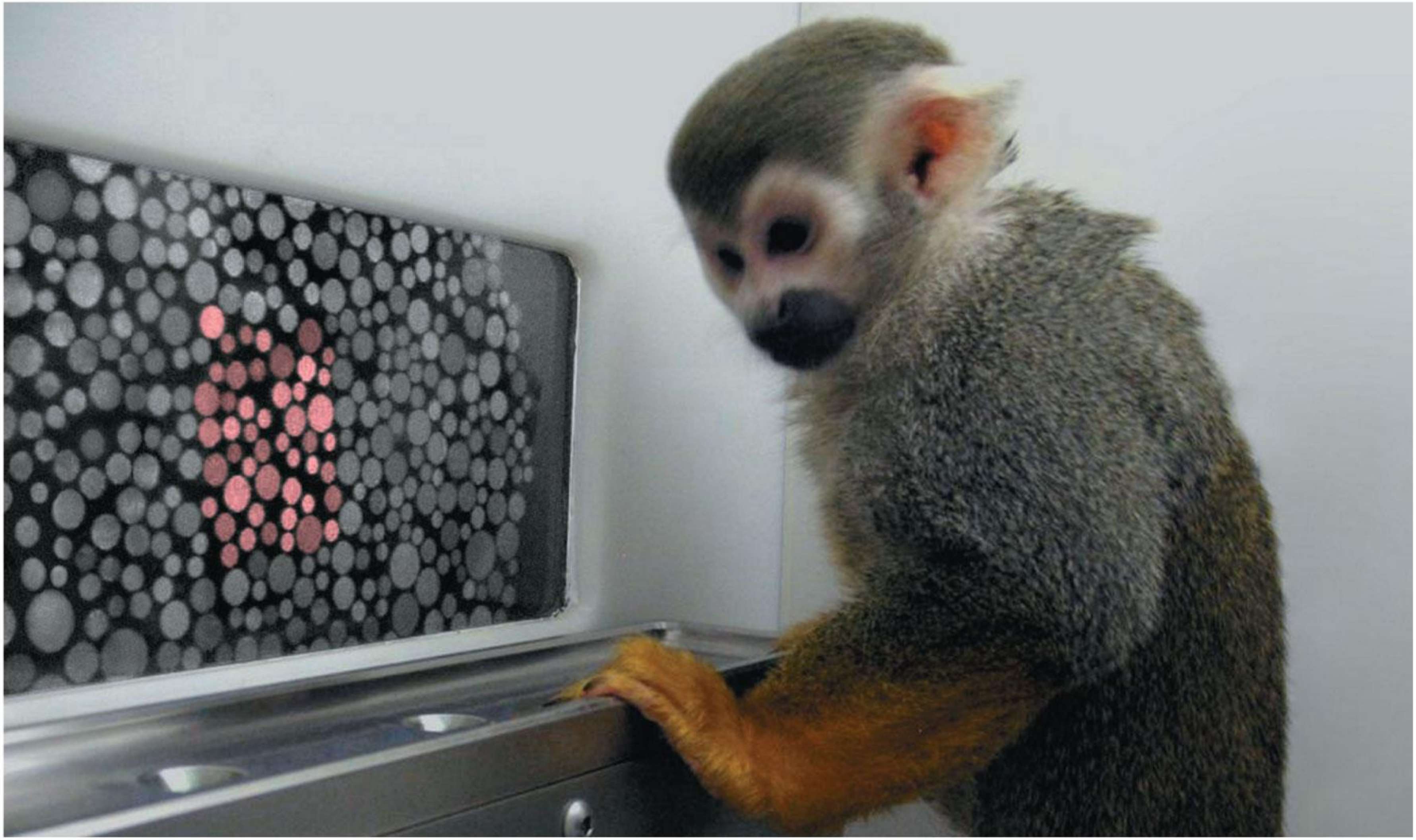
Color Vision

- Among vertebrates, most fish, amphibians, and reptiles, including birds, have very good color vision
- Humans and other primates are among the minority of mammals with the ability to see color well
- Mammals that are nocturnal usually have a high proportion of rods in the retina

- In humans, perception of color is based on three types of cones, each with a different visual pigment: red, green, or blue
- These pigments are called photopsins and are formed when retinal binds to three distinct opsin proteins

- Abnormal color vision results from alterations in the genes for one or more photopsin proteins
- In 2009, researchers studying color blindness in squirrel monkeys made a breakthrough in gene therapy

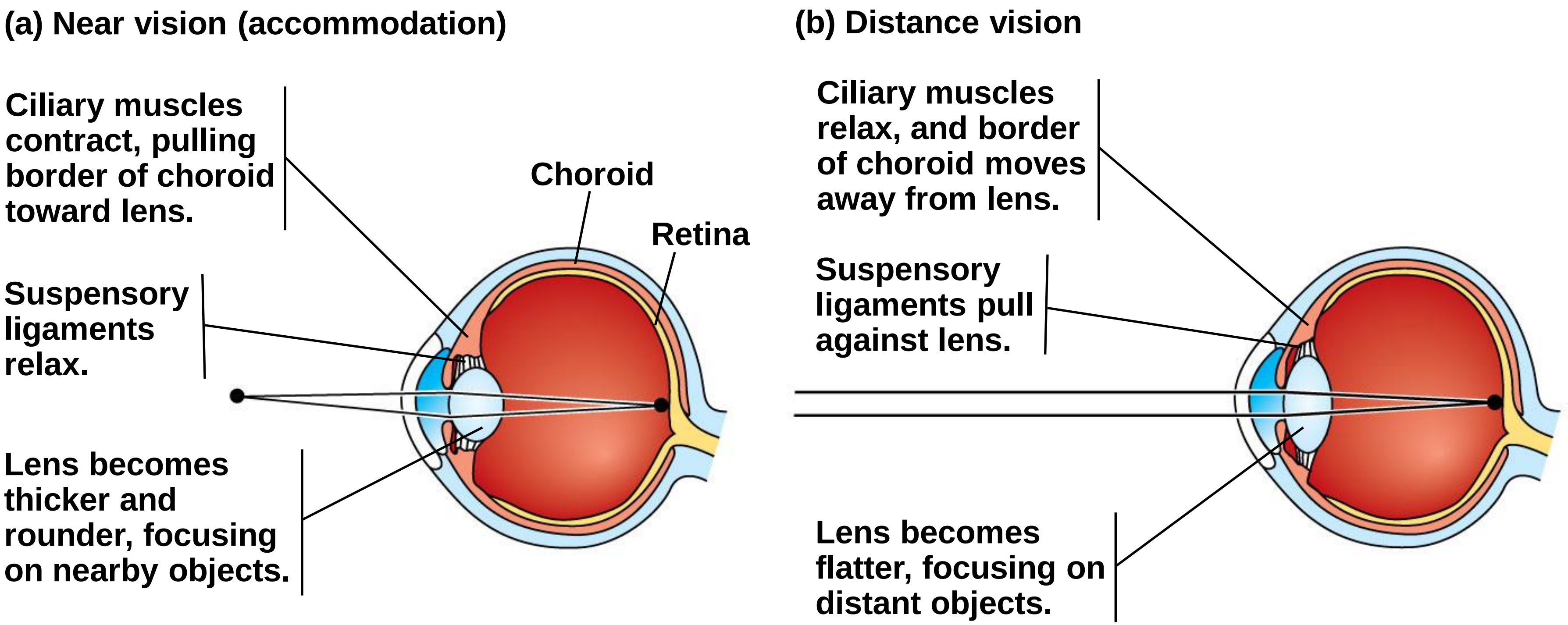
Figure 50.21



The Visual Field

- The brain processes visual information and controls what information is captured
- Focusing occurs by changing the shape of the lens
- The **fovea** is the center of the visual field and contains no rods, but a high density of cones

Figure 50.22



(a) Near vision (accommodation)
Ciliary muscles contract, pulling border of choroid toward lens.
Choroid
Retina
Suspensory ligaments relax.
Lens becomes thicker and rounder, focusing on nearby objects.
(b) Distance vision
Ciliary muscles relax, and border of choroid moves away from lens.
Suspensory ligaments pull against lens.
Lens becomes flatter, focusing on distant objects.

Figure 50.22a

(a) Near vision (accommodation)

Ciliary muscles contract, pulling border of choroid toward lens.

Suspensory ligaments relax.

Lens becomes thicker and rounder, focusing on nearby objects.

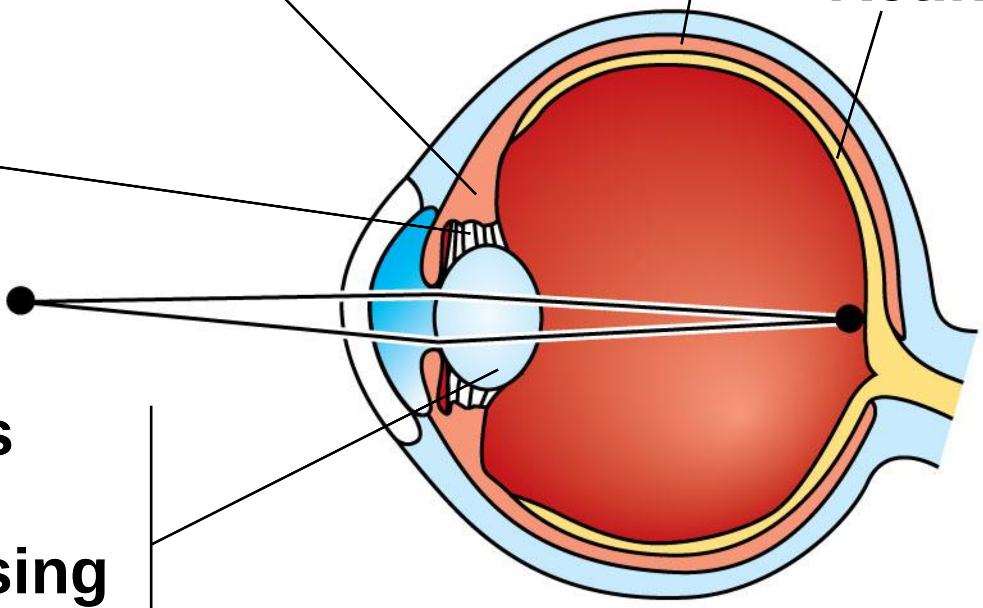
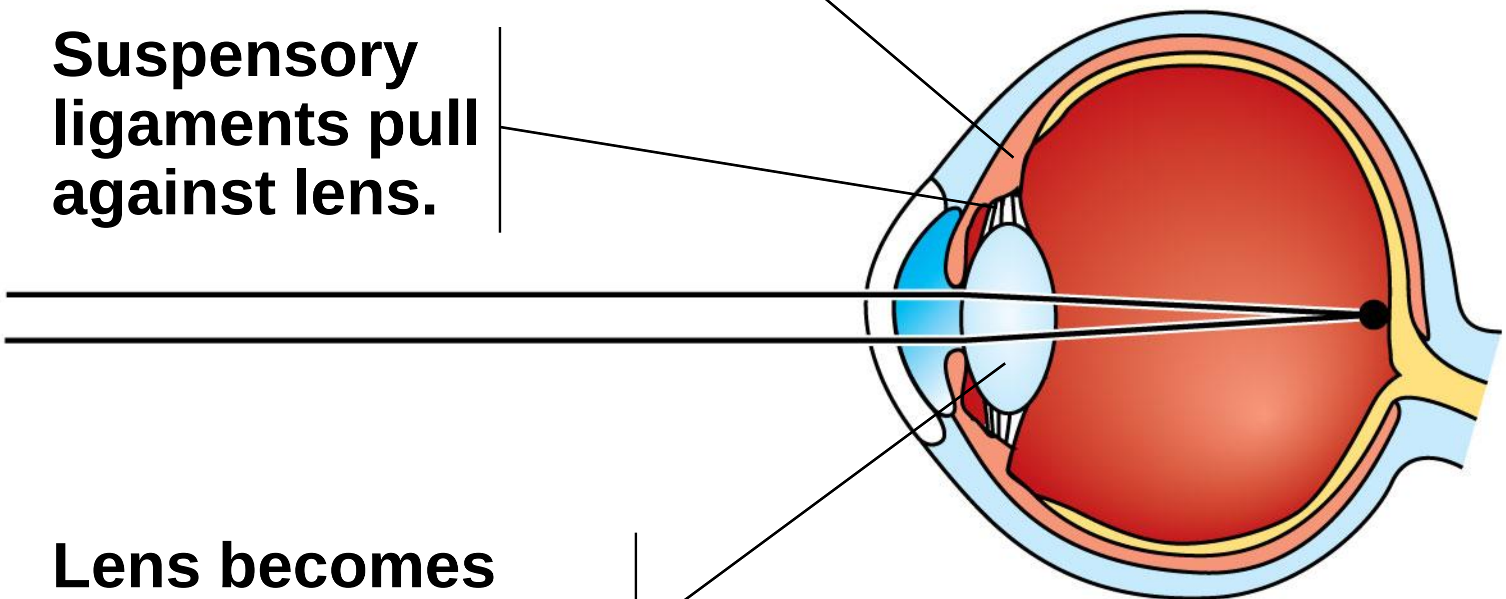


Figure 50.22b

(b) Distance vision

Ciliary muscles relax, and border of choroid moves away from lens.

Suspensory ligaments pull against lens.



Lens becomes flatter, focusing on distant objects.

Concept 50.4: The senses of taste and smell rely on similar sets of sensory receptors

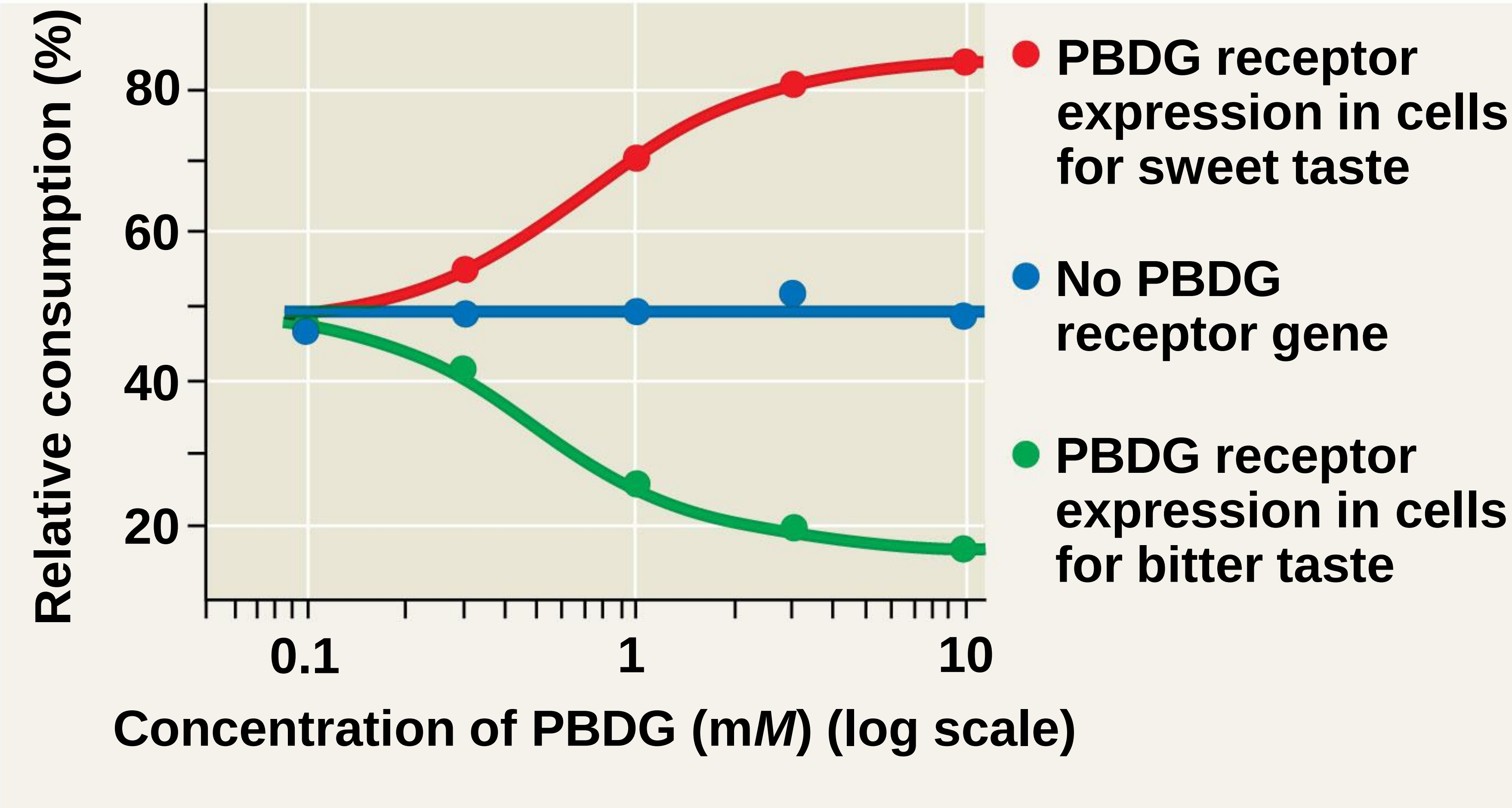
- In terrestrial animals
  - **Gustation** (taste) is dependent on the detection of chemicals called **tastants**
  - **Olfaction** (smell) is dependent on the detection of **odorant** molecules
- In aquatic animals there is no distinction between taste and smell
- Taste receptors of insects are in sensory 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)
- Researchers have identified receptors for each of the tastes except salty
- Researchers believe that an individual taste cell expresses one receptor type and detects one of the five tastes

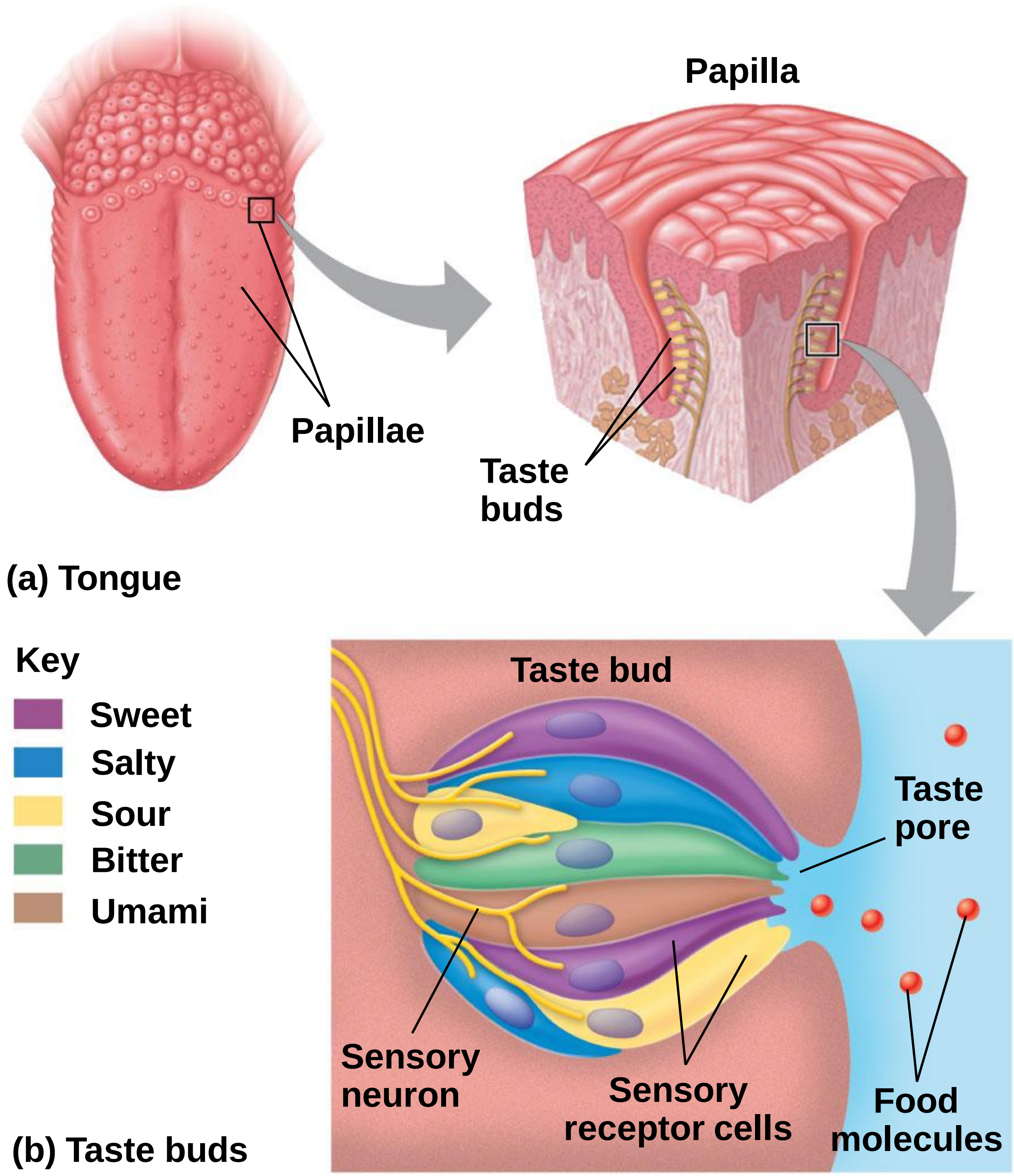
Figure 50.23

RESULTS



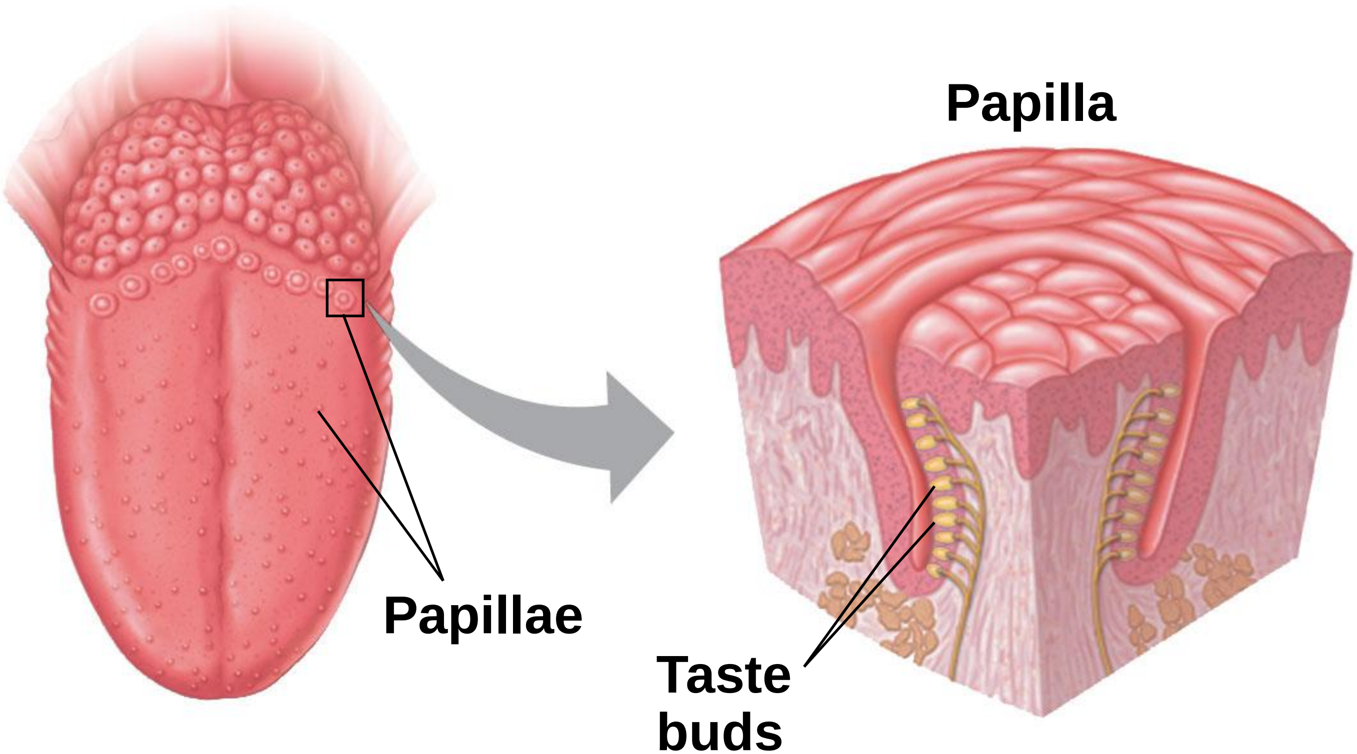
- Receptor cells for taste in mammals are modified epithelial cells organized into taste buds, located in several areas of the tongue and mouth
- Any region with taste buds can detect any of the five types of taste

Figure 50.24



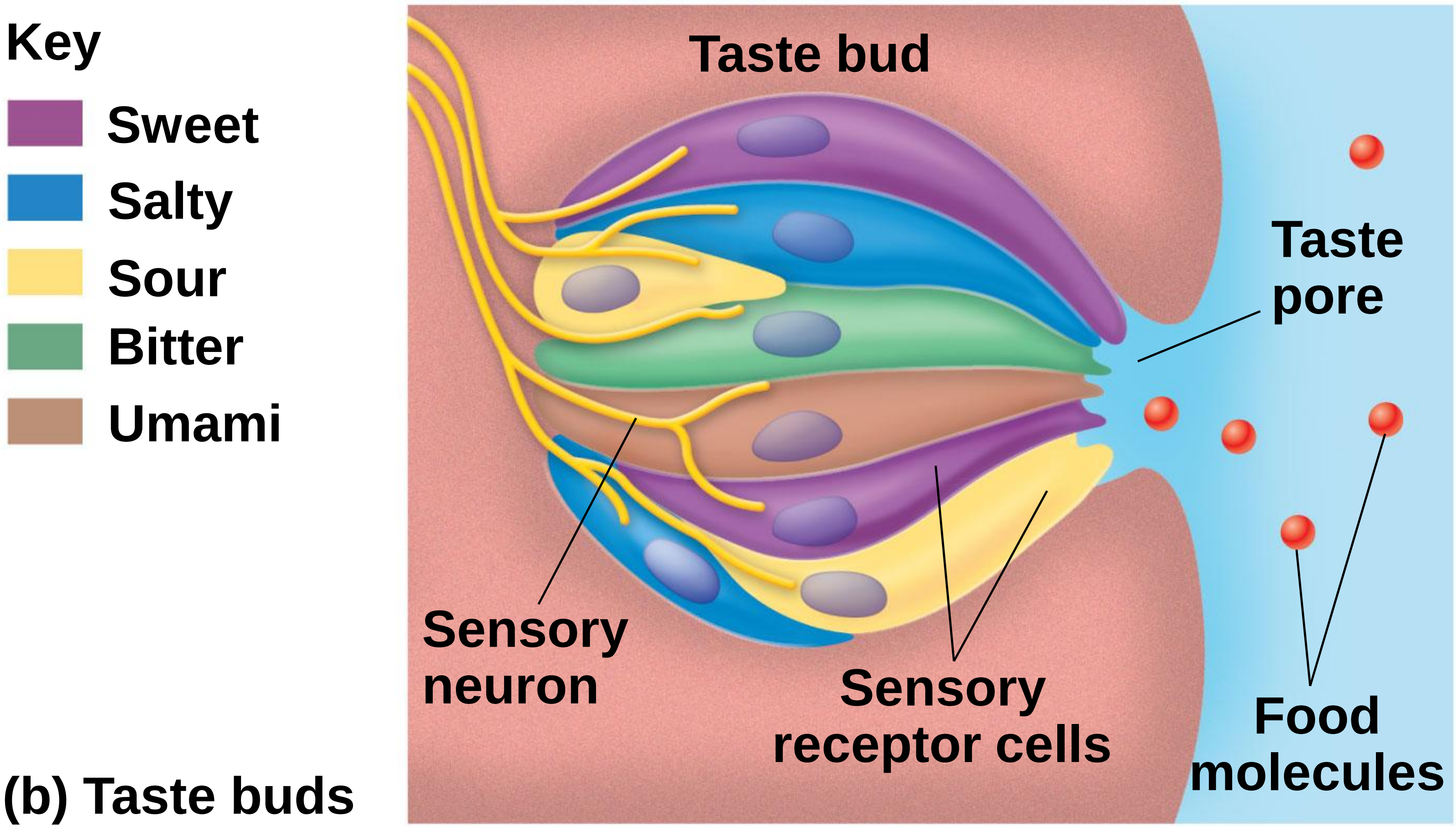
Papilla
Papillae
Taste buds
(a) Tongue
Key
Sweet
Salty
Sour
Bitter
Umami
Taste bud
Taste pore
Sensory neuron
Sensory receptor cells
Food molecules
(b) Taste buds

Figure 50.24a



(a) Tongue

Figure 50.24b

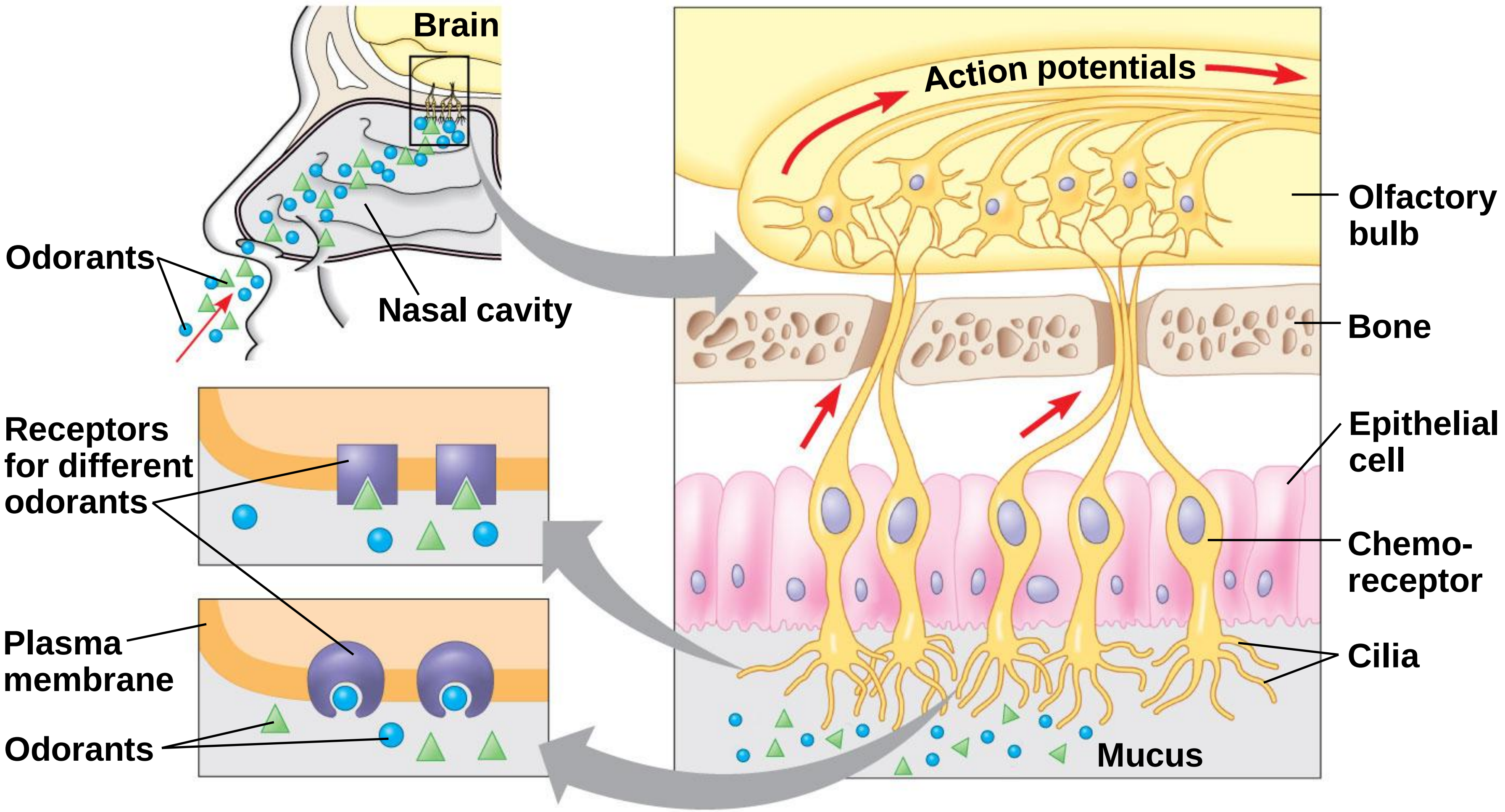


(b) Taste buds

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
- Humans can distinguish thousands of different odors
- Although receptors and brain pathways for taste and smell are independent, the two senses do interact

Figure 50.25



Brain
Odorants
Nasal cavity
Action potentials
Olfactory bulb
Bone
Epithelial cell
Chemo-receptor
Cilia
Mucus
Receptors for different odorants
Plasma membrane
Odorants

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; extension is passive

Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** moves bones and the body, and 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 two strands of a 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

Figure 50.26

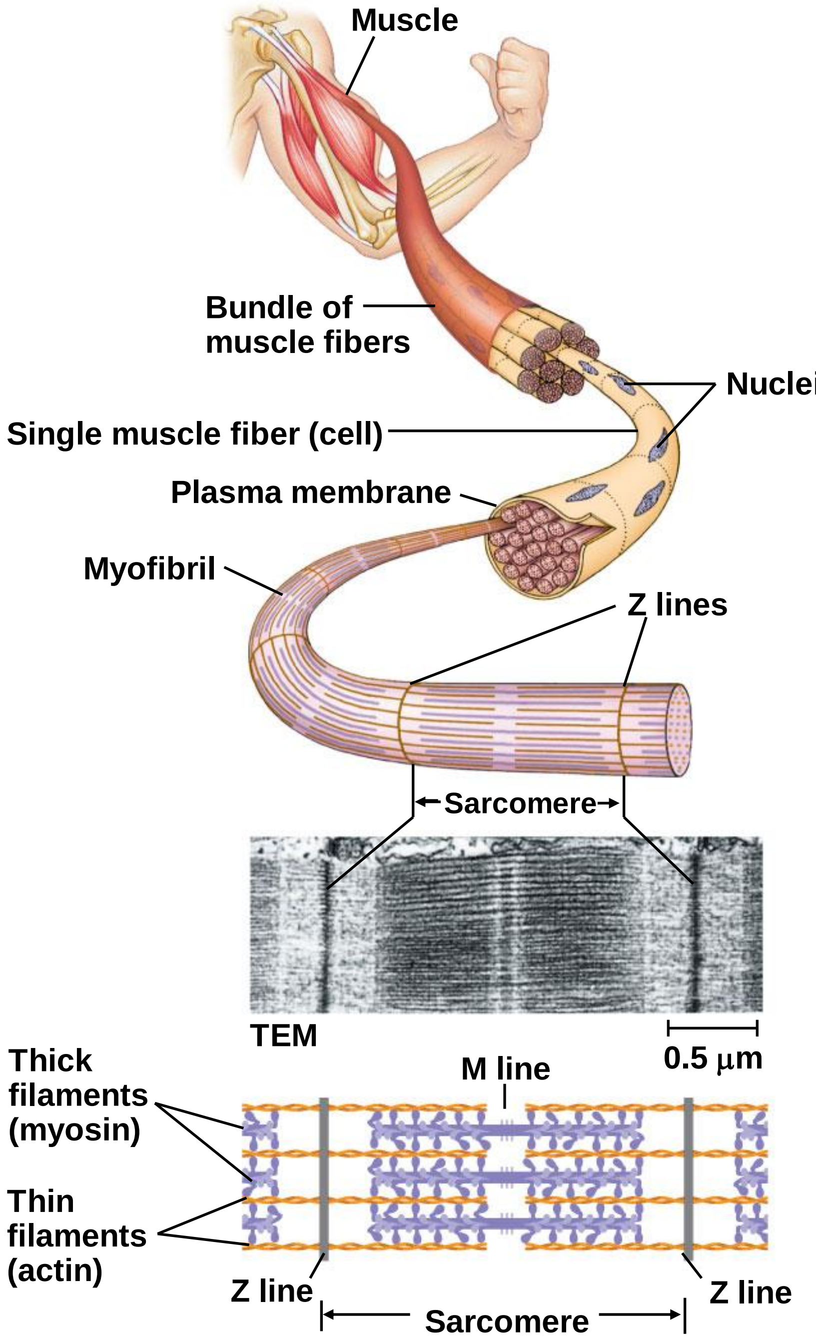

Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere
TEM
0.5 μm
Thick filaments (myosin)
M line
Thin filaments (actin)
Z line
Z line
Sarcomere

Figure 50.26a

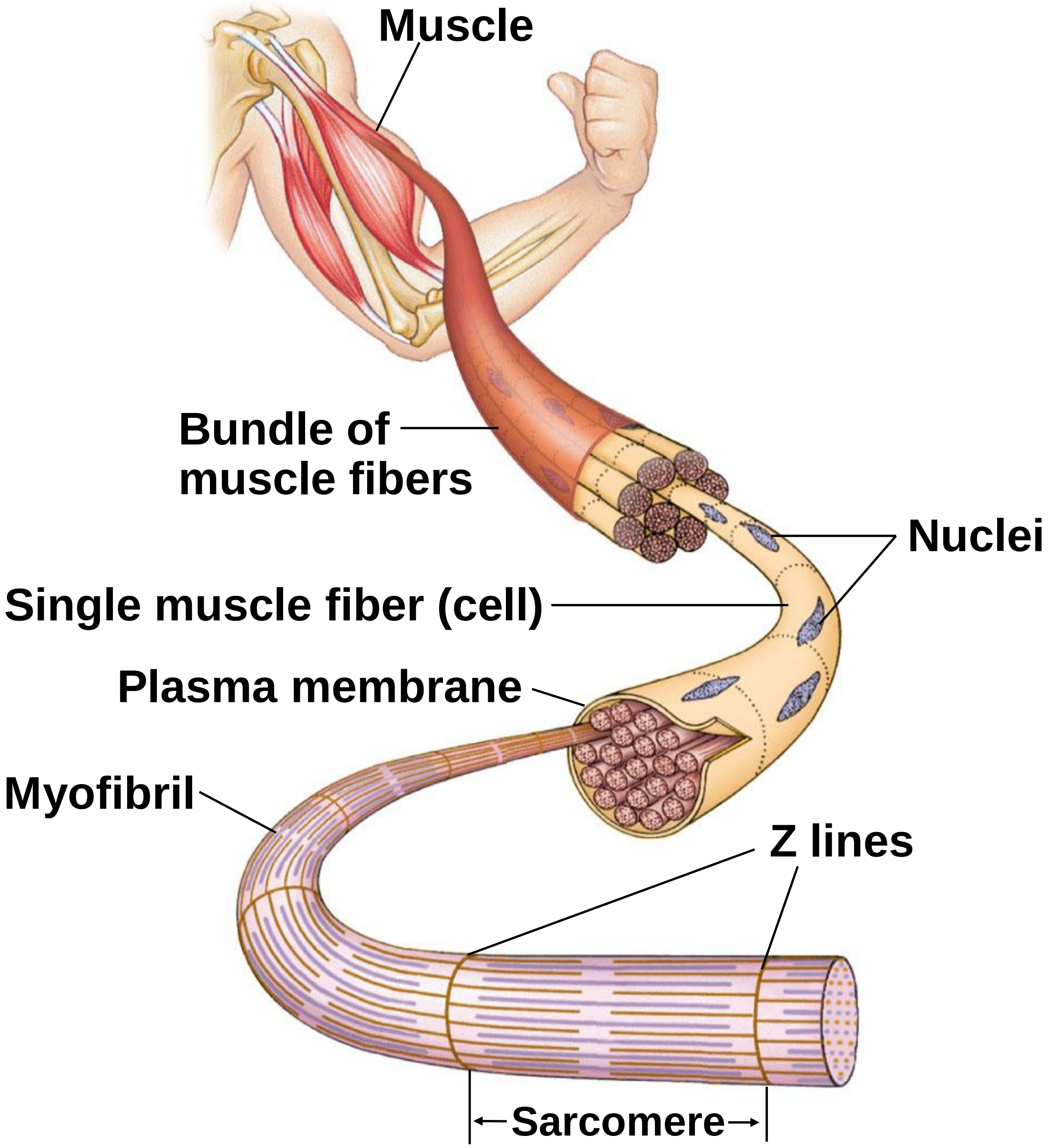


Figure 50.26b

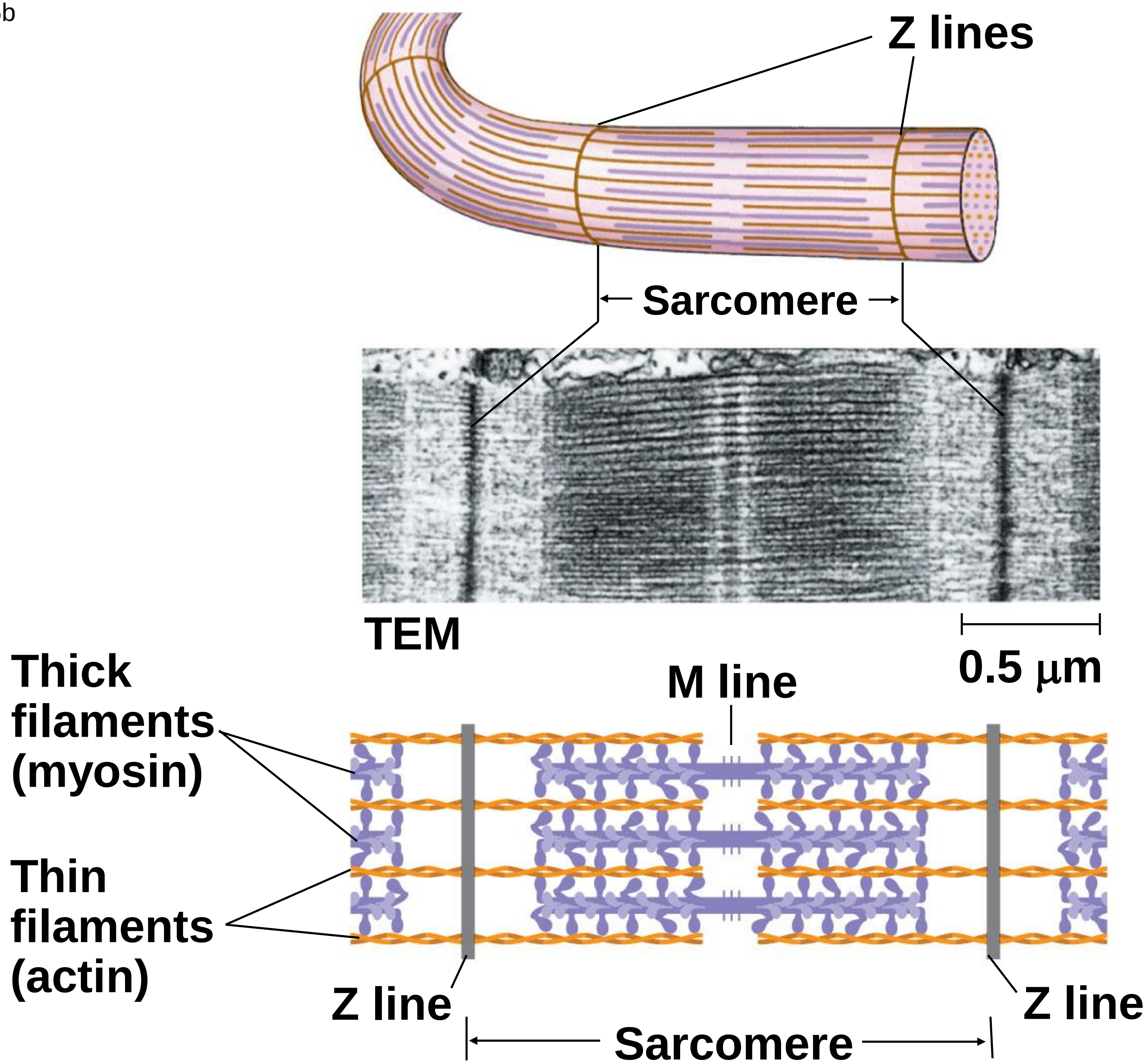
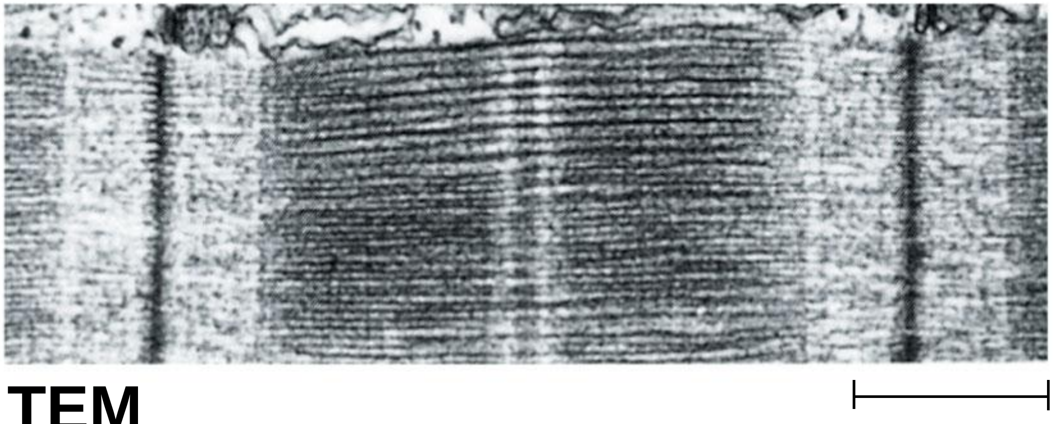


Figure 50.26c



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

Figure 50.27

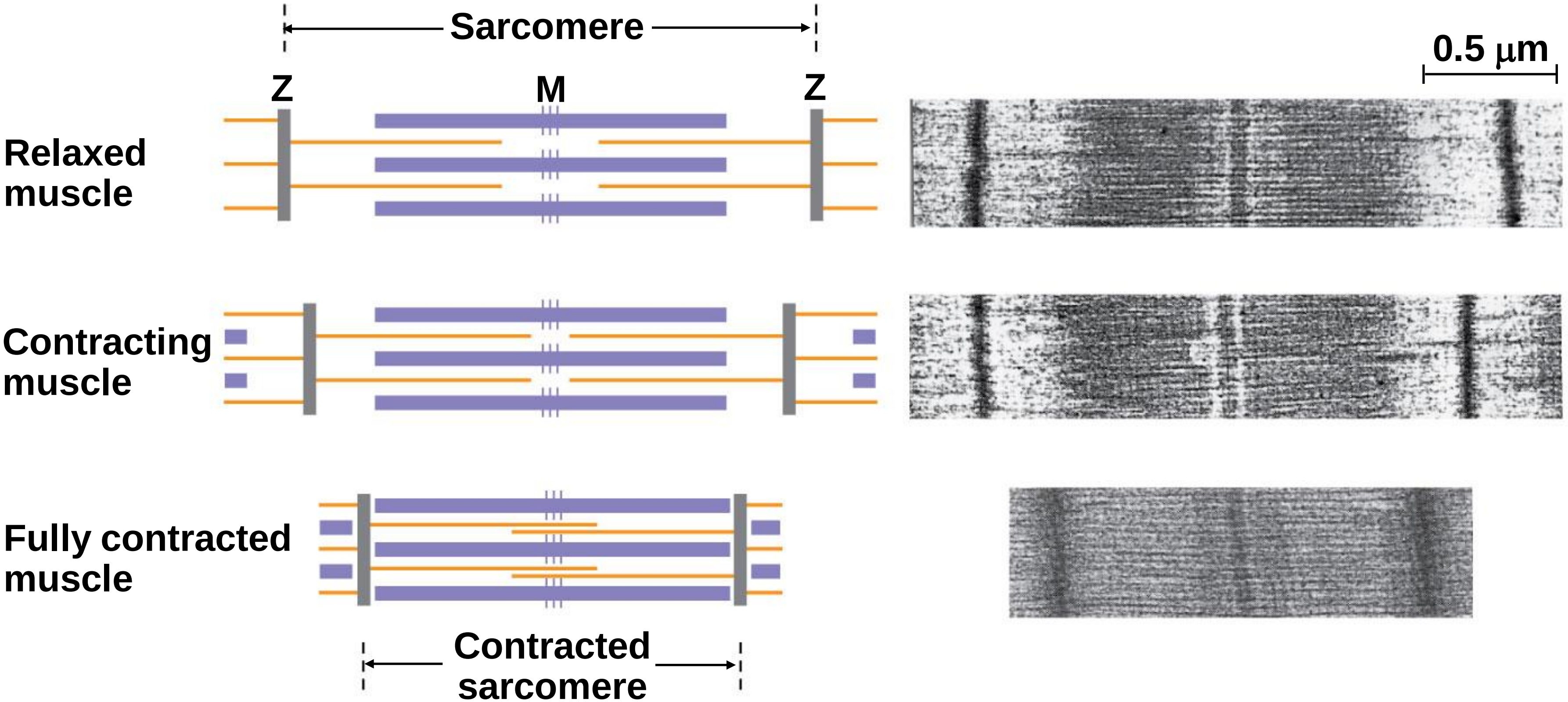

Sarcomere
0.5 µm
Z
M
Z
Relaxed muscle
Contracting muscle
Fully contracted muscle
Contracted sarcomere

Figure 50.27a

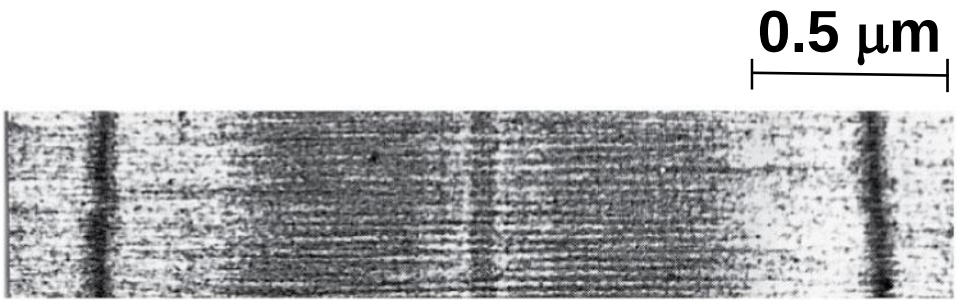


Figure 50.27b

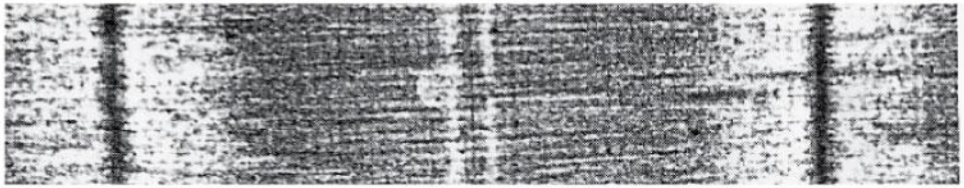
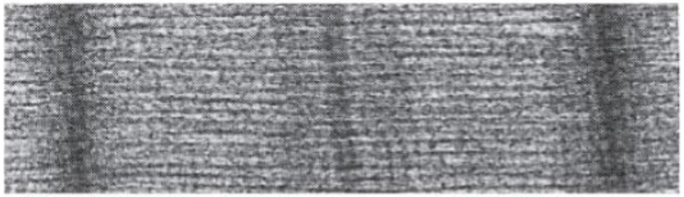


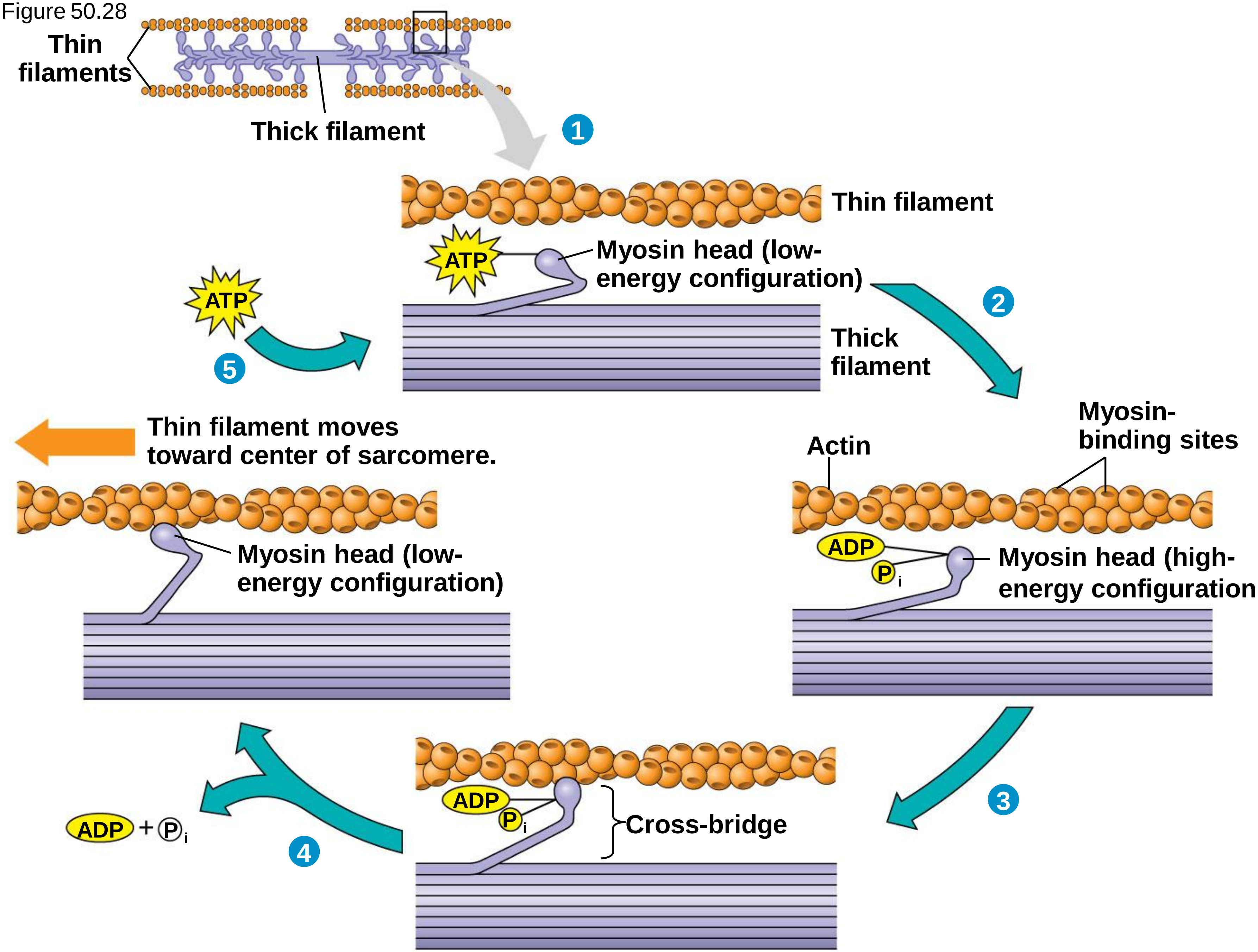
Figure 50.27c



- The sliding of filaments relies on interaction between actin and myosin
- 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
- Muscle contraction requires repeated cycles of binding and release

- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction

Figure 50.28



Thin filaments
Thick filament
1
Thin filament
ATP
Myosin head (low-energy configuration)
Thick filament
2
ATP
5
Thin filament moves toward center of sarcomere.
Actin
Myosin-binding sites
ADP
P i
Myosin head (high-energy configuration
Myosin head (low-energy configuration)
ADP
P i
Cross-bridge
3
ADP + P i
4

Figure 50.28a-1

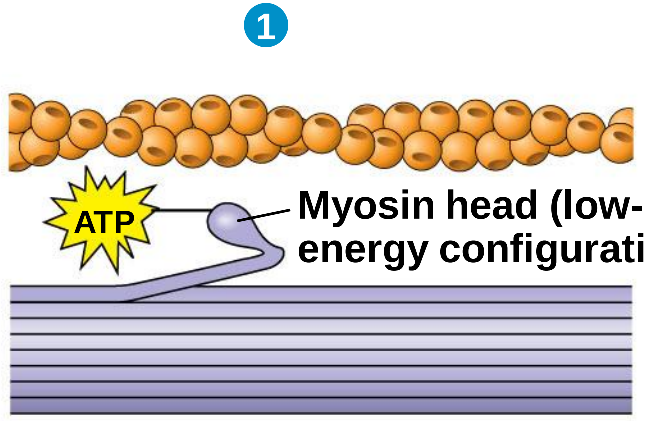


Figure 50.28a-2

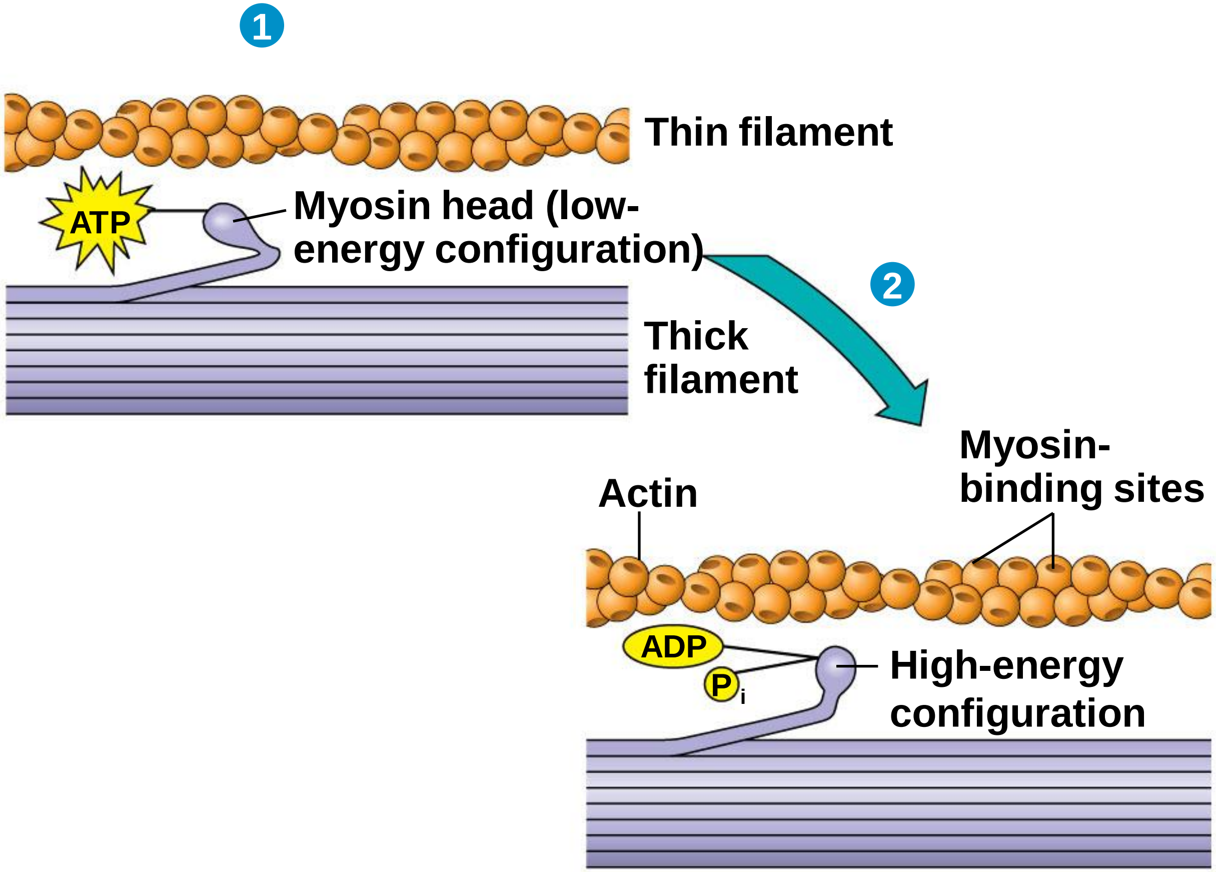


Figure 50.28a-3

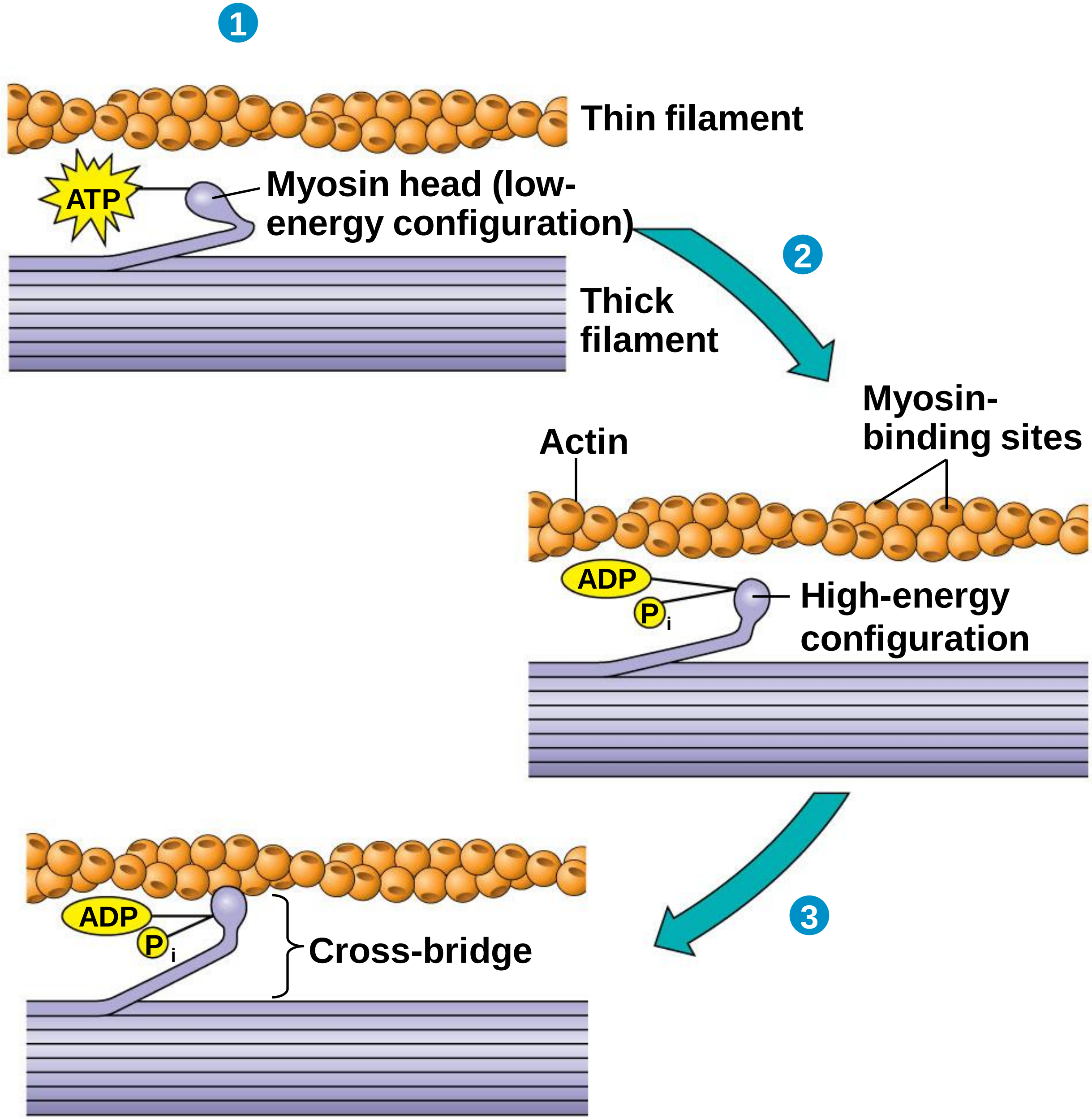


Figure 50.28a-4

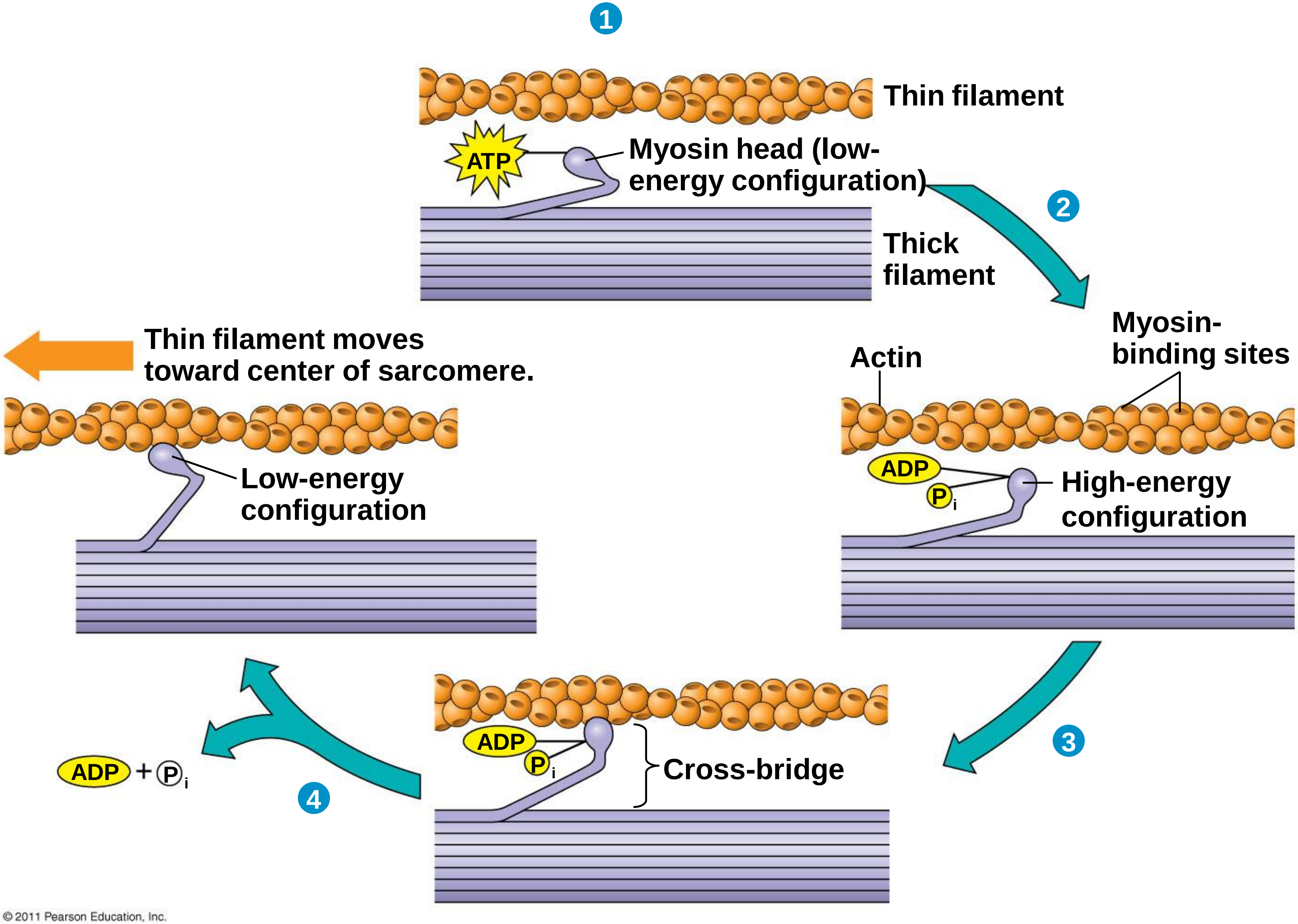
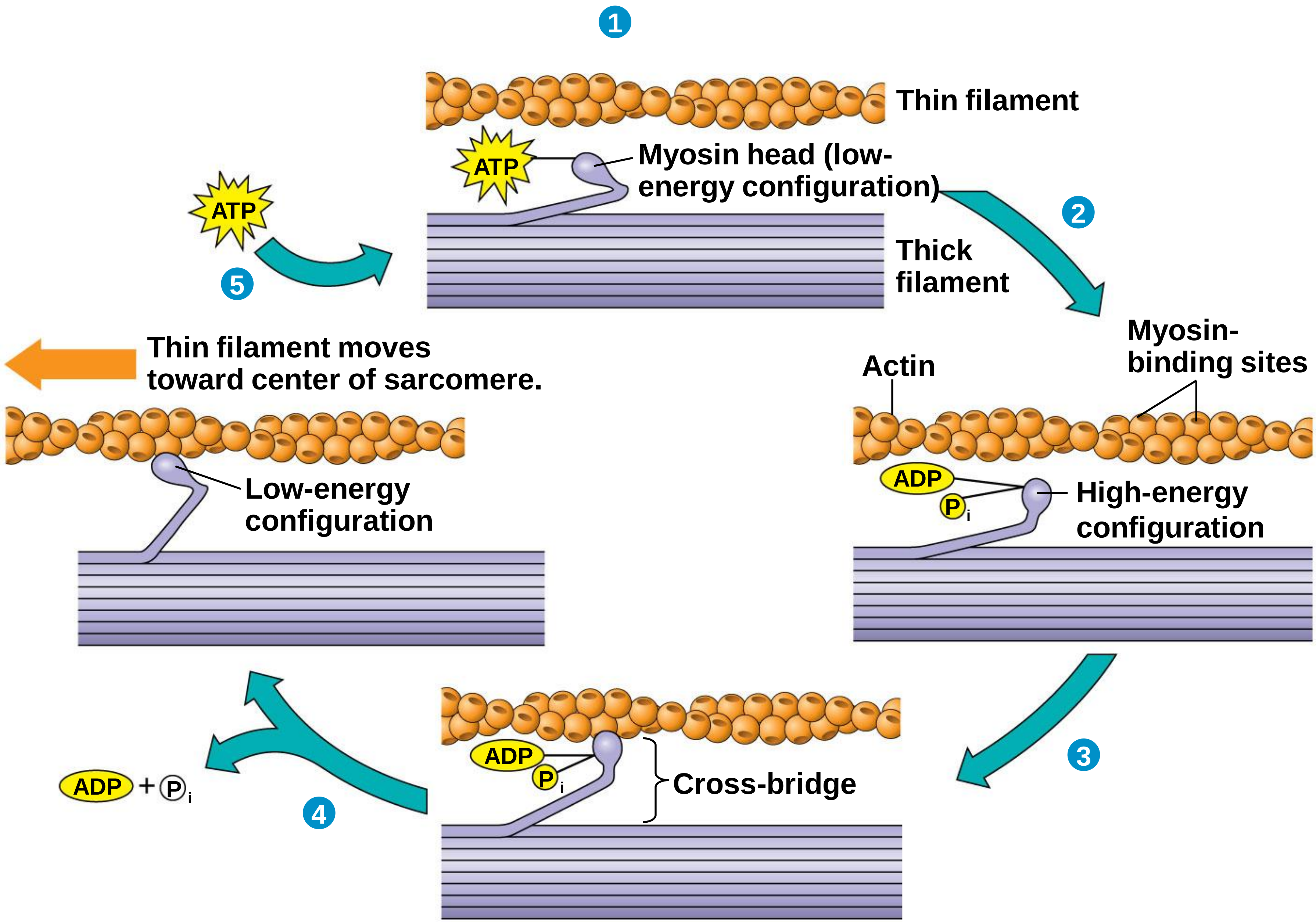


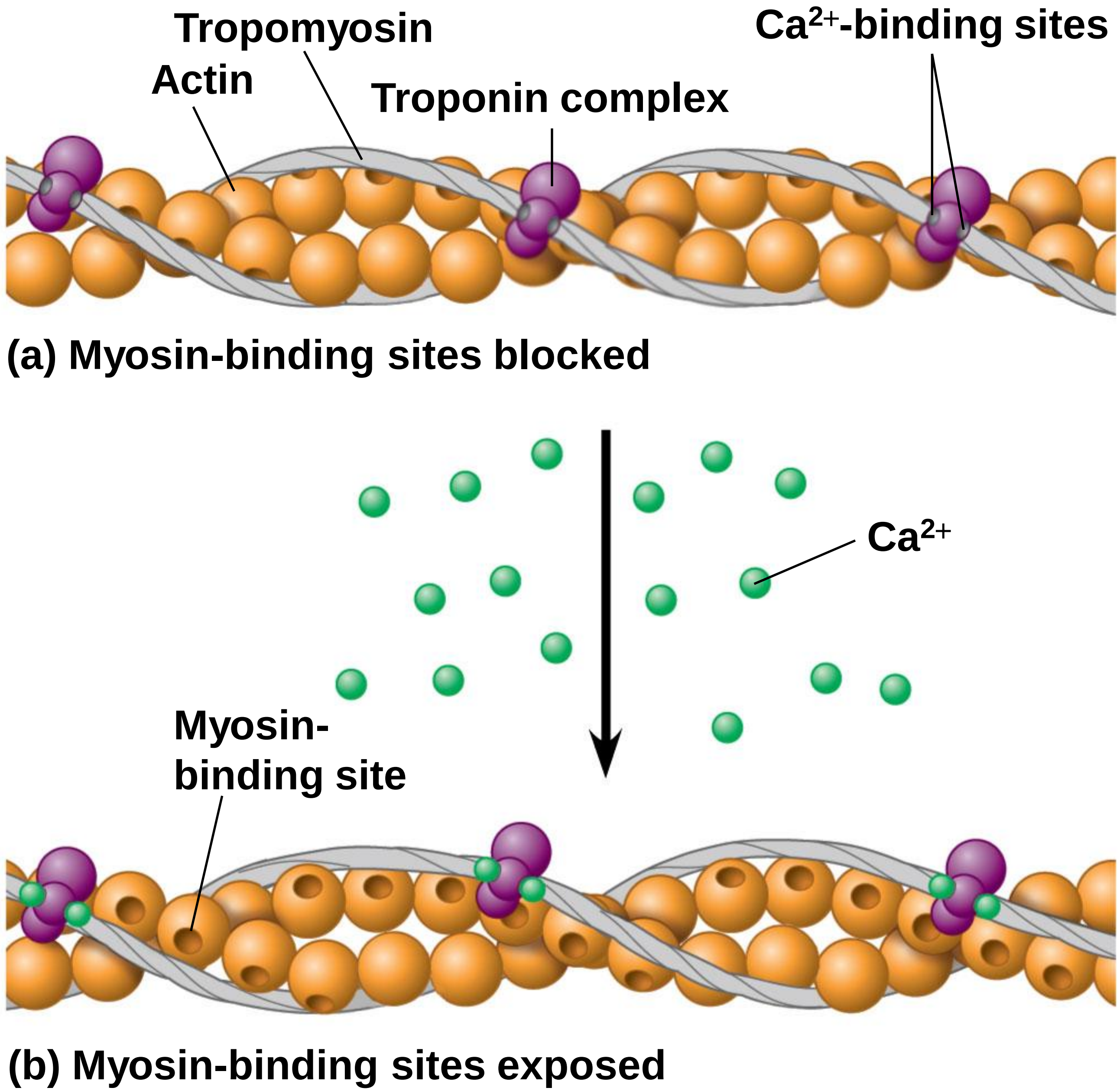
Figure 50.28a-5



The Role of Calcium and Regulatory Proteins

- The regulatory protein **tropomyosin** and the **troponin complex**, a set of additional proteins, bind to actin strands on thin filaments when a muscle fiber is at rest
- This prevents actin and myosin from interacting

Figure 50.29

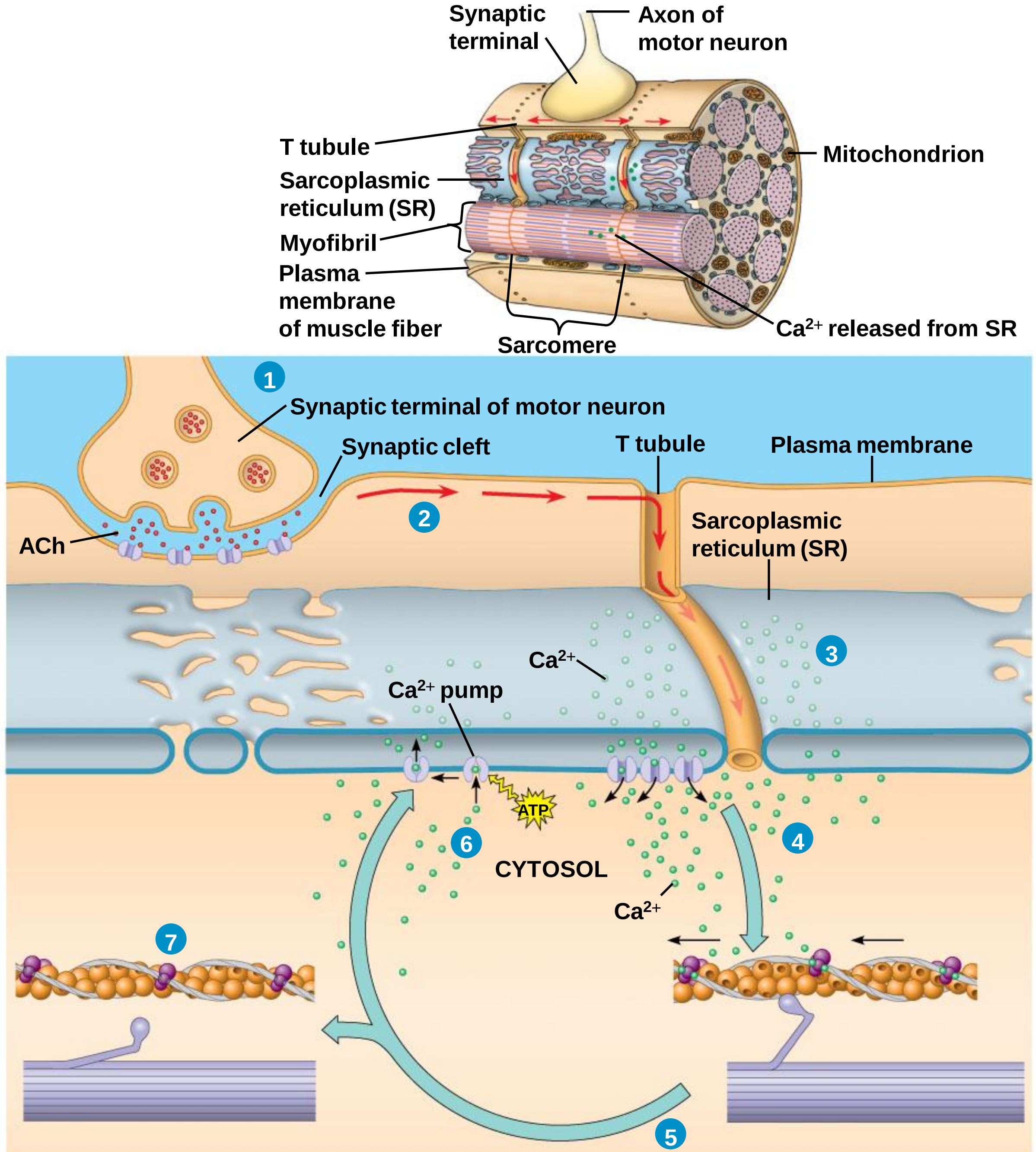


Tropomyosin
Actin
Troponin complex
Ca2+-binding sites
(a) Myosin-binding sites blocked
Ca2+
Myosin-
binding site
(b) Myosin-binding sites exposed

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

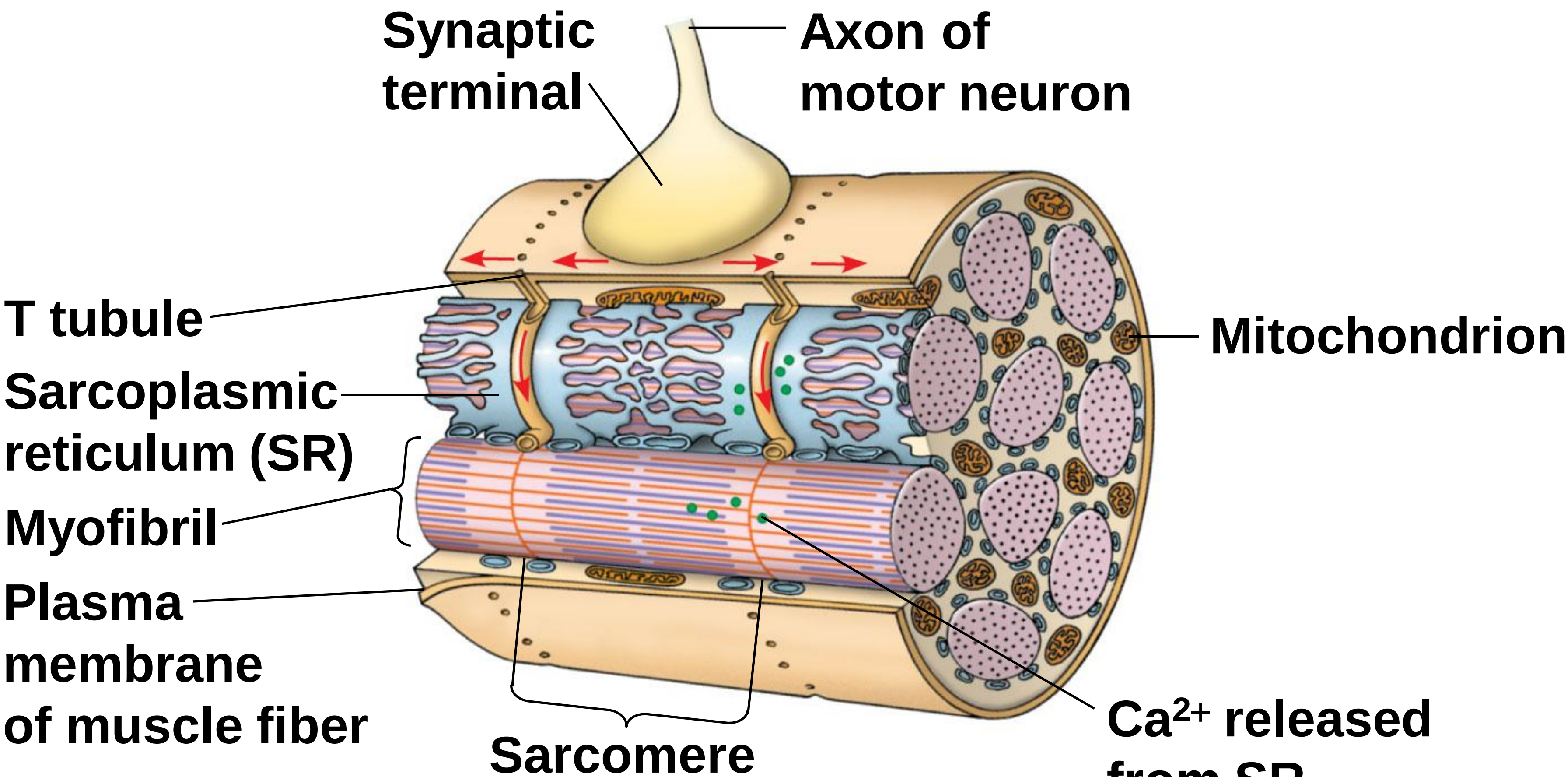
- The stimulus leading to contraction of a muscle fiber is an action potential in a motor neuron that makes a synapse with the muscle fiber
- The synaptic terminal of the motor neuron releases the neurotransmitter acetylcholine
- Acetylcholine depolarizes the muscle, causing it to produce an action potential

Figure 50.30



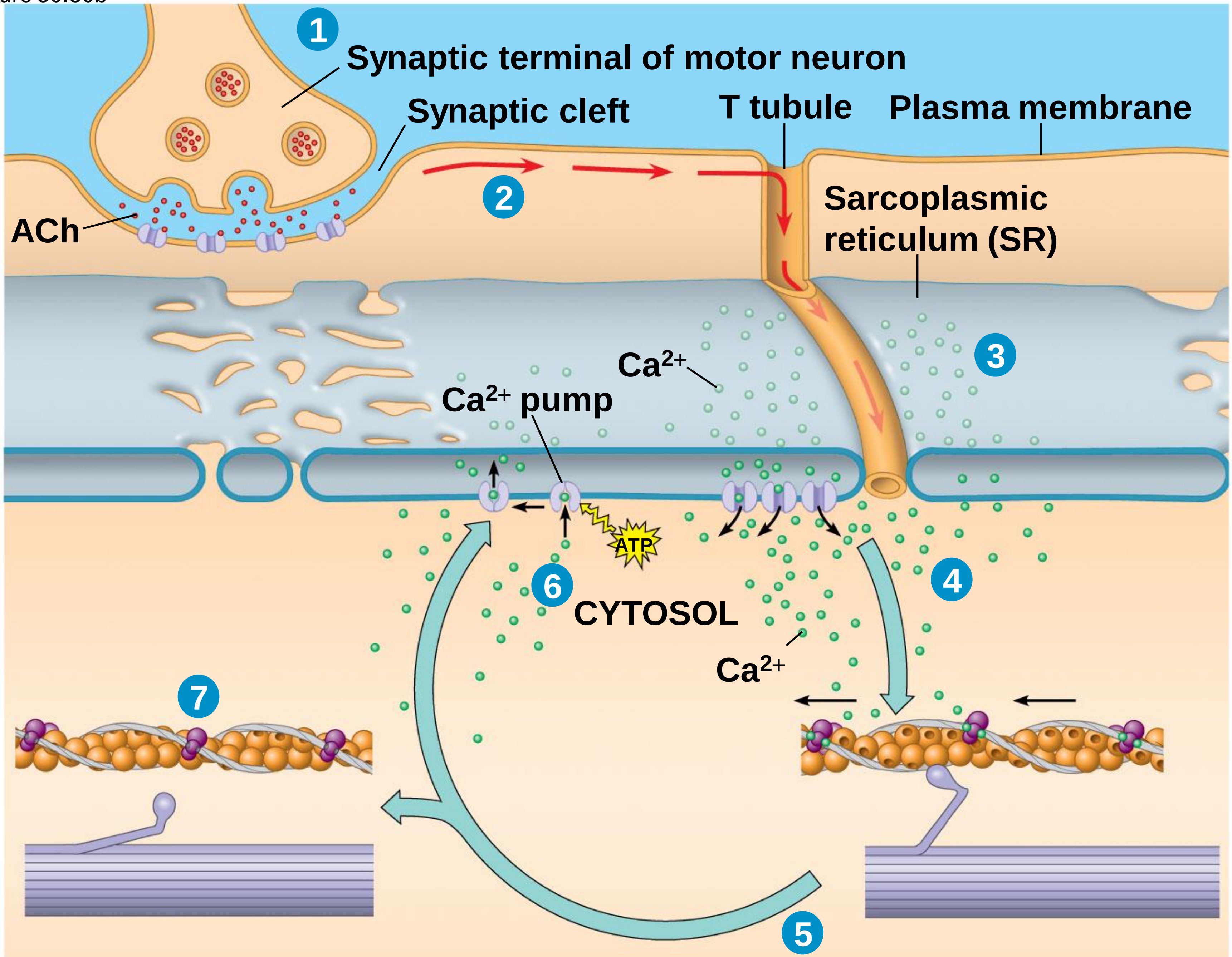
Synaptic terminal
Axon of motor neuron
T tubule
Sarcoplasmic reticulum (SR)
Myofibril
Plasma membrane of muscle fiber
Sarcomere
Mitochondrion
Ca2+ released from SR
1
Synaptic terminal of motor neuron
Synaptic cleft
T tubule
Plasma membrane
ACh
2
Sarcoplasmic reticulum (SR)
3
Ca2+
Ca2+ pump
ATP
6
CYTOSOL
4
Ca2+
7
5

Figure 50.30a



- 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

Figure 50.30b



- When motor neuron input stops, the muscle cell relaxes
- Transport proteins in the SR pump Ca^{2+} out of the cytosol
- Regulatory proteins bound to thin filaments shift back to the myosin-binding sites

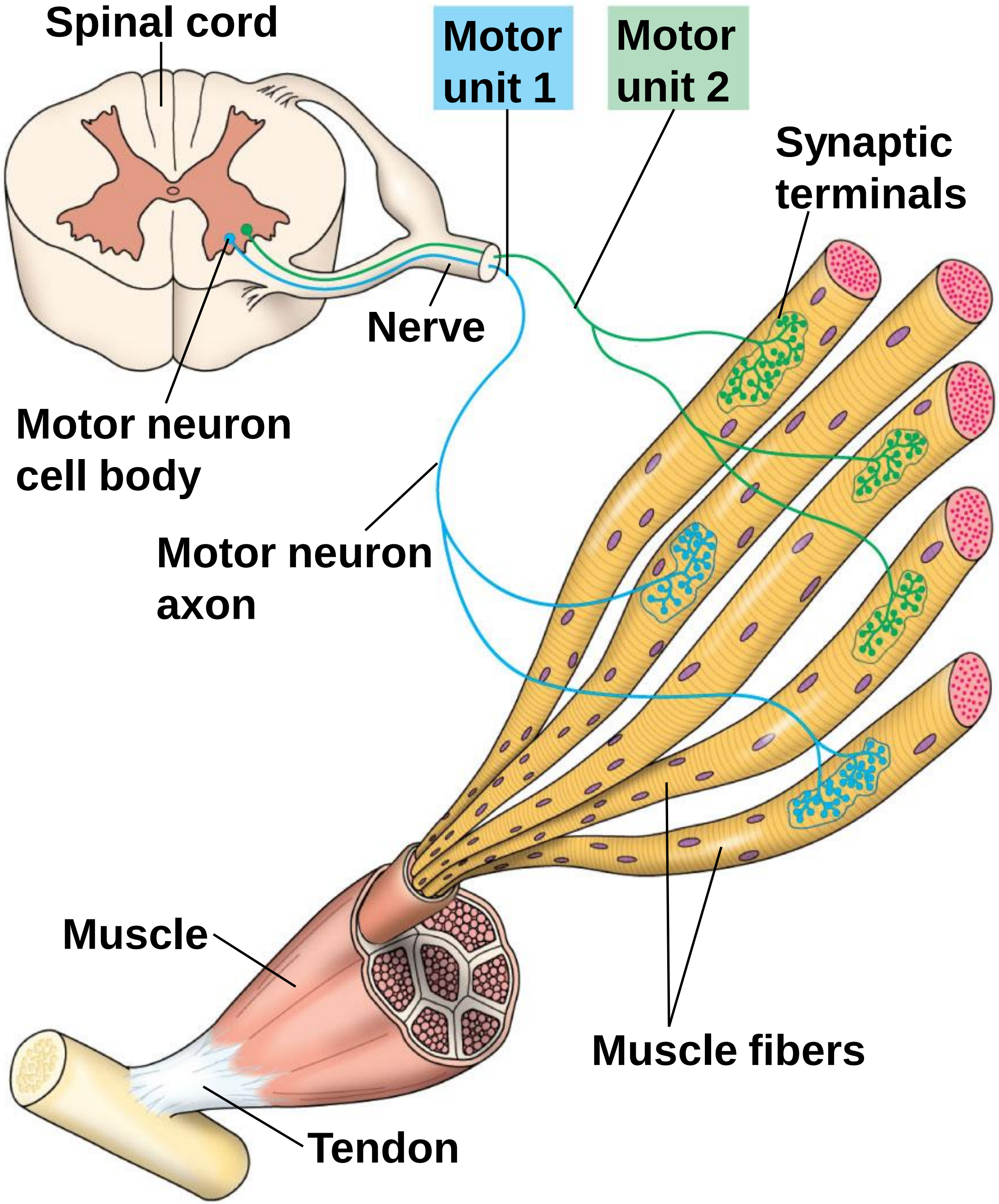
- Amyotrophic lateral sclerosis (ALS), formerly called Lou Gehrig’s disease, interferes with the excitation of skeletal muscle fibers; this disease is usually fatal
- Myasthenia gravis is an autoimmune disease that attacks acetylcholine receptors on muscle fibers; treatments exist for this disease

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 vertebrates, each motor neuron may synapse with multiple muscle fibers, although each fiber is controlled by only one motor neuron
- A **motor unit** consists of a single motor neuron and all the muscle fibers it controls

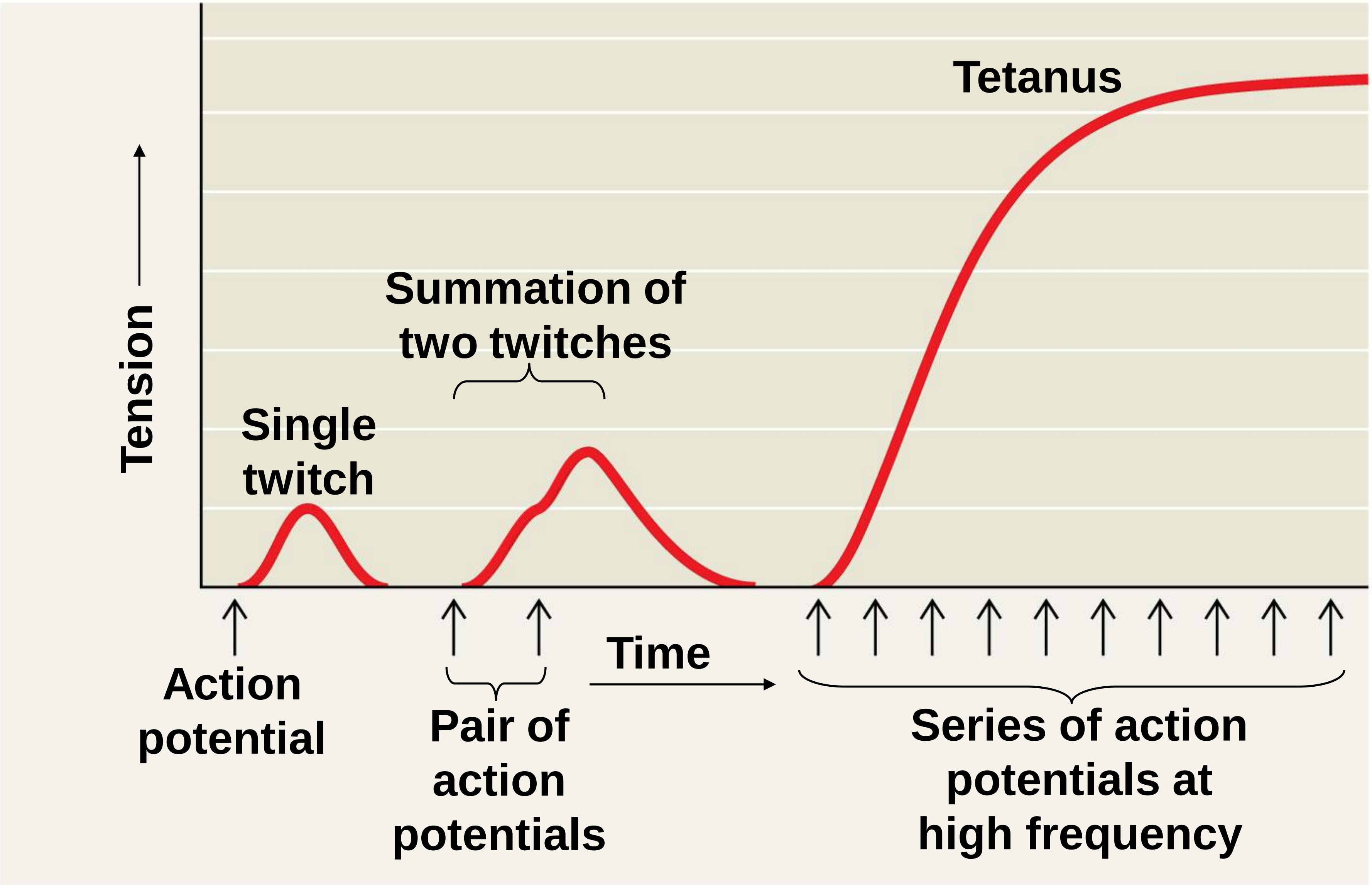
Figure 50.31



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

- 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

Figure 50.32


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

- There are several distinct types of skeletal muscles, each of which is adapted to a particular function
- They are classified by the source of ATP powering the muscle activity or by the speed of muscle contraction

Oxidative and Glycolytic Fibers

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

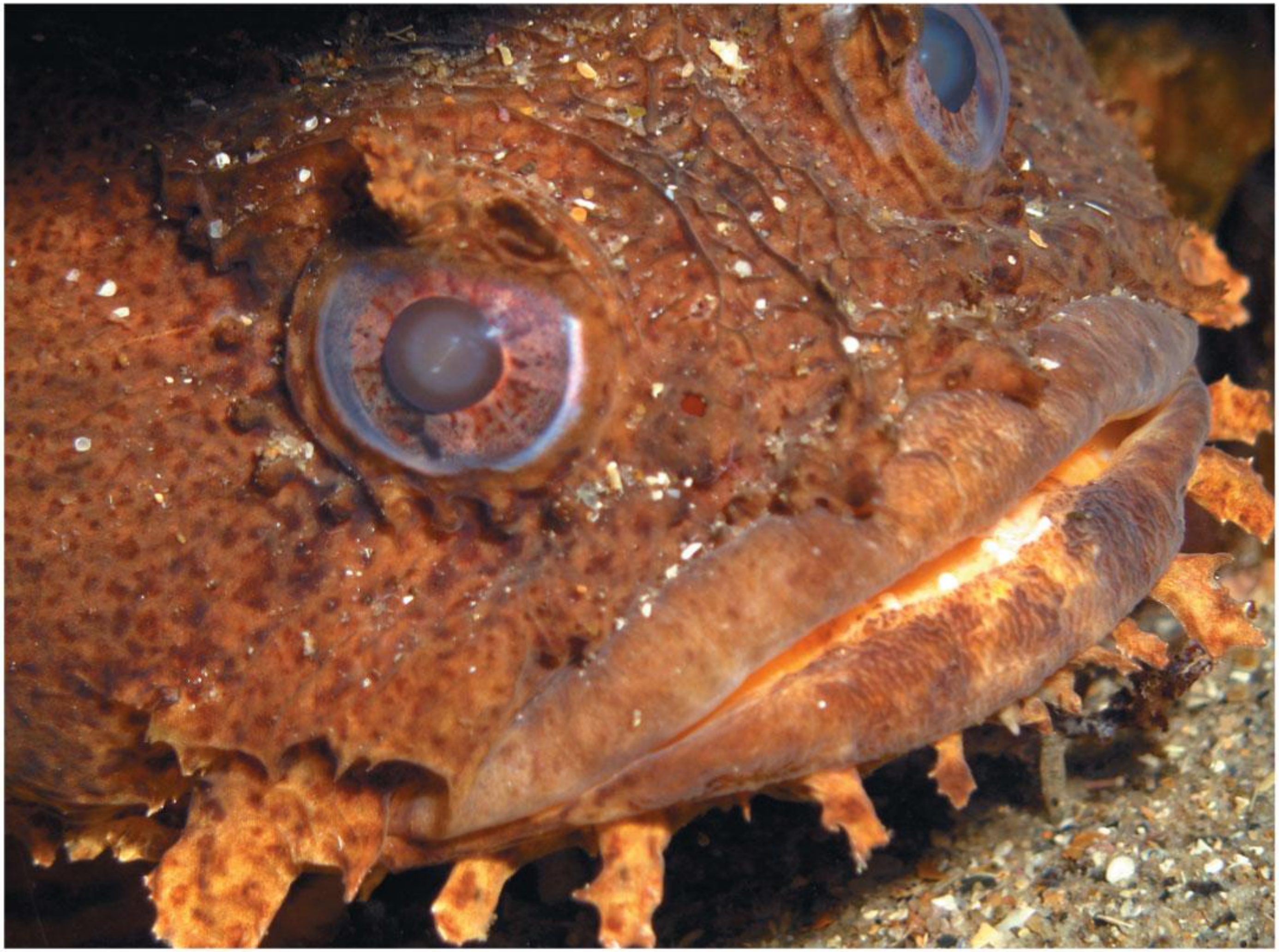
- Glycolytic fibers use glycolysis as their primary source of ATP
- Glycolytic fibers have less myoglobin than oxidative fibers, and tire more easily
- In poultry and fish, light meat is composed of glycolytic fibers, while dark meat is composed of oxidative fibers

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
- Some vertebrates have muscles that twitch at rates much faster than human muscles
- In producing its characteristic mating call, the male toadfish can contract and relax certain muscles more than 200 times per second

Figure 50.33



Other Types of Muscle

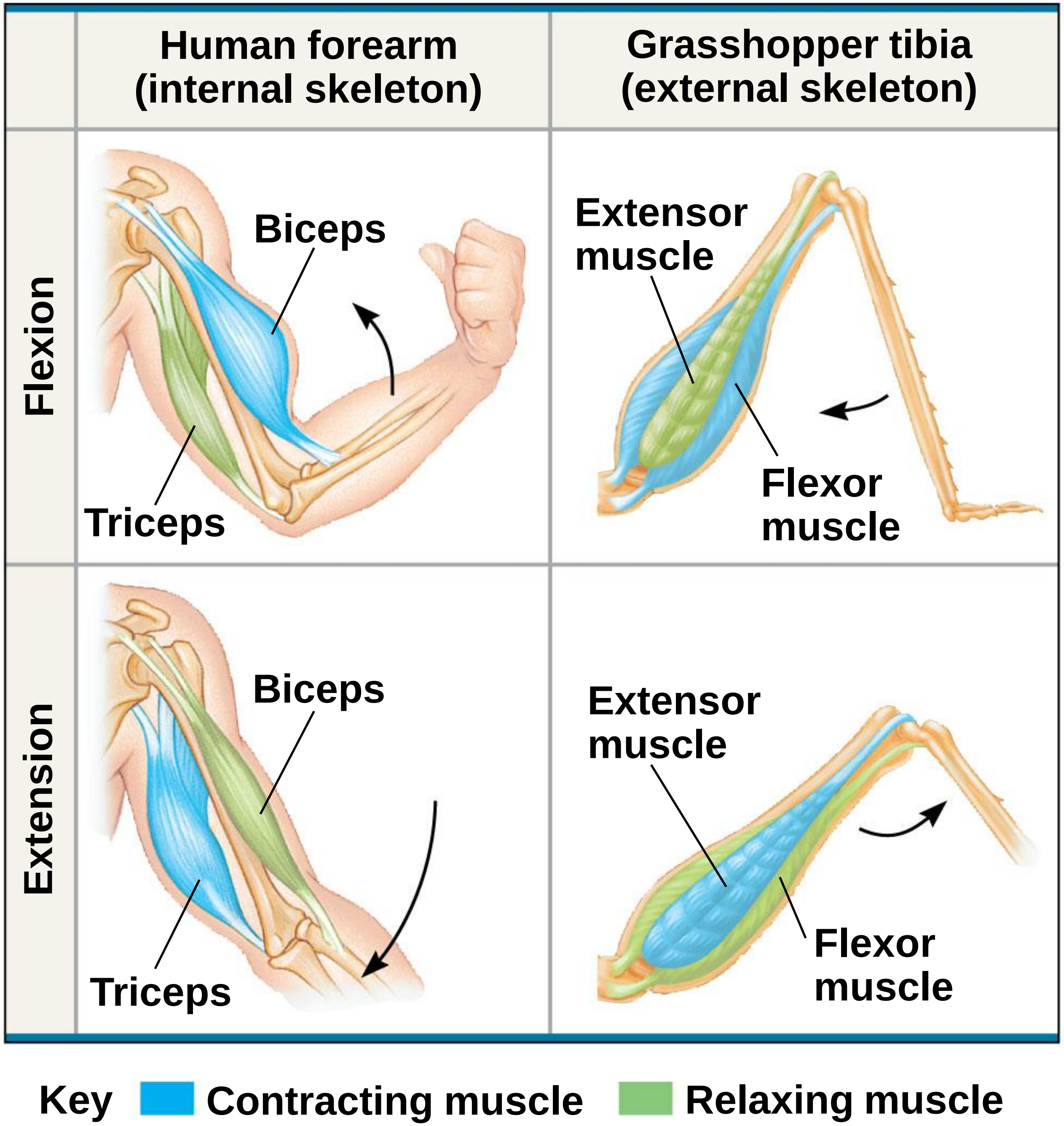
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
- **Cardiac muscle**, found only in the heart, consists of striated cells electrically connected by **intercalated disks**
- Cardiac muscle can generate action potentials without neural input

- In **smooth muscle**, found mainly in walls of hollow organs such as those of the digestive tract, 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, the actions of which are coordinated by the nervous system
- The skeleton provides a rigid structure to which muscles attach
- Skeletons function in support, protection, and movement

Figure 50.34



Human forearm
(internal skeleton)
Grasshopper tibia
(external skeleton)
Flexion
Biceps
Triceps
Extensor
muscle
Flexor
muscle
Extension
Biceps
Triceps
Extensor
muscle
Flexor
muscle
Key
Contracting muscle
Relaxing muscle

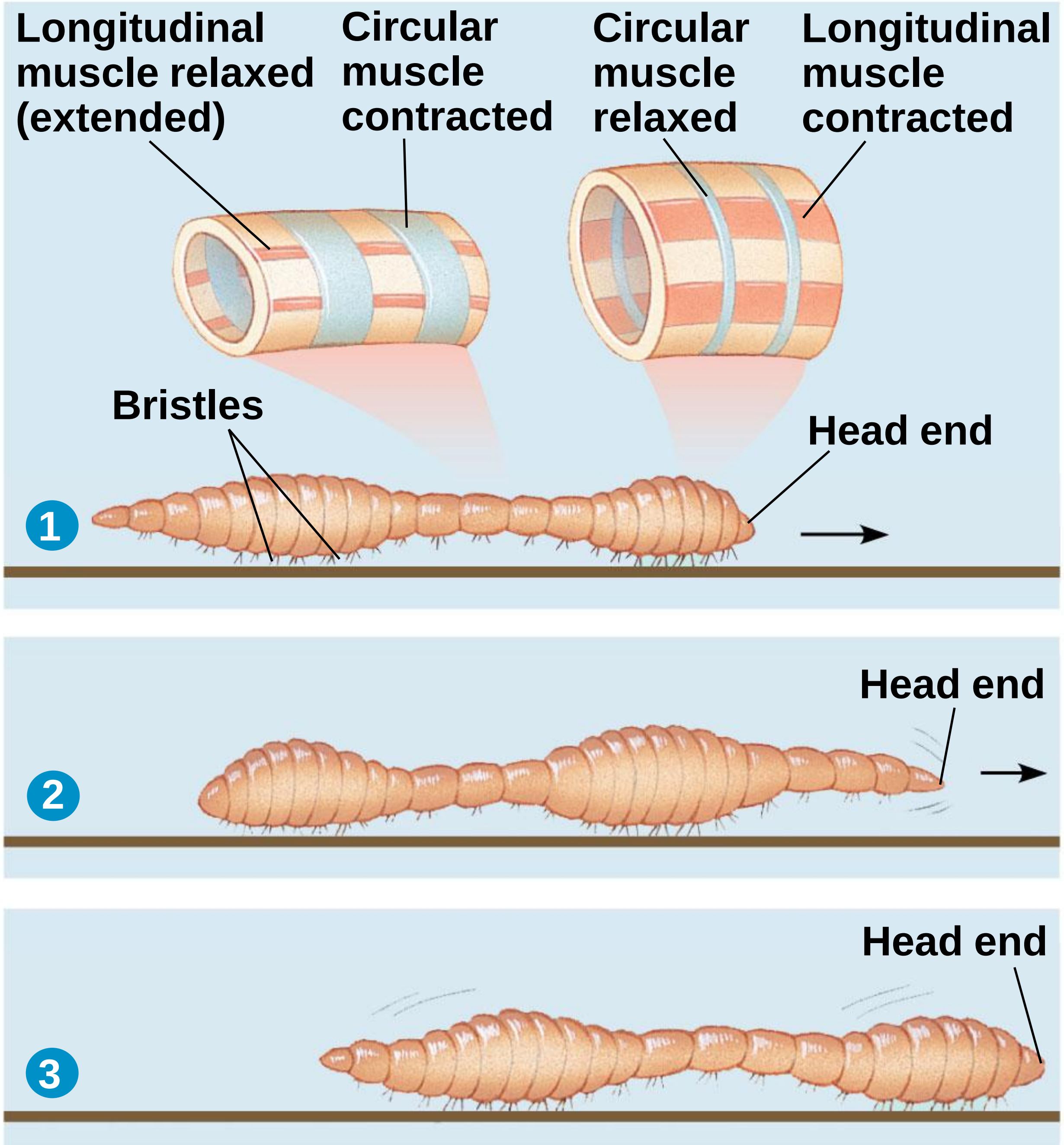
Types of Skeletal Systems

- 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

Figure 50.35


Longitudinal muscle relaxed (extended)
Circular muscle contracted
Circular muscle relaxed
Longitudinal muscle contracted
Bristles
Head end
1
2
Head end
3
Head end

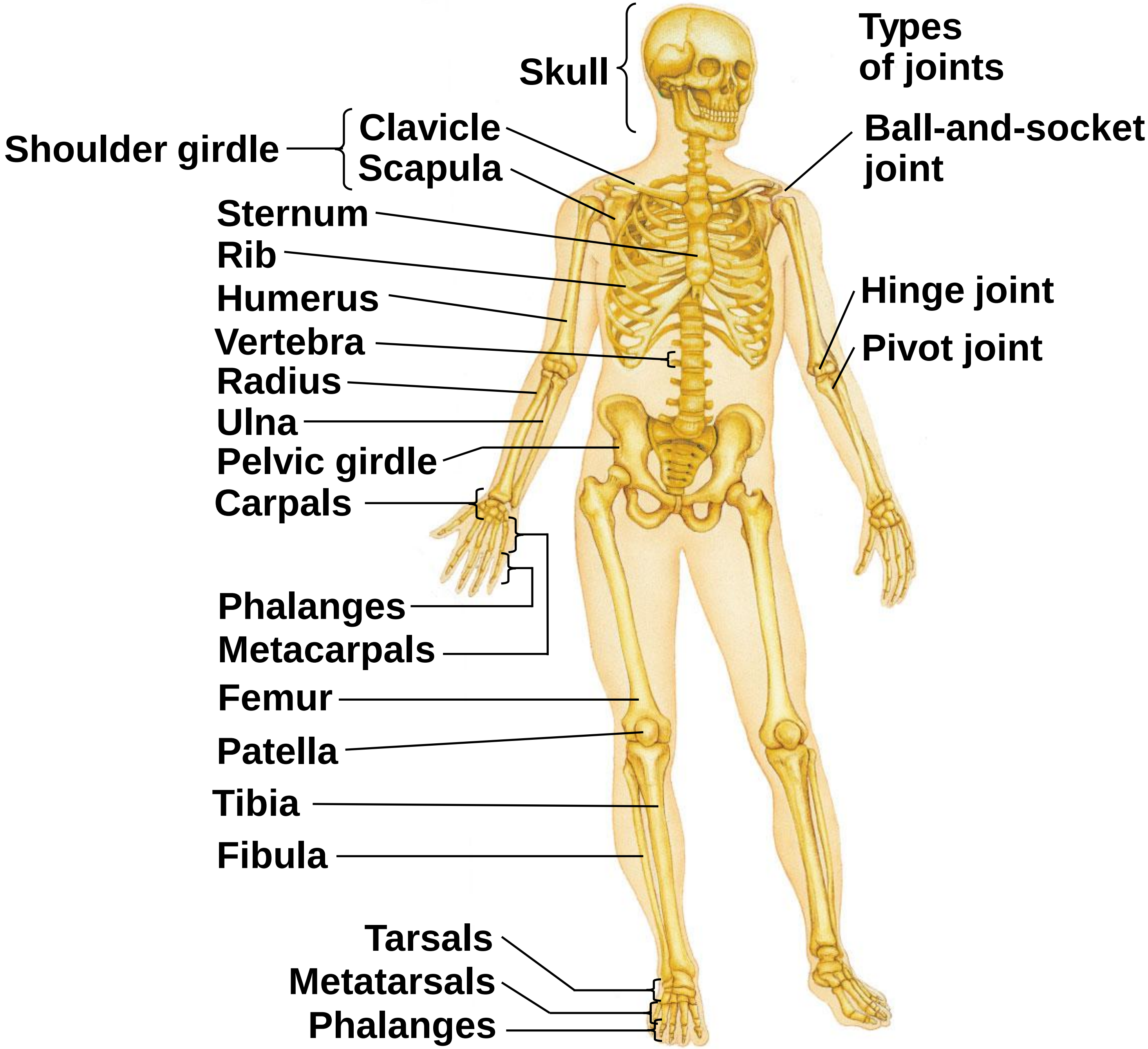
Exoskeletons

- An **exoskeleton** is a hard encasement deposited on the surface of an animal
- Exoskeletons are found in most molluscs and arthropods
- Arthropods have a jointed exoskeleton called a cuticle, which can be both strong and flexible
- The polysaccharide **chitin** is often found in arthropod cuticle

Endoskeletons

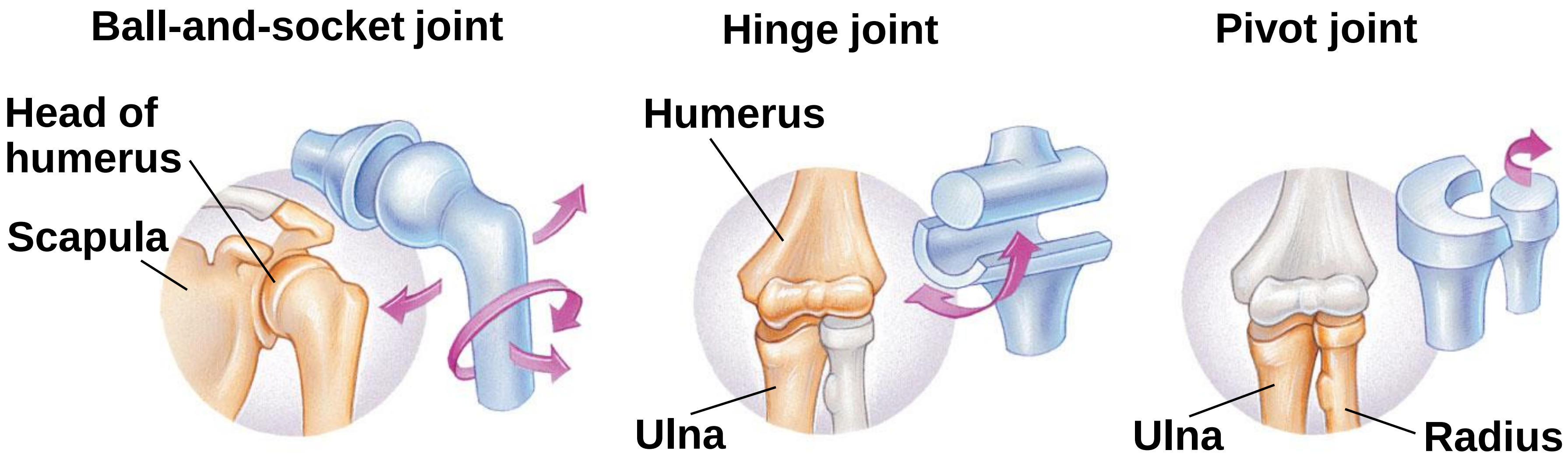
- An **endoskeleton** consists of a hard internal skeleton, buried in soft tissue
- Endoskeletons are found in organisms ranging from sponges to mammals
- A mammalian skeleton has more than 200 bones
- Some bones are fused; others are connected at joints by ligaments that allow freedom of movement

Figure 50.36



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

Figure 50.37


Ball-and-socket joint
Head of humerus
Scapula
Hinge joint
Humerus
Ulna
Pivot joint
Ulna
Radius

Size and Scale of Skeletons

- An animal's body structure must support its size
- The weight of a body increases with the cube of its dimensions while the strength of that body increases with the square of its dimensions

- The skeletons of small and large animals have different proportions
- 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

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

Figure 50.38

Swimming

- In water, friction is a bigger problem than gravity
- Fast swimmers usually have a sleek, torpedo-like 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

Flying

- Active 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, as well as large bones with air-filled regions

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

- Animals specialized for swimming expend less energy per meter traveled than equivalently sized animals specialized for flying or running
- Large animals travel more efficiently than smaller animals adapted to the same mode of transport

Figure 50.39

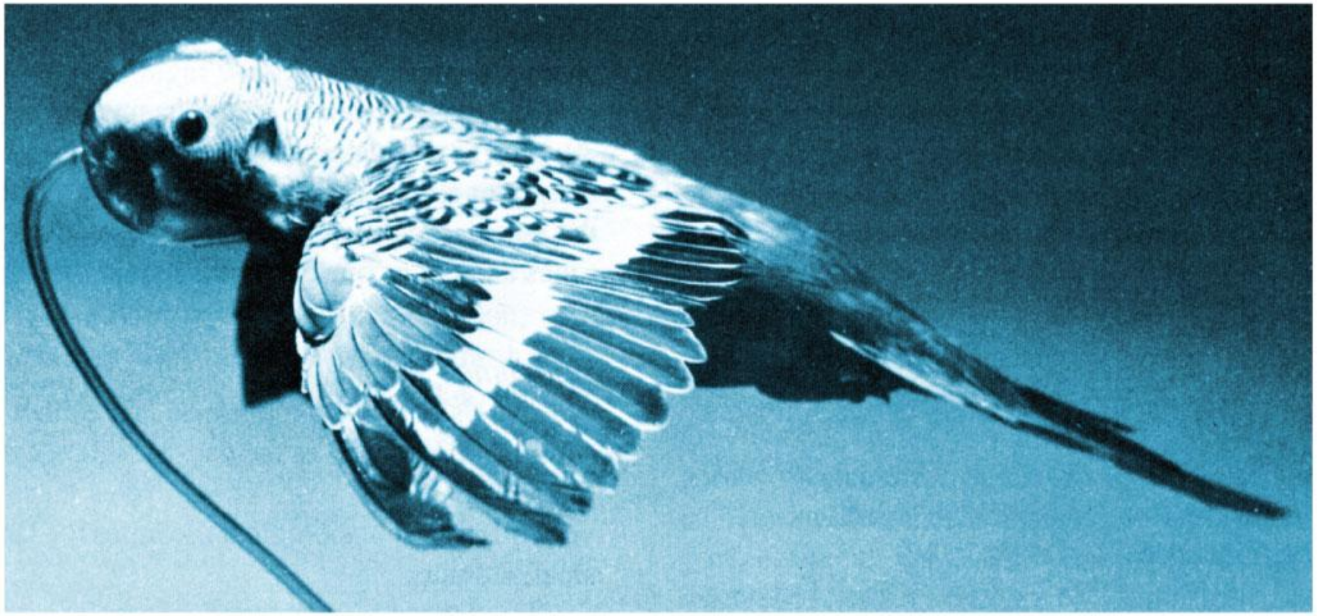


Figure 50.40

RESULTS

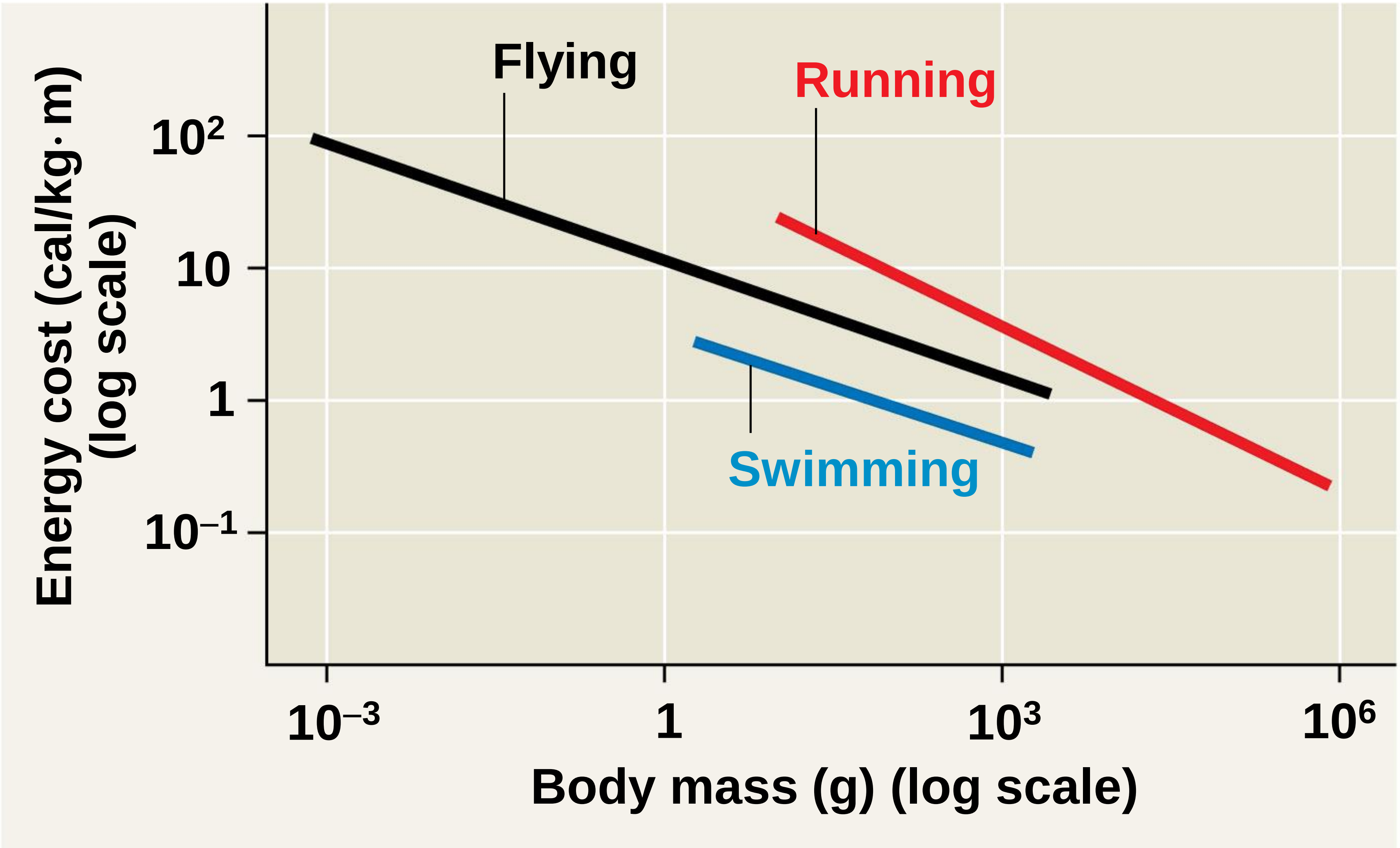


Figure 50.UN01

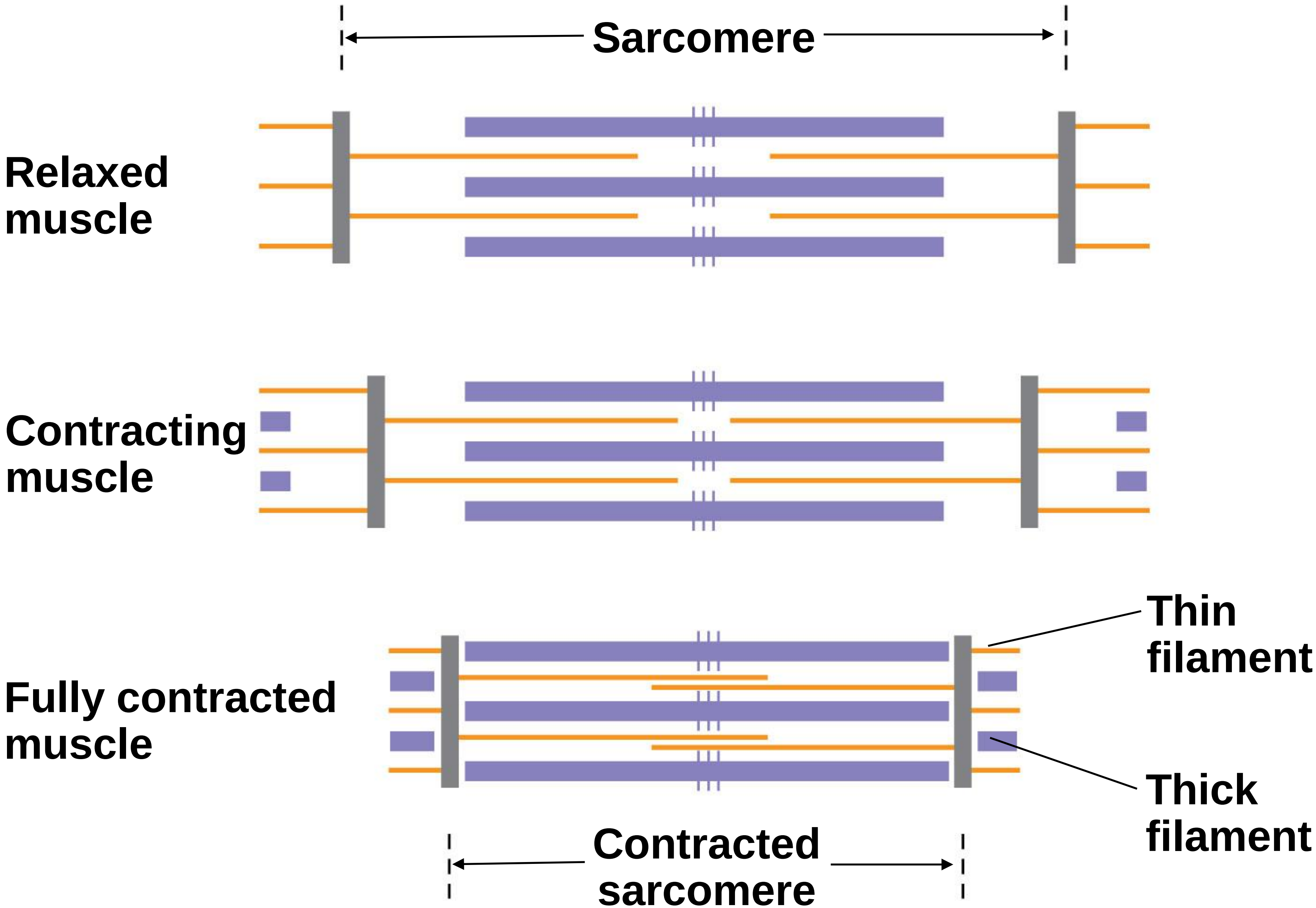


Figure 50.UN02

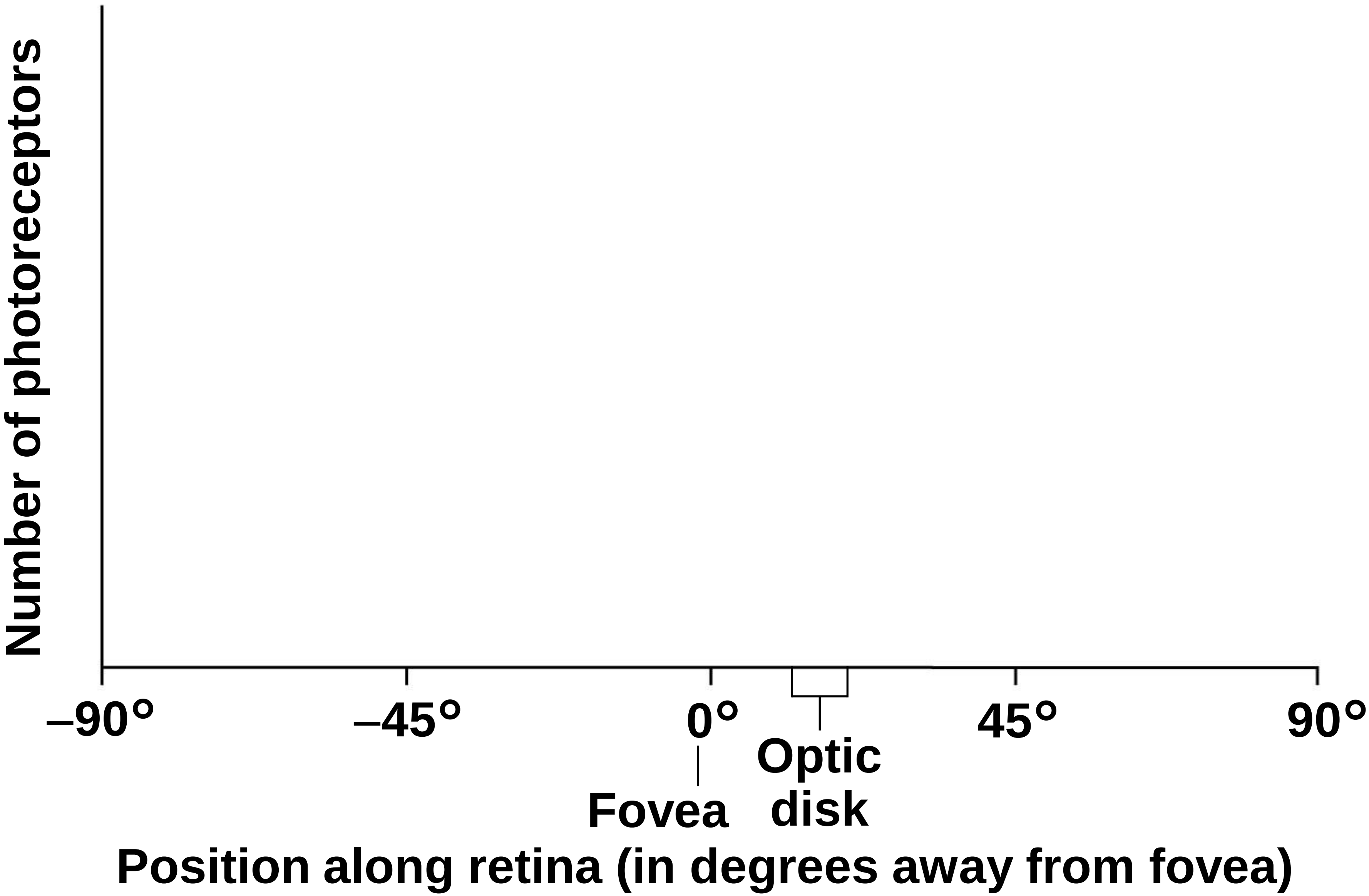


Figure 50.UN03