Life's Common Challenges

Response: Sense & Respond

Life's Common Challenges

Introduction

Main Idea

- ***Sensing and consequently Responding to the environment is an absolute necessity for all organisms.***

- You might recall in an earlier unit that all organisms can sense some kind(s) of environmental stimuli.

- This unit will focus on the organisms response to those stimuli.

- You might also recall that many responses occur at the cellular level, but again this unit will focus on responses at the organismal level.

Locomotion & Growth

- ***For many organisms, Responding to environmental stimuli often involves moving to or away from a stimulus.***
  - *Locomotion-* is the ability to move place to place, the act of self propulsion.
- ***For some organisms growing towards or away from a stimulus is the best they can do.***
  - ***The focus of this unit is responding to stimuli through movement, since some organisms do not technically move I am using a liberal interpretation of "moving" to include <u>self propulsion</u> as well as <u>growth</u>.***

Locomotion & Growth

- *Motile Organisms*- have the ability to move place to place.
- *Sessile Organisms*- do not have the ability to move place to place, they are anchored to a substrate for most of their life.
- ***Most animals, protists and bacteria can move. (that's 3 out the 5 kingdoms).***
  - As a side note no animal (and likely true for protists and bacteria) is completely and absolutely sessile.
  - Even sessile organisms can move in emergencies, or can move to new sites for food or at least had a motile stage in their life.
- ***If we include growth as form of movement (or at least responding to stimuli), then we can include plants and fungi in our discussion***

Motility...Trade Offs

- **Motility certainly has its advantages.**
  - Helps to search and obtain food.
  - Helps to search and find mates.
  - Allows organisms to disperse or migrate
  - Helps organisms to avoid predation or other dangerous stimuli
- **Motility also has a price**
  - Energetically it is expensive!

Life's Common Challenges

Review: "Sensing"

SENSING THE ENVIRONMENT

- **Before an animal can RESPOND to its environment it must first sense its environment!**
- Sensory pathways have in common four basic functions: sensory reception, transduction, transmission, and perception.
- Although sensory pathways vary from unicellular organisms to complex animals the four basic functions loosely hold true

SENSING THE ENVIRONMENT

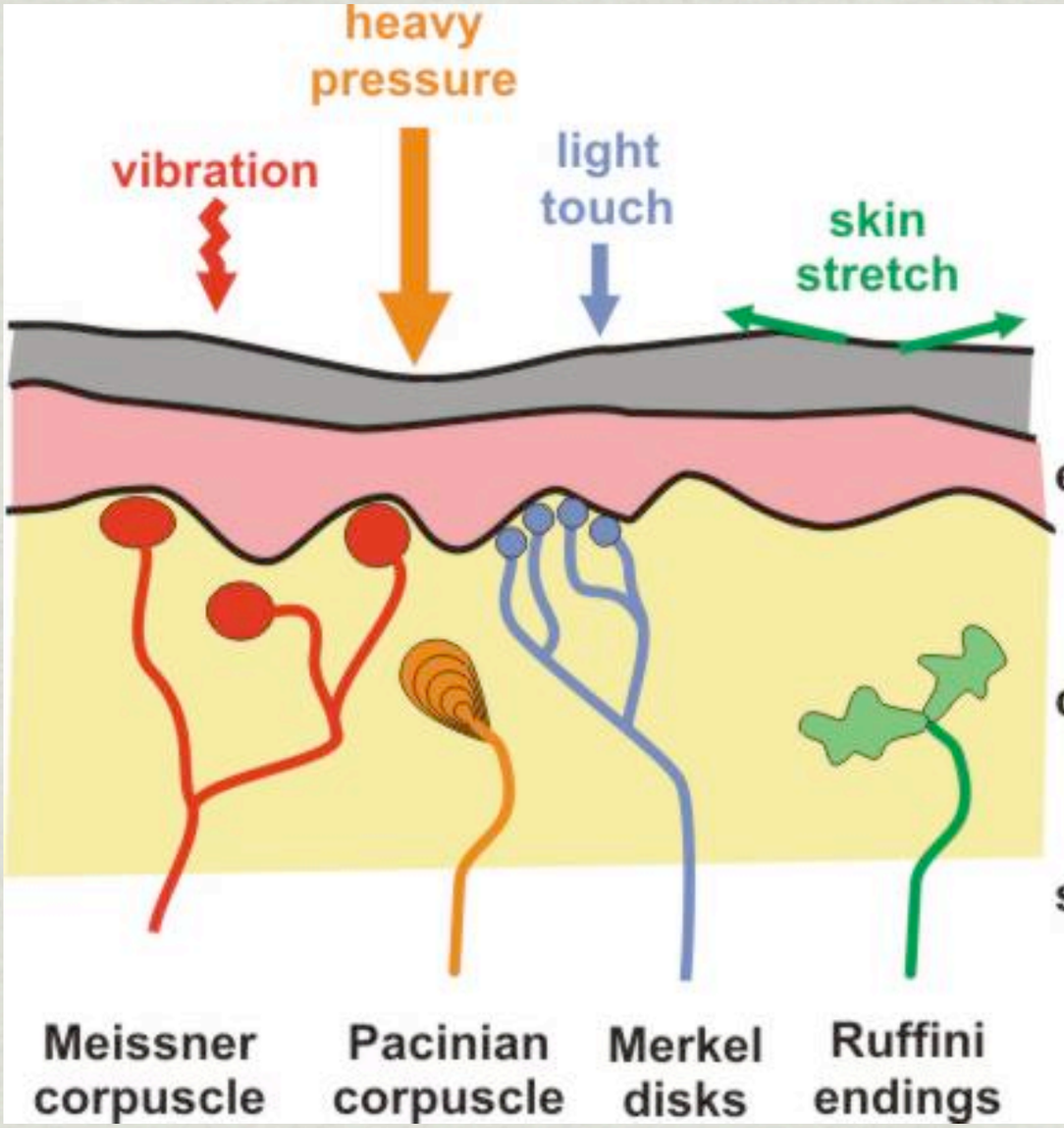
- The first step in interacting with the environment is detecting stimuli.
  - All stimuli represent forms of energy

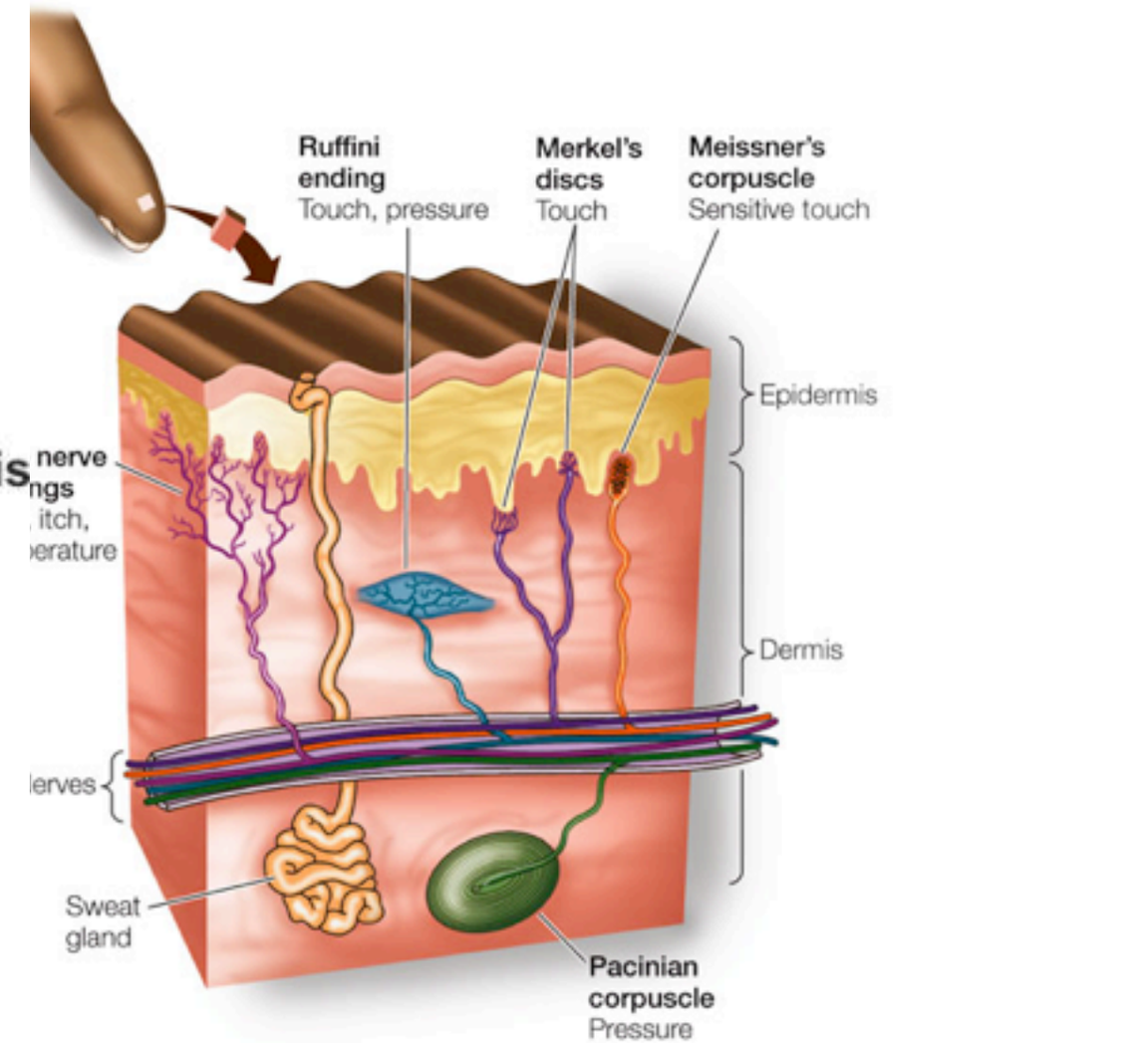
SENSORY RECEPTION

- Begins with the detection of stimulus by sensory cells (multicellular organism)
- These sensory cells have sensory receptors that detect the stimuli directly. (unicellular and multicellular organisms)
- The type of stimuli regularly detected include: electromagnetic radiation, pressure, temperature, chemicals

Mechanoreceptors

- Sense physical deformation caused by forms of mechanical energy such as pressure, touch, stretch, motion and sound





Chemoreceptors

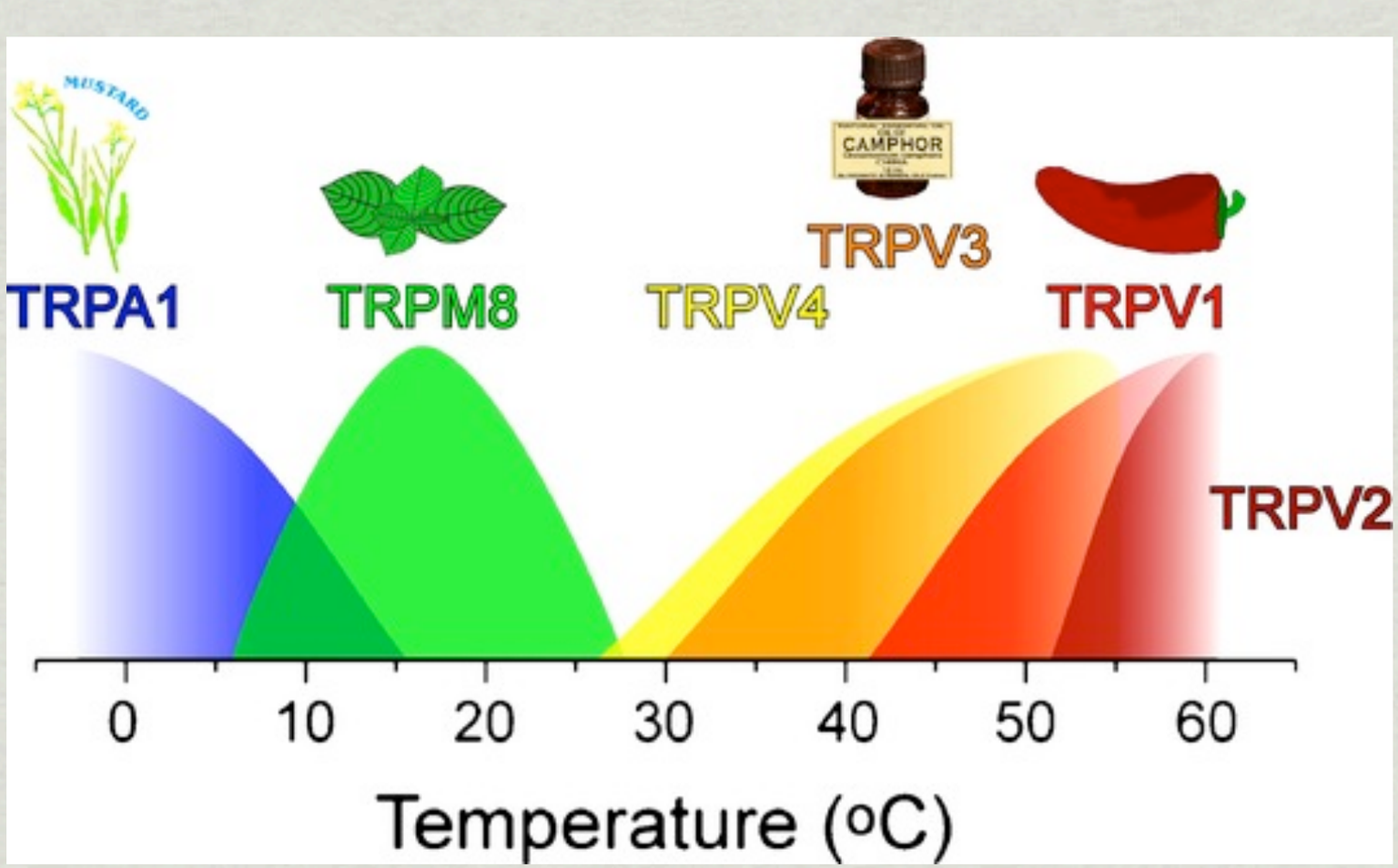
- Transmit information about specific molecules or total solute concentration.
  - Osmoreceptors in brain detect concentration of blood and generate perception of thirst if blood in concentrated
  - Many organisms have receptors for specific molecules such as oxygen, carbon dioxide, glucose and amino acids.

Electromagnetic Receptors

- Detect various forms of electromagnetic energy such as light, infrared, UV, electricity and magnetism.
  - Snakes detect infrared radiation.
  - Pigeons detect magnetic fields.
  - Platypus detects electric fields.

Thermoreceptors

- Detect heat and cold.
  - Mammals have different kinds of thermoreceptors that belong to a family of receptors called “TRP’s”
  - Each TRP receptor detects a different temperature range.



Photoreceptors

- Detect wavelengths of visible light: Roy G. Biv
  - Rods and cones detect light in vertebrates.

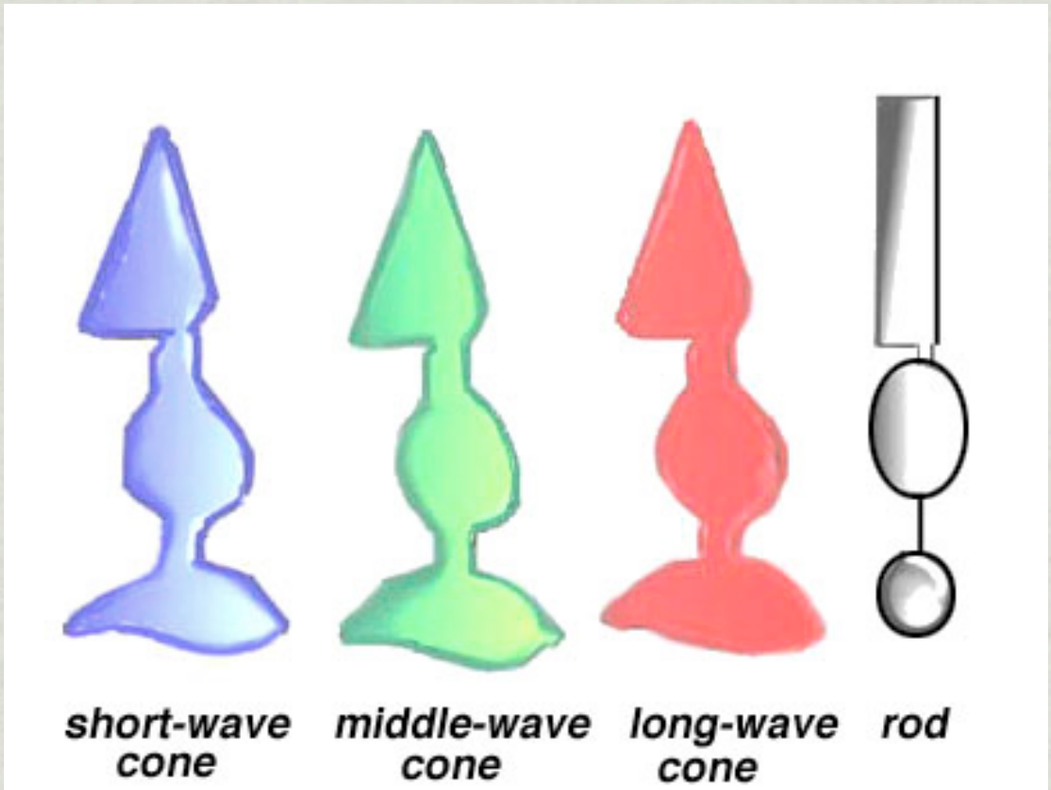


Fig. 13. There are four photoreceptor types in the human retina. Short-wavelength cones (blue), medium wavelength cones (green), long wavelength cones (red) and rods.

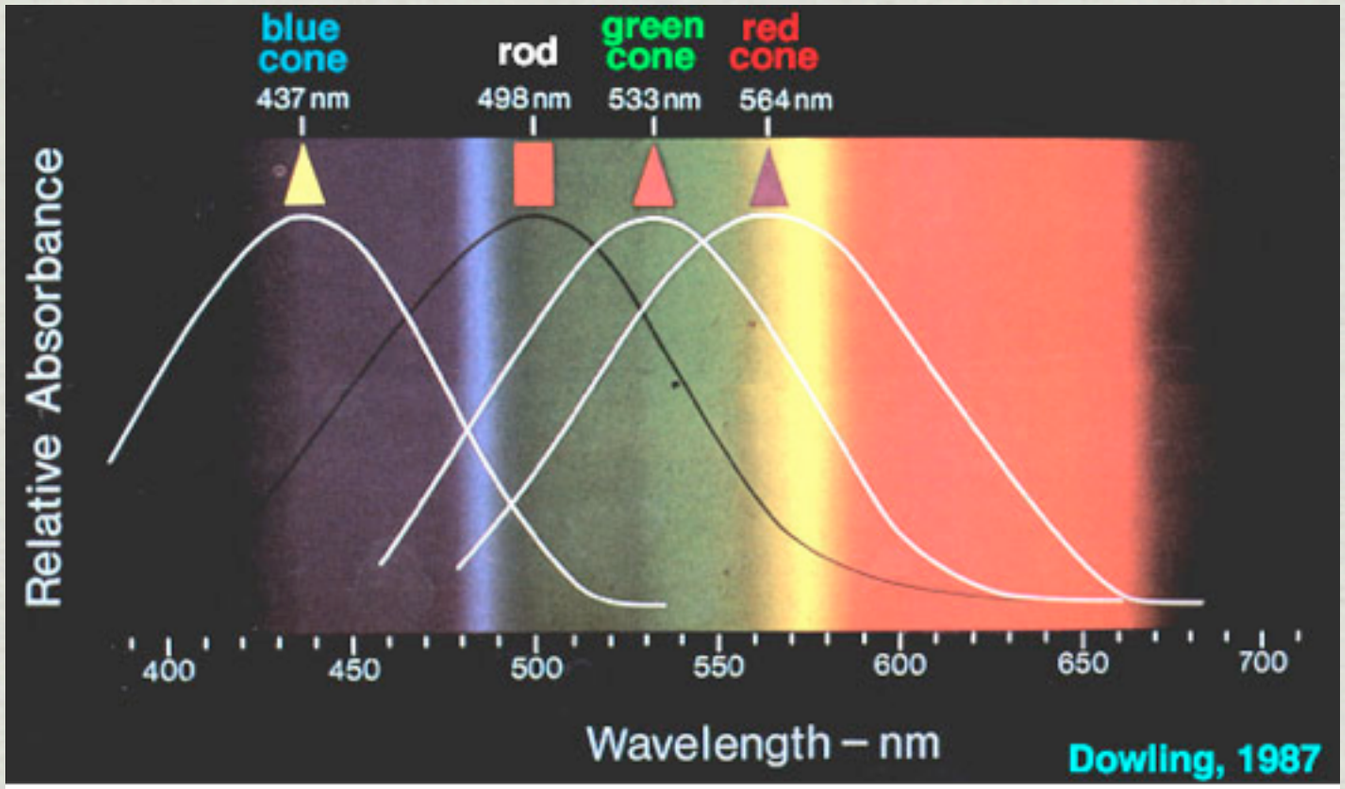


Fig. 14.The peak spectral sensitivities of the the 3 cone types and the the rods in the primate retina (Brown and Wald, 1963). From Dowling's book (1987).

Nociceptors (Pain Receptors)

- Detect extremes: temperature, pressure, heat or chemicals.
  - Many of the other receptors can act as a pain receptors in cases of extreme stimuli.
- Pain is an important defensive trigger as it cause the organism to withdraw from danger

Receptors Outside of Higher Organisms

- All cells and all multicellular organisms have receptors able to detect mechanical, chemical, electromagnetic and heat stimuli.
  - Bacteria can detect light stimuli using *bacteriorhodopsin* or *bacteriophytochrome* receptors, they also can detect chemicals
  - Plants can detect light stimuli using *phytochrome* receptors, they also can detect touch, gravity, chemicals

SENSORY PERCEPTION

- When the electrical impulse from the sensory cell(s) reaches the brain the neuronal circuits interpret this information and generate a perception.
- Perceptions include colors, sounds, tastes, smells
- **Perceptions are constructions formed in the brain and do not exist outside it!**

Receptors in Simple Organisms

RECALL...

- The main difference in simple and complex organisms lies in perception,complex animals create perceptions .
- Perceptions are interpreted. Interpretations lead to a variety of behaviors and responses
- **Simple organisms do not create perception but rather exhibit *taxis* and *tropisms*.**
  - **They simply move (taxis) towards or away from the stimulus or they grow (tropism) towards or away from stimuli.**

Life's Common Challenges

Introduction Transduction & Transmission

Main Idea

- ***Although receptors detect certain stimuli this detection is not enough alone to warrant a response.***

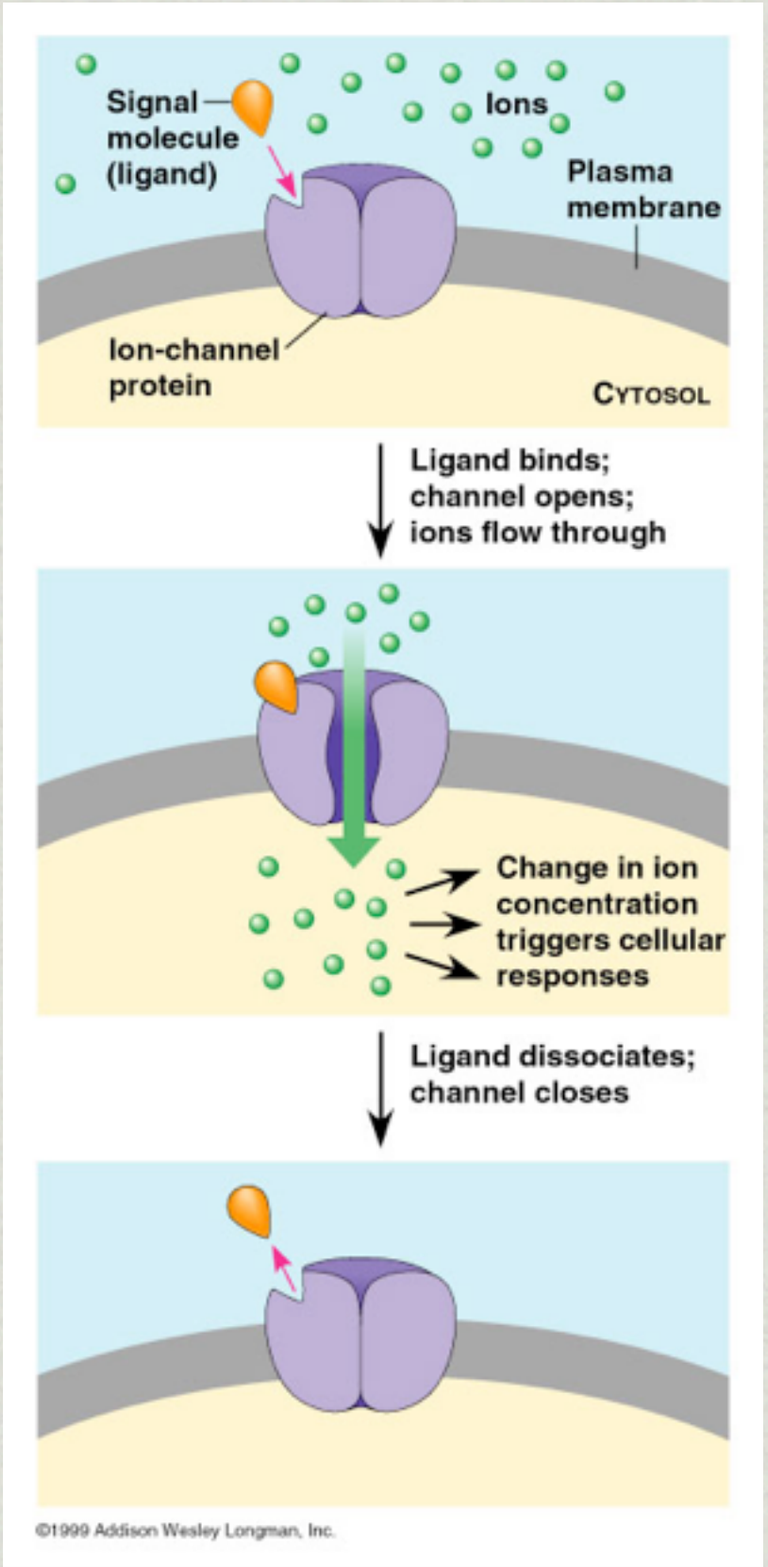
- First, the the detected stimulus must be converted or transduced so that a change in membrane potential results in the receptor cell.

- Secondly, this membrane potential must be transmitted to the effector cells.

- You might also recall that many responses occur at the cellular level, but again this unit will focus on responses at the organismal level.

SENSORY TRANSDUCTION

- The conversion of a physical or chemical stimulus to change in membrane potential of the cell with the sensory receptor.
- This is necessary for both unicellular and multicellular organisms



SENSORY TRANSMISSION

- Changing the membrane potential of the sensory cell initiates the action potential (electrical impulse) to the central nervous system.
- In other words the sensory cell must tell the brain that it received the stimulus
- Obviously this would not need to take place in a unicellular organism because the changing potential would be the message itself.

Animals

Sensory Transduction & Transmission

INFORMATION PROCESSING

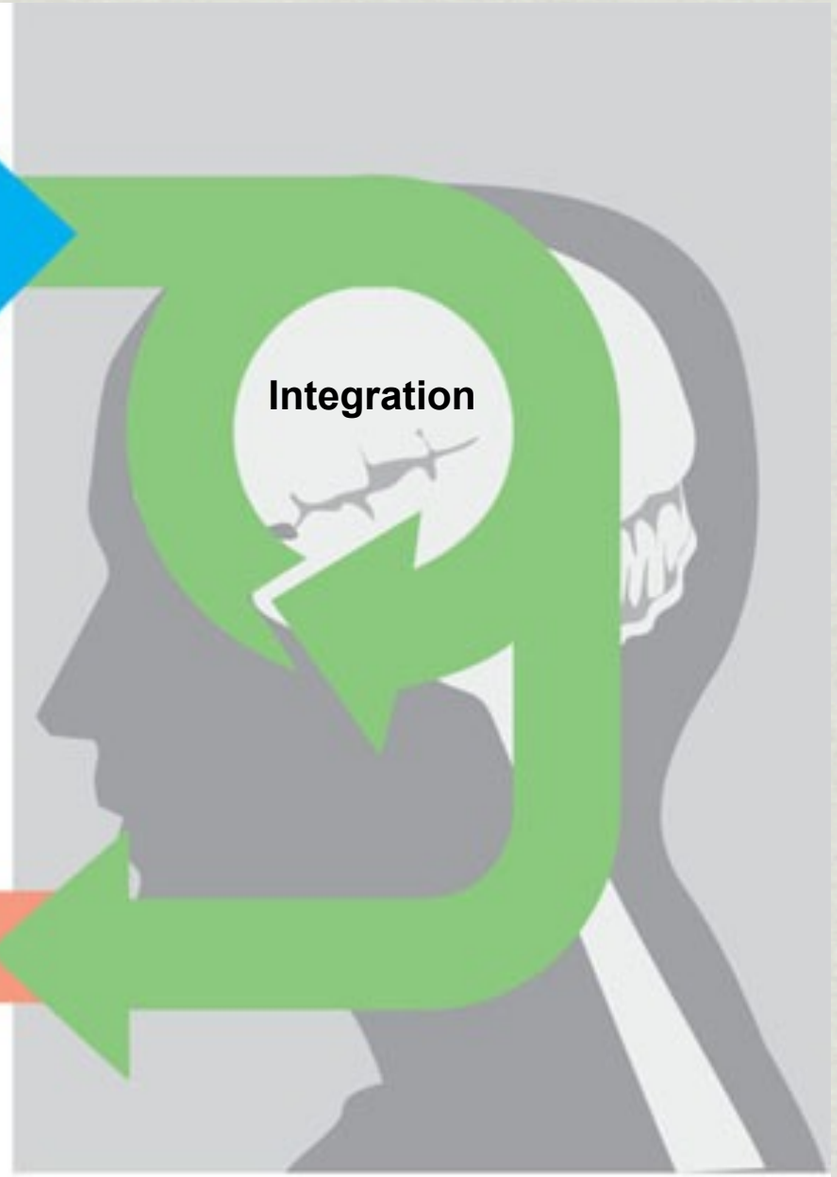
Sensor

Effector

Sensory input

IN GENERAL

Motor output



Peripheral nervous system (PNS)

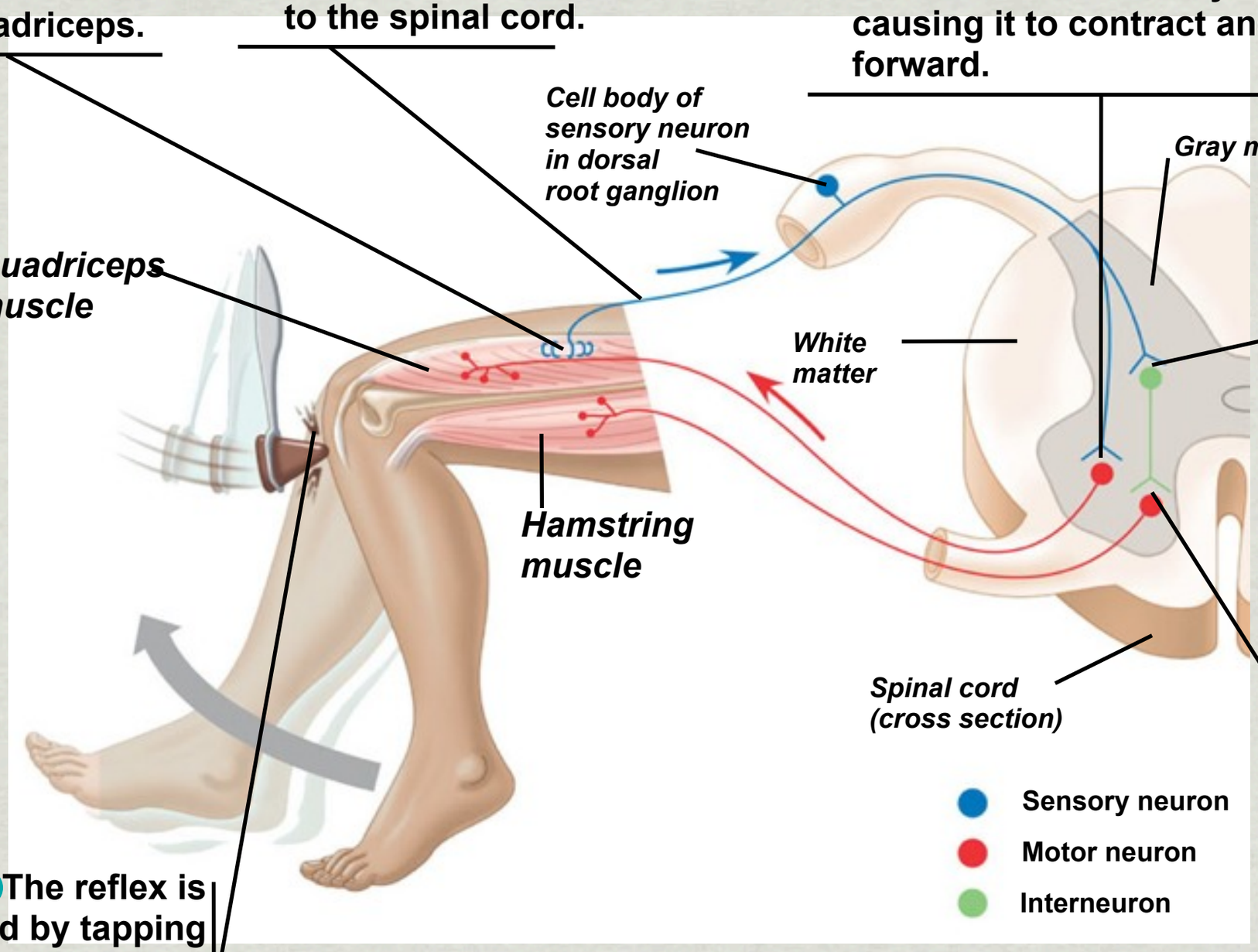
Central nervous system (CNS)

INFORMATION PROCESSING

2 Sensors detect a sudden stretch in the quadriceps.

3 Sensory neurons convey the information to the spinal cord.

4 The sensory neurons communicate with motor neurons that supply the quadriceps. The motor neurons convey signals to the quadriceps, causing it to contract and jerking the lower leg forward.



5 Sensory neurons from the quadriceps also communicate with interneurons in the spinal cord.

1 The reflex is initiated by tapping the tendon connected to the quadriceps (extensor) muscle.

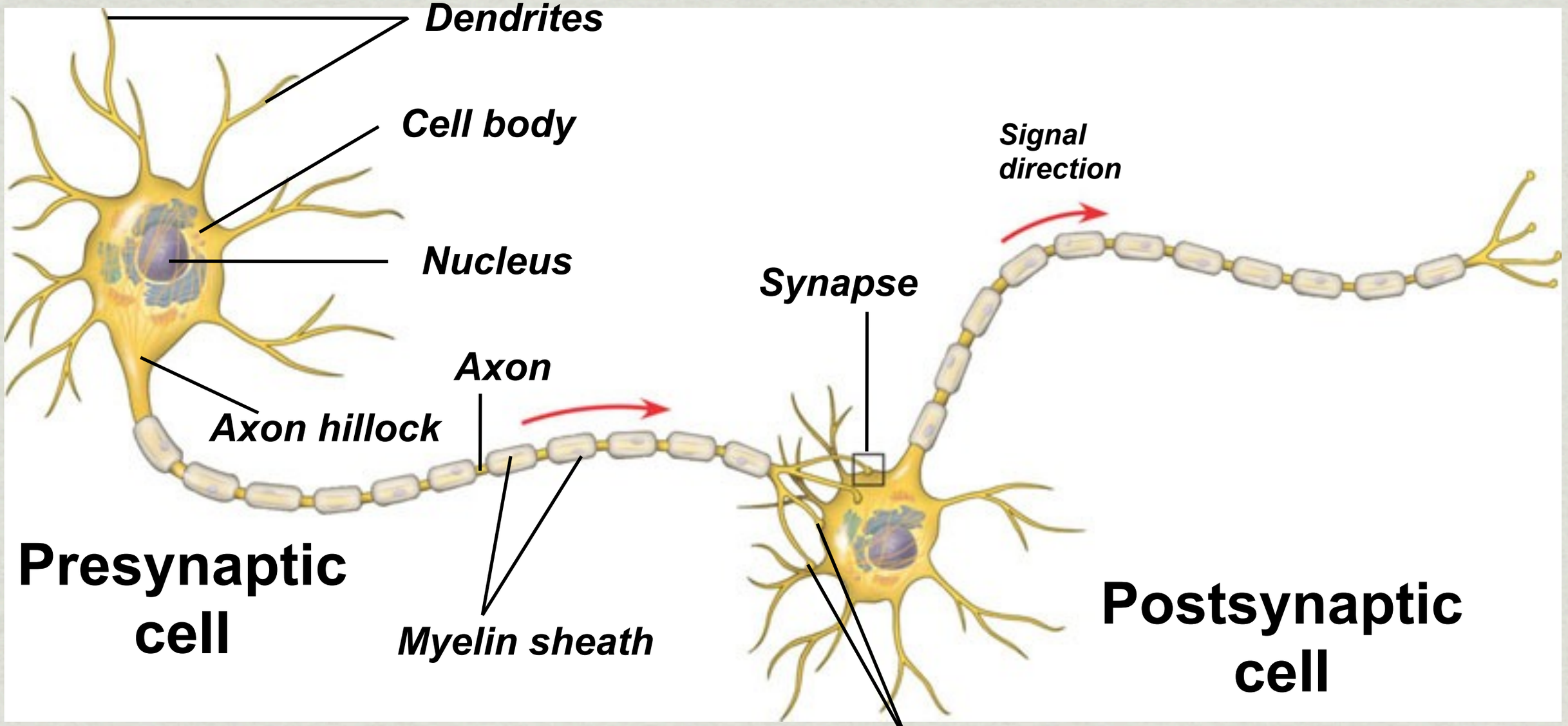
6 The interneurons inhibit motor neurons that supply the hamstring (flexor) muscle. This inhibition prevents the hamstring from contracting, which would resist the action of the quadriceps.

A SPECIFIC EXAMPLE

NEURONS: Structure & Function

- **Neurons are the functional units of nervous systems.**
  - **Neurons transmit signals from one location in the body to another .**
  - **The most striking feature about these cells are the fiber like extensions called projections (dendrites & axons)**
- As you might expect neuron structure varies according to its specific function but for this particular class we will.

Neuron: STRUCTURE



Neuron: STRUCTURE

- **Dendrite(s)-** receive incoming information
- **Cell Body-** contains nucleus and other organelles
- **Axon Hillock-** where cell body meets axon, generates electrical impulses
- **Axon-** conducts incoming information to the end of the neuron
- **Myelin Sheath-** insulating layer around axon, increases impulse speed
- **Synaptic Terminal(s)-** relays information to target cell
- **Synapse-** site where synaptic terminal meets target cell

Neuron: FUNCTION (resting potentials)

- **Every cell has a voltage or membrane potential across its membrane.**
- **Every cell is negatively charged inside relative to the outside.**
- **Ion pumps and channels are responsible for creating and maintaining the resting potential**
- **Resting potentials exist in a neuron when it is NOT sending impulses**

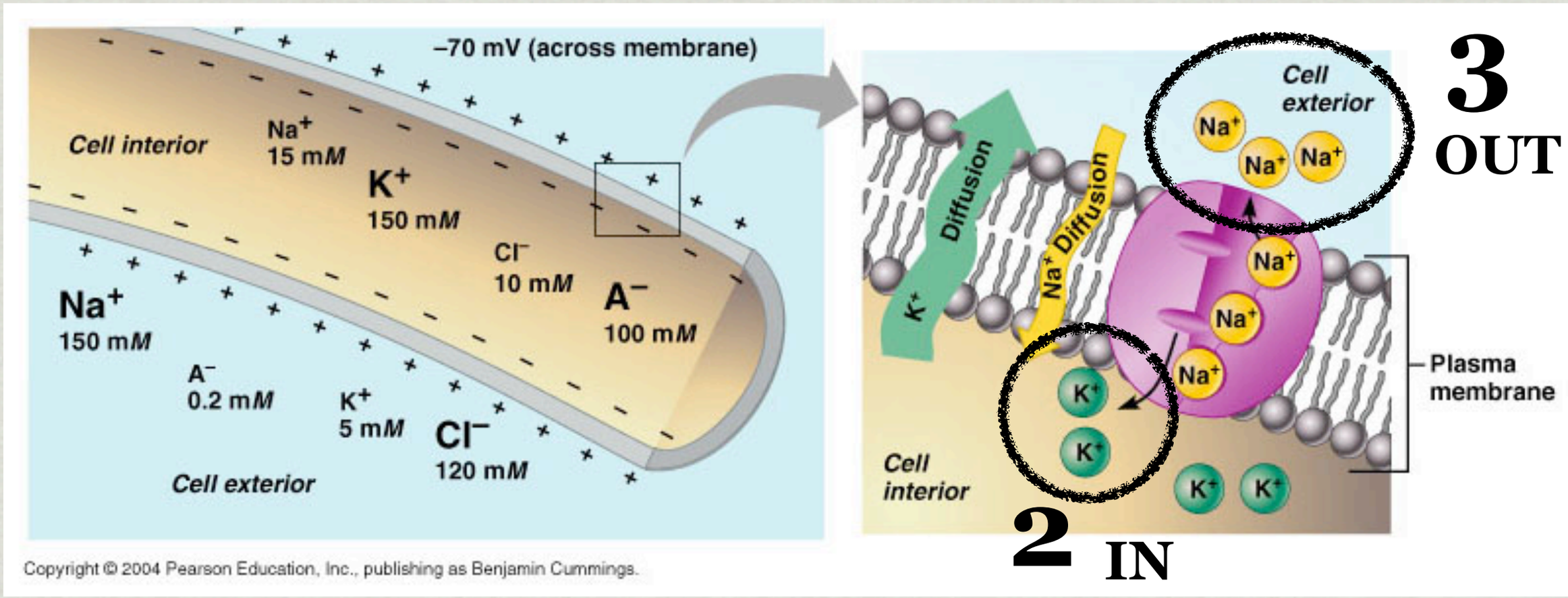
"Side Bar"

Electrical Potentials and Currents

- **electrophysiology** – cellular mechanisms for producing electrical potentials and currents
  - basis for neural communication and muscle contraction
- **electrical potential** – a difference in the concentration of charged particles between one point and another
- **electrical current** – a flow of charged particles from one point to another
  - in the body, **currents** are movement of ions, such as Na^+ or K^+ through gated channels in the plasma membrane
  - gated channels are opened or closed by various stimuli
  - enables cell to turn electrical currents on and off
- living cells are polarized
- resting membrane potential (RMP) – charge difference across the plasma membrane
  - -70 mV in a resting, unstimulated neuron
  - negative value means there are more negatively charged particles on the inside of the membrane than on the outside

Neuron: FUNCTION (resting potentials)

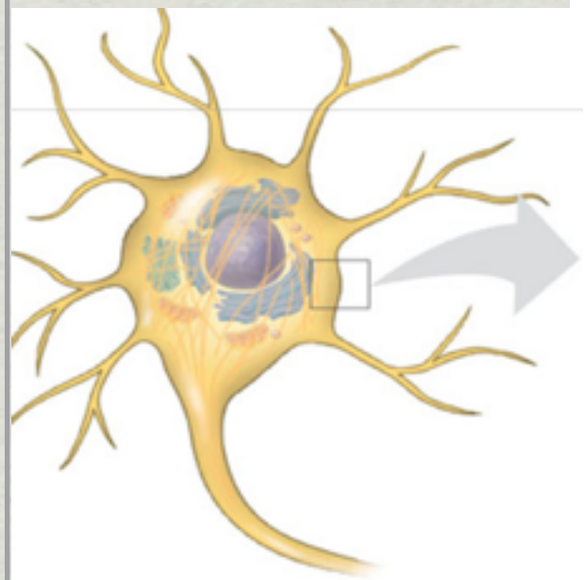
- **Resting potentials are generated and maintained by sodium/potassium ion pumps.**

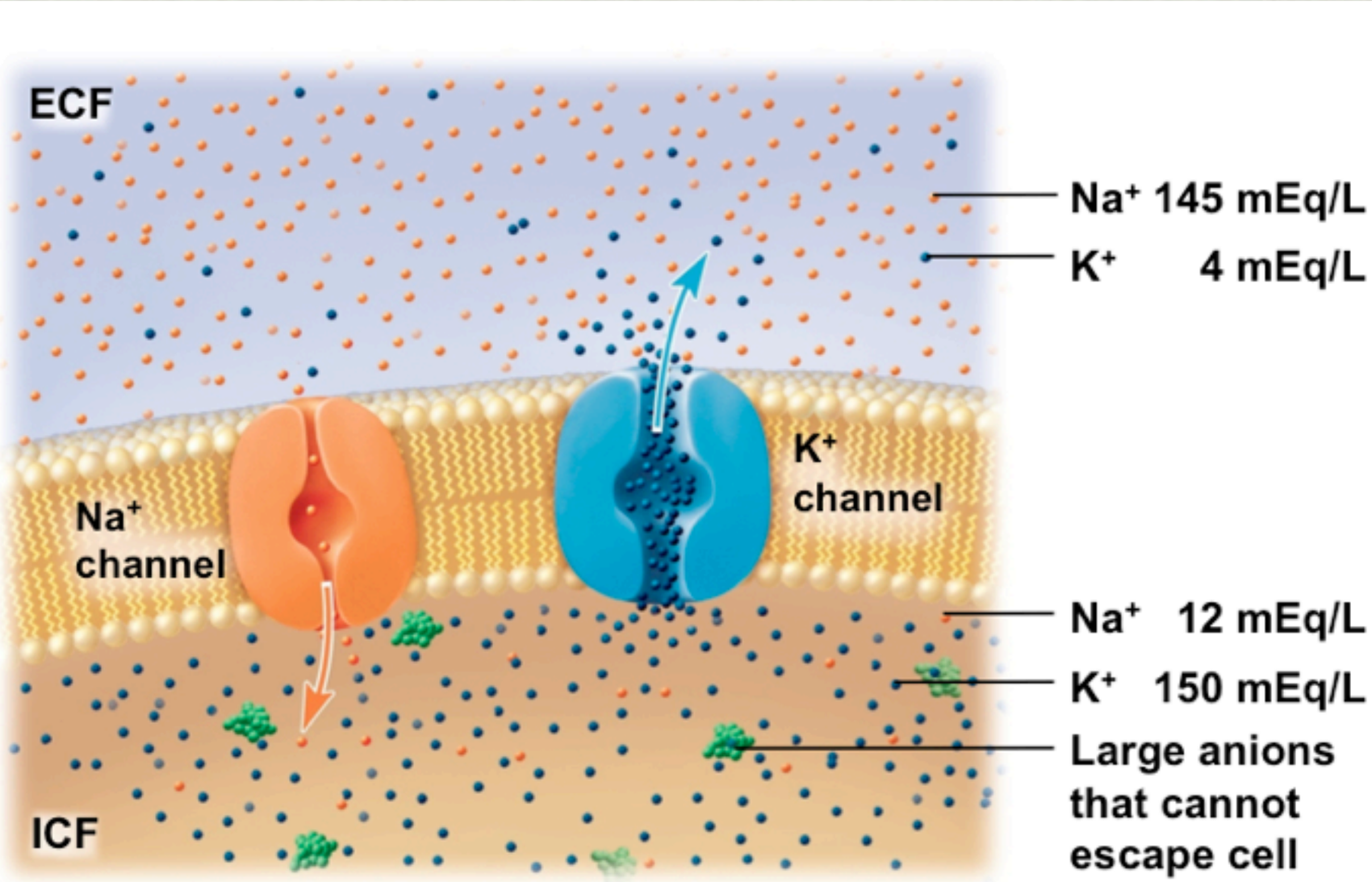


THE UNEQUAL TRANSPORT OF NA+ AND K+ RESULTS IN THE VOLTAGE ON THE LEFT

Neuron: FUNCTION (resting potentials)

- **Resting potentials depend on ionic gradients across a membrane.**





- Na^+ concentrated greater outside of cell (ECF)
- K^+ concentrated greater inside cell (ICF)

Neuron: FUNCTION (resting potentials)

Factors Contributing to the Creation of Resting Membrane Potential

- **cytoplasmic anions** can not escape
  - due to size or charge (phosphates, sulfates, small organic acids, proteins, ATP, and RNA)
  - All carry negative charges

- **potassium ions (K^+)** have the greatest influence on RMP
  - plasma membrane is more permeable to K^+ than any other ion
  - leaks out until electrical charge of cytoplasmic anions attracts it back in and equilibrium is reached and net diffusion of K^+ stops
  - K^+ is about 40 times as concentrated in the ICF as in the ECF

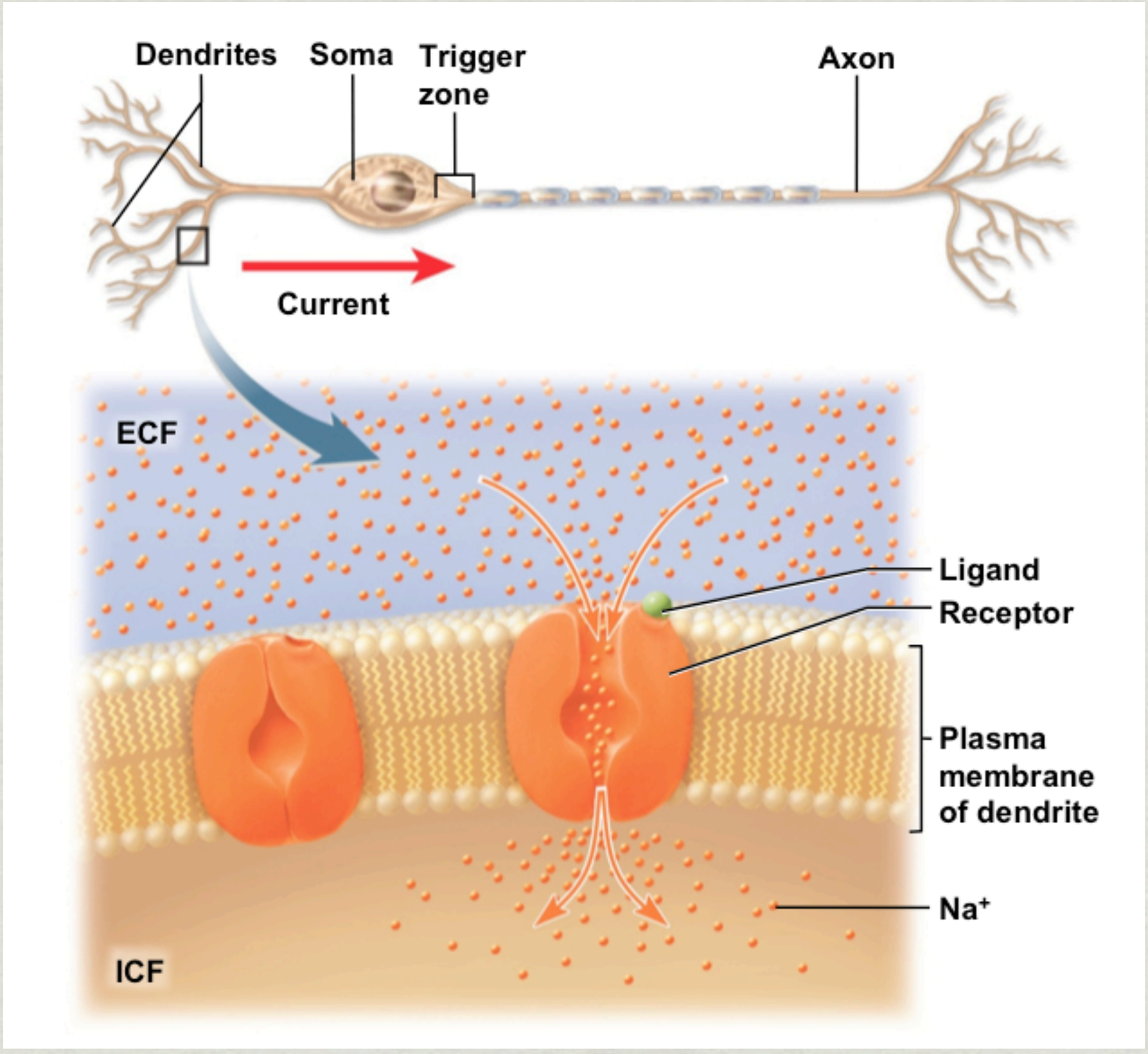
- membrane much less permeable to high concentration of **sodium (Na^+)** found outside the cell
  - some leaks and diffuses into the cell down its concentration gradient
  - Na^+ is about 12 times as concentrated in the ECF as in the ICF
  - resting membrane is much less permeable to Na^+ than K^+

- **Na^+/K^+ pumps** out 3 Na^+ for every 2 K^+ it brings in
  - works continuously to compensate for Na+ and K+ leakage, and requires great deal of ATP
  - 70% of the energy requirement of the nervous system
  - necessitates glucose and oxygen be supplied to nerve tissue (energy needed to create the resting potential)
  - pump contributes about -3 mV to the cell's resting membrane potential of -70 mV

Neuron: FUNCTION (local potentials)

- disturbances in membrane potential when a neuron is stimulated
- **neuron response** begins at the **dendrite**, spreads through the **soma**, travels down the **axon**, and ends at the **synaptic knobs**
- when **neuron is stimulated** by chemicals, light, heat or mechanical disturbance
  - opens the Na^+ gates and allows Na^+ to rush in to the cell
  - Na^+ inflow neutralizes some of the internal negative charge
  - voltage measured across the membrane drifts toward zero
  - depolarization
    - case in which membrane voltage shifts to a less negative value
    - Na^+ diffuses for short distance on the inside of the plasma membrane producing a current
    - travels towards the cell's trigger zone
    - this short-range change in voltage is called a **local potential**

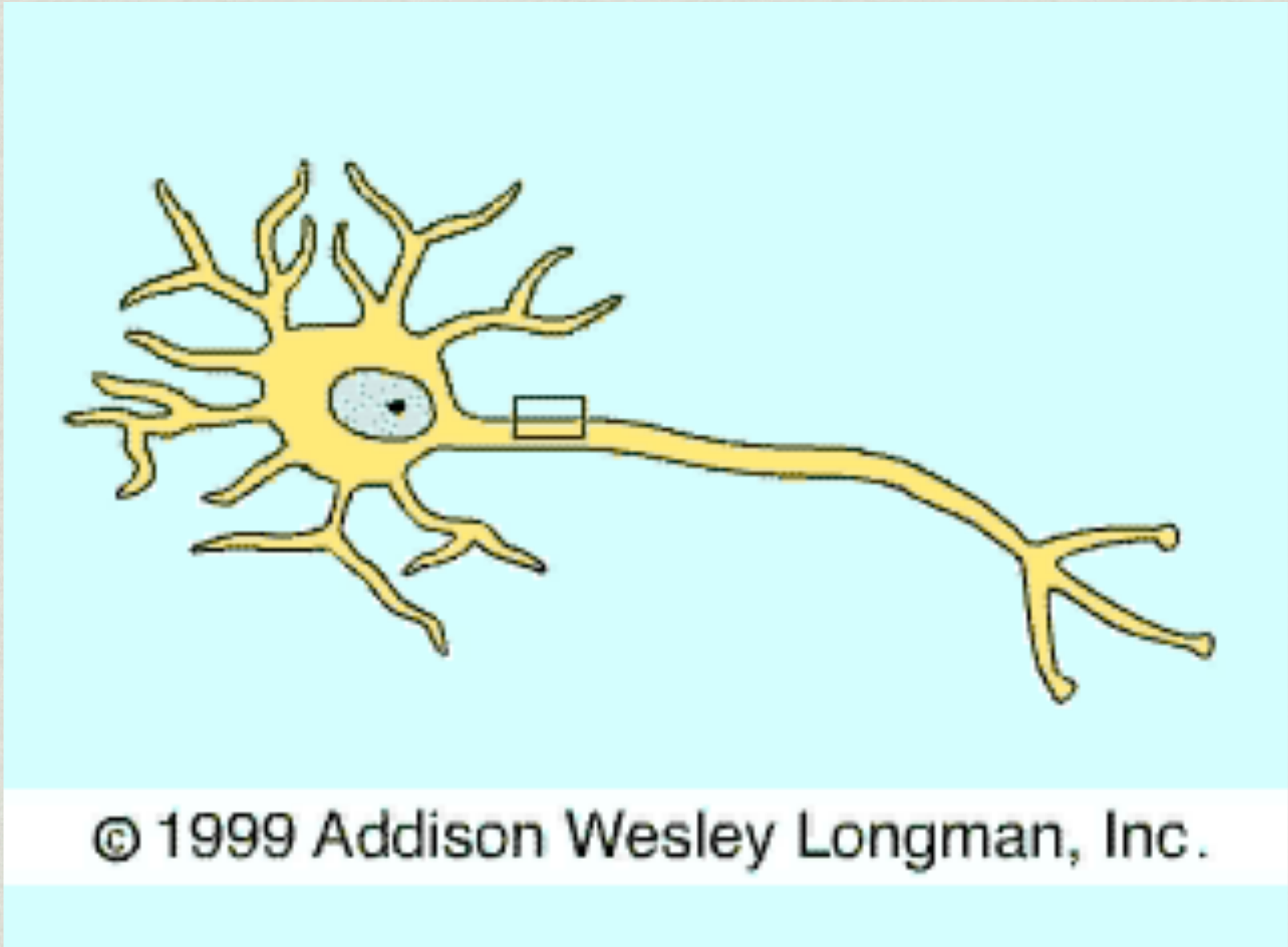
Excitation of a neuron by a chemical stimulus



Neuron: FUNCTION (action potentials)

- **Action potentials exist in a neuron when it IS sending impulses.**
- **It results in a rapid and dramatic change in ion concentrations.**
- **Voltage gated channels are responsible for the generation of action potentials.**
- **Action potentials do not exist unless threshold values are reached.**

Neuron: FUNCTION (action potentials)

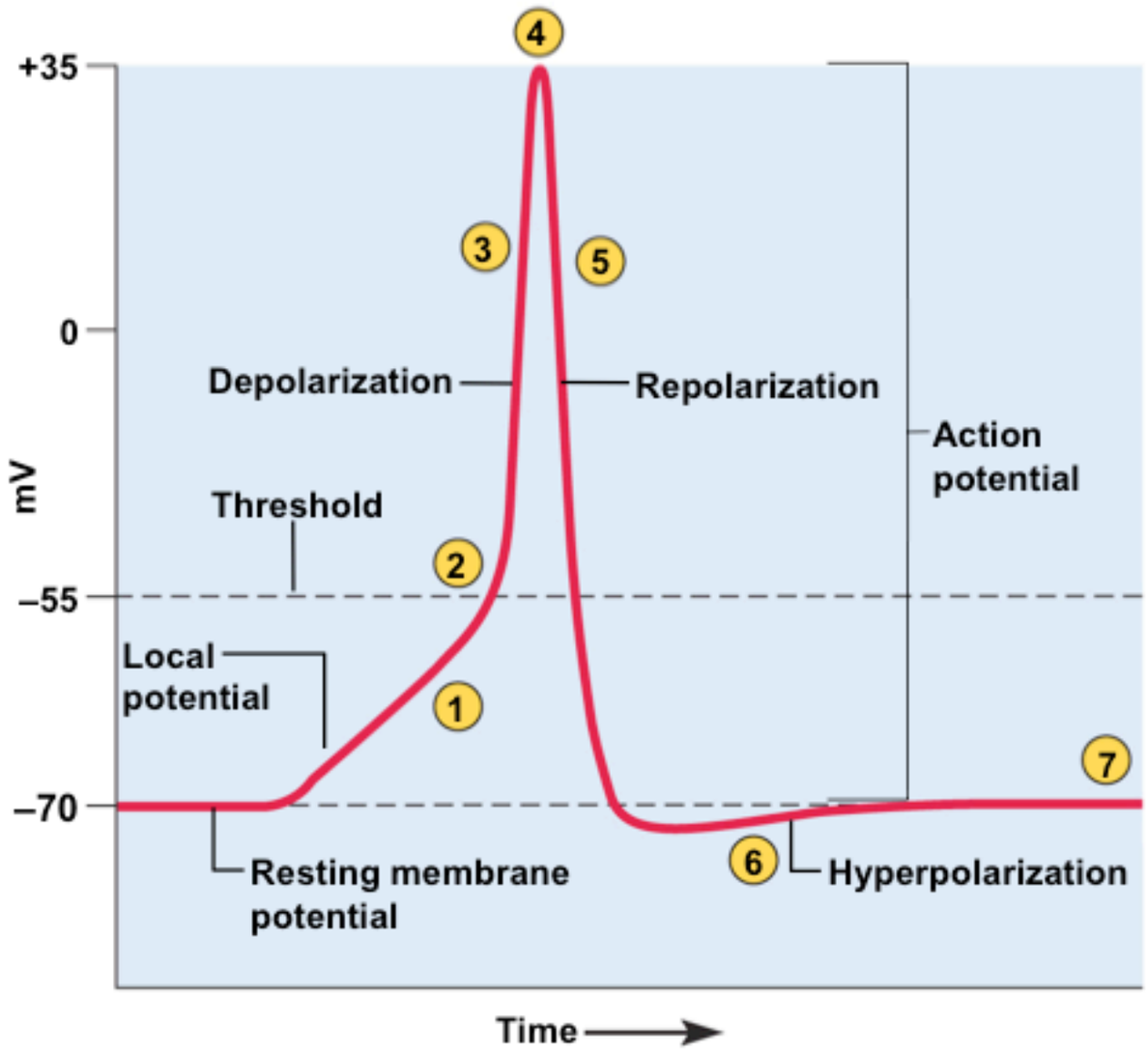


Neuron: FUNCTION (action potentials)

- When threshold is reached
  - neuron 'fires' and produces an action potential
  - more and more Na^+ channels open in in the trigger zone in a positive feedback cycle creating a rapid rise in membrane voltage – **spike**
  - when rising membrane potential passes 0 mV, Na^+ gates are inactivated
    - begin closing
    - when all closed, the voltage peaks at +35 mV
    - membrane now positive on the inside and negative on the outside
    - polarity reversed from RMP - **depolarization**
  - by the time the voltage peaks, the **slow K^+ gates** are fully open
    - K^+ repelled by the positive intracellular fluid now exit the cell
    - their outflow **repolarizes** the membrane
      - shifts the voltage back to negative numbers returning toward RMP
  - K^+ gates stay open longer than the Na^+ gates
    - slightly more K^+ leaves the cell than Na^+ entering
    - drops the membrane voltage 1 or 2 mV more negative than the original RMP – negative overshoot – **hyperpolarization** or **afterpotential**
  - Na^+ and K^+ switch "places" across the membrane during an action potential

Neuron: FUNCTION (action potentials)

- only a thin layer of the cytoplasm next to the cell membrane is affected
  - in reality, very few ions are involved
- action potential is often called a **spike** – happens so fast
- characteristics of action potential versus a local potential
  - **all-or-none law**
    - if threshold is reached, neuron fires at its maximum voltage
    - if threshold is not reached it does not fire
  - **nondecremental** - do not get weaker with distance
  - **irreversible** - once started goes to completion and can not be stopped

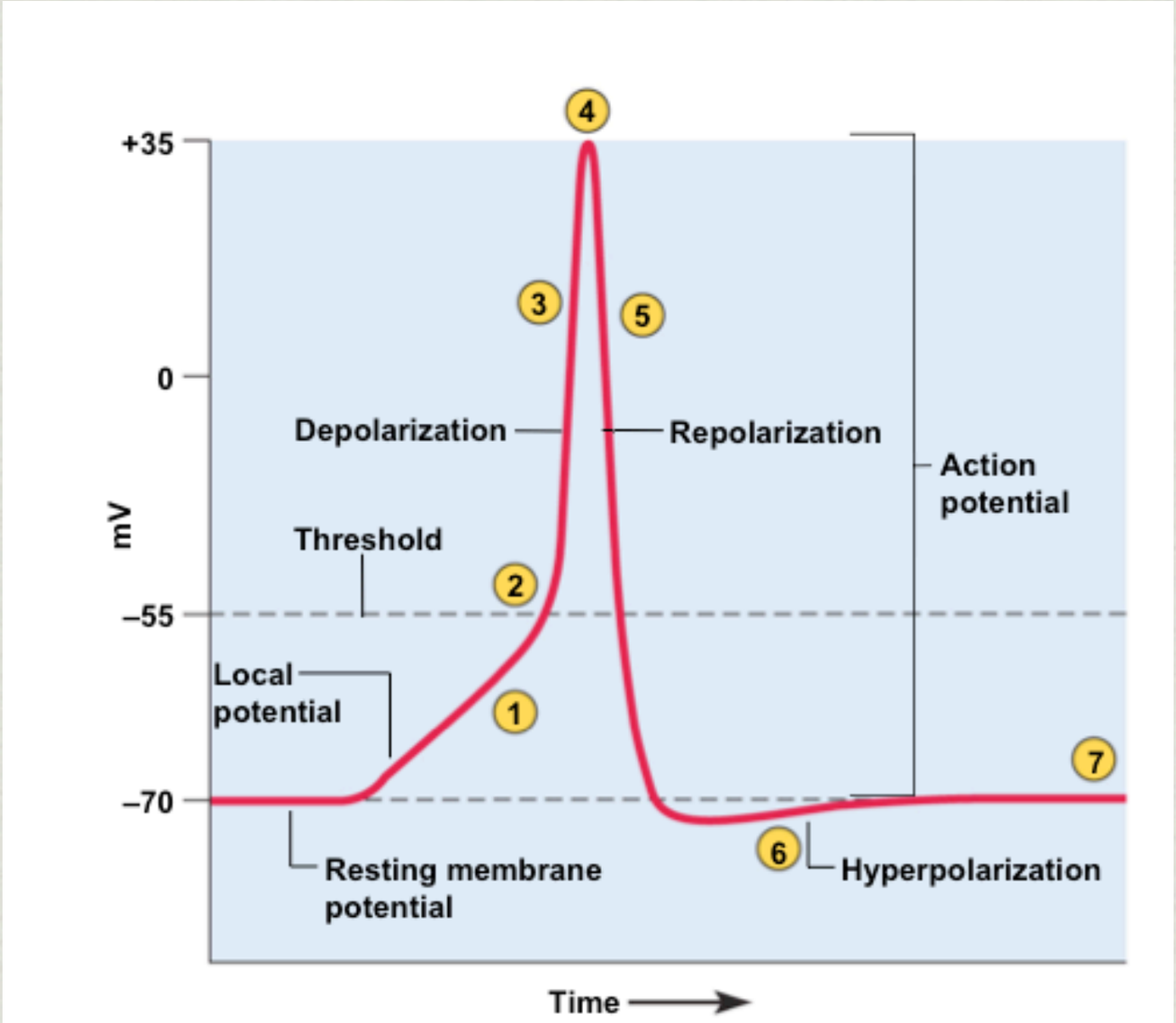


REVIEW- (action potentials)

1. Some Gated Na+ channels open

2. All Gated Na+ channels open, The K+ remained closed

3. Na+ ions rush inside the neuron



4. Gated Na+ channels begin to close as K+ channels begin to open

5. All Gated K+ channels open, The Na+ channels are now closed

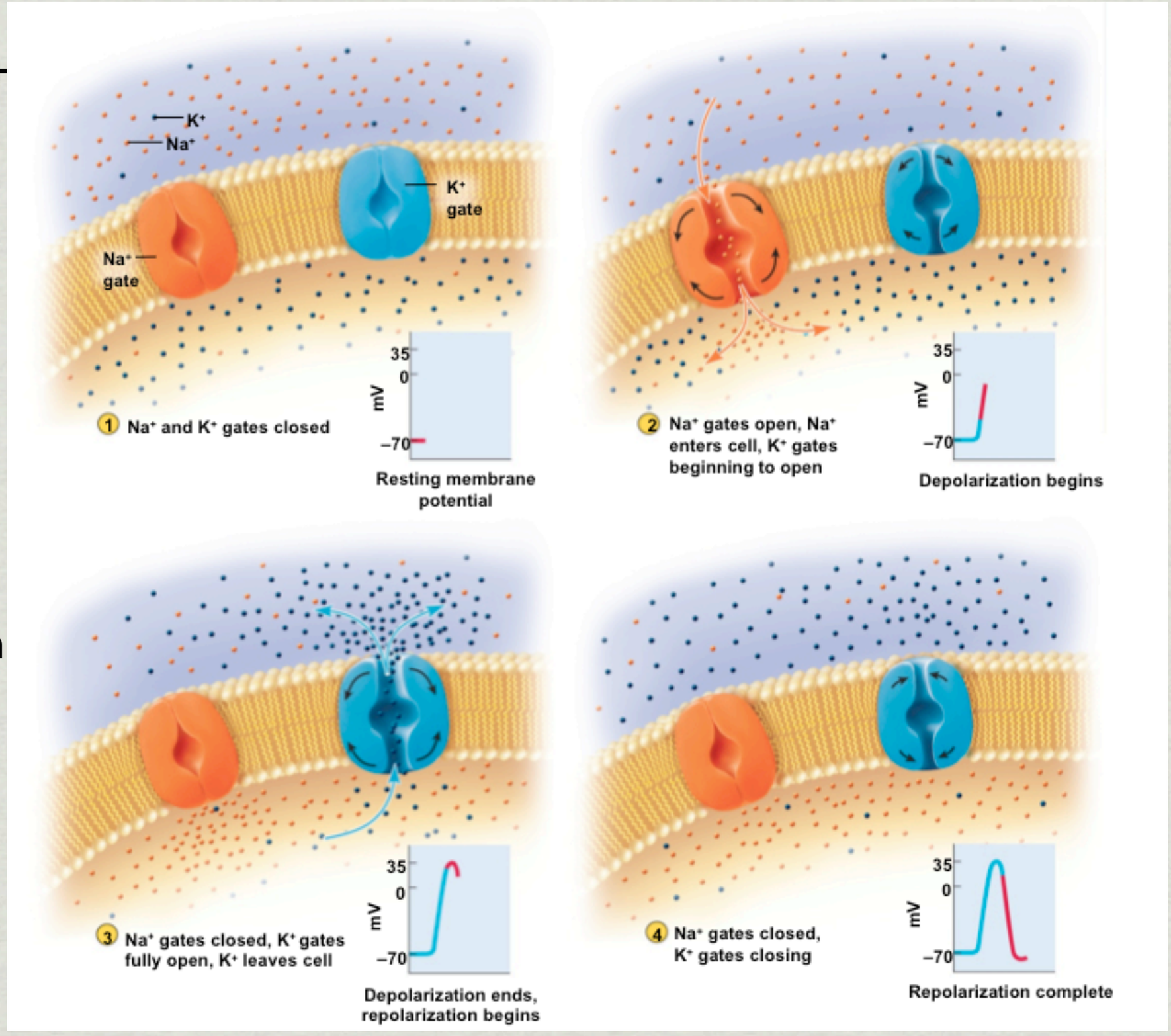
6. Gated K+ channels begin to close

7. All Gated Na+ channels closed, All K+ channels are closed

Neuron: FUNCTION (action potentials)

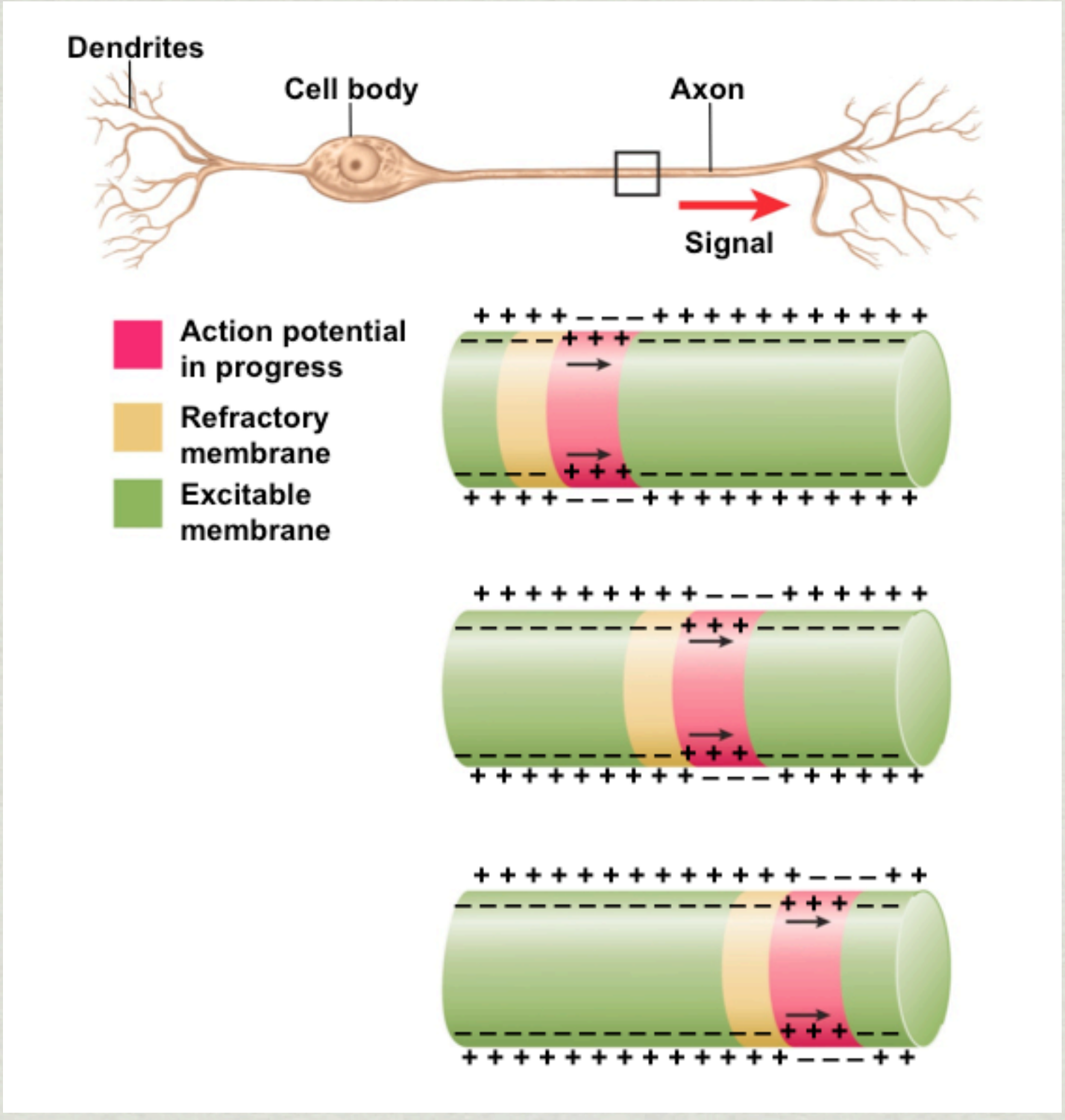
Remember the Na+/K+ pumps work continuously but they are not pictured here

A cool fact: the human body spends 33% of its total energy to run the Na+/K+ pumps



Neuron: (action potential conduction)

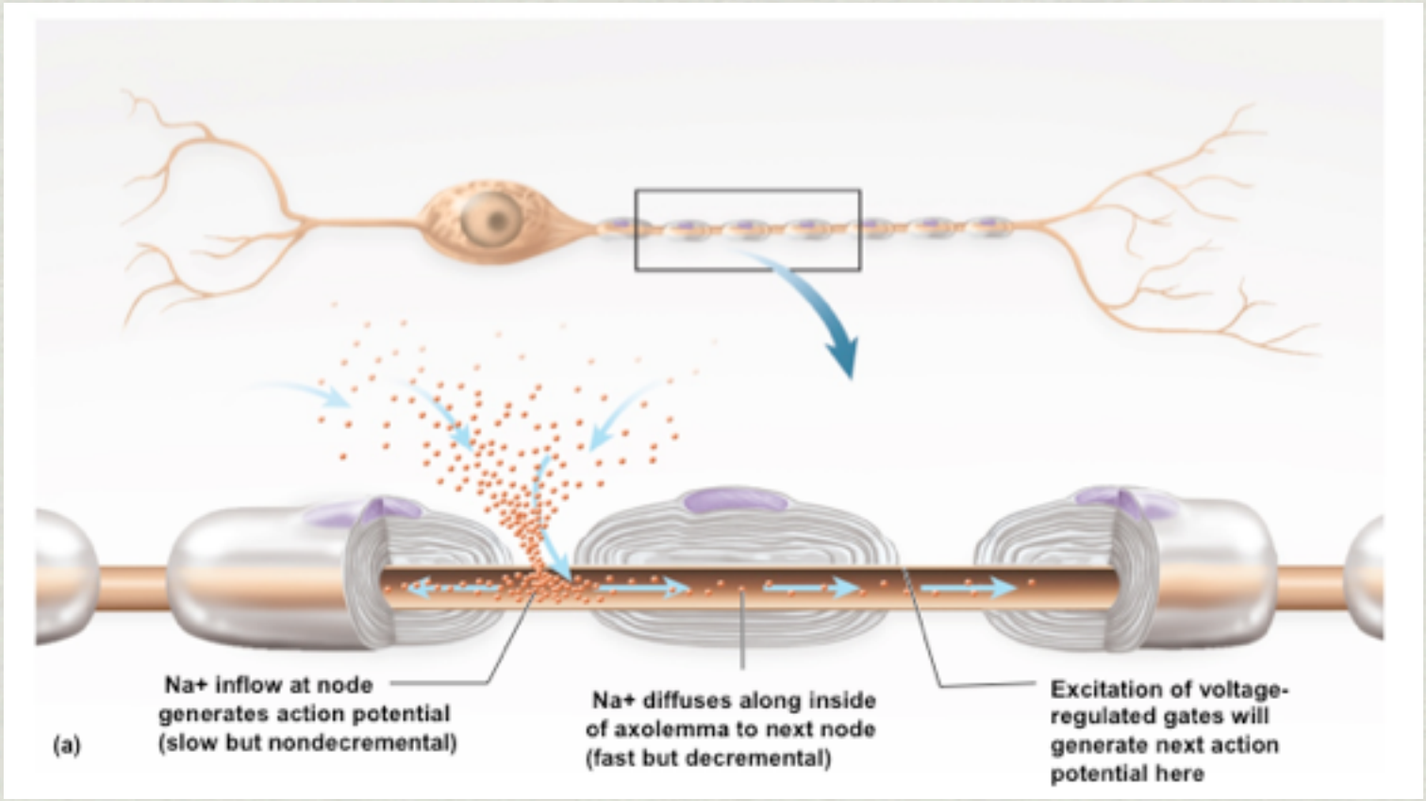
This example shows a neuron that is NOT myelinated!

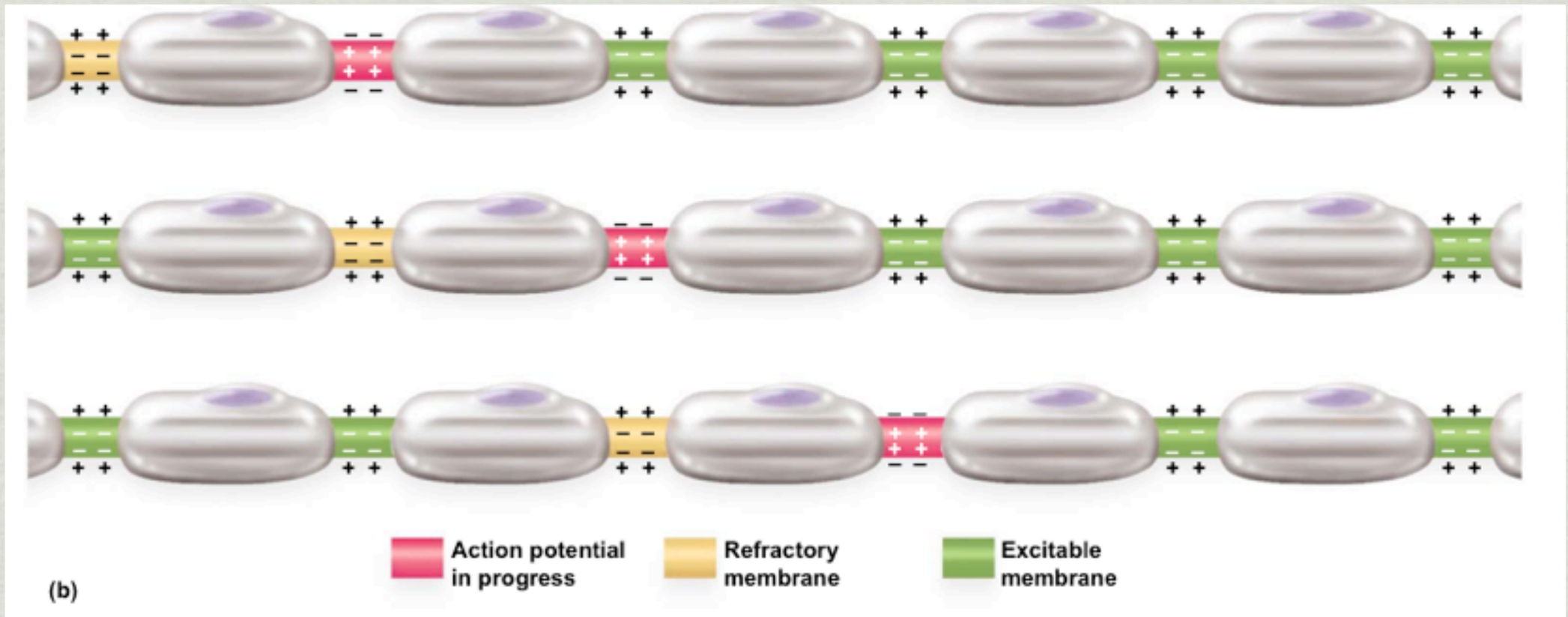


Neuron: (action potential conduction)

This example shows a neuron that IS myelinated!

Faster!

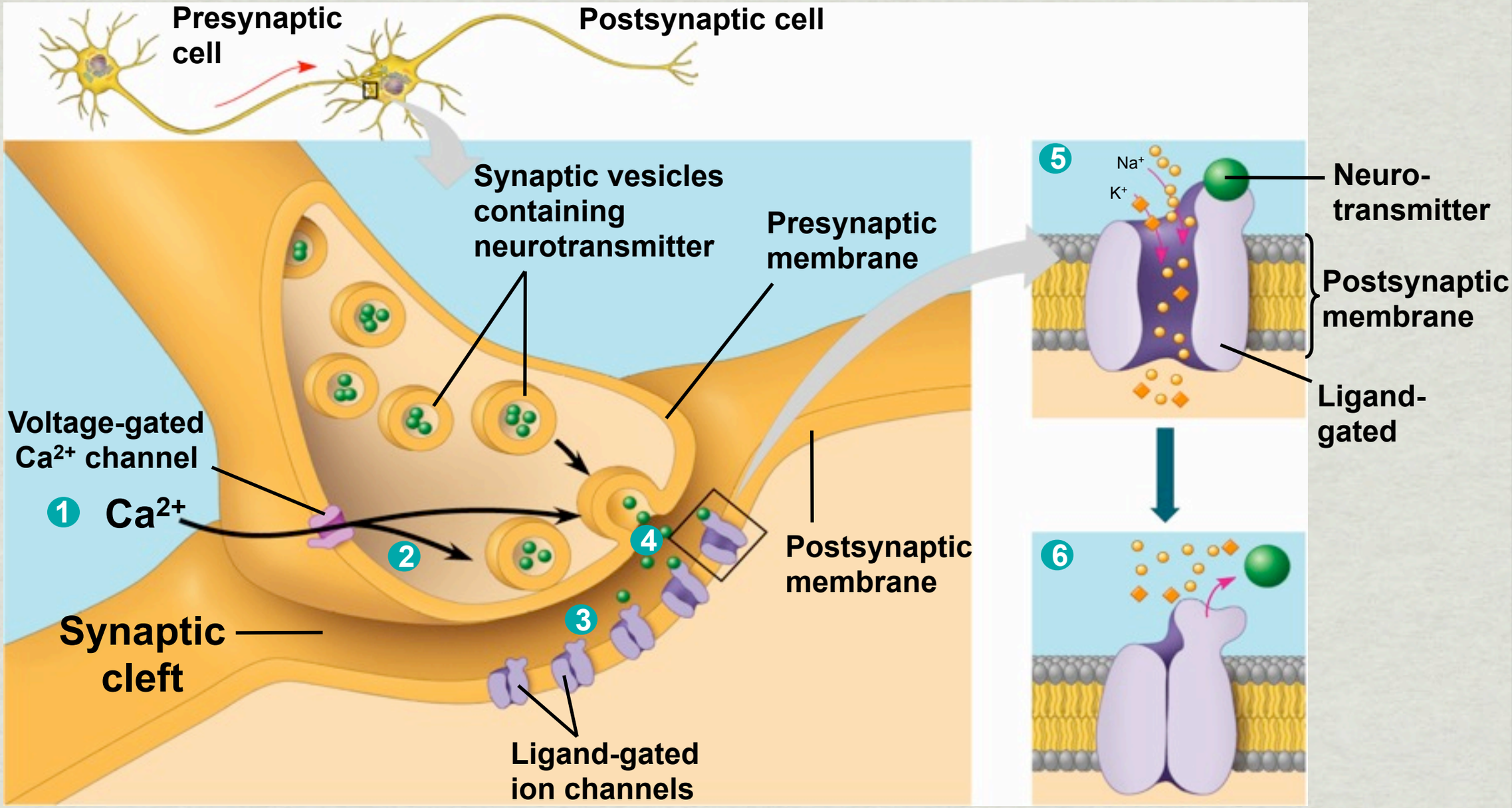




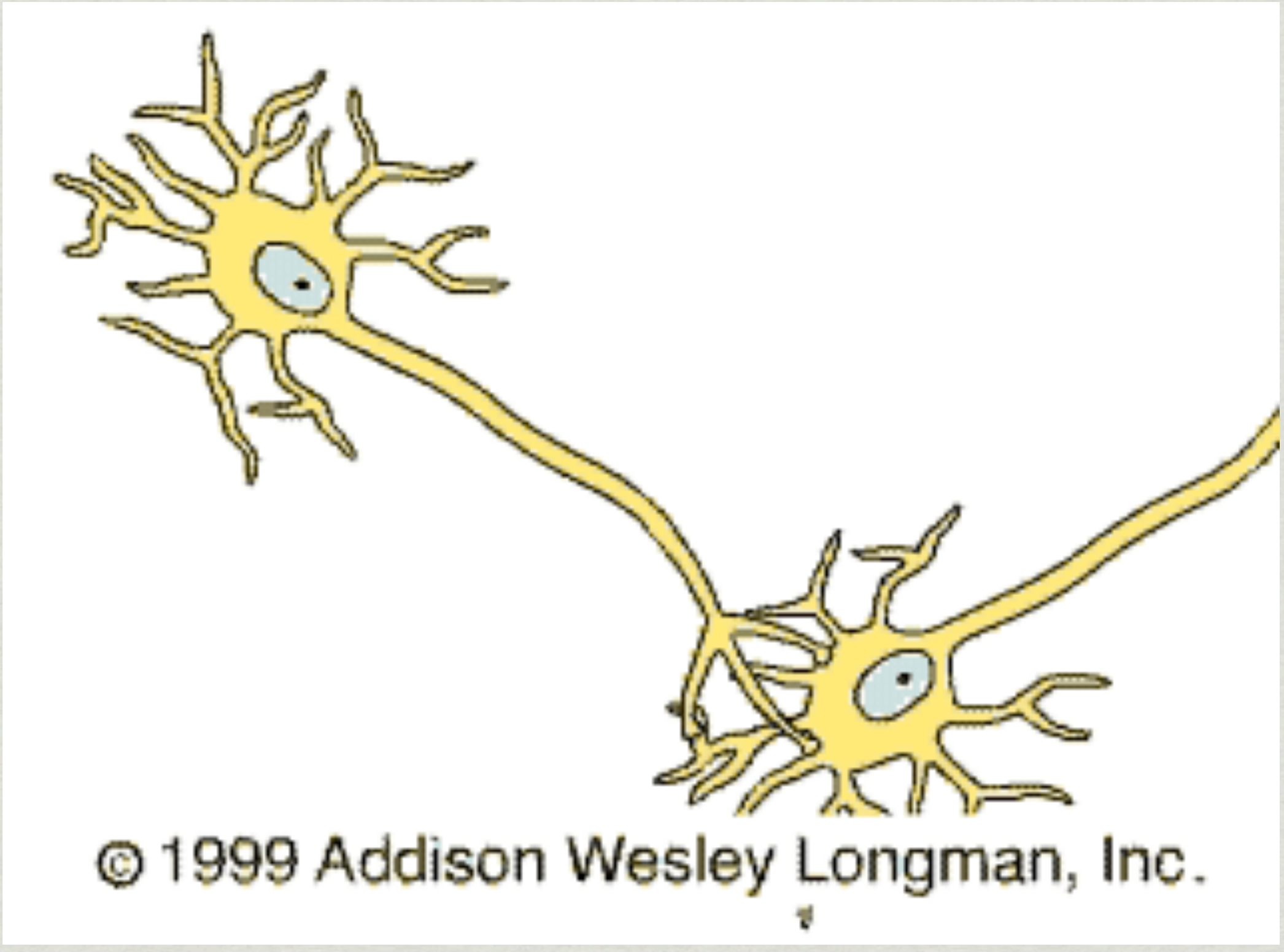
Neuron: FUNCTION (synaptic transmission)

- **Nerve cells communicate with other cells at synapses.**
- **An electric synapse occurs where the electrical impulse flows from one nerve cell through a gap junction into another nerve cell.**
- **A chemical synapse occurs where the electrical impulse reaches the end of one nerve cell, is converted to a chemical message that binds to an effector cell.**
  - **Effector cells include other nerves, muscles or glands**
  - **This type of synapse is more common.**

Neuron: FUNCTION (synaptic transmission)

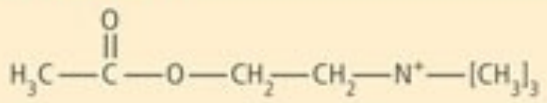
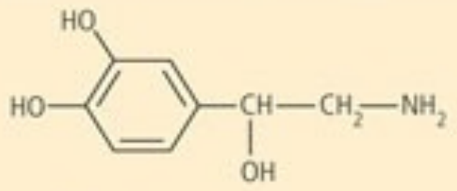
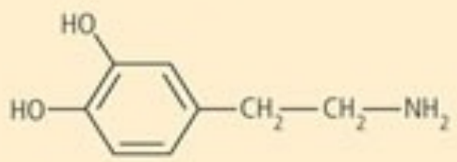
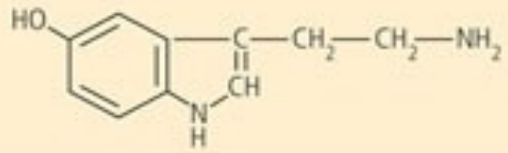
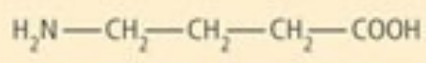
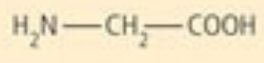
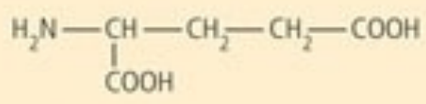
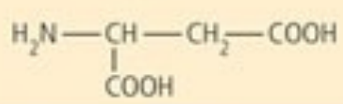


Neuron: FUNCTION (synaptic transmission)



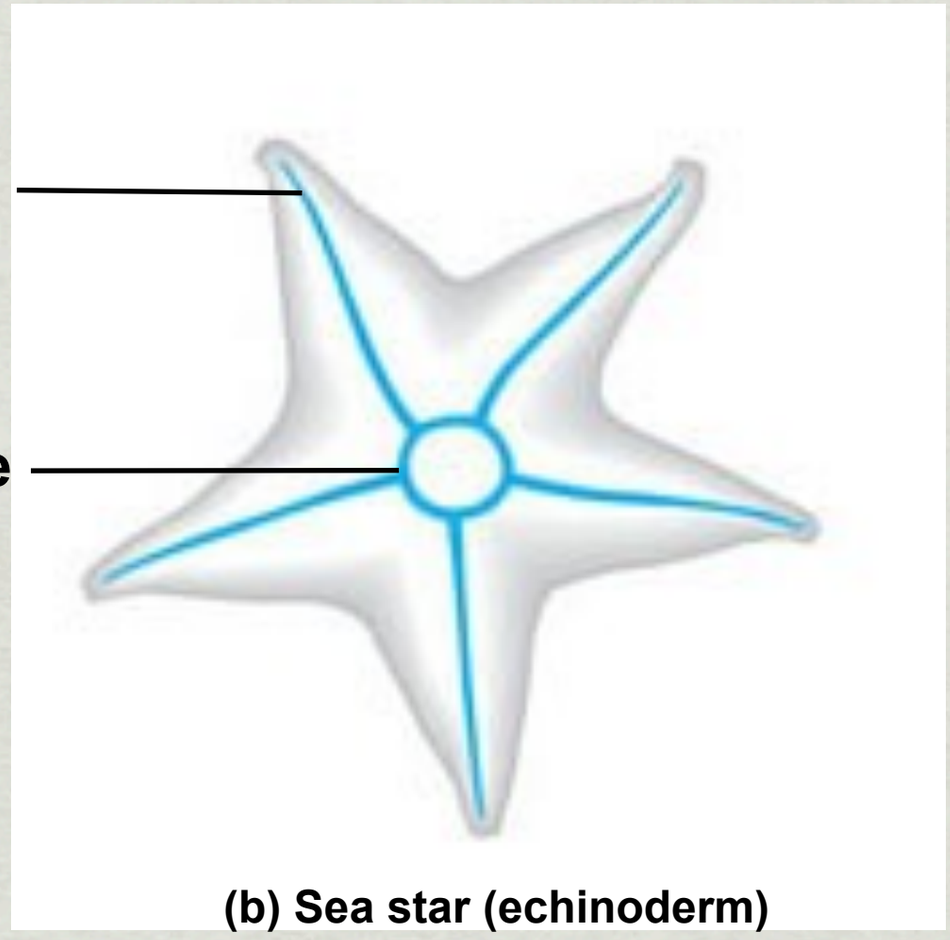
Neurotransmitters

Table 48.1 Major Neurotransmitters

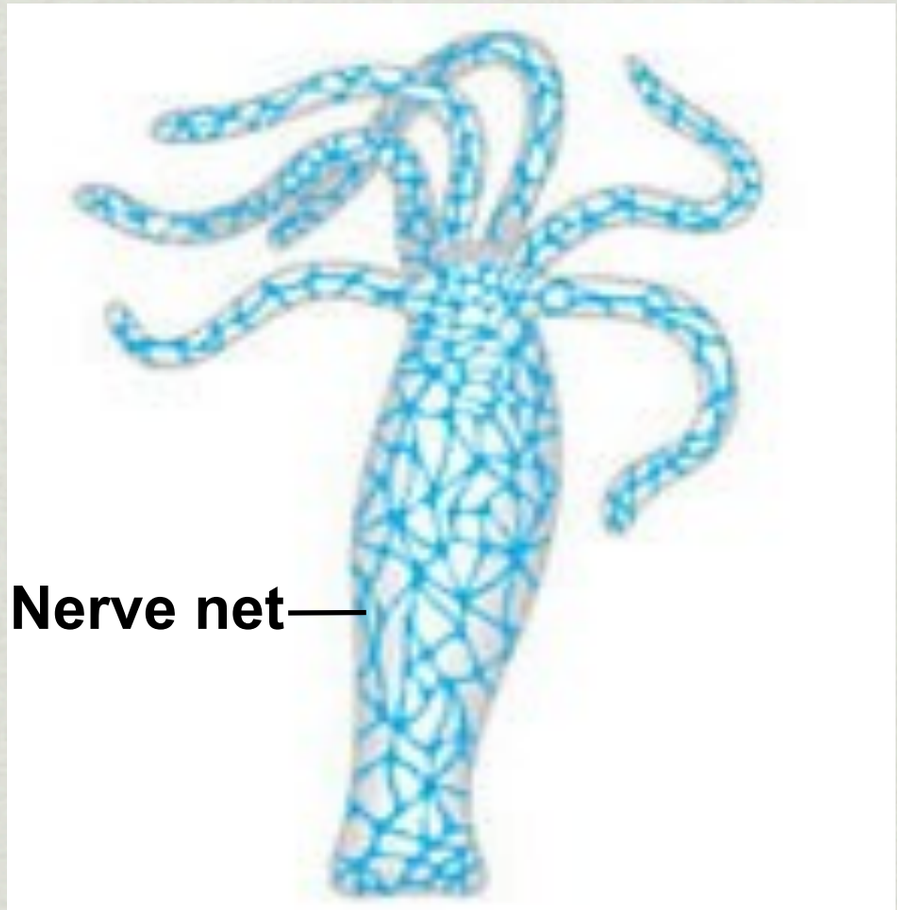
Neurotransmitter	Structure	Functional Class	Secretion Sites
Acetylcholine		Excitatory to vertebrate skeletal muscles; excitatory or inhibitory at other sites	CNS; PNS; vertebrate neuromuscular junction
Biogenic Amines			
Norepinephrine		Excitatory or inhibitory	CNS; PNS
Dopamine		Generally excitatory; may be inhibitory at some sites	CNS; PNS
Serotonin		Generally inhibitory	CNS
Amino Acids			
GABA (gamma aminobutyric acid)		Inhibitory	CNS; invertebrate neuromuscular junction
Glycine		Inhibitory	CNS
Glutamate		Excitatory	CNS; invertebrate neuromuscular junction
Aspartate		Excitatory	CNS
Neuropeptides (a very diverse group, only two of which are shown)			
Substance P	Arg—Pro—Lys—Pro—Gln—Gln—Phe—Phe—Gly—Leu—Met	Excitatory	CNS; PNS
Met-enkephalin (an endorphin)	Tyr—Gly—Gly—Phe—Met	Generally inhibitory	CNS

Organization of Nervous Systems

- **The simplest nervous systems have neurons arranged in neural nets.**



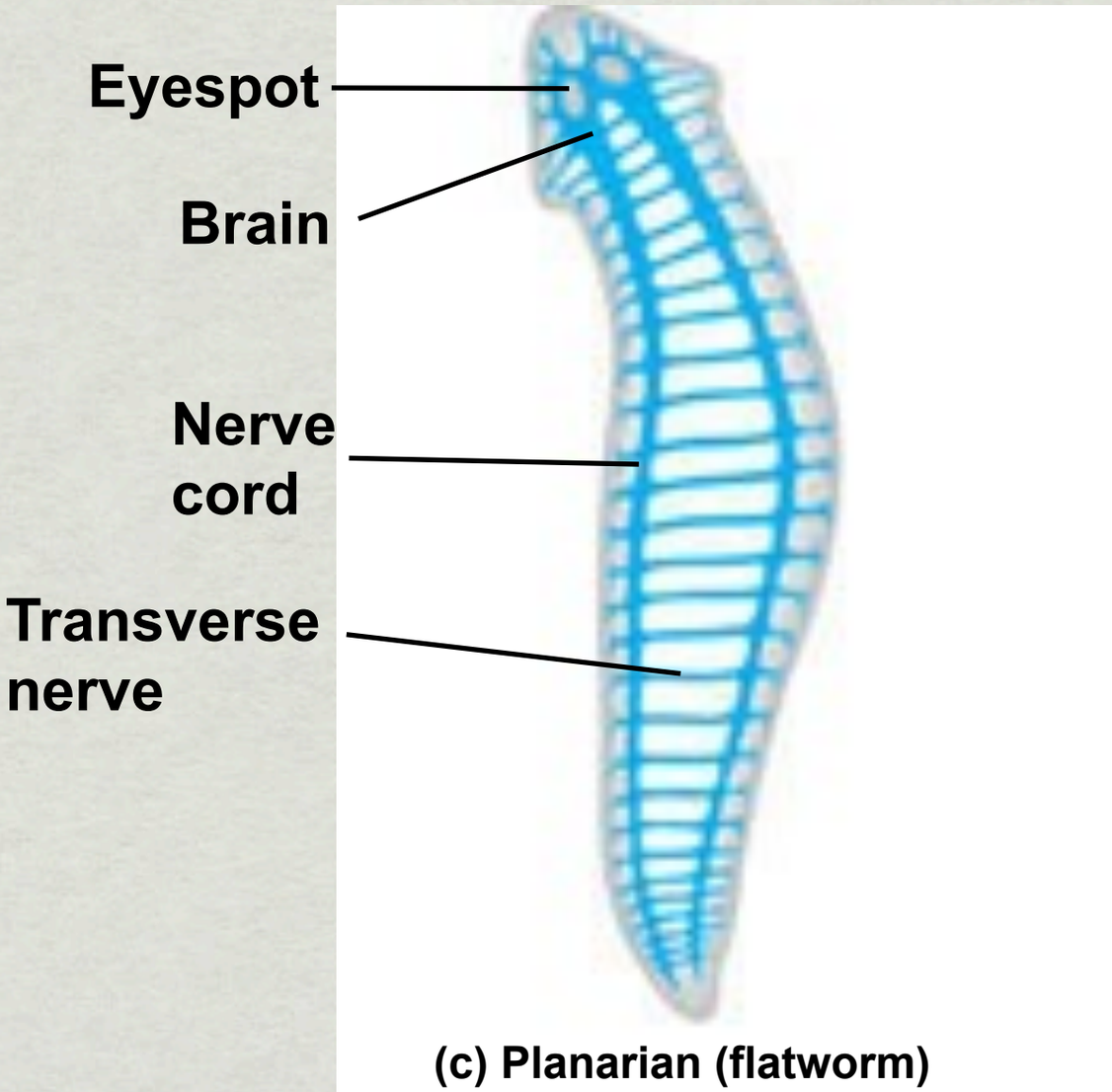
(b) Sea star (echinoderm)



(a) Hydra (cnidarian)

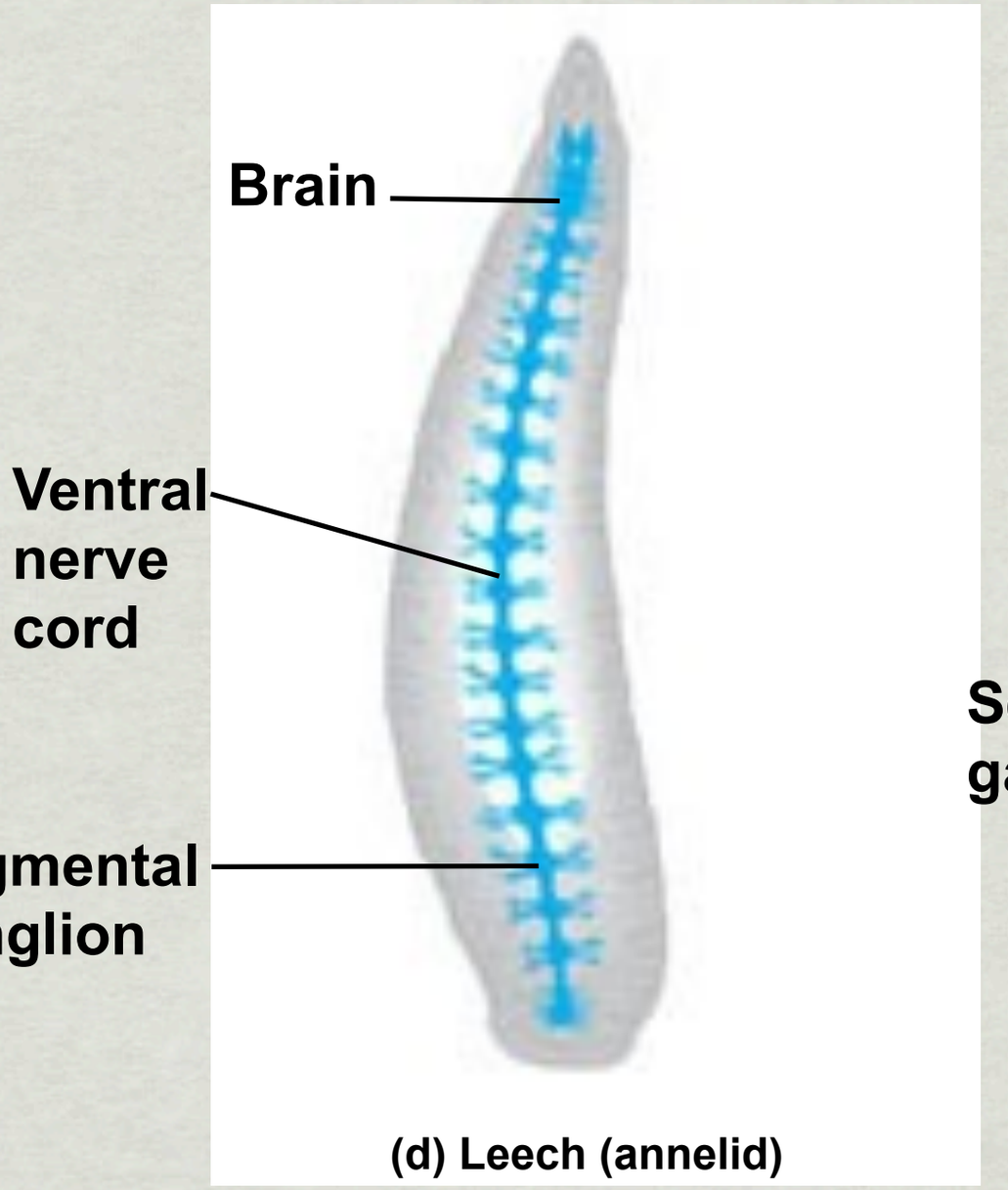
Organization of Nervous Systems

- **In simple cephalized (head) animals a central nervous system is evident.**

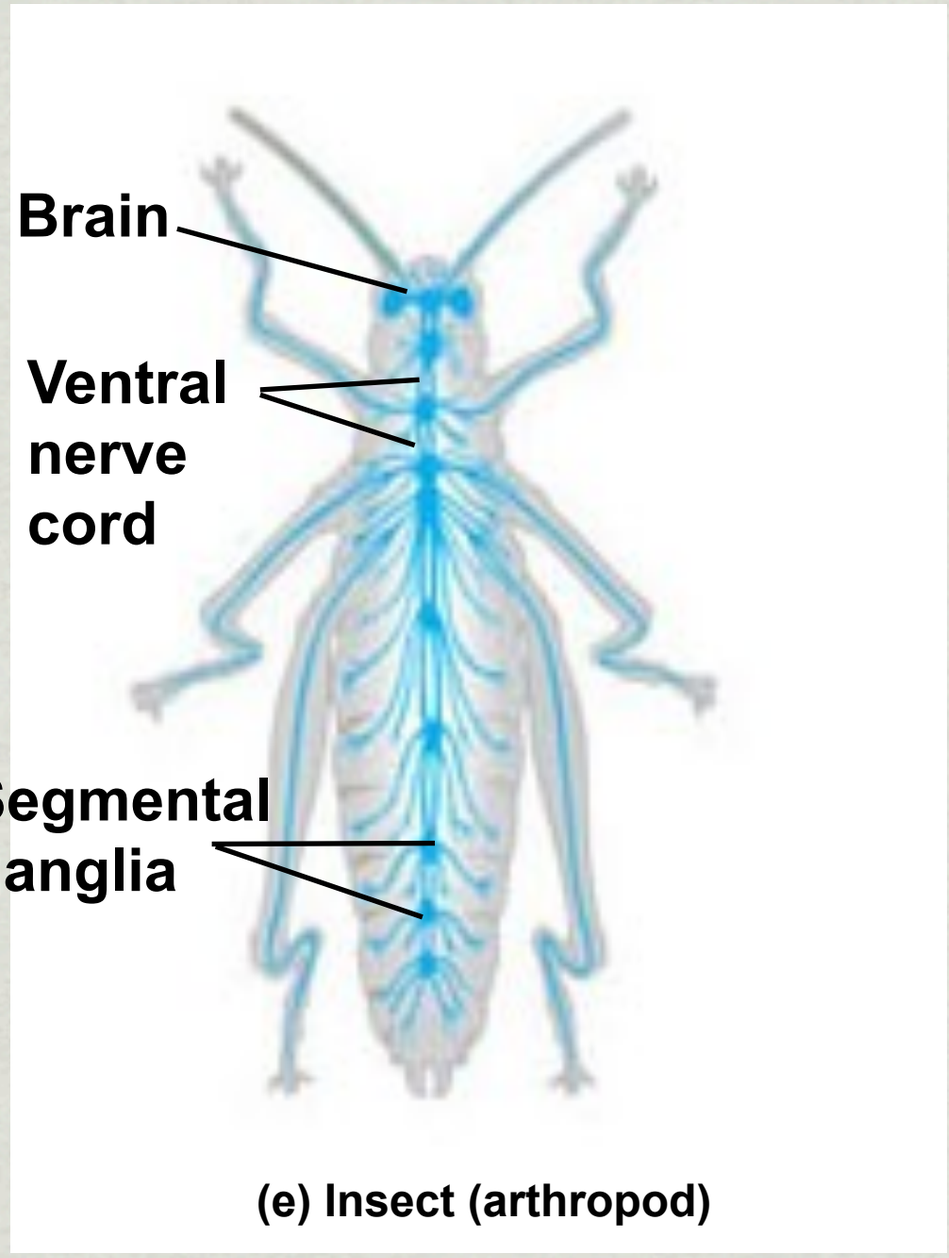


Organization of Nervous Systems

- **Annelids and arthropods have segmented nerves that make up a peripheral nervous system.**



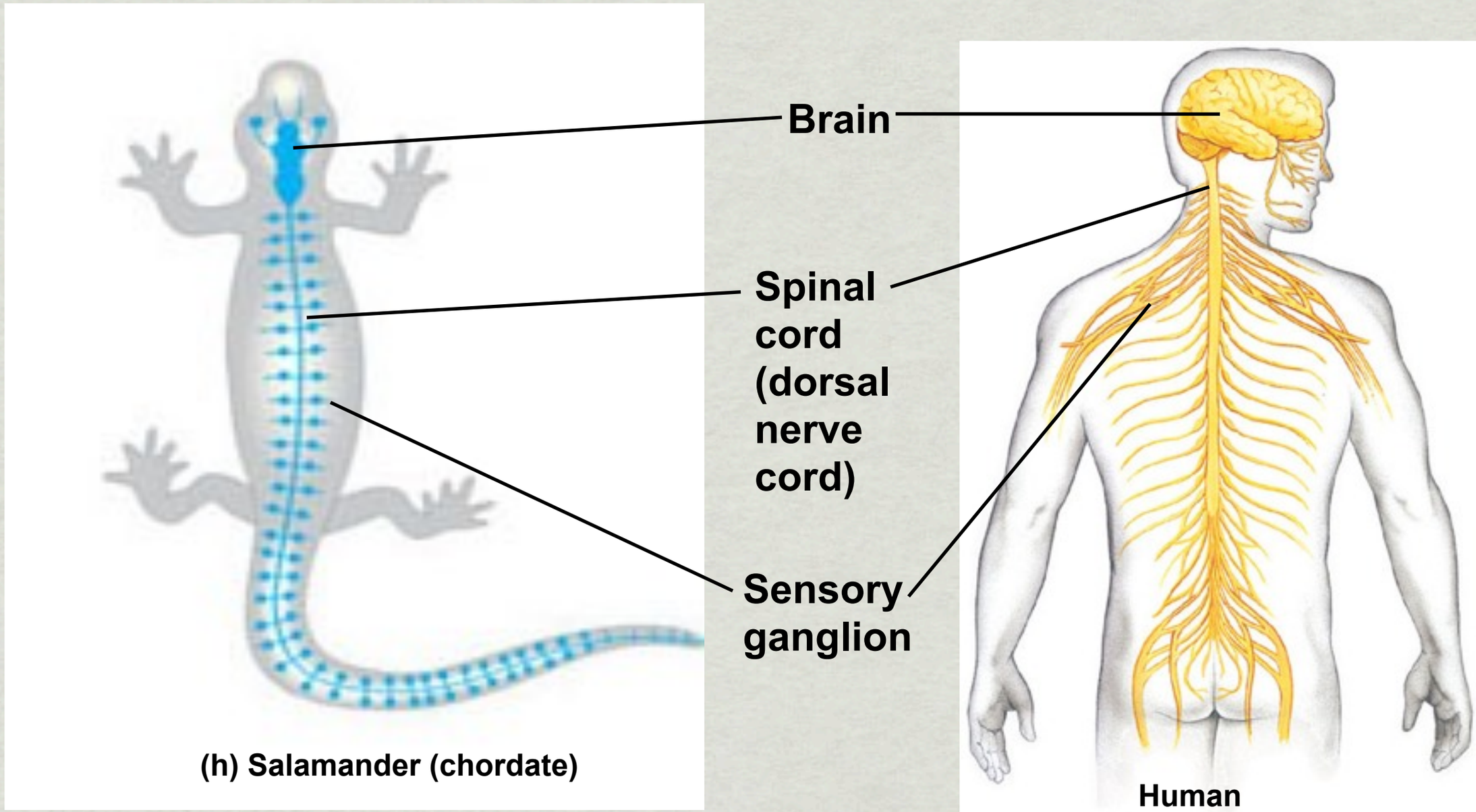
(d) Leech (annelid)



(e) Insect (arthropod)

Organization of Nervous Systems

- **Vertebrates have a (CNS) with a brain and spinal cord and a peripheral nervous system that connects to CNS.**



Human Brain & Spinal Cord

- **The brain provides integrative power that underlies the complex behavior of vertebrates.**
- **The spinal cord integrates simple processes and conveys information to and from the brain**

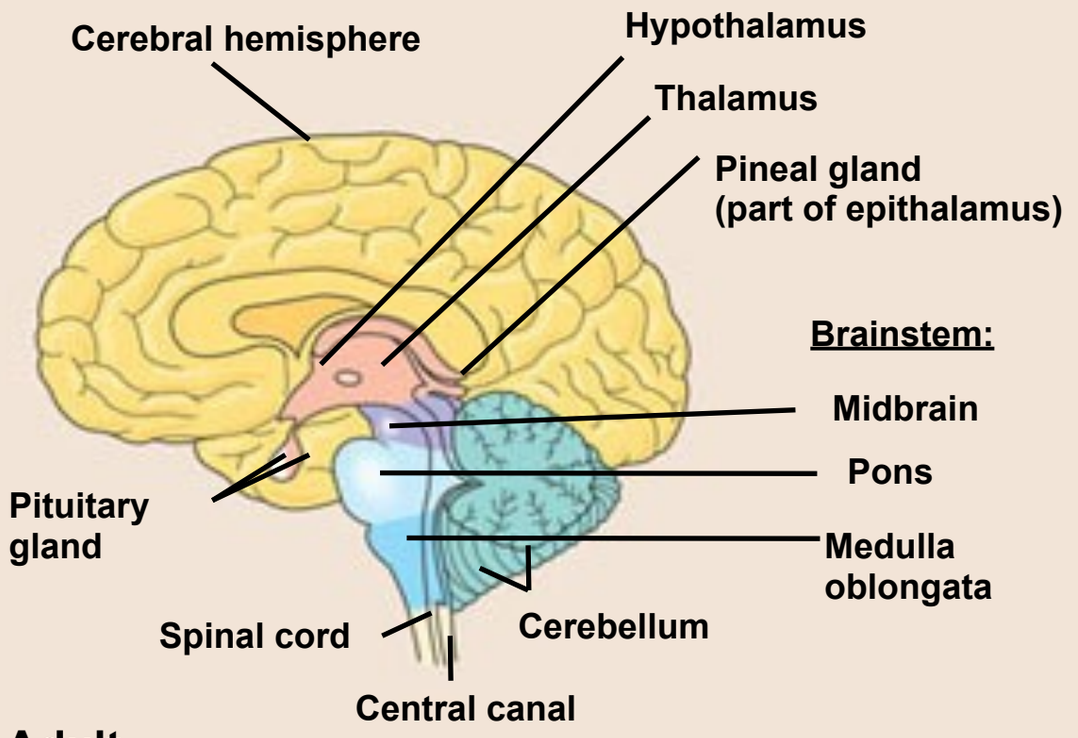
Cerebrum (cerebral hemispheres; includes cerebral cortex, white matter, basal nuclei)

Diencephalon (thalamus, hypothalamus, epithalamus)

Midbrain (part of brainstem)

Pons (part of brainstem), **cerebellum**

Medulla oblongata (part of brainstem)



Adult

Plants

Sensory Transduction & Transmission

Sensory Transduction & Transmission

- **Plants do NOT process information in the way that animals do.**
- **Plants do NOT have neurons and central nervous system.**
- **Plants MAY TRANSMIT information in a similar fashion like animals.**
- **Plants DO have receptors & membrane potentials.**
- **Plants DO sense stimuli and react to stimuli.**
- **Plants DO TRANSDUCE stimuli into reactions.**

Sensory Transduction & Transmission

- Some experiments have detected electrical impulses moving through plants.
  - The impulses detected did move much slower than action potentials in animals
- Plants do NOT have neurons but their cells are joined by plasmodesmata and at least in conception membrane potentials could pass from cell to cell.
- Bottom Line! The jury is still out. This an active area of research that looks to better understand the role(s) and mechanism(s) of electrical transmission in plants.

Fungi

Sensory Transduction & Transmission

Sensory Transduction & Transmission

- **Fungi do NOT process information in the way that animals do.**
- **Fungi do NOT have neurons and central nervous system.**
- **Fungi MAY TRANSMIT information in a similar fashion like animals.**
- **Fungi DO have receptors & membrane potentials.**
- **Fungi DO sense stimuli and react to stimuli.**
- **Fungi DO TRANSDUCE stimuli into reactions.**

Sensory Transduction & Transmission

- **The information on electrical transmission in fungi is limited.**

- **Fungi do NOT have neurons but their cells are joined by continuously and again like plants and at least in conception membrane potentials could pass from cell to cell.**

Protists

Sensory Transduction & Transmission

Sensory Transduction & Transmission

- **Single celled protists do NOT process information in the way that animals do.**
- **Single celled protists do NOT have neurons and do NOT generate action potentials.**
- **Single celled protists do NOT TRANSMIT information like animals.**
- **Single celled protists DO have receptors & membrane potentials.**
- **Single celled protists DO sense stimuli and react to stimuli.**
- **Single celled protists DO TRANSDUCE stimuli into reactions.**

Bacteria

Sensory Transduction & Transmission

Sensory Transduction & Transmission

- **Bacteria do NOT process information in the way that animals do.**
- **Bacteria do NOT have neurons and do NOT generate action potentials.**
- **Bacteria do NOT TRANSMIT information like animals.**
- **Bacteria DO have receptors & membrane potentials.**
- **Bacteria DO sense stimuli and react to stimuli.**
- **Bacteria DO TRANSDUCE stimuli into reactions.**

Life's Common Challenges

Review: "Responses"

RESPONDING TO THE ENVIRONMENT

- Responses at the intracellular level involve proteins.
  - Responses at this level, usually comes down to some change in protein activity or synthesis.
- **Responses at the organismal level involves taxes and tropisms.**
  - **Mobile organisms move towards or away from stimuli.**
  - **Stationary organisms change their pattern of growth or development in response to stimuli**
- Responses by animals are characterized as regulation or conformation.

Responses at the organismal level involve taxes and tropisms

- **Taxis:** is an innate behavioral response by an organism with motility towards or away from a stimulus, positive taxes move toward stimulus while negative taxes are away from the stimulus..

- **Tropisms:** growth of an organism (usually a plant) in response to a stimulus, positive tropisms show growth toward stimulus while negative tropisms are away from the stimulus.

RESPONDING TO GRAVITY

GRAVITROPISM

PHOTOTROPISM

RESPONDING TO LIGHT

CHEMOTAXIS BY A WHITE BLOOD CELL

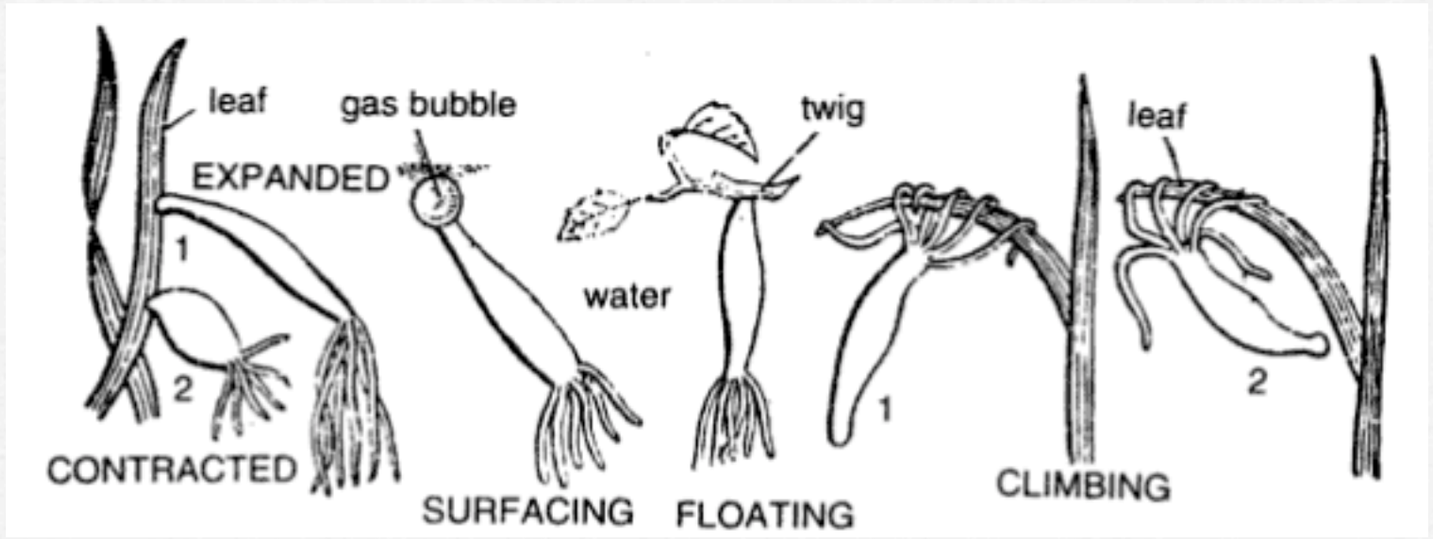
Animals

Locomotion

Types of Locomotion

- **Movement is the hallmark of animals.**
  - Even sessile organisms move their body parts .
    - Sponges beat flagella to generate water currents that draw in and trap food.
    - Sea anemones wave tentacles to capture prey.
- **Most animals are however mobile.**
  - They spend a great deal of time moving...looking for prey, avoiding predation and of course looking for mates.

Locomotion in the Sessile Hydra?



The hydra spends most of its time attached to substrate

But retains the ability to move under certain conditions

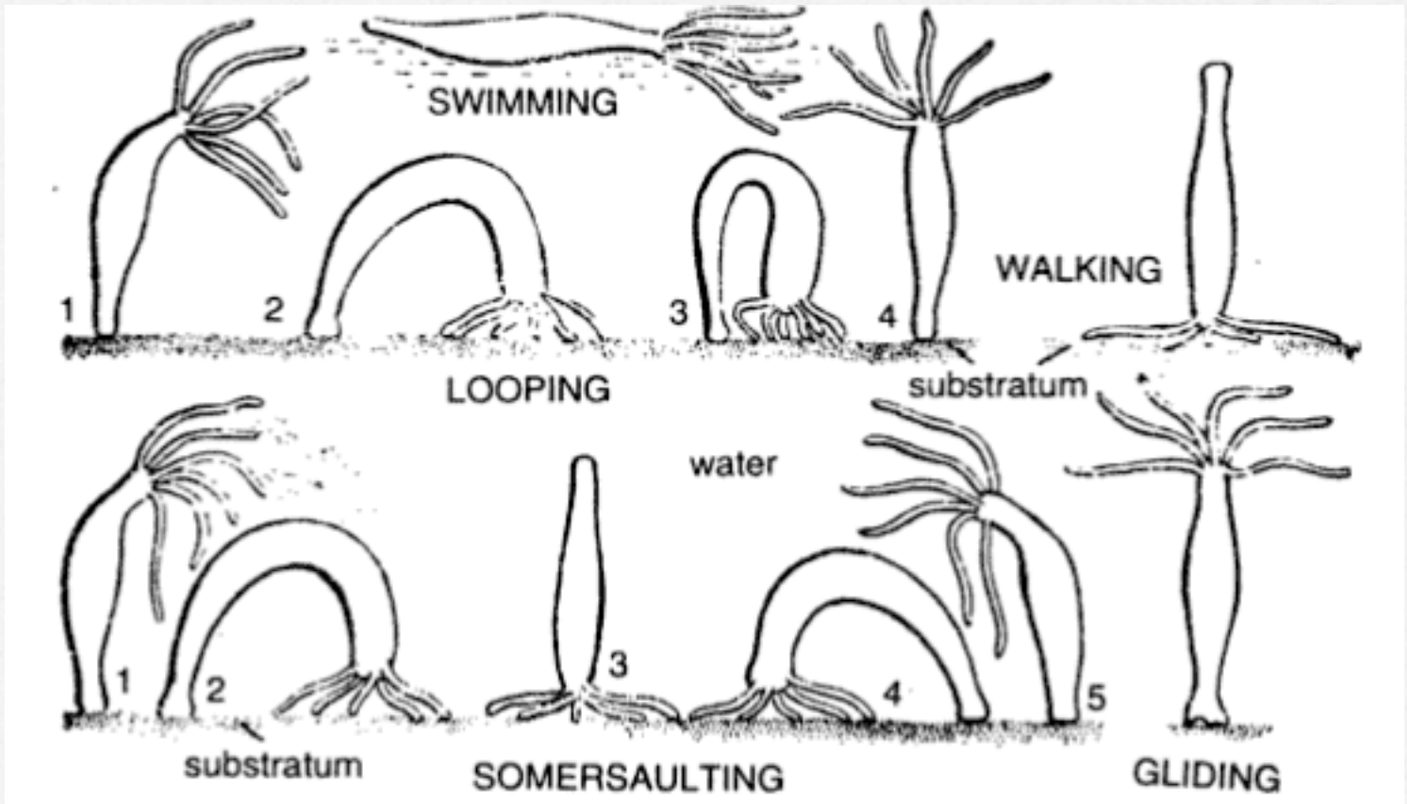


Fig. : Types of locomotion in *Hydra*

Types of Locomotion

- **Movement is the hallmark of animals.**
  - Even sessile organisms move their body parts .
    - Sponges beat flagella to generate water currents that draw in and trap food.
    - Sea anemones wave tentacles to capture prey.
- **Most animals are however mobile.**
  - They spend a great deal of time moving...looking for prey, avoiding predation and of course looking for mates.

Types of Locomotion

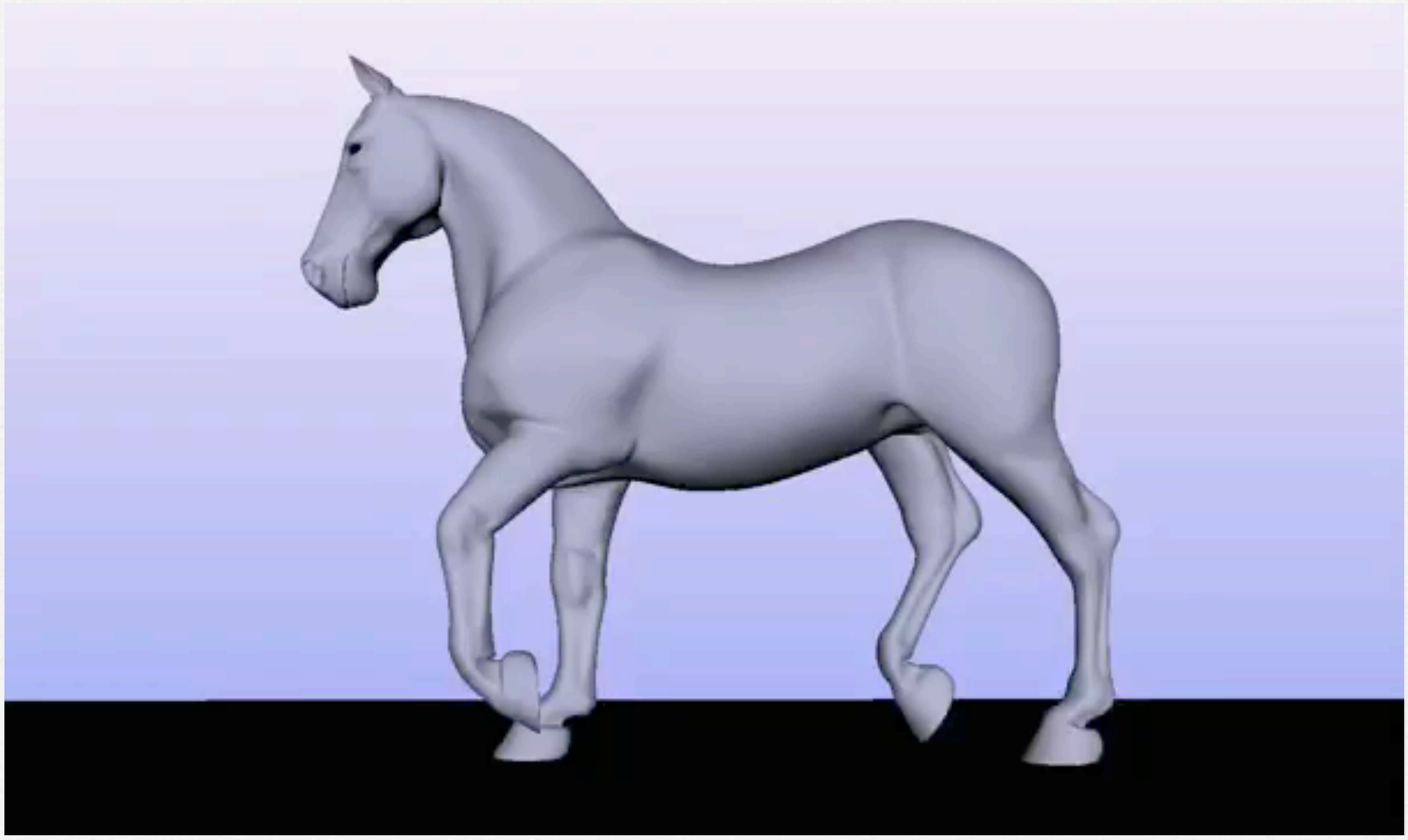
- **Friction** and **gravity** tend to keep an animal in place and oppose locomotion.
  - Animals must overcome these forces in order to move.
- **Body plans reflect adaptations that minimize the effect of these two forces.**

Locomotion on Land

- **Movements include walking, running, hopping, leaping, crawling, burrowing and slithering.**
  - These motions require that the animal supports itself and moves itself both against gravity.
    - The muscular system and the skeletal system together can oppose gravity and move the organism. (discussed later)
  - Walking, running and hopping have an additional requirement... balance.
  - Crawling, burrowing and slithering do not require balance but they do have their own requirements...overcoming friction.

- **Three great groups of terrestrial animals-mollusks, arthropods and vertebrates-each move over land in different ways.**
    - Mollusks(snails, slugs) are least efficient, they secrete a path of mucus and glide along, pushing with a muscular foot.
    - Arthropods and vertebrates have rapid means of locomotion, their bodies are raised above ground and moved forward by pushing against the ground with a series of jointed appendages.
    - Vertebrates are tetrapods (four limbs) while arthropods have six or more limbs.
    - Having more limbs adds stability but sacrifices speed
        - *a sprinting cheetah can have all limbs off the ground, bringing friction to an absolute minimum (insects can never to do this because their legs get in the way of each other*

Locomotion on Land



Notice that foot remains in contact with ground
this will of course help the organism to balance

Locomotion on Land

In this video all four feet come off the ground but the momentum helps the organism keep the balance

Locomotion on Land

Notice this animal is low to ground, gravity plays a smaller role but friction is significant

Swimming

- Most animals are reasonably buoyant in water, thus gravity is not much of a factor.
- Water is however much more dense and viscous compared to air and thus friction is a major problem.
    - As a result many of the swimming animals have a "torpedo like" shape. The remaining animals will likely have shapes that decrease the effect of drag (friction).
- Although the shapes of swimming animals are very similar, swimming occurs in diverse ways...

Swimming

Insects and vertebrates use their legs like oars to push against water.

Swimming

Squids and scallops are jet propelled, taking in water and squirting it back out in bursts.

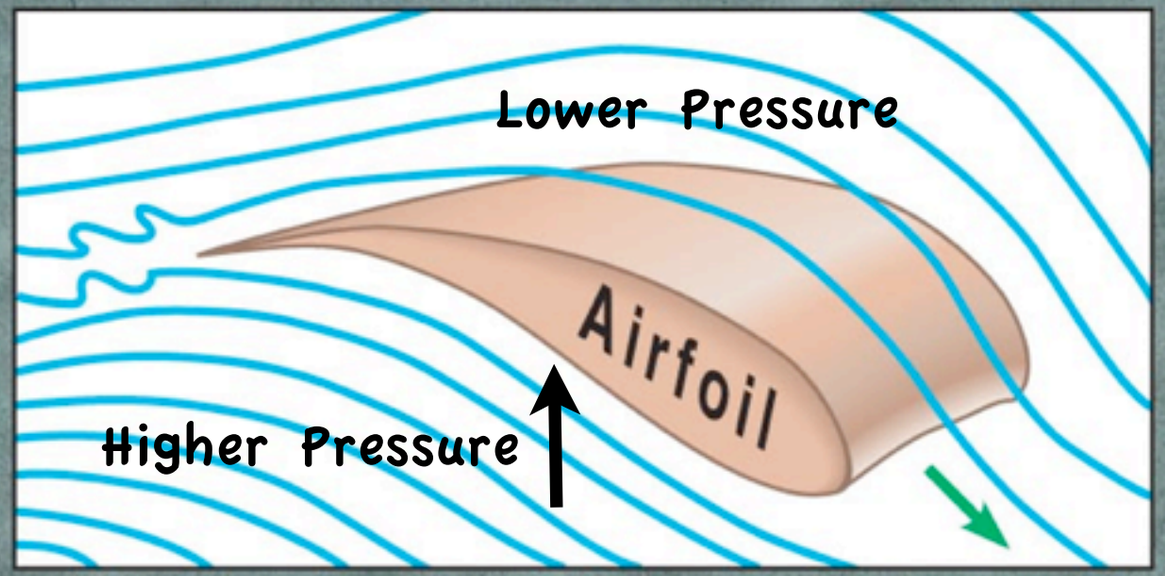
Swimming

Sharks and bony fish move their body side to side, while whales and dolphins move their body up and down.

Flying

- Active flight (opposed to gliding) has evolved four times in animal groups- insects, reptiles, birds and mammals.
  - flight first evolved 200 million years ago in (reptiles) pterosaurs
  - birds and bats are the only flying vertebrates
- Obviously gravity poses the greatest challenge and friction is of little concern.
- Flight requires its own set of adaptations: large but hollow bones, no urinary bladder, no teeth, wings
  - The body is "torpedo like" to once again diminish drag
  - The key to flight is wing shape, all wings are airfoils.

Air travels farther over the top surface, it moves faster, creating lift over the wings.



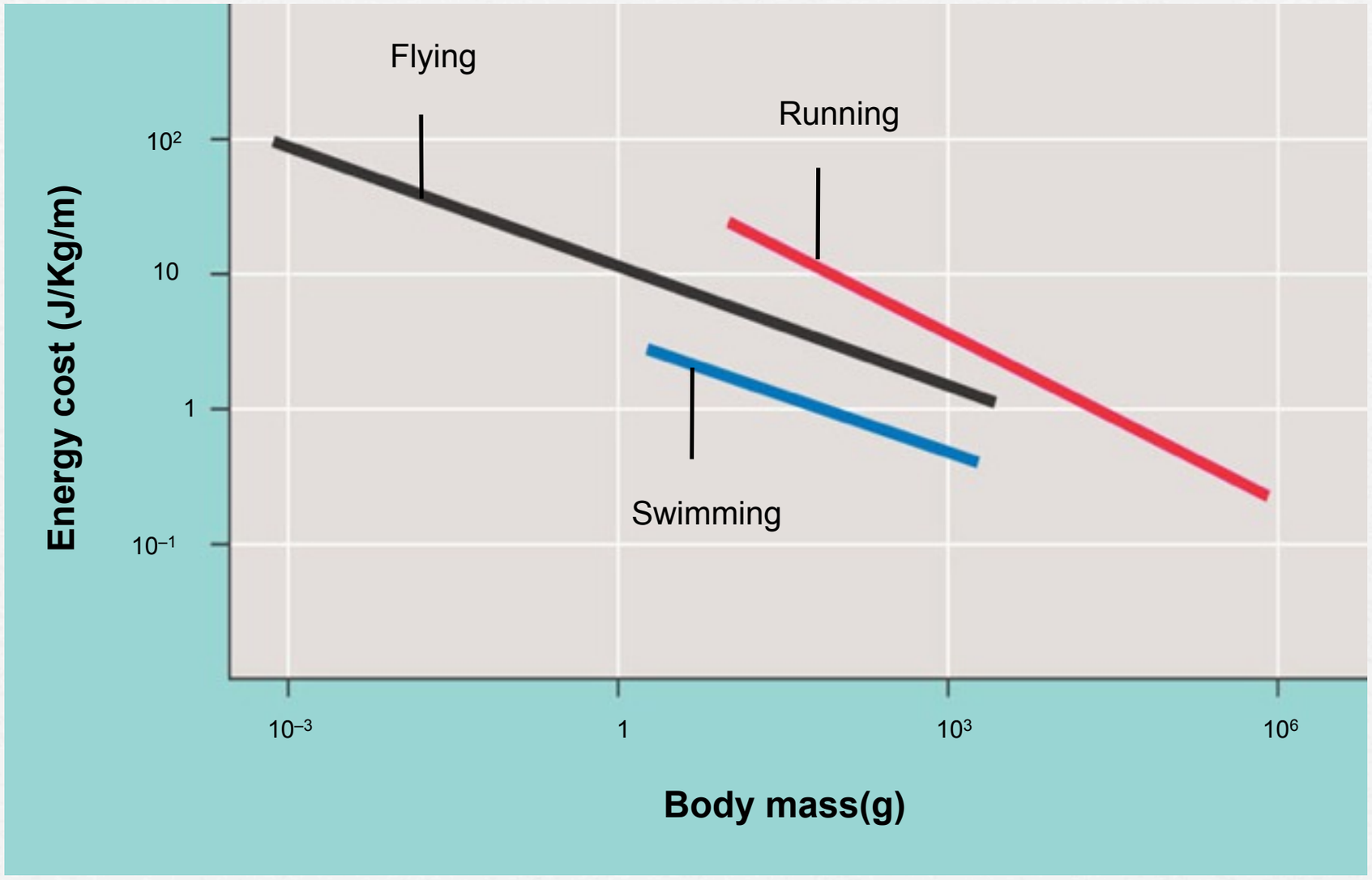
Insects push down against the air with their wings.
This provides enough lift to keep insects in the air.

Flying

Energy Costs of Locomotion

- ***The energy cost for locomotion-*** is the amount of fuel it takes to transport a given amount of body weight over a set distance.
- Any energy (food) that fuels locomotion is energy that can not be used other activities such as growth or reproduction.
- As a result any adaptation either structural or behavioral that maximizes the efficiency of locomotion increases that organisms evolutionary fitness.

Energy Costs of Locomotion



For animals of a given body mass, swimming is the most energy-efficient and running the least energy-efficient mode of locomotion.

In any mode, a small animal expends more energy per kilogram of body mass than a large animal.

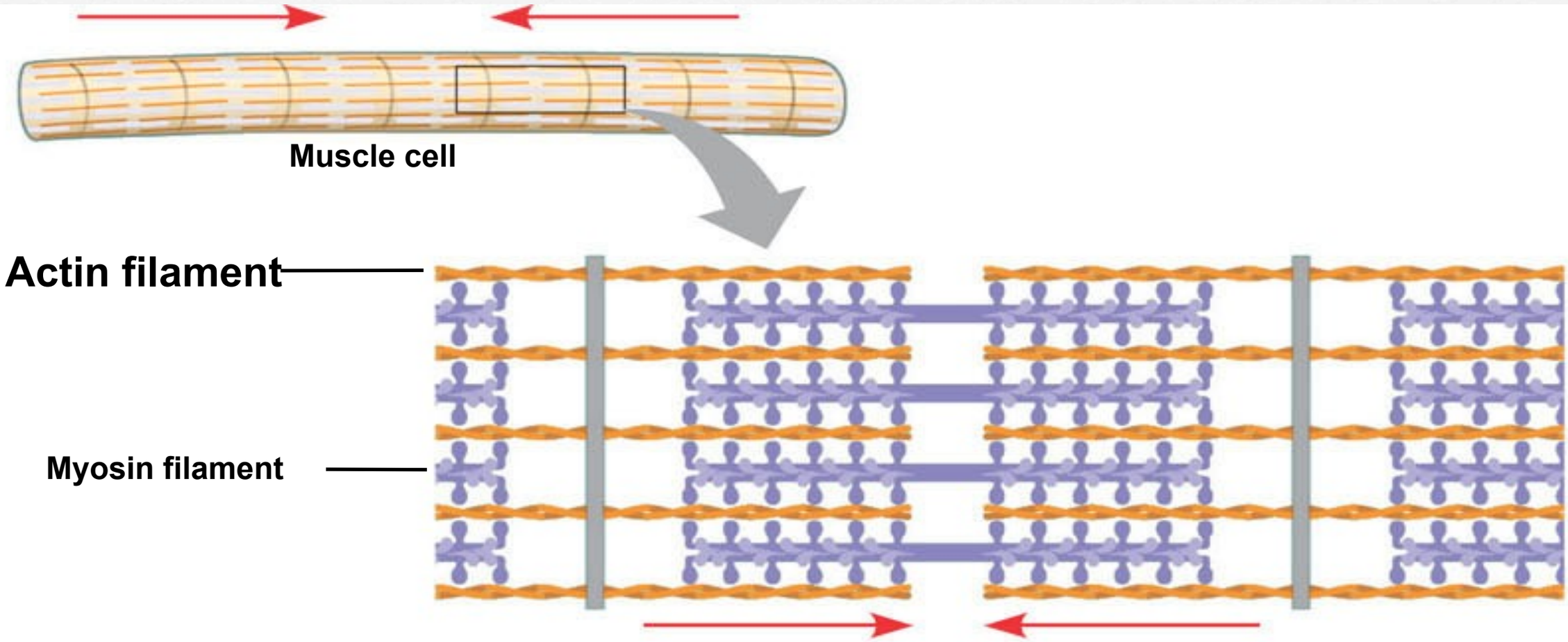
***When we look at energy cost per minute (instead of per meter) flying is the least energy-efficient mode of locomotion.**

How are animals able to move?

- **RECALL: Moving requires that the animal supports itself and moves itself both against gravity.**
- To accomplish this animals require two systems: the muscular system and the skeletal systems
- The muscular system provides the movement for organism.
- The skeletal system supports the organism and is also required for movement.

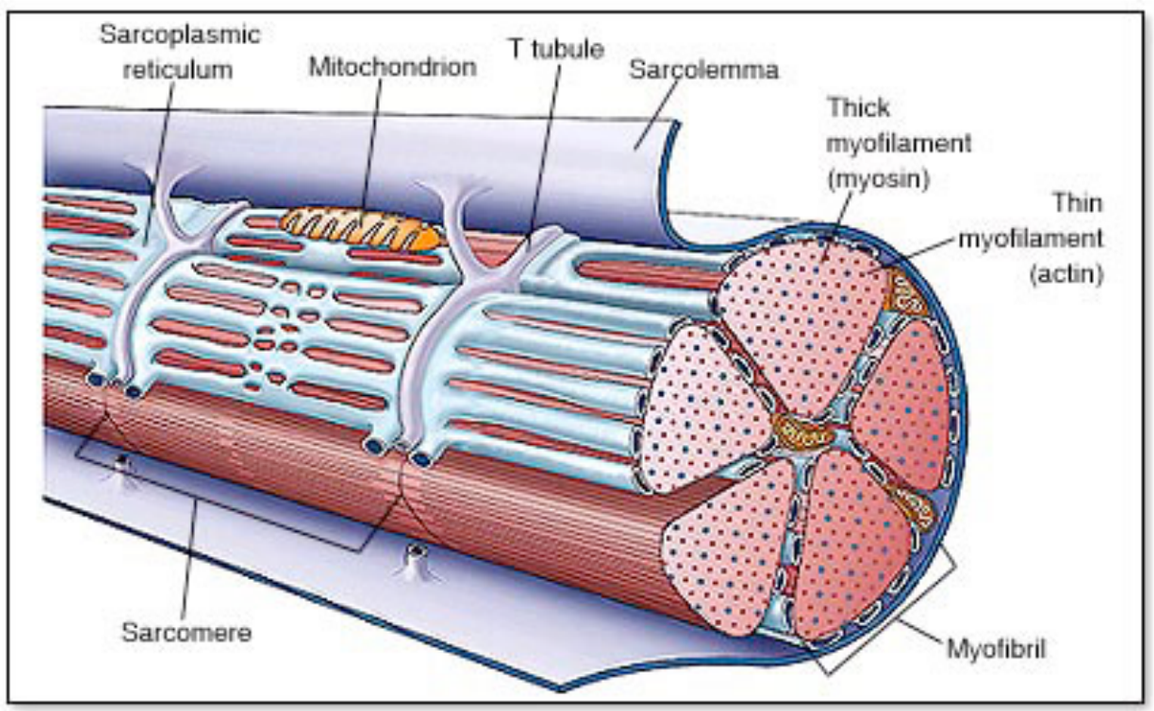
Muscular System

- Muscle cell function relies on microfilaments, the actin components of the cytoskeleton that function in cell motility.



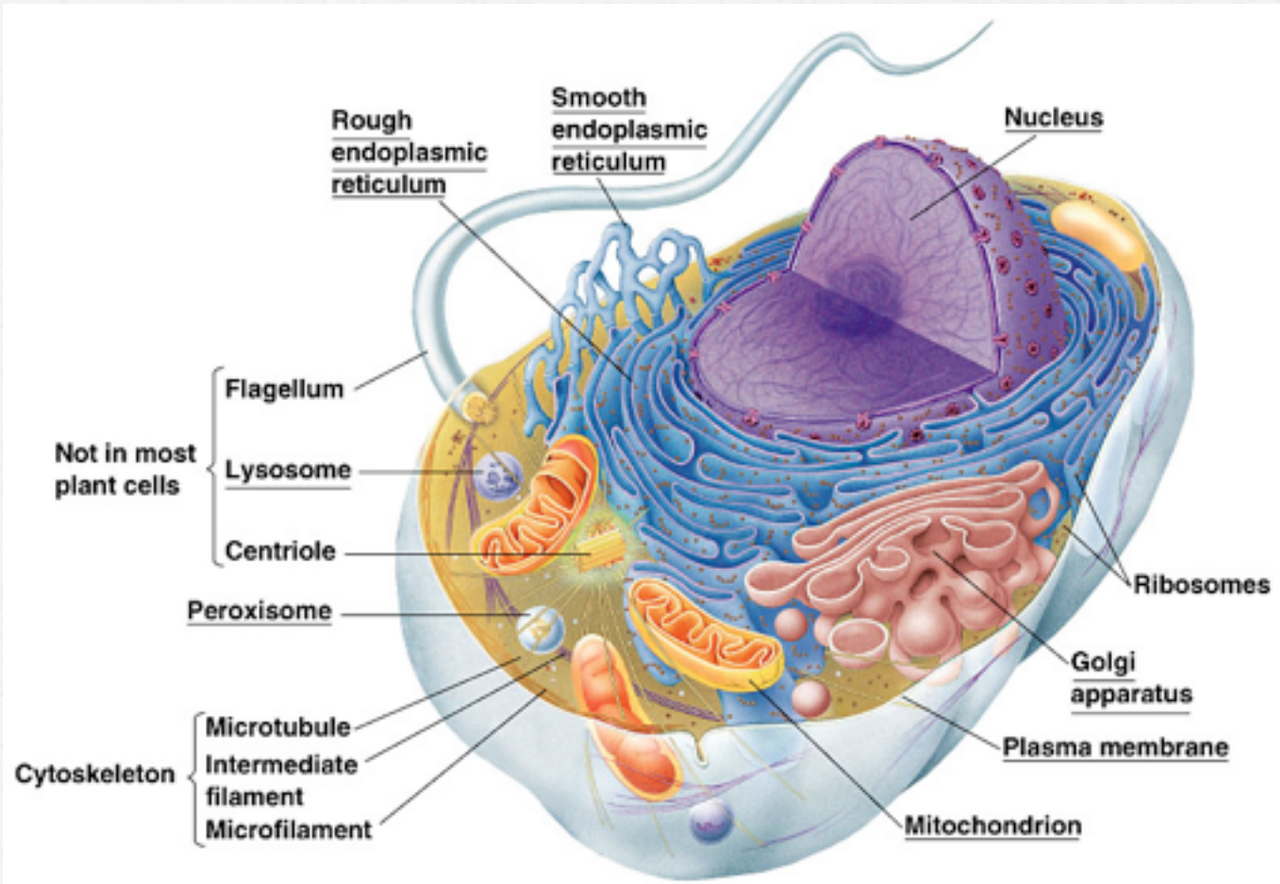
Muscle cells do not look like typical cells. "Typical cells" as depicted in textbooks have no function and their structure is used as starting point for teaching/learning.

Muscle cells do have a function and their structure reflects this function!

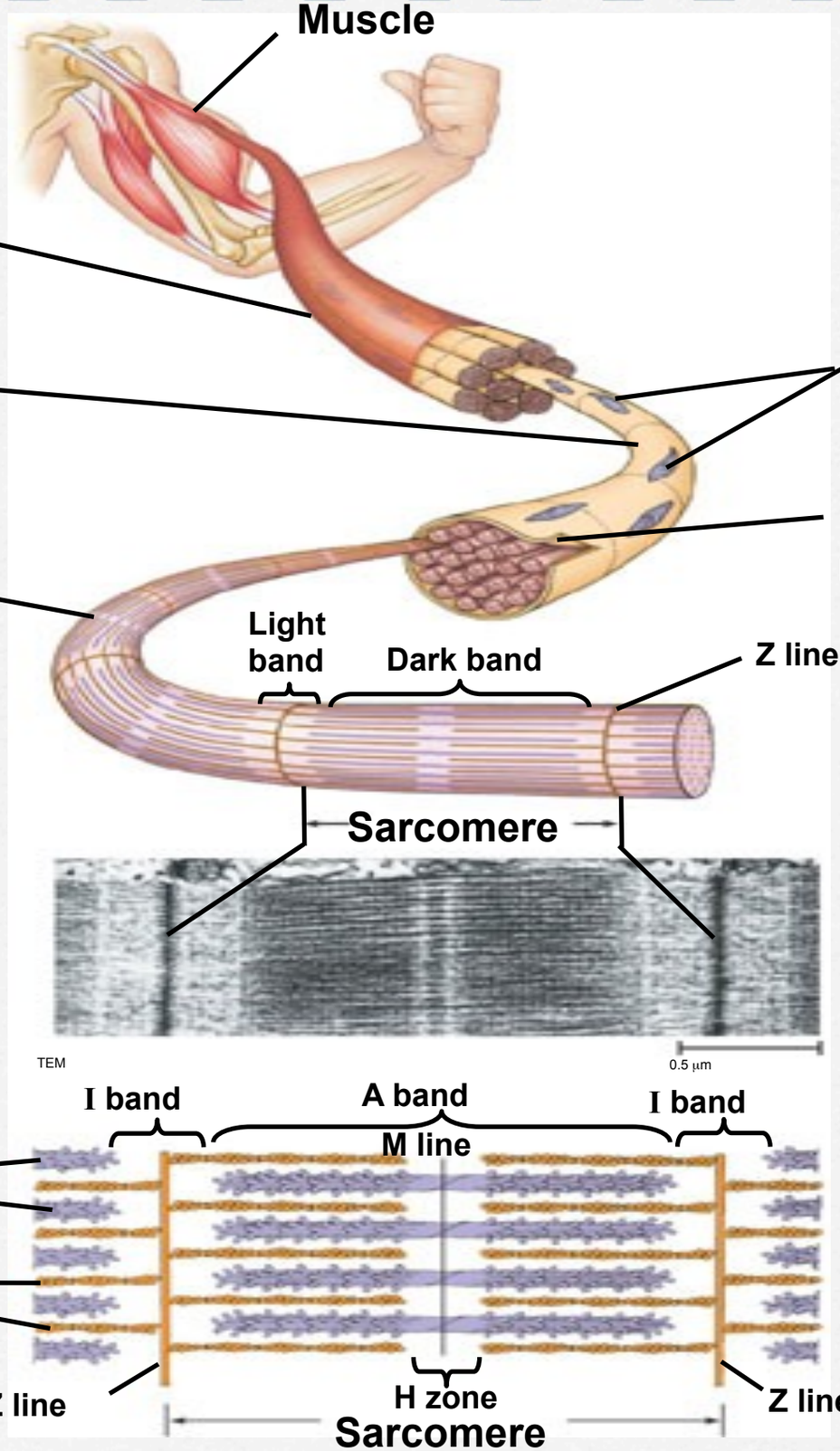


Muscle Cell

Typical Cell



Skeletal Muscle



Multiple nuclei result from fusion of numerous embryonic cells

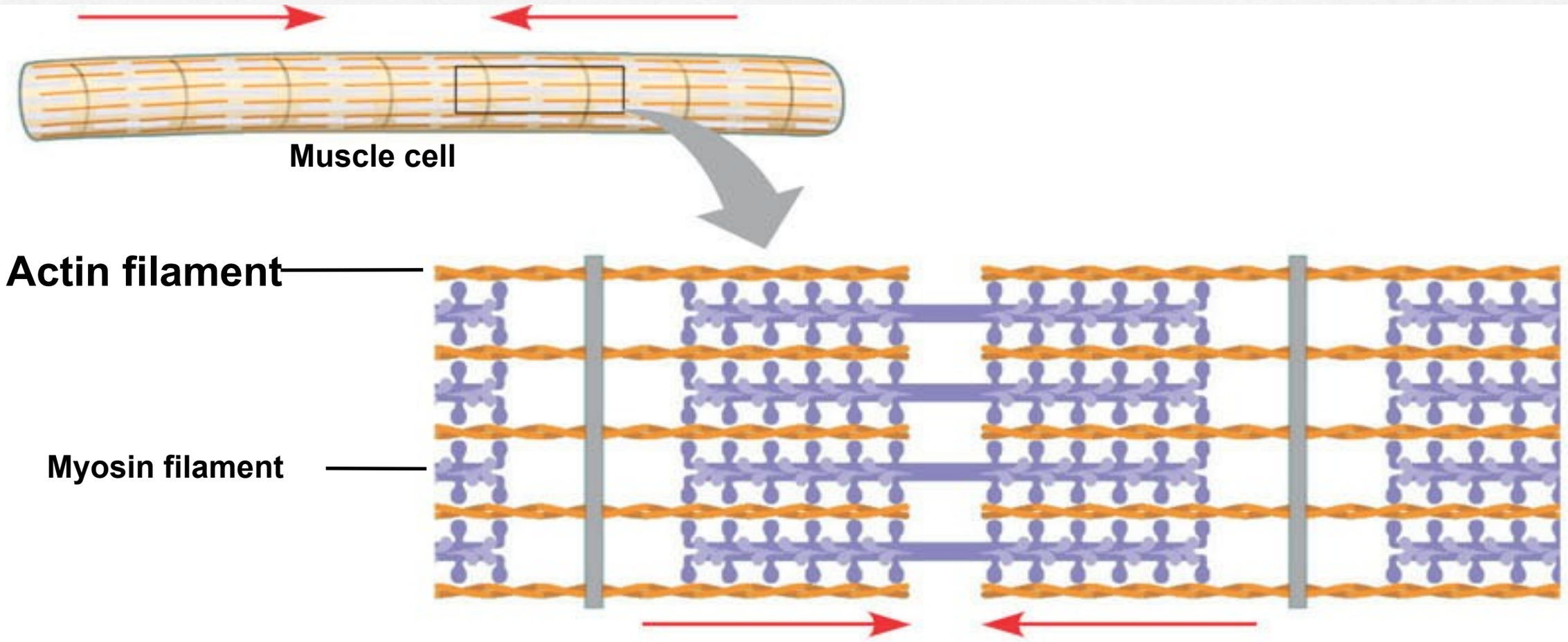
Basic contractile unit of muscle cells

Muscle Contraction

- Muscle contraction is powered by chemical energy, muscle extension occurs passively.
- Muscles shorten during contraction and lengthen during relaxation.

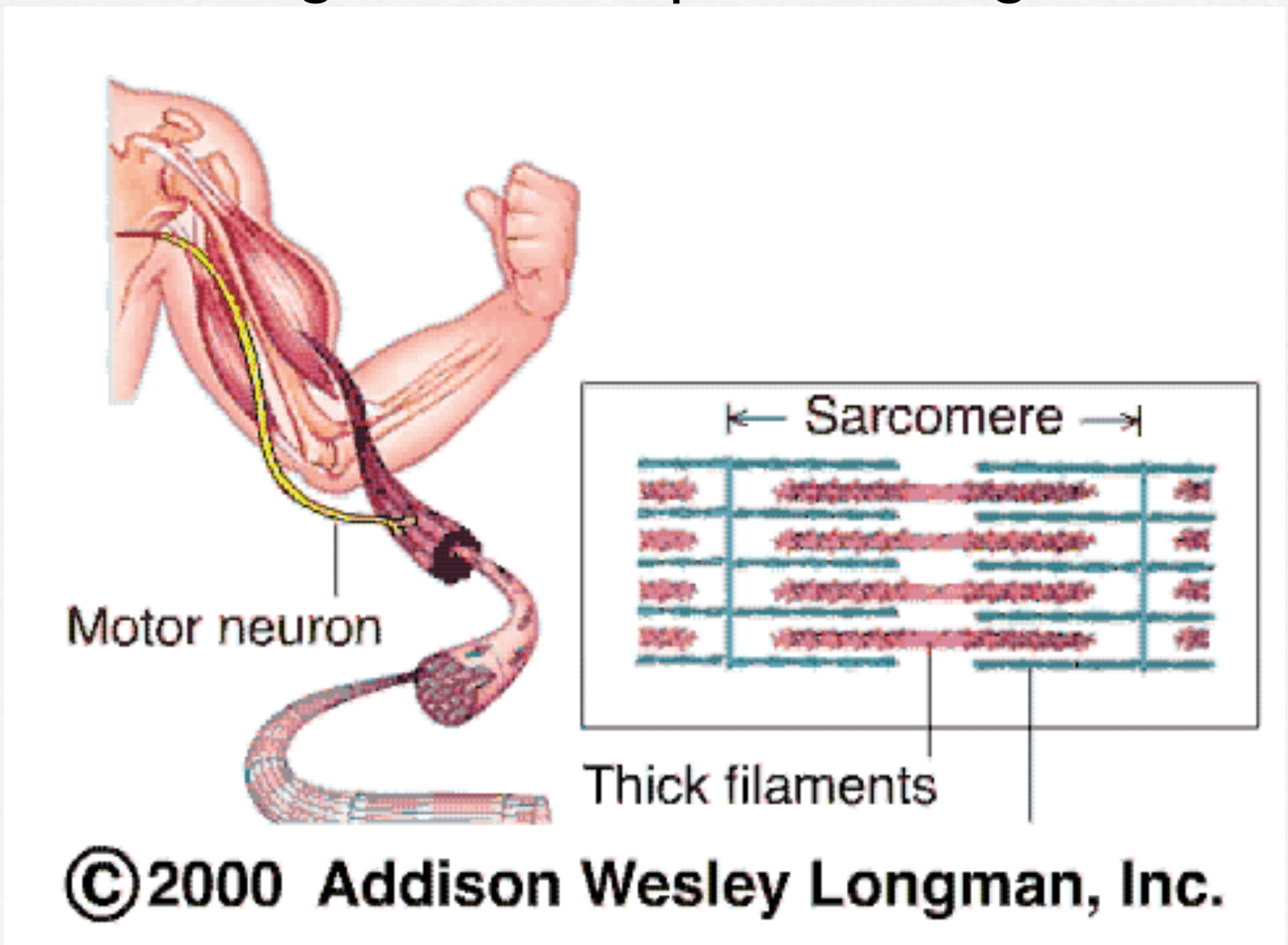
Sliding Filament Theory

- We can begin to understand muscle contraction by focusing on the contraction of a single sarcomere.



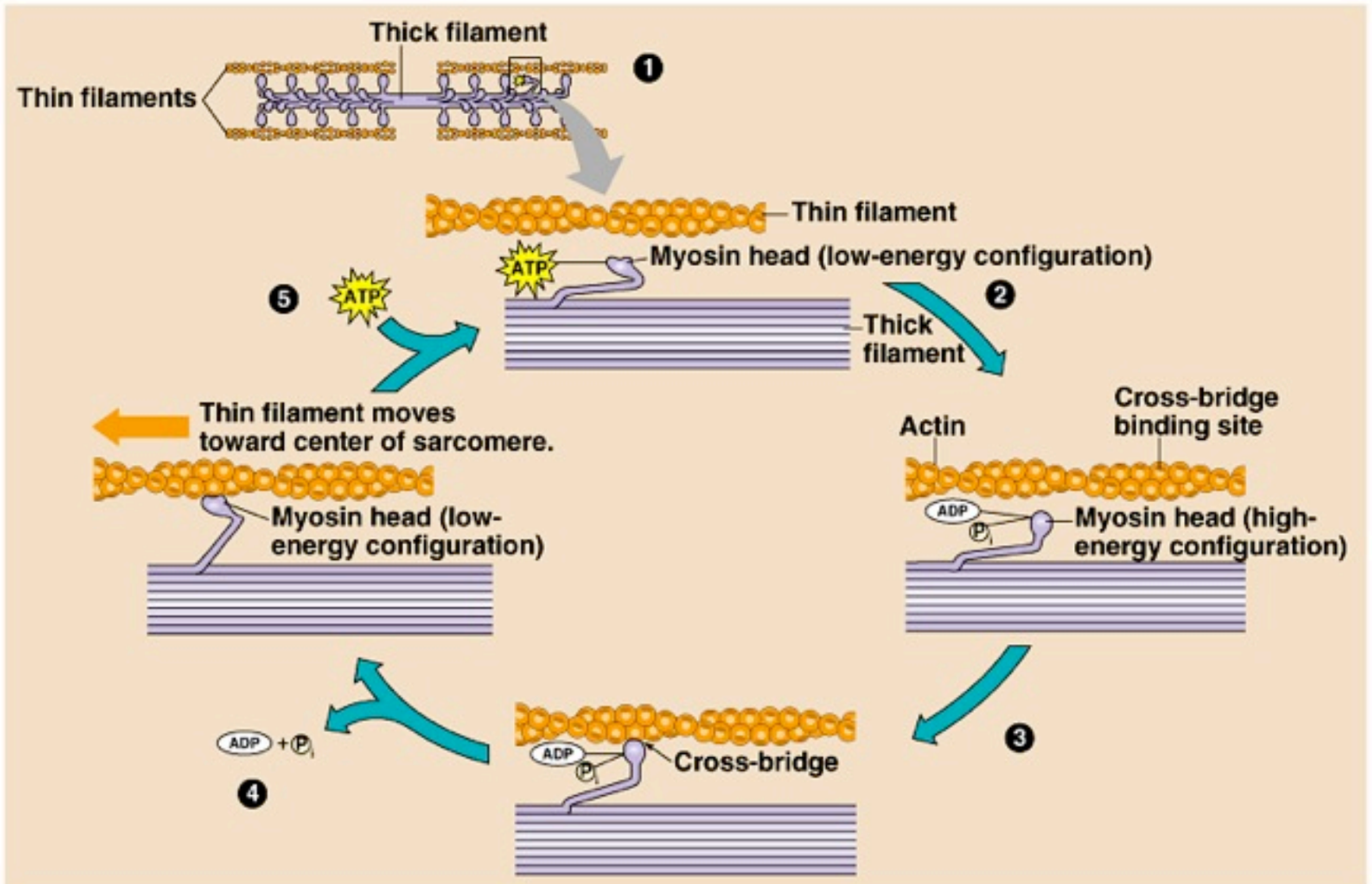
Sliding Filament Theory

- Sliding Filament Theory- the thin and thick filaments slide past one another, increasing their overlap, shortening the sarcomere.



Sliding Filament Theory

- Illustration Review



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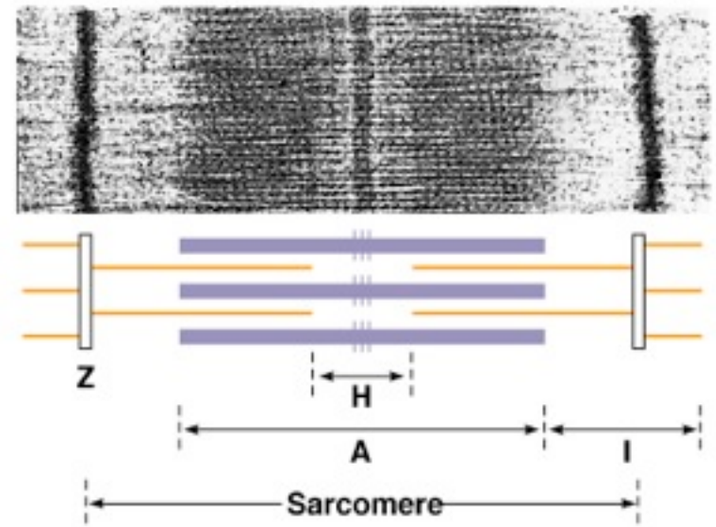
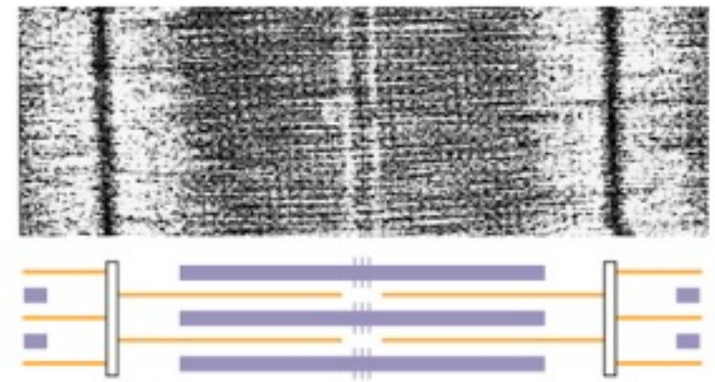
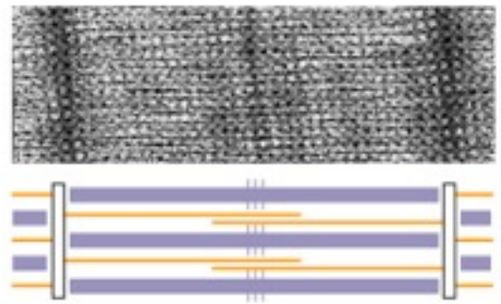


(a) Muscle relaxed (extended)



(b) Muscle contracting



(c) Muscle contracted

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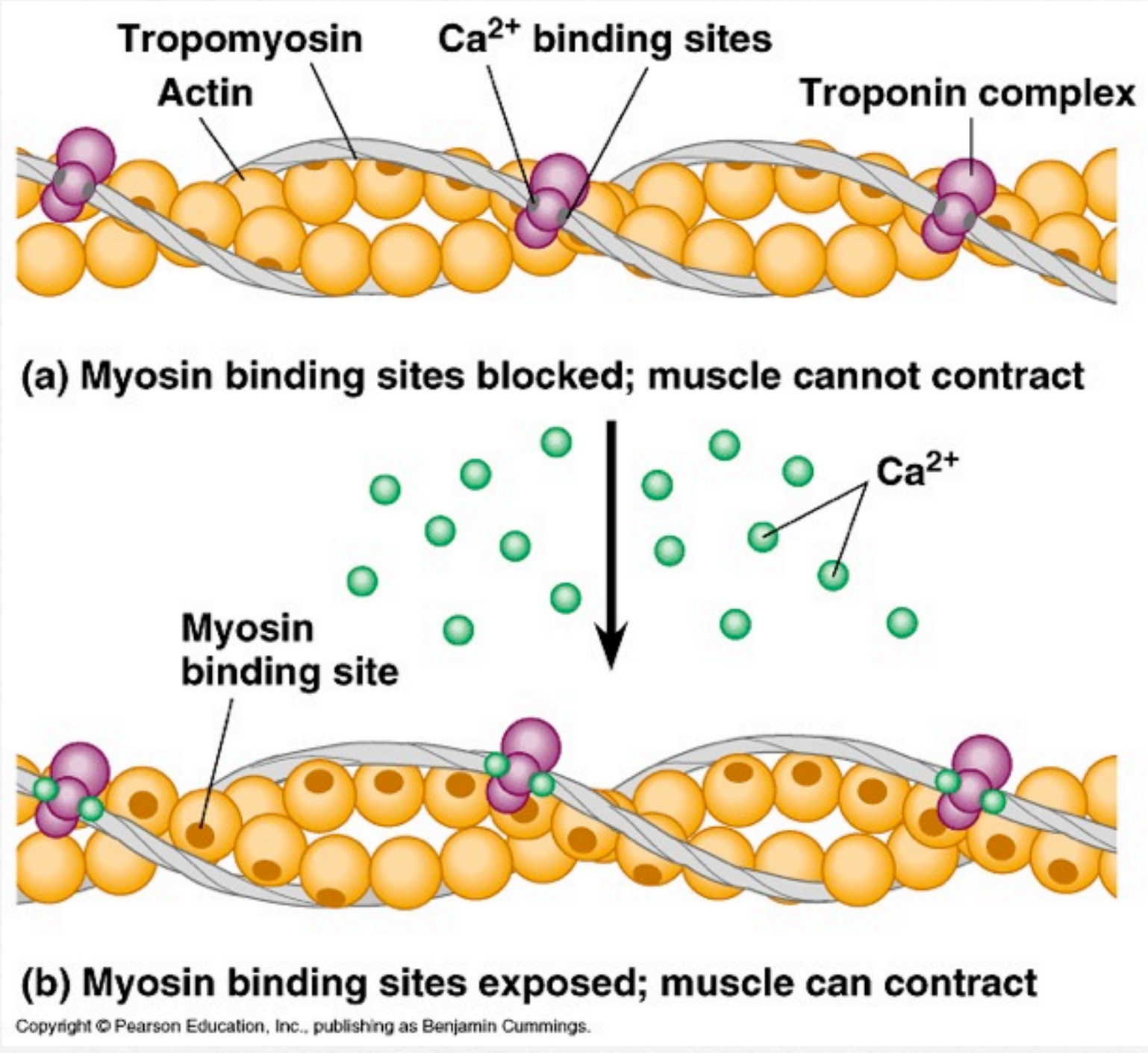
Role of Calcium in Contraction

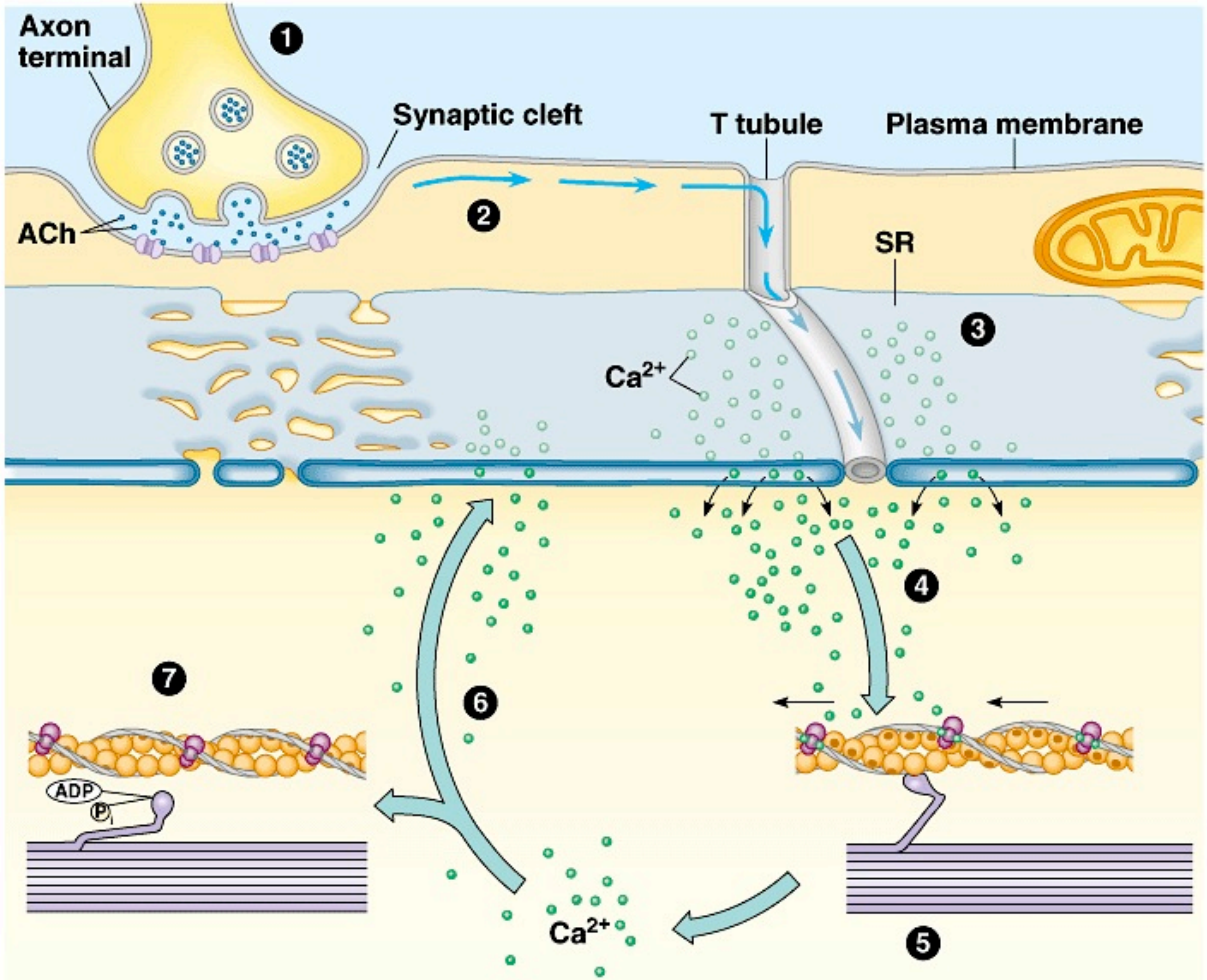
- Illustration Review



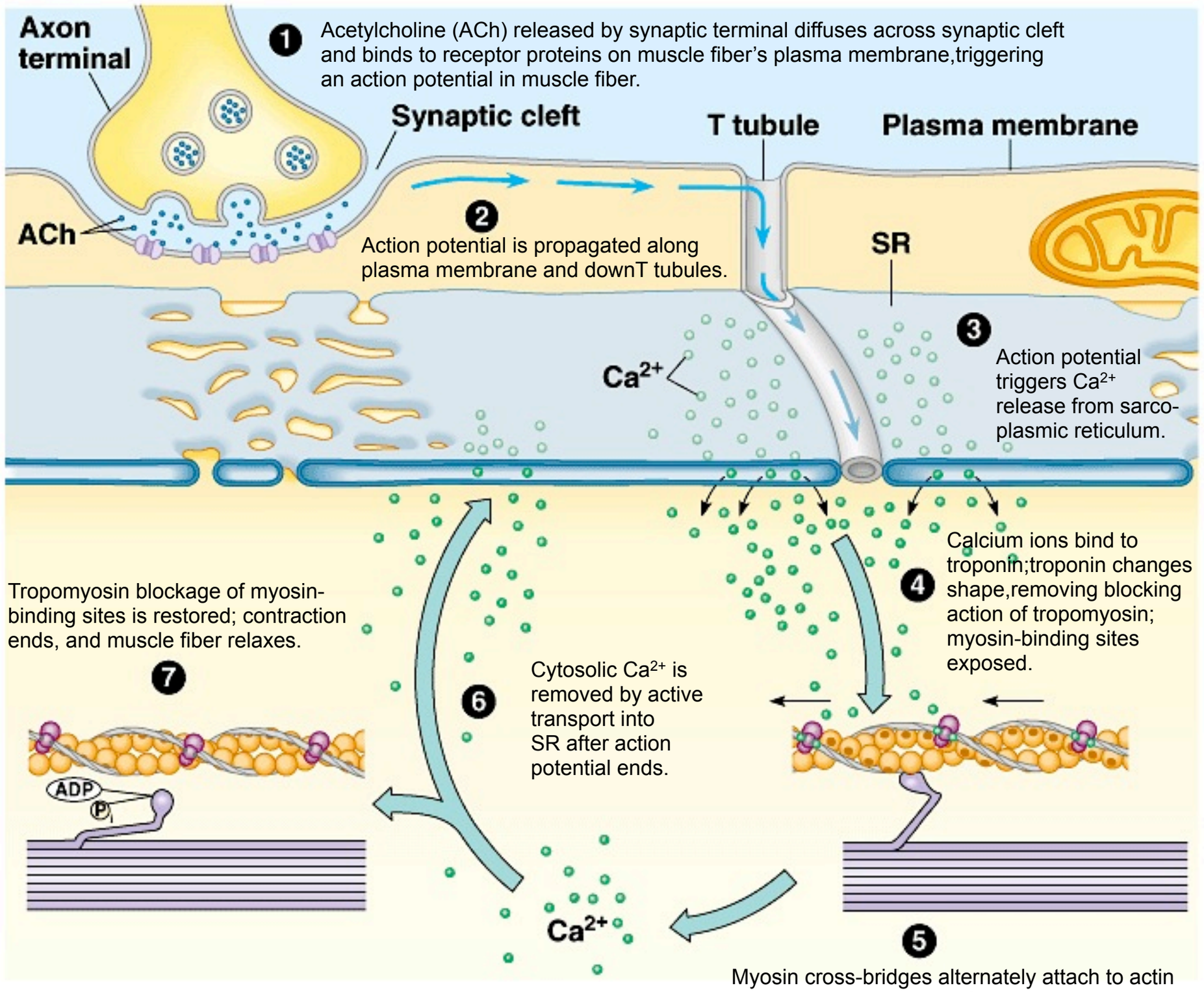
Skeletal Muscle Contraction Sequence

1. Acetylcholine (ACh) released by [illegible]
2. Action potential is propagated [illegible]
3. [illegible]
4. [illegible]
5. Myosin cross- [illegible]
6. Cytosolic Ca^{2+} is [illegible]
7. [illegible]

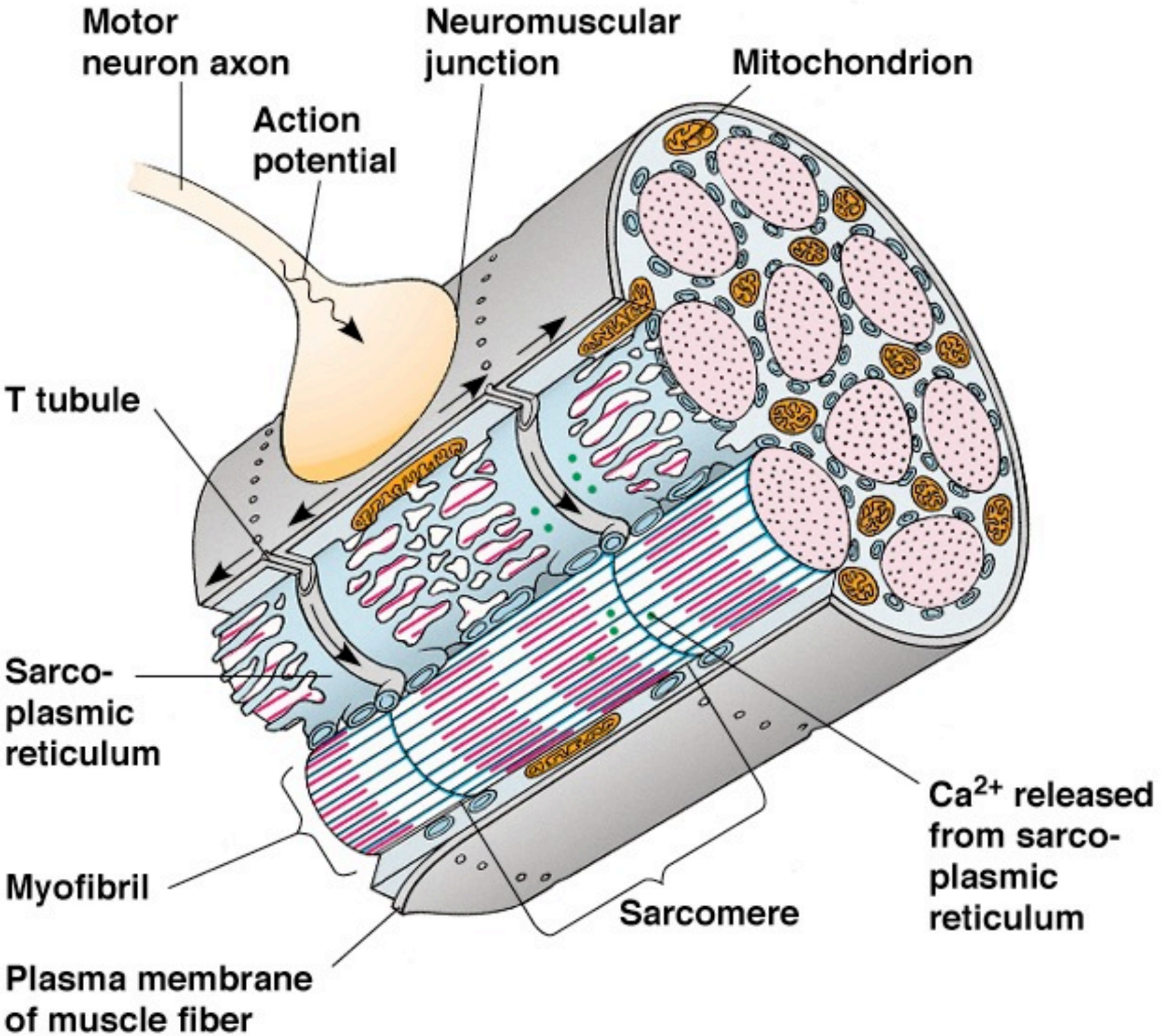
[illegible] sliding of filaments [illegible] muscle fiber.



Skeletal Muscle Contraction Sequence



Review Muscle Cell



Skeletal System

- The skeletal system of animals serves three roles: support, movement and protection.
  - The skeletons role in protection is fairly obvious and straightforward, where as its role as support and movement is less so.
  - More importantly, support and movement are applicable to this unit we will therefore focus on these functions.

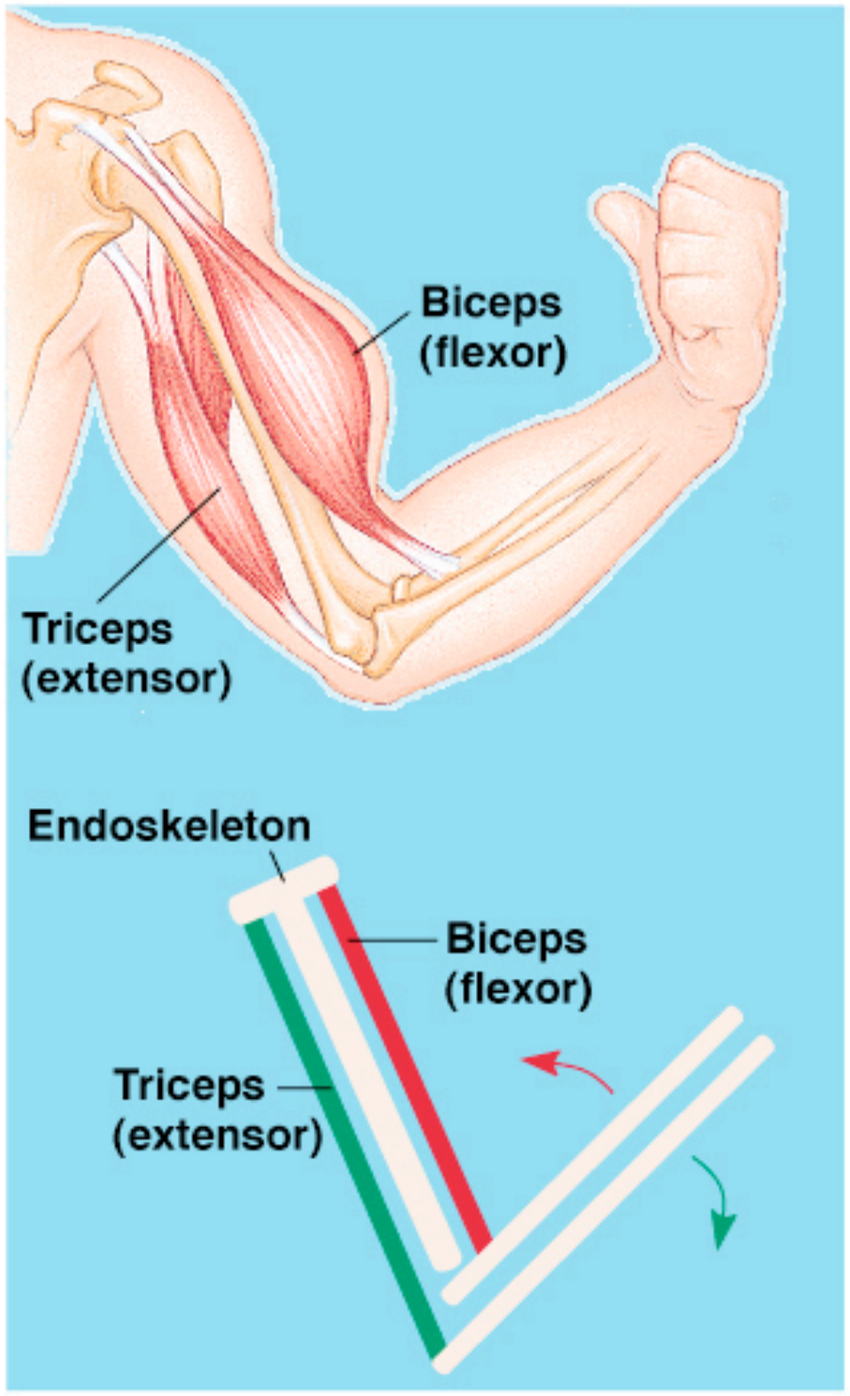
Skeletal System: Support

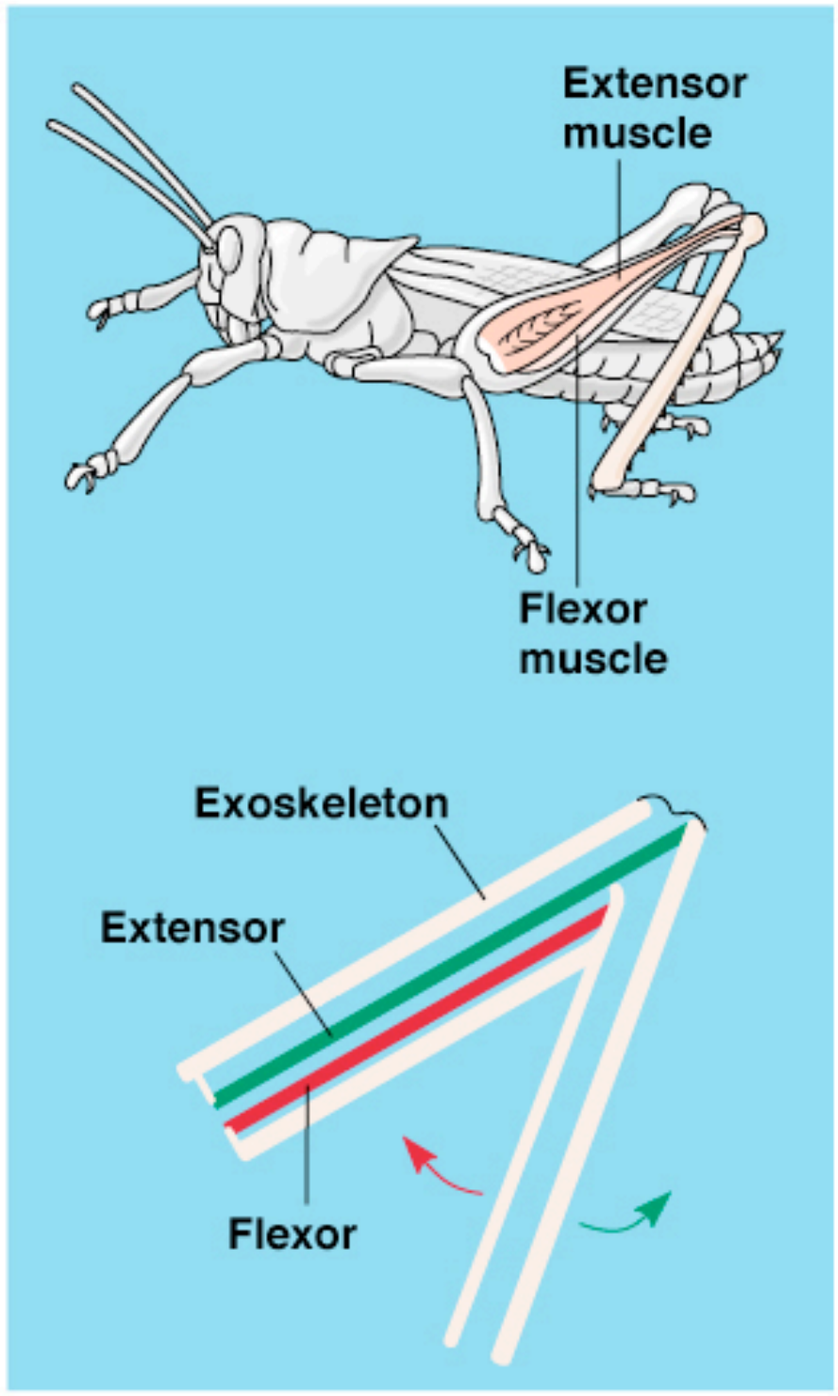
- Animals without a skeleton would collapse under the weight of gravity, the skeleton is rigid and opposes gravity.
  - Consider a human without the skeleton our tissues would fall to ground in heap.
- Animals without a skeleton would be formless, without a framework to maintain its shape.
  - A human has two arms and legs because our skeleton has that conformation, fish are torpedo shaped because their skeleton is shaped like a torpedo,etc
    - Recall the importance of shape in the efficiency of locomotion. **It is structure that dictates function!**

Skeletal System: Movement

- Converting muscle contractions into movements requires a skeleton- a rigid structure to which muscles attach.
- Remember it is the skeleton that provides shape, if muscles pull and move bones then they change the shape of the organism and of course moving requires that the organism changes it shape!
- Because muscle only contracts, moving a body part back and forth typically requires two muscles, one for each directional movement.

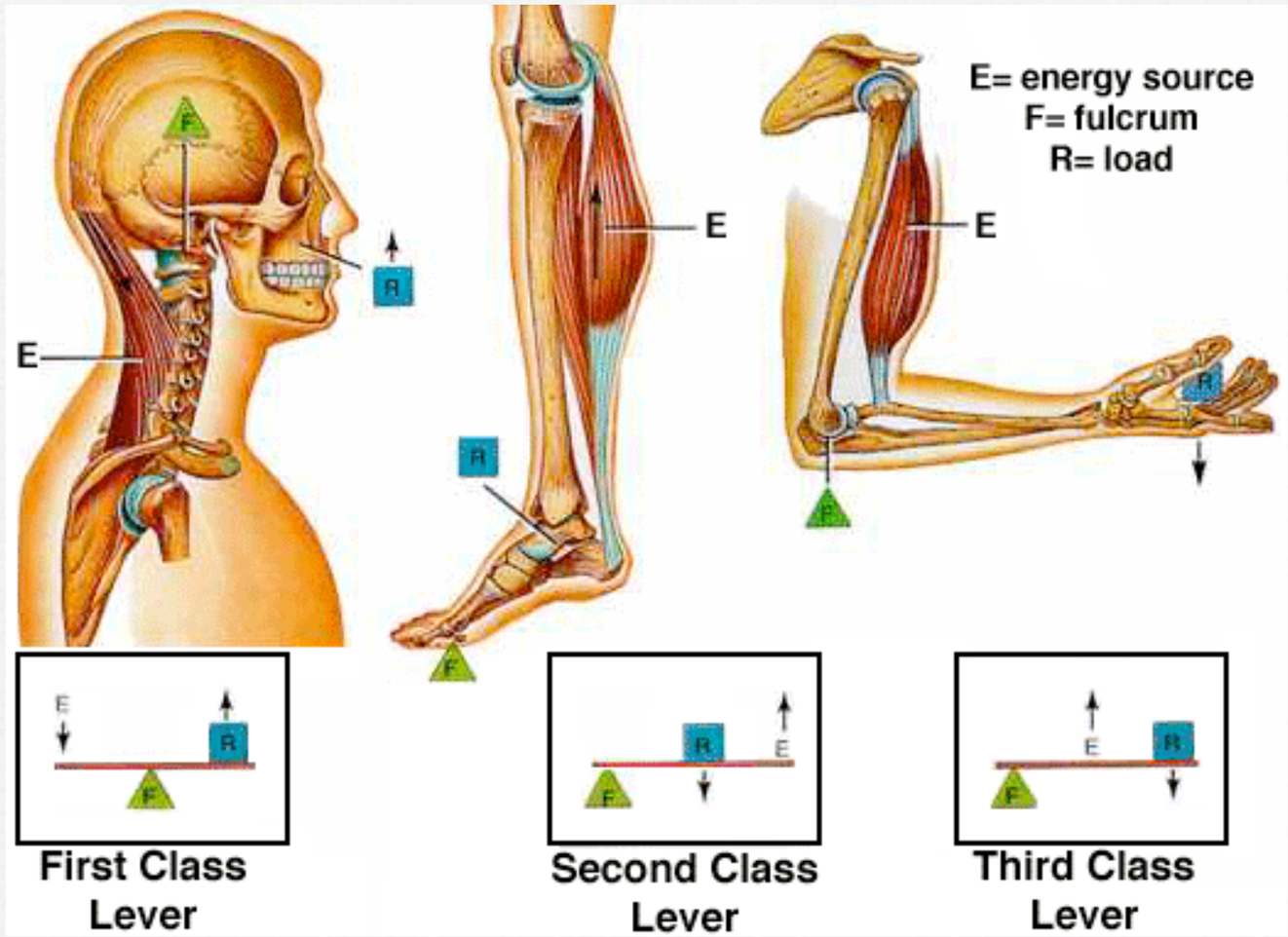
Interaction of Muscle and Bones



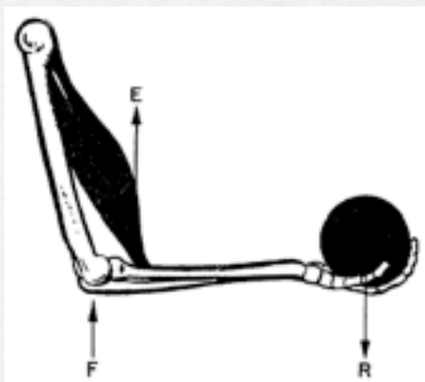


Notice the "red" muscle decreases the angle of the joint while the "green" muscle increases the angle of the joint.

Appendages as Levers



A biceps curl is an example of a third-class lever. The load is the weight held in the hand, the fulcrum is the elbow joint and the effort is provided by the bicep muscles of the arm.



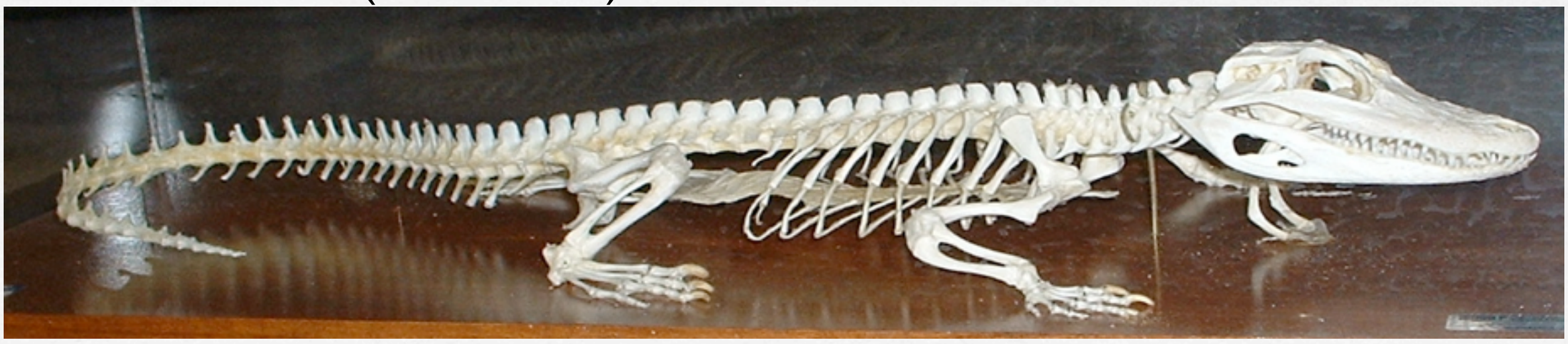
The contraction of the muscles in the upper arm pulls the lower arm up. The muscles move a short distance compared to the end of the lever (the lower arm). The speed of movement in the lower arm is helpful for throwing a ball or swinging a tennis racket.

Types of Skeletal Systems

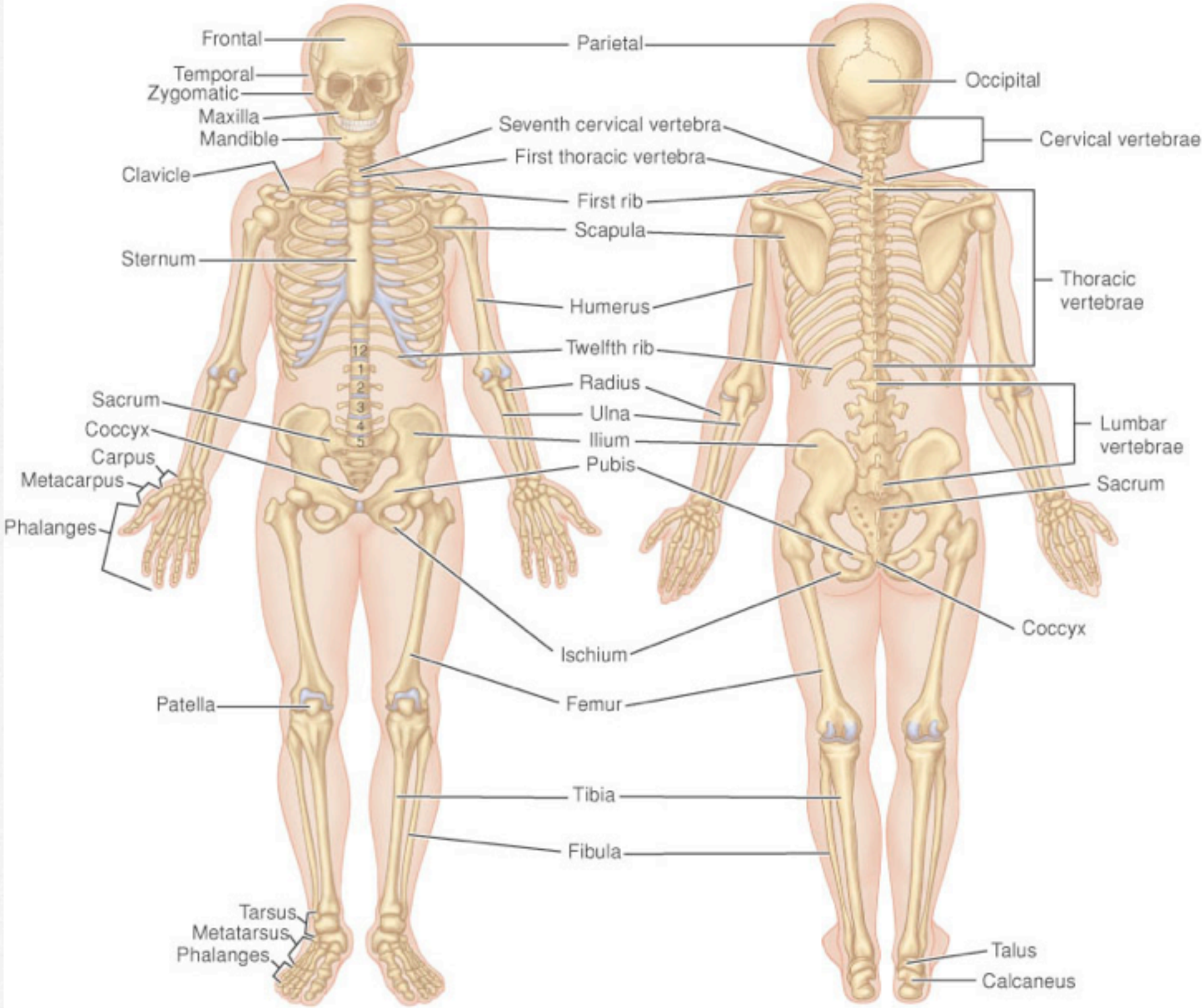
- Skeletons come in three main forms: Endoskeletons(Internal), Exoskeletons(external) and Hydrostatic Skeletons(fluid based)

Endoskeletons

- Endoskeletons are found from sponges to mammals
- Endoskeletons are hardened and internal
- Endoskeletons are living
  - Endoskeletons consist of protein and inorganic material (non-chordates)
  - Endoskeletons consist of cartilage, bone or some combo of the two (chordates)



The human body has 206 bones



Exoskeletons

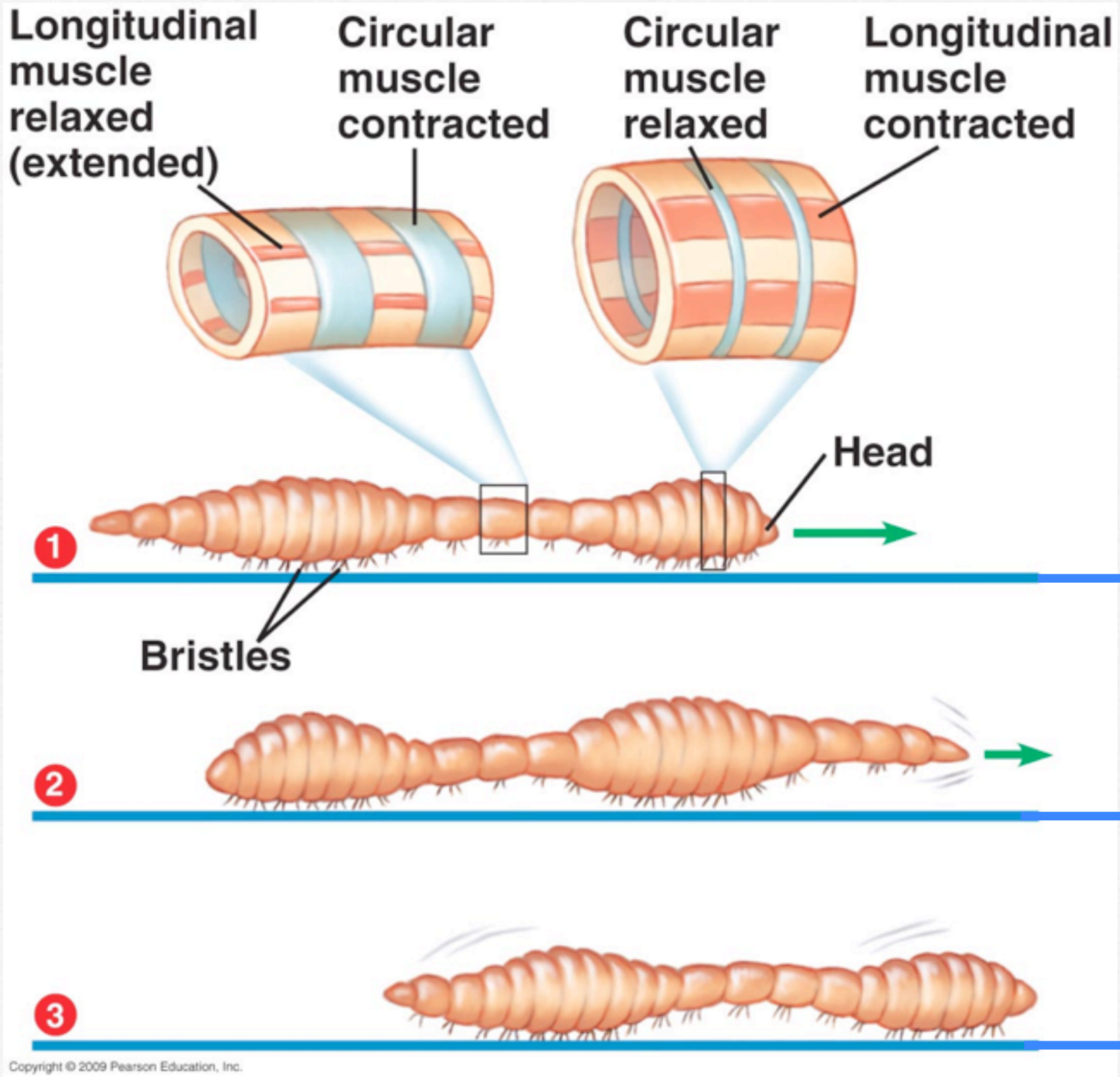
- Exoskeletons are hard encasements deposited on the animals body
- Exoskeletons are not living
  - Mollusks (ex. clams) shells are made from calcium carbonate
  - Insects have jointed exoskeletons called *cuticles*, they are made from a mix of *chitin* (polysaccharide) and protein
  - Crustaceans have exoskeletons that consist of chitin, protein and calcium carbonate

When arthropods have growth spurts they shed their exoskeleton (molting) and produce a larger one

Hydrostatic Skeletons

- Hydrostatic skeletons consists of fluid held under pressure in a closed body compartment.
  - Found in most cnidarians, flatworms, nematodes and annelids
  - Well suited for aquatic environments
    - On land these skeletons can only support crawling and burrowing (no walking or running)
- These animals move by using muscles to change the shape of the fluid filled compartments
  - Consider the earthworm...

Locomotion in Earthworms



(1) Body segments at the head and just in front of the rear are short and thick (longitudinal muscles contracted; circular muscles relaxed) and anchored to the ground by bristles. The other segments are thin and elongated (circular muscles contracted; longitudinal muscles relaxed.)

(2) The head has moved forward because circular muscles in the head segments have contracted. Segments behind the head and at the rear are now thick and anchored, thus preventing the worm from slipping backward.

(3) The head segments are thick again and anchored in their new positions. The rear segments have released their hold on the ground and have been pulled forward.


ARKive

Plants

Locomotion?Growth

Main Idea

- ***Sensing and consequently <u>Responding</u> to the environment is an absolute necessity for all organisms…EVEN PLANTS.***

- You might recall in an earlier unit that all organisms can sense some kind(s) of environmental stimuli.

- We will focus on responses at the organismal level.

  - ***The focus of this unit is responding to stimuli through movement, since some organisms do not technically move I am using a liberal interpretation of "moving" to include <u>self propulsion</u> as well as <u>growth</u>.***

Locomotion & Growth

- ***For many organisms, Responding to environmental stimuli often involves moving to or away from a stimulus.***
  - *Plants can not move!*
- ***For some organisms growing towards or away from a stimulus is the best they can do.***
  - Plants are stationary and generally respond to environmental cues by adjusting their individual patterns of growth and development.

Growth Responses in Plant

- Plants respond to a number of different stimuli.
- We will look at how plants will adjust their growth and development toward the following stimuli:
  - Light, Gravity, Mechanical Stress and Environmental Stress
  - Recall if plant growth results in a plant's organs bending to or away from a stimulus it is called a tropism.
  - Keep in mind not all plant responses involve tropisms.

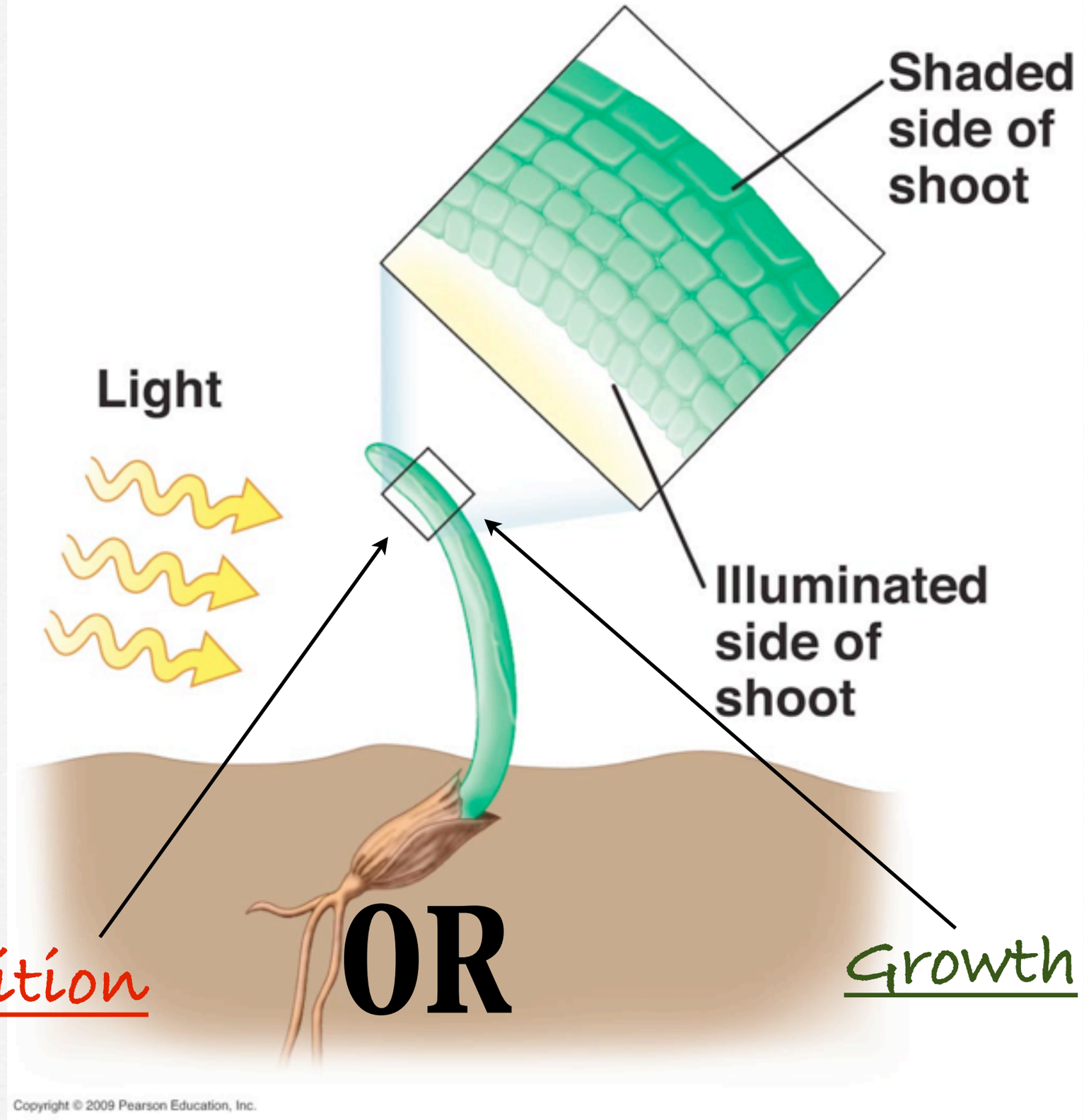
Phototropism

- Plants grow towards light.
- This results in straight upward growth unless the light source is not directly overhead in which case the plant may bend and grow towards the light. (tropism)

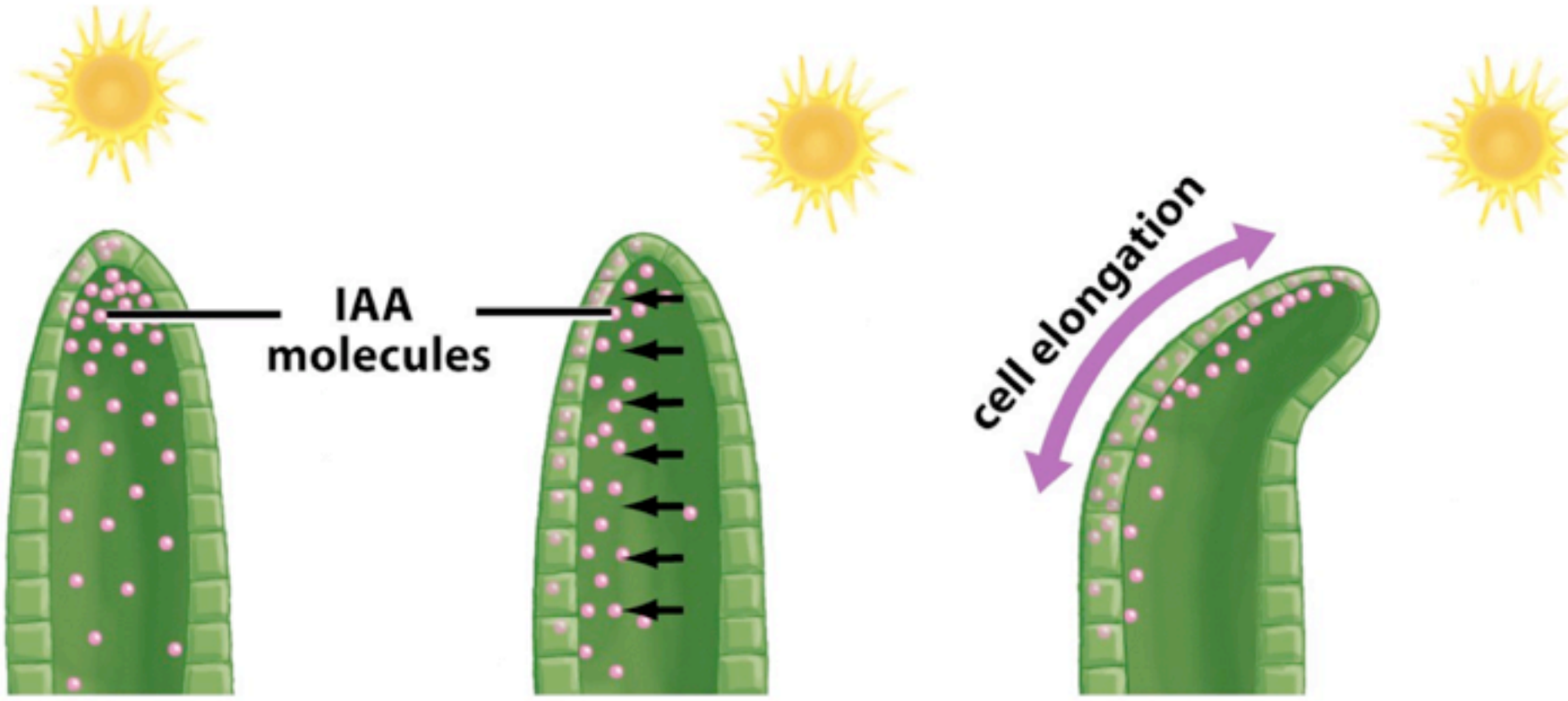
phototropism image

Phototropism

- Plants go grow in one direction by inhibiting certain cells from growing while allowing other cells to grow.



Phototropism



(a) When sunlight is overhead, the IAA molecules produced by the apical meristem are distributed evenly in the shoot.

(b) Once the sunlight shines on the shoot at an angle, the IAA molecules move to the far side and induce the elongation of cells on that side.

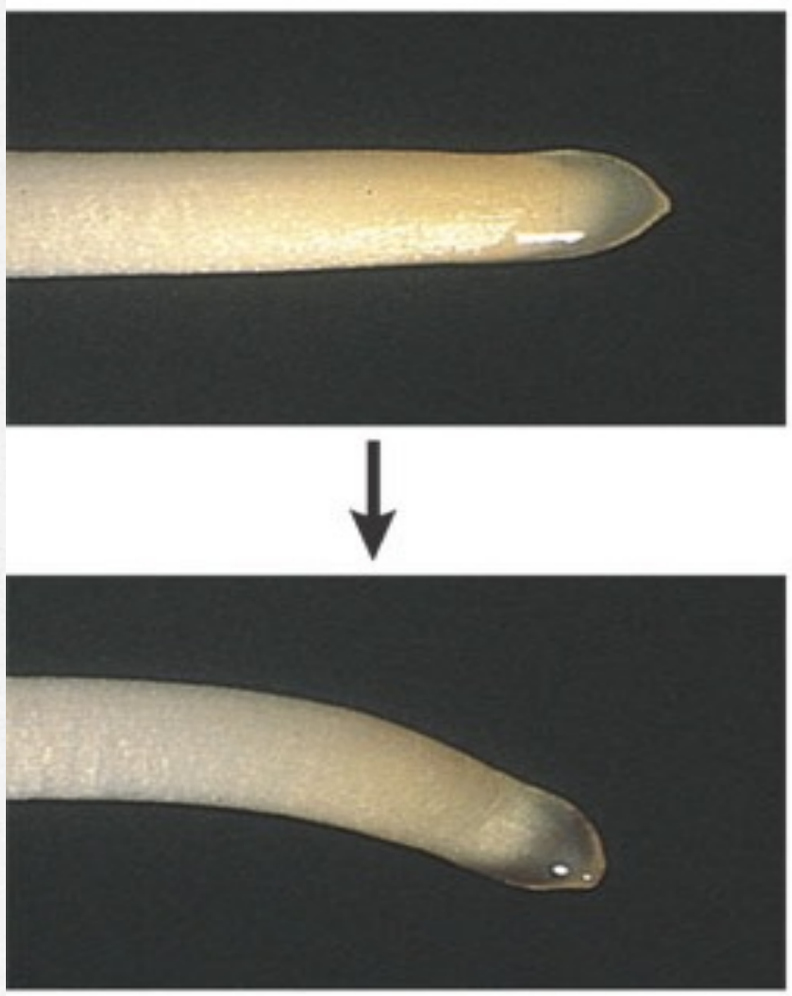
(c) Cell elongation results in the bending of the shoot toward the light.

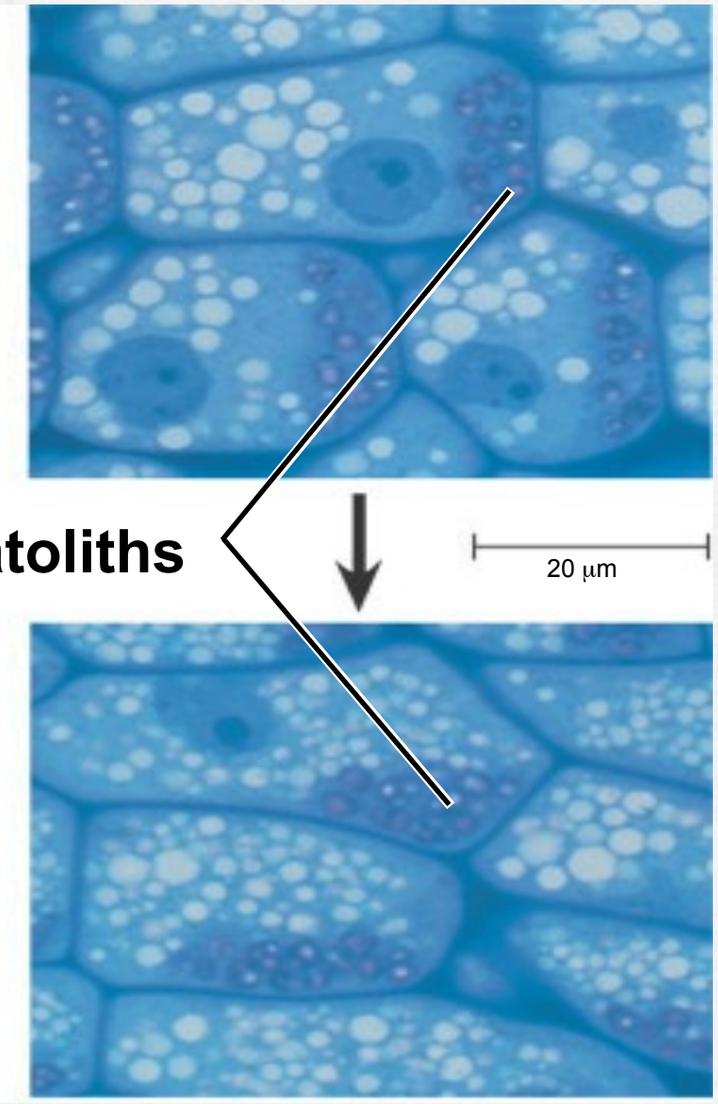
Figure 30-22 A Brief Guide to Biology, 1/e

- Photoreceptors detect the direction of light
- The plant hormone auxin (IAA) moves away from light
- The plant hormone auxin triggers cell growth

Gravitropism

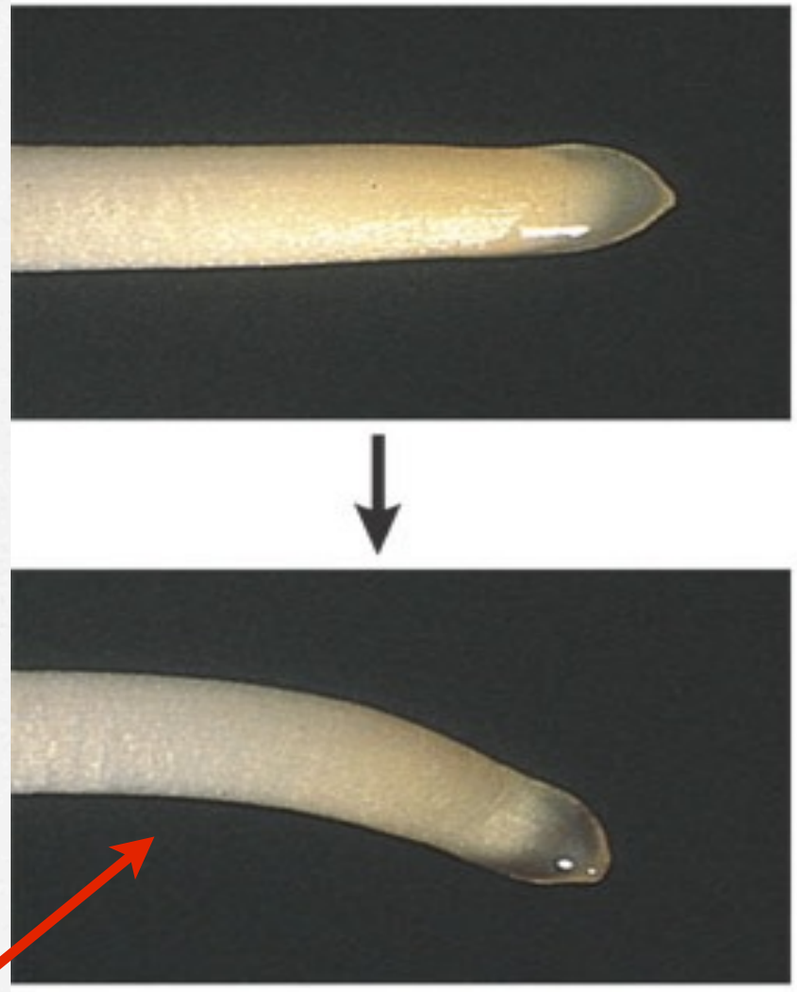
- Plants may detect gravity by the settling of statoliths
  - Specialized plastids containing dense starch grains

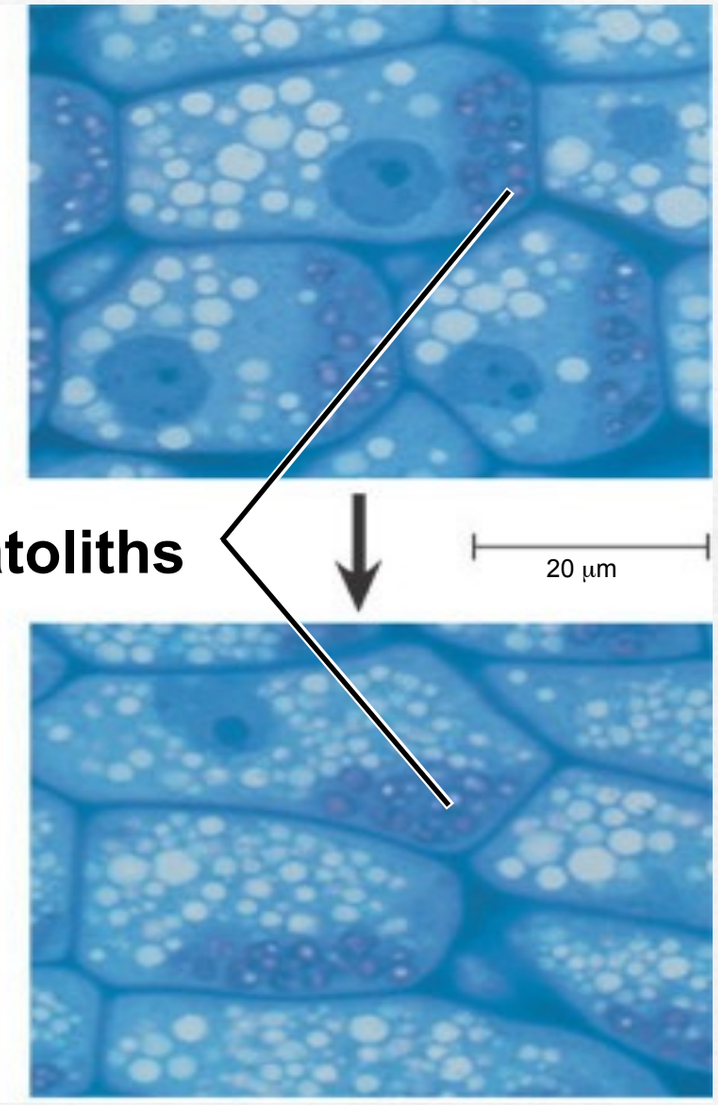




Some evidence suggests that dense organelles or proteins may also contribute to this response

Differing rates of elongation by cells on opposite sides





Do you think this is a root or shoot?

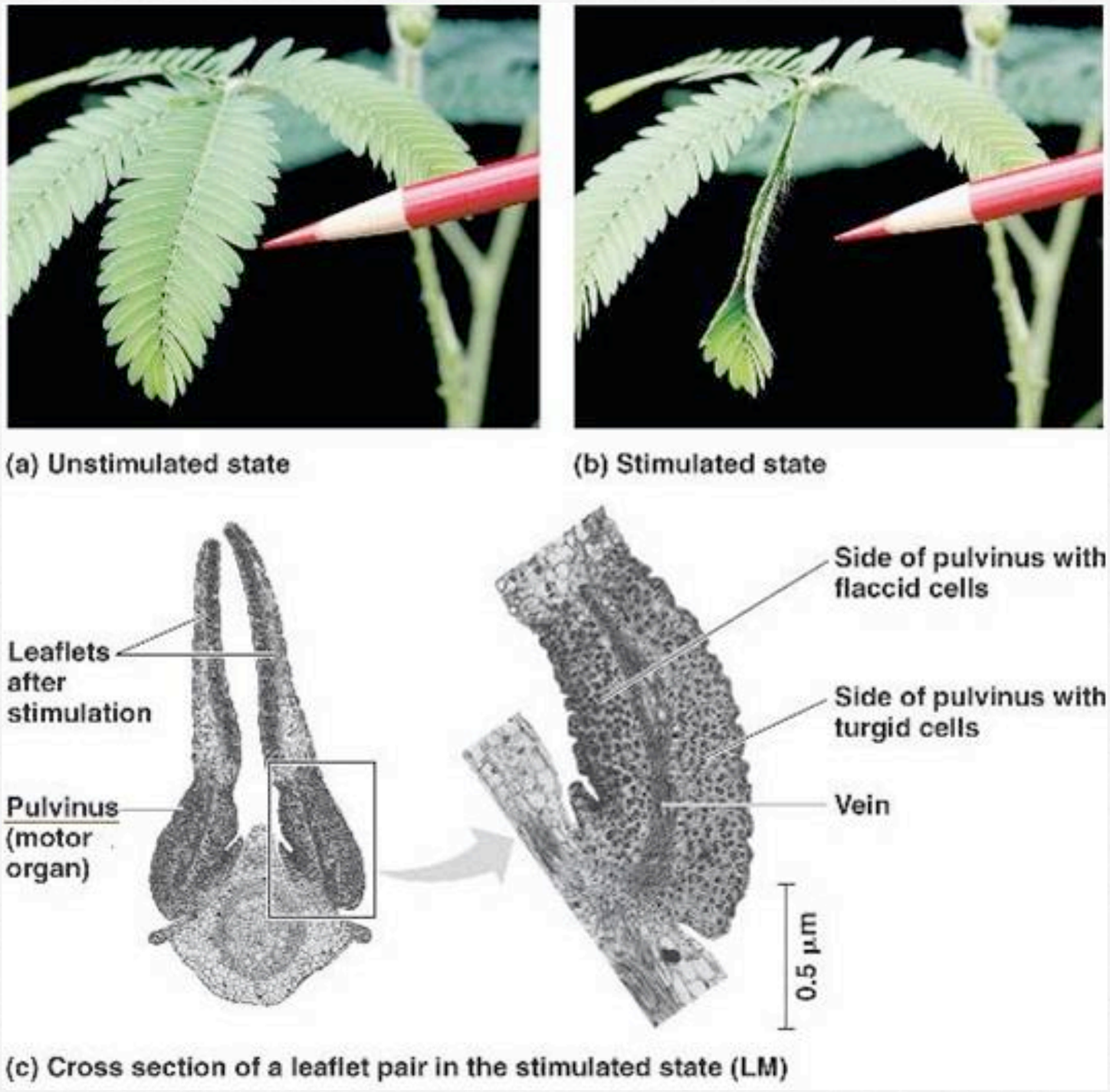
Thigmotropism

- Plants can grow directional from mechanical stimuli, touch.
  - Trees growing on a windy mountain ridge usually have shorter, stockier trunks compared similar trees in sheltered areas

WHY?

- Some plants have been become touch specialists.

- *Mimosa pudica*



Potassium leaves

motor cells

↓

water follows

↓

Motor cells

become flaccid

↓

Plant leaflets move!

WHY?

WHY?

Additional Plant Responses

- Germinating seeds when conditions are appropriate
- Opening & Closing of stomata
- Leaf abscission in deciduous trees (leaves fall before winter)
- Seasonal Flowering
- Wilting during drought

Fungi

Growth

Main Idea

- ***Sensing and consequently <u>Responding</u> to the environment is an absolute necessity for all organisms…EVEN FUNGI.***

- You might recall in an earlier unit that all organisms can sense some kind(s) of environmental stimuli.

- We will focus on responses at the organismal level.

  - ***The focus of this unit is responding to stimuli through movement, since some organisms do not technically move I am using a liberal interpretation of "moving" to include <u>self propulsion</u> as well as <u>growth</u>.***

Locomotion & Growth

- ***For many organisms, Responding to environmental stimuli often involves moving to or away from a stimulus.***
  - *Fungi can not move!*
- ***For some organisms growing towards or away from a stimulus is the best they can do.***
  - Fungi are stationary and generally respond to environmental cues by adjusting their individual patterns of growth and development.

Protists

Locomotion

Main Idea

- ***Sensing and consequently Responding to the environment is an absolute necessity for all organisms.***

- You might recall in an earlier unit that all organisms can sense some kind(s) of environmental stimuli.

- This unit will focus on the organisms response to those stimuli.

- You might also recall that many responses occur at the cellular level, but again this unit will focus on responses at the organismal level.

Locomotion & Growth

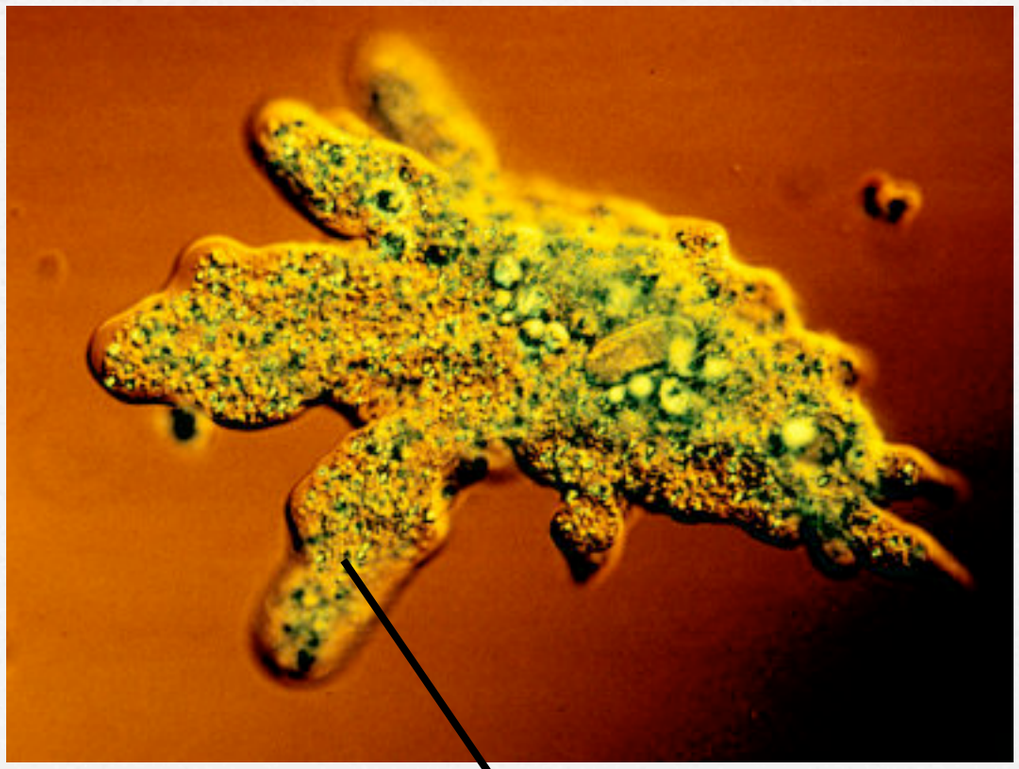
- ***For many organisms, Responding to environmental stimuli often involves moving to or away from a stimulus***.
  - *Locomotion*- is the ability to move place to place, the act of self propulsion.

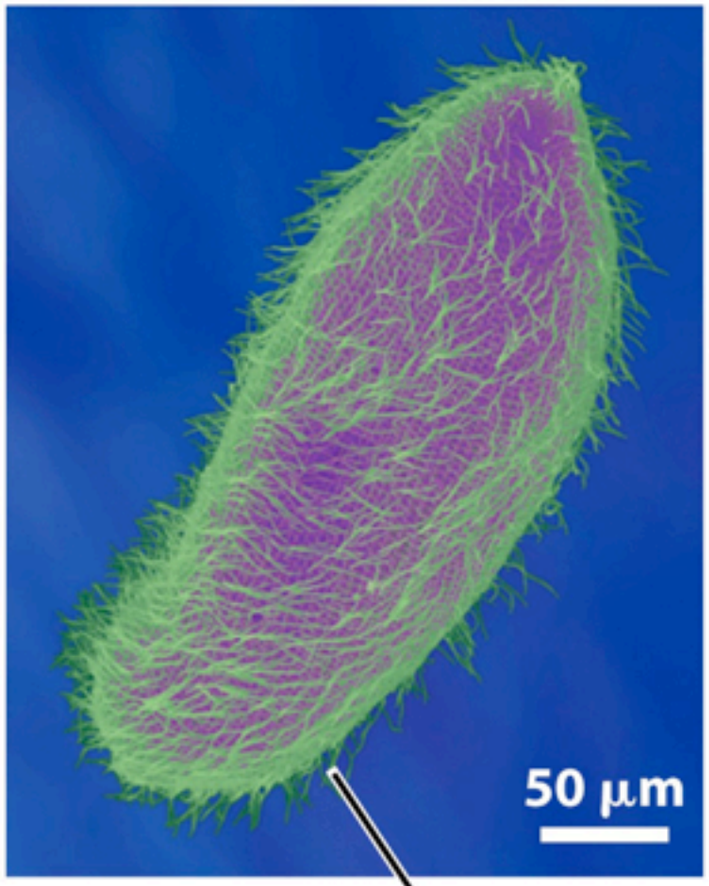
Motility...Trade Offs

- **Motility certainly has its advantages.**
  - Helps to search and obtain food.
  - Helps to search and find mates.
  - Allows organisms to disperse or migrate
  - Helps organisms to avoid predation or other dangerous stimuli
- **Motility also has a price**
  - Energetically it is expensive!

Locomotion in Protists

- Like animals protists have several kinds of adaptations for moving.
  - Pseudopods, Cilia, Flagella





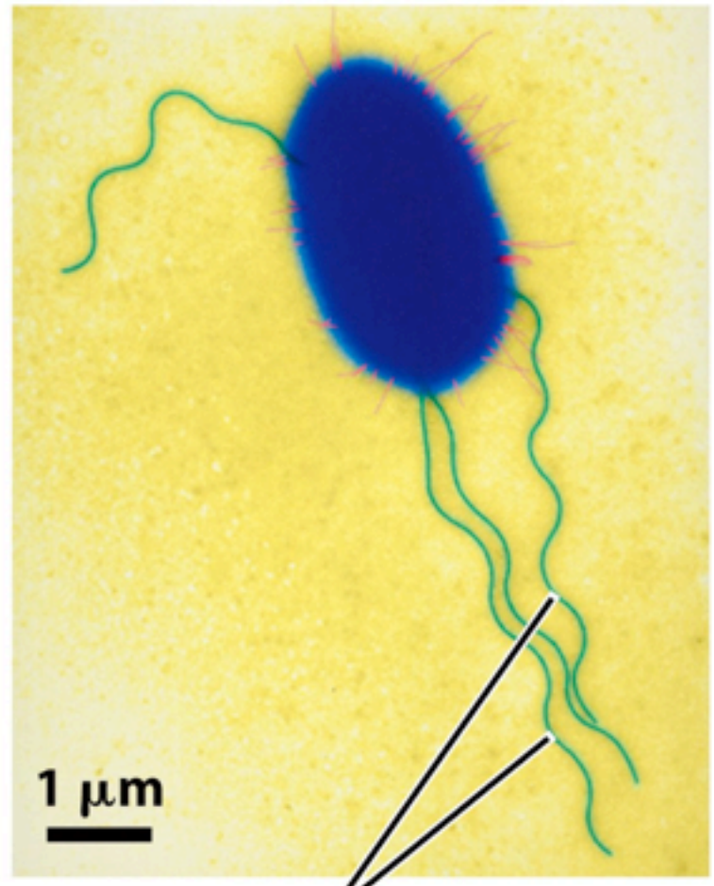


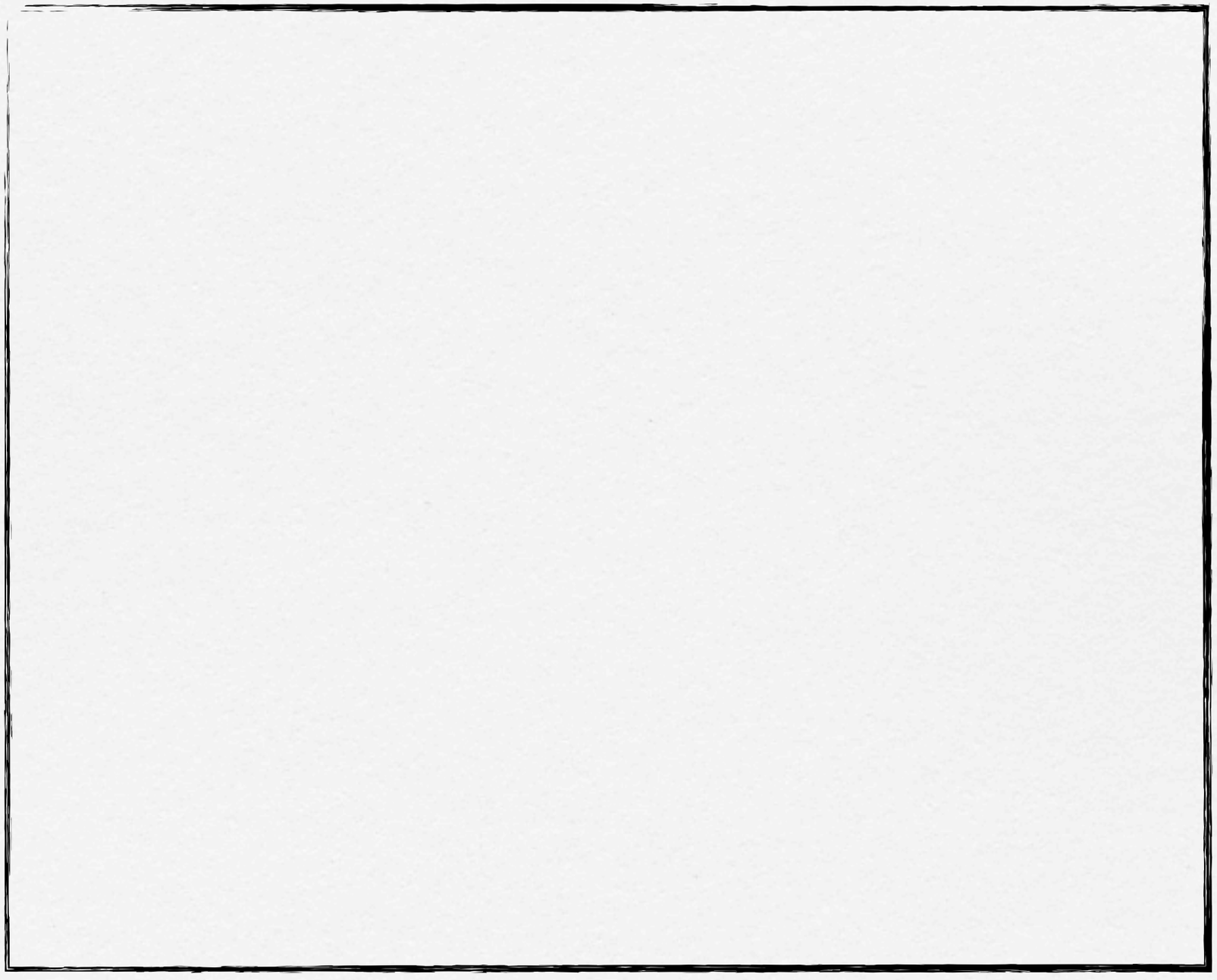
Figure 7-38 Biological Science, 2/e

Pseudopods

- Pseudopods (false feet)- temporary fingerlike outpushings of the cell surface.
- Amoeboid movement- the cell crawls along a surface by extending cellular extensions (pseudopods) and moving toward them.
  - The cell extends/projects using actin filaments
  - Cell surface proteins make strong attachments to the surface
  - Myosin & Actin interact near the cell's trailing end, causes contraction of that region, loosening cell surface attachments, and pulling it forward toward the pseudopods


Nikon MicroscopyU
Digital Video Gallery
Amoeba
(Protozoan)
Through the Nikon Eclipse
E600 Microscope with
Apodized Phase Contrast

Simulated Amoeba searching for food

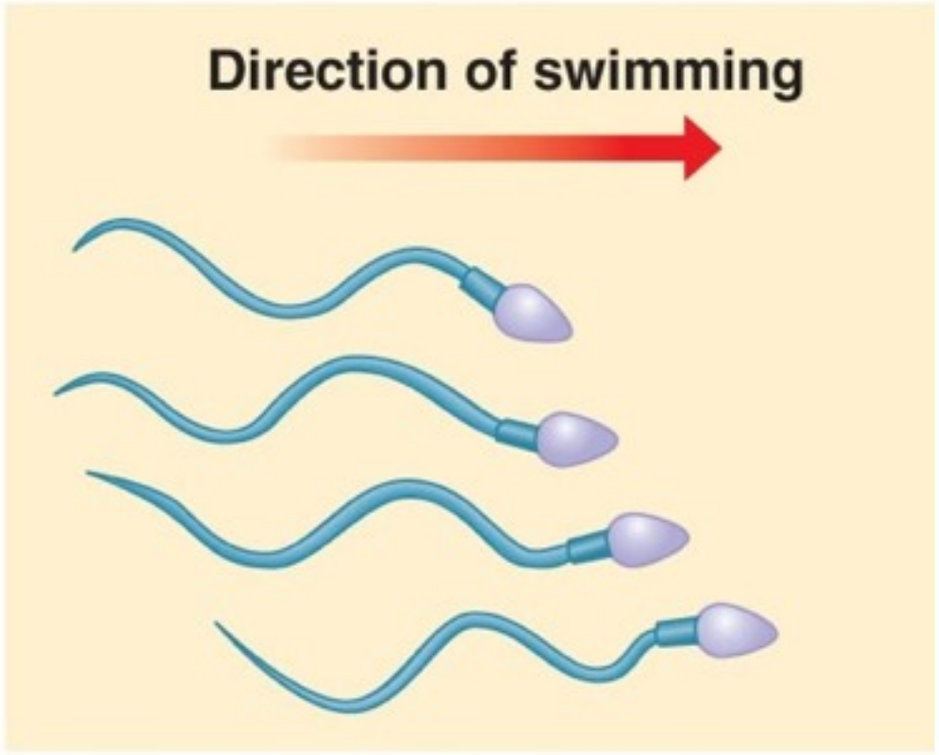


Cilia

- Many protists use cilia, like oars to propel them through the water.
- Cilia usually occur in large numbers.
- Cilia have a back and forth motion.
- Cilia have same diameter as flagella but are much shorter.

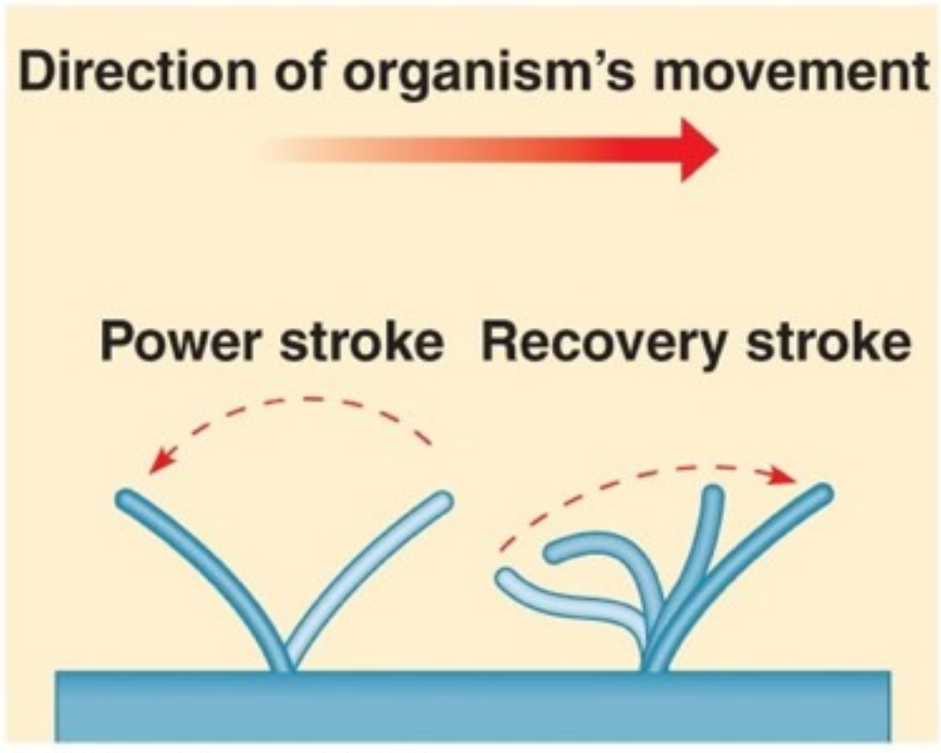
Eukaryotic Flagella

- Many protists use flagella, like a whip to propel them through the water.
- Flagella usually limited to one a few.
- Flagella use a snake-like motion.
- Flagella have same diameter as cilia but are much longer.



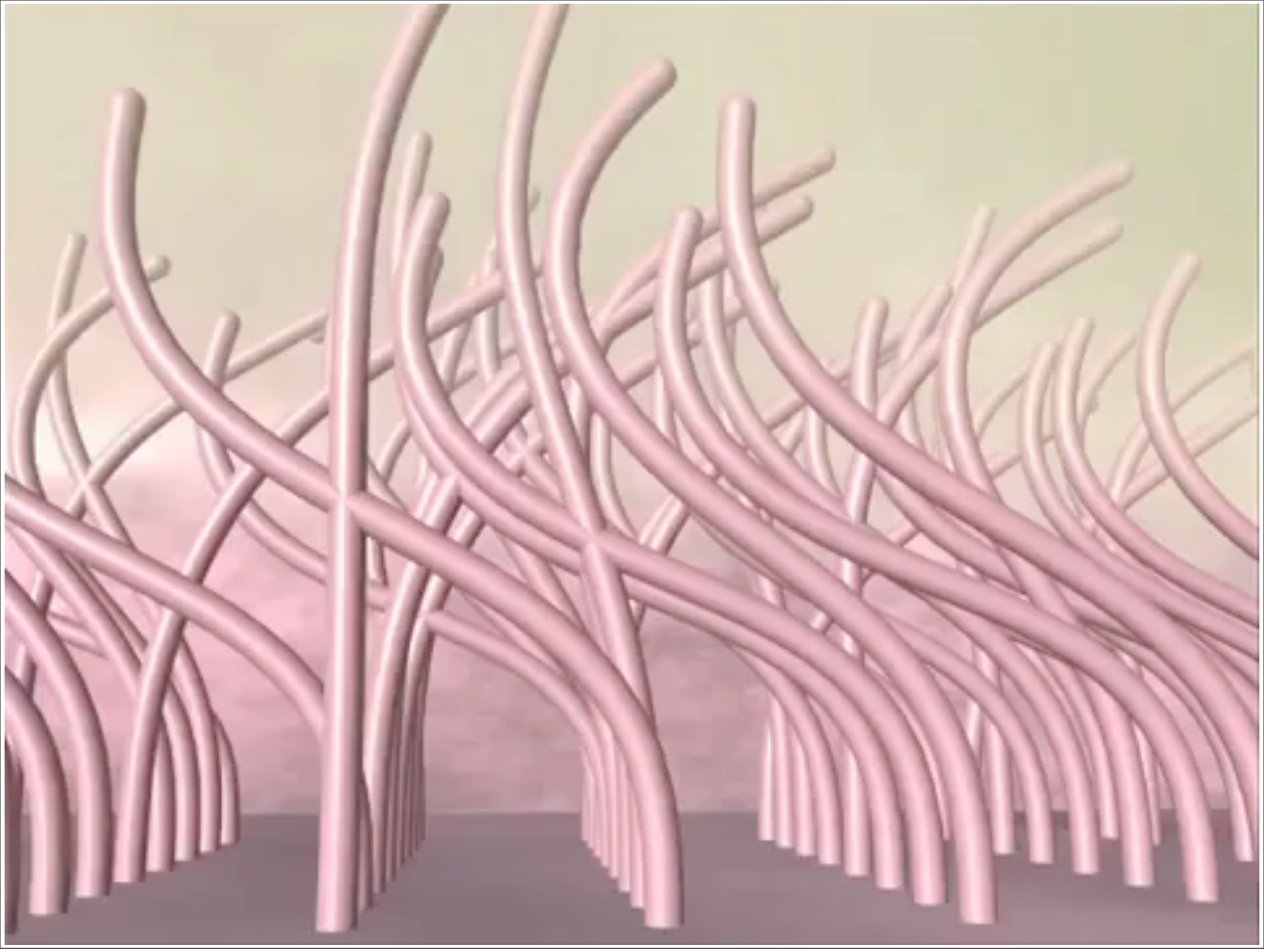
(a) Motion of flagella

5 μm



(b) Motion of cilia

15 μm



Possible Explanation...aka Hypothesis

Structure

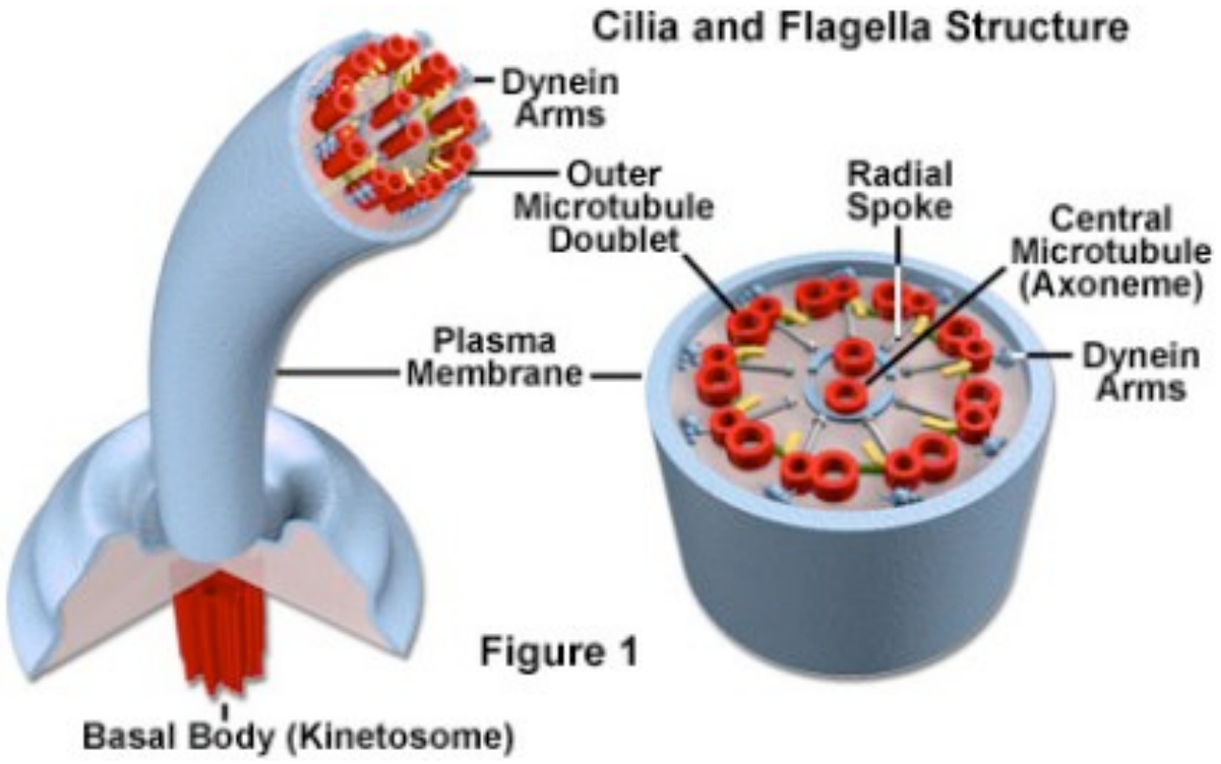
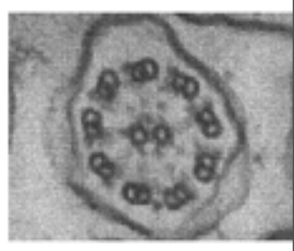


Figure 1

Both cilia and flagella consist of:

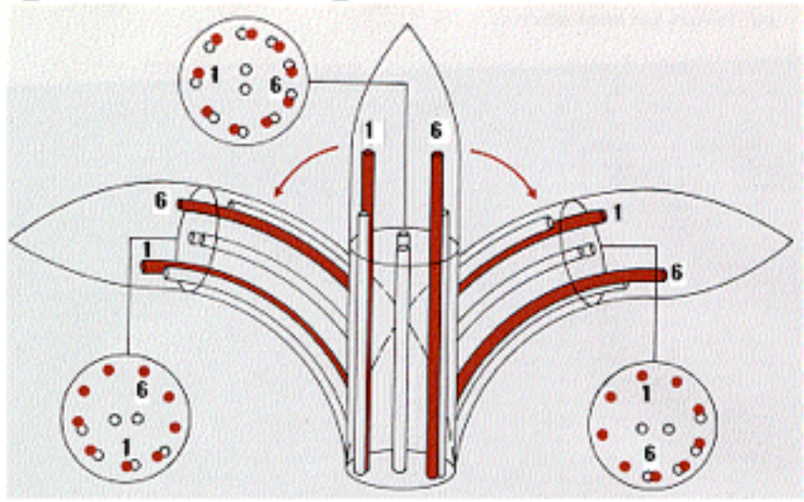


- a cylindrical array of 9 filaments consisting of:
  - a complete microtubule extending into the tip of the cilium;
  - a partial microtubule that doesn't extend as far into the tip.
  - cross-bridges of the motor protein **dynein** that extend from the complete microtubule of one filament to the partial microtubule of the adjacent filament.
- a pair of single microtubules running up through the center of the bundle, producing the "9+2" arrangement.
- The entire assembly is sheathed in a membrane that is an extension of the plasma membrane.

This electron micrograph (courtesy of Peter Satir) shows a cilium in cross section.

Sliding Filament Model of Bending

- Remember: the partial microtubules do not extend as far into the tip as the complete microtubules.
- So if a slice is made a short distance back from the tip,
  - A straight cilium should show the complete pattern (center of diagram).
  - In a bent cilium, approximately half the filaments on the upper side should be retracted because of the greater arc on the convex side. So the partial microtubules would disappear being drawn below the plane of the slice. As seen here, bending to the left causes the partial microtubules 4, 5, 6, 7, and 8 to disappear.
  - When the cilium bends the other way, the partial microtubules on the opposite side disappear while they reappear on what is now the lower or concave side.
- Electron micrographs (made by Peter Satir) have verified this model precisely.



Can you identify similarities between sliding filament theory in muscles and phototropism?

Cilia and Flagella Review

- **Cellular extensions that project from the cell.**
- Cilia and Flagella have similar diameters but cilia usually occur in large numbers where flagella are limited to one or a few
- The structure of these extensions are the same
  - The microtubule arrangement is referred to as "9+2"
- Many unicellular eukaryotes use cilia or flagella for locomotion
  - Sperm of animals, plants and fungi use flagella to move
  - Cilia is often used to move fluid over a surface
  - ATP provides energy for movement

Bacteria

Locomotion

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- **Motility also has a price**
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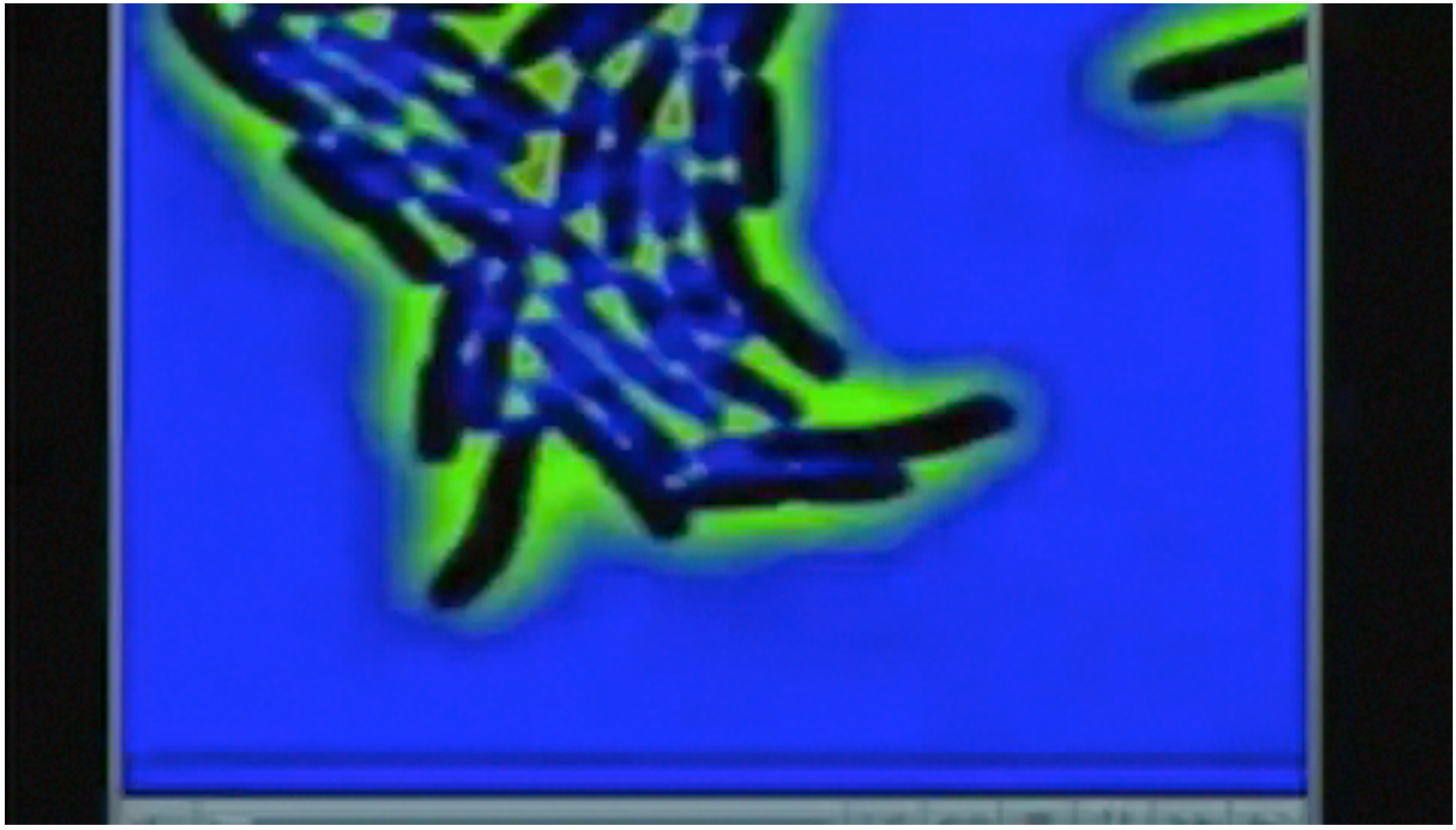
Bacteria Locomotion

- **Bacteria move a number a different ways.**
  - Swimming
    - uses flagella which vary in position and number on different bacteria
    - rate of 10-60 cell lengths/sec, a cheetah moves at a rate of 25 body lengths/sec
  - Gliding
  - Twitching
    - uses a "grappling hook" that is extended, anchored and retracted with great force
  - Move vertically by adjusting buoyancy

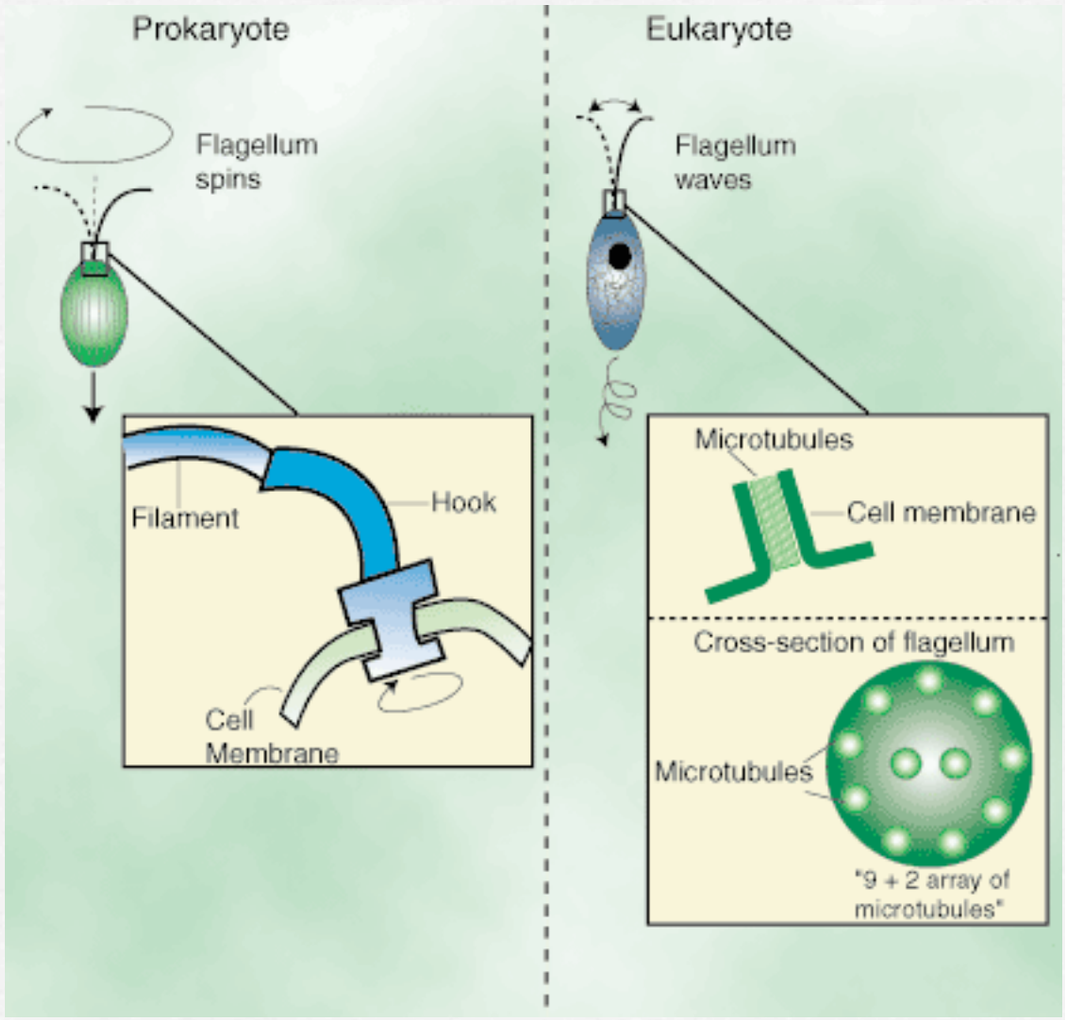
Prokaryotic Flagella (Motor)



Bacteria invented the wheel!

Bacteria Flagella

- **Differs in structure and function of eukaryotic flagella.**
  - Eukaryotic flagella produces a "whip-like" motion
  - Prokaryotic flagella produces a "propeller" motion



Bacteria Flagella

- **Prokaryotic flagella can navigate by changing the rotation of its flagella**
  - Clockwise rotation causes the bacteria to "tumble" and change direction
  - Counter-Clockwise rotation causes the bacteria to "run" in one straight or curved direction