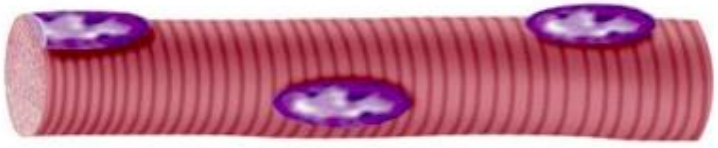
The Muscular System

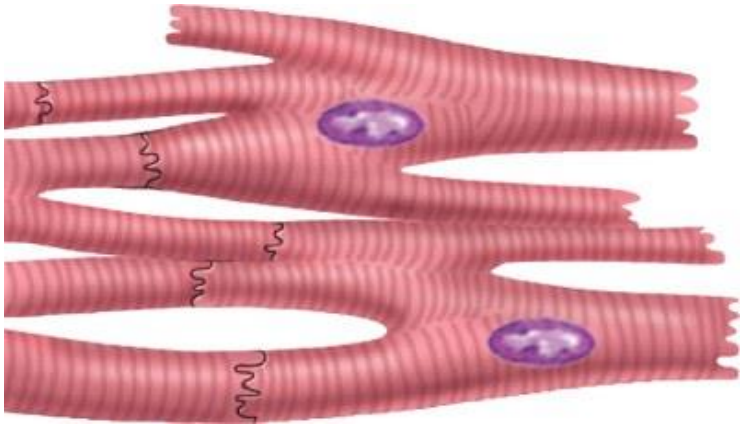
Functions of Muscular Tissue

- Like nervous tissue, muscles are excitable or "irritable"
  - they have the ability to respond to a stimulus
- Unlike nerves, however, muscles are also:
  - **Contractible** (they can shorten in length)
  - **Extensible** (they can extend or stretch)
  - **Elastic** (they can return to their original shape)

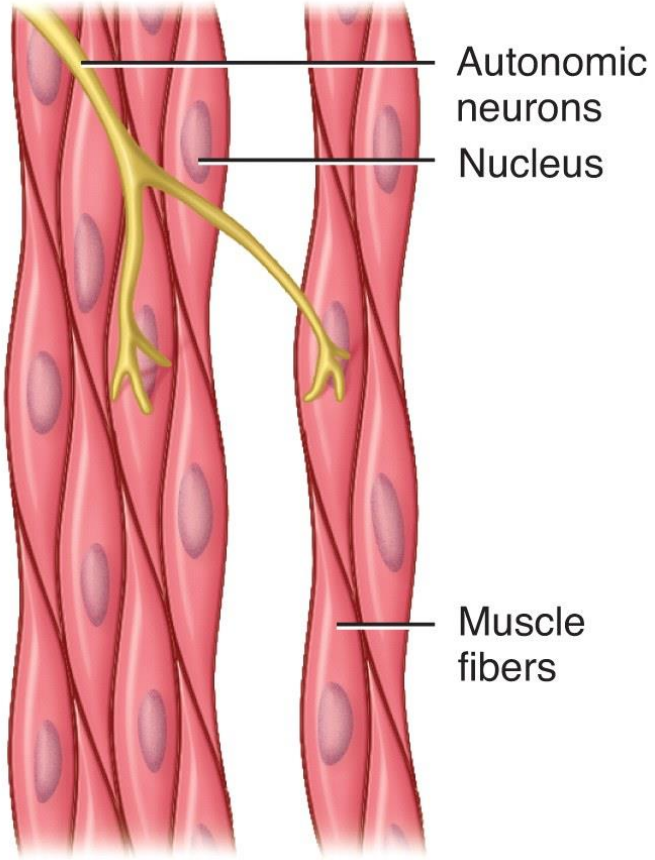
Three Types of Muscular Tissue



(a) Skeletal muscle

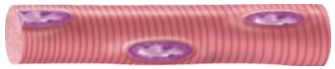
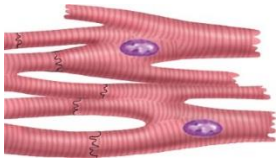


(b) Cardiac muscle



(c) Visceral smooth muscle

Three Types of Muscular Tissue

	Location	Function	Appearance	Control
Skeletal 	skeleton	movement, heat, posture	**striated**, multi-nucleated (eccentric), fibers parallel	**voluntary**
Cardiac 	heart	pump blood continuously	**striated**, one central nucleus	**involuntary**
Visceral (smooth muscle) 	G.I. tract, uterus, eye, blood vessels	Peristalsis, blood pressure, pupil size, erects hairs	**no striations**, one central nucleus	**involuntary**

Muscular System

- **Skeletal muscle is the only organ of the muscular system**
- **Skeletal muscle is composed of skeletal muscle tissue and also contains nervous tissue, blood vessels and connective tissue**
- **Half of the body's weight is muscle tissue**
  - **Skeletal muscle = 40% in males, 32% in females**
  - **Cardiac muscle = 10%**

Skeletal muscle fibers (cells) are arranged into bundles called fascicles

Fascicles are bound by connective tissue

Four different connective tissue coverings

Deep fascia

Surrounds entire skeletal muscle and extends beyond its length

Epimysium

Closely surrounds skeletal muscle, binds fascicles together

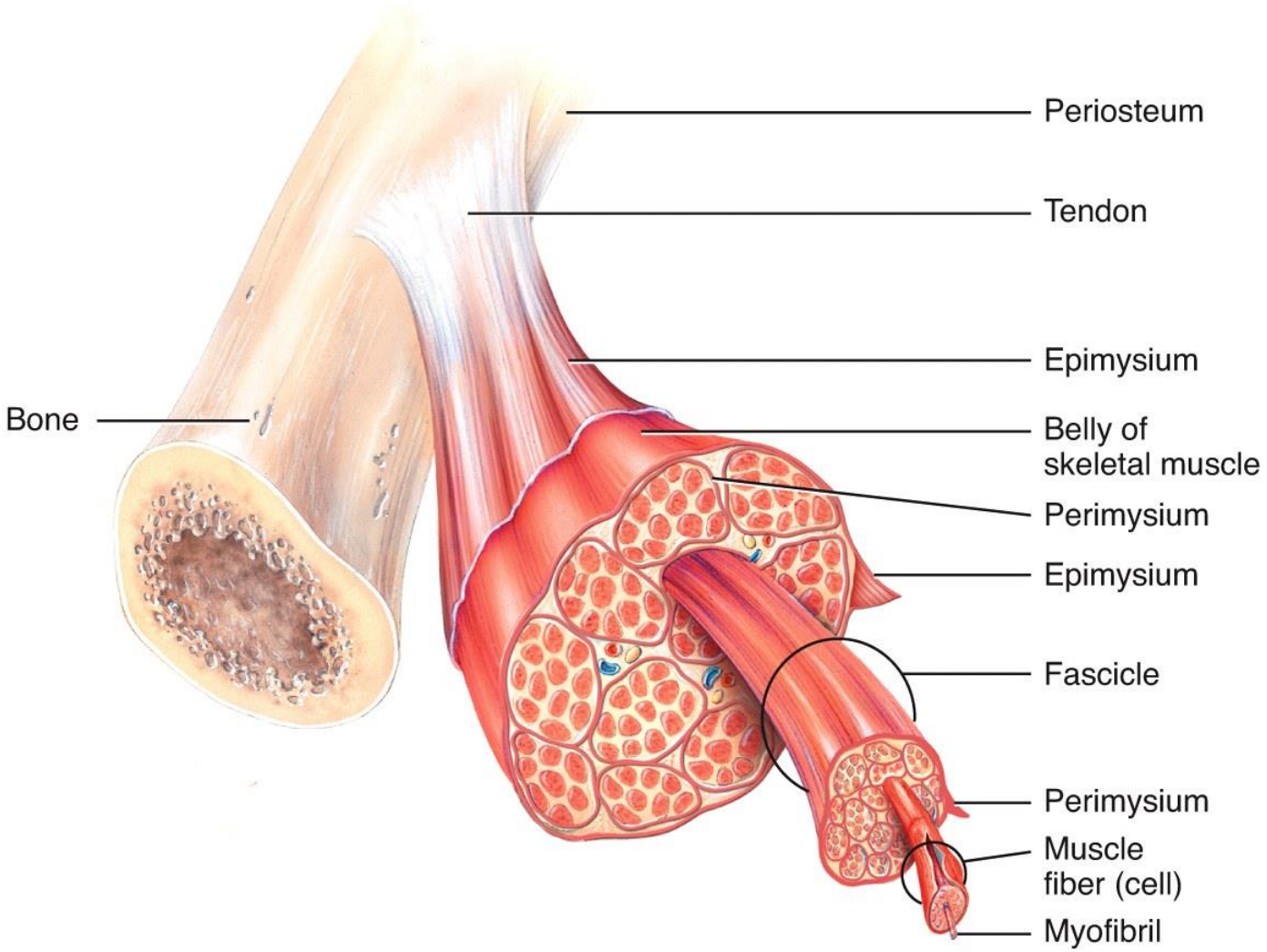
Perimysium

Surrounds each fascicle

Endomysium

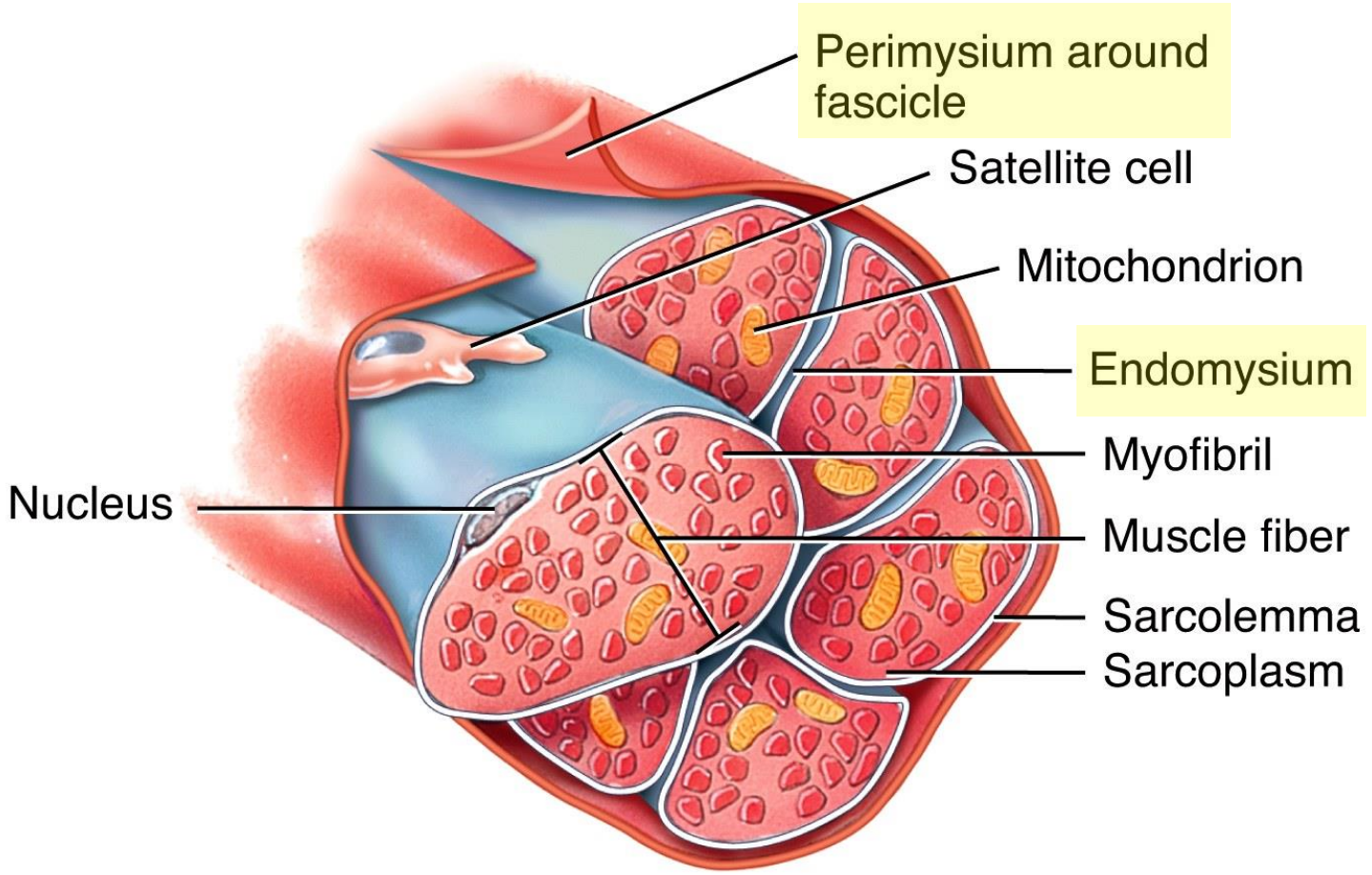
Surrounds each muscle fiber (cell)

Organization of Muscle Tissue



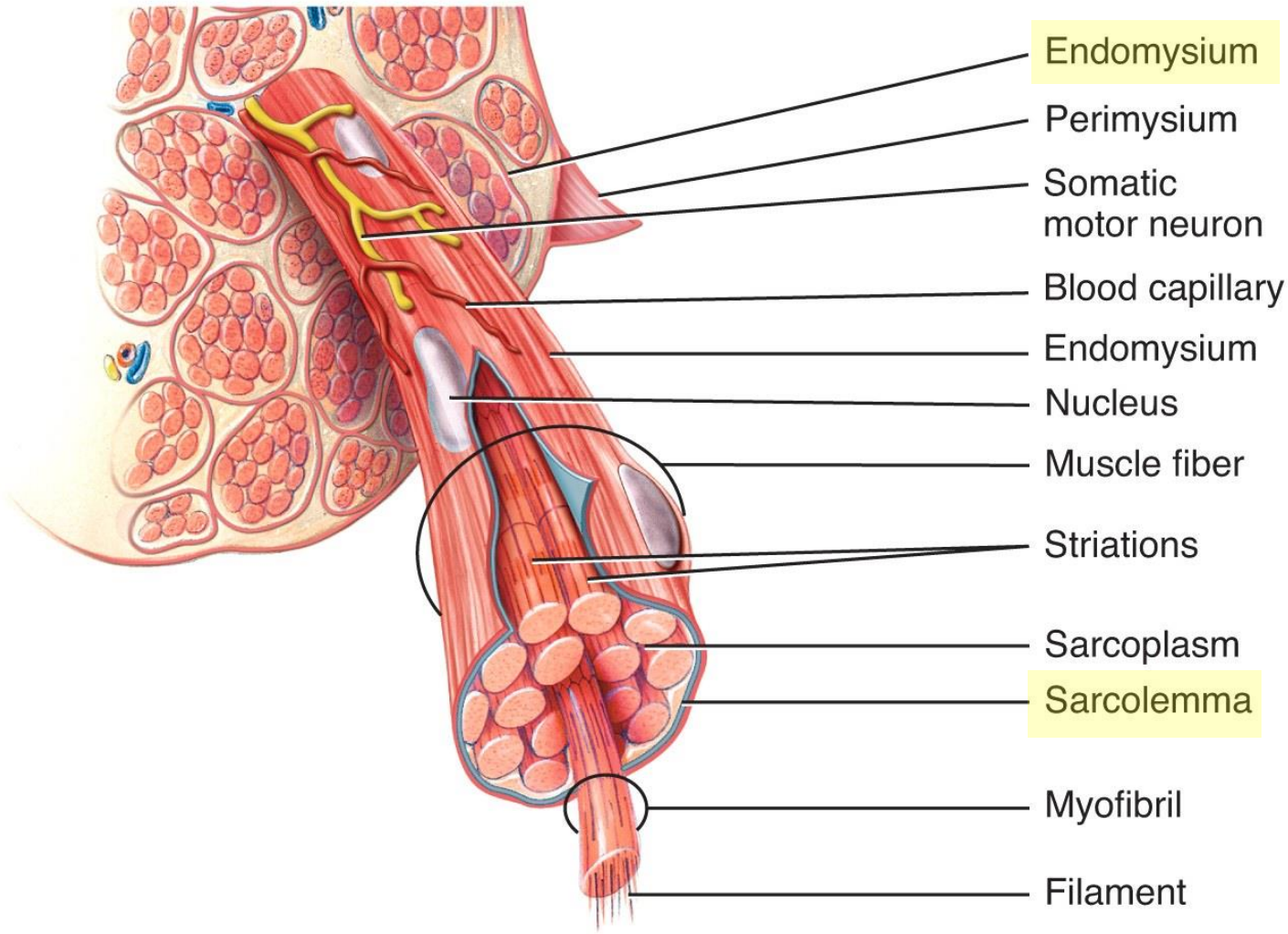
A muscle, a fasciculus, and a fiber all visualized

Organization of Muscle Tissue



Organization of a fasciculus

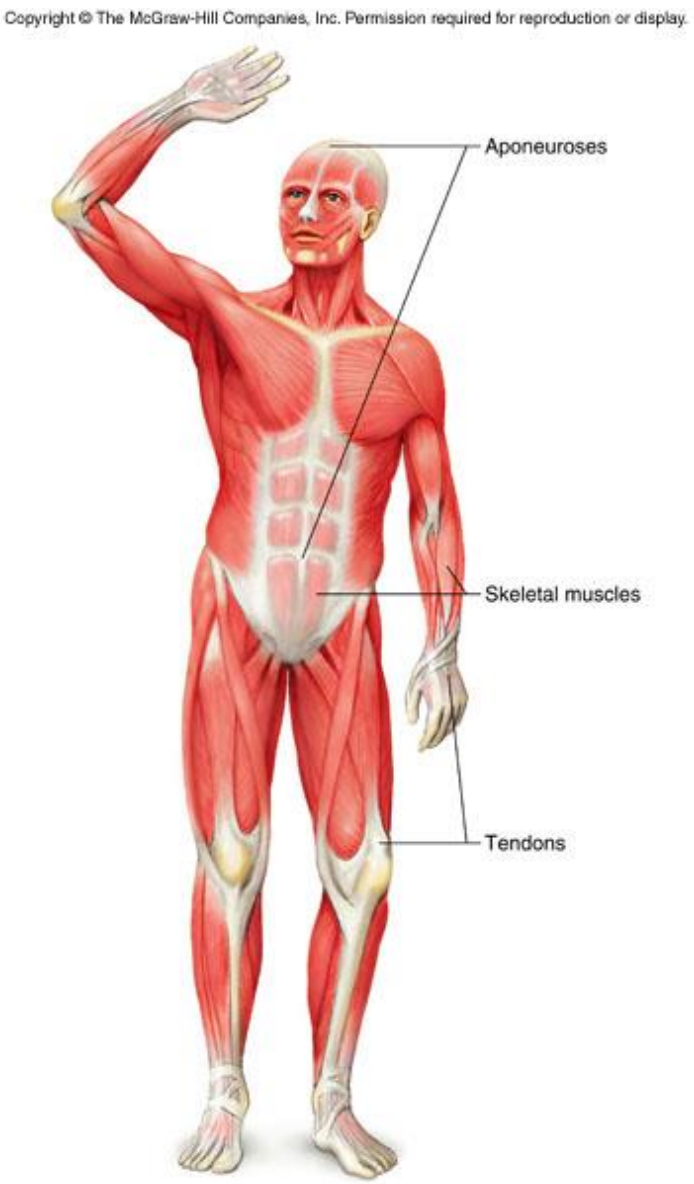
Organization of Muscle Tissue



Organization of a muscle fiber

Connective Tissue Coverings

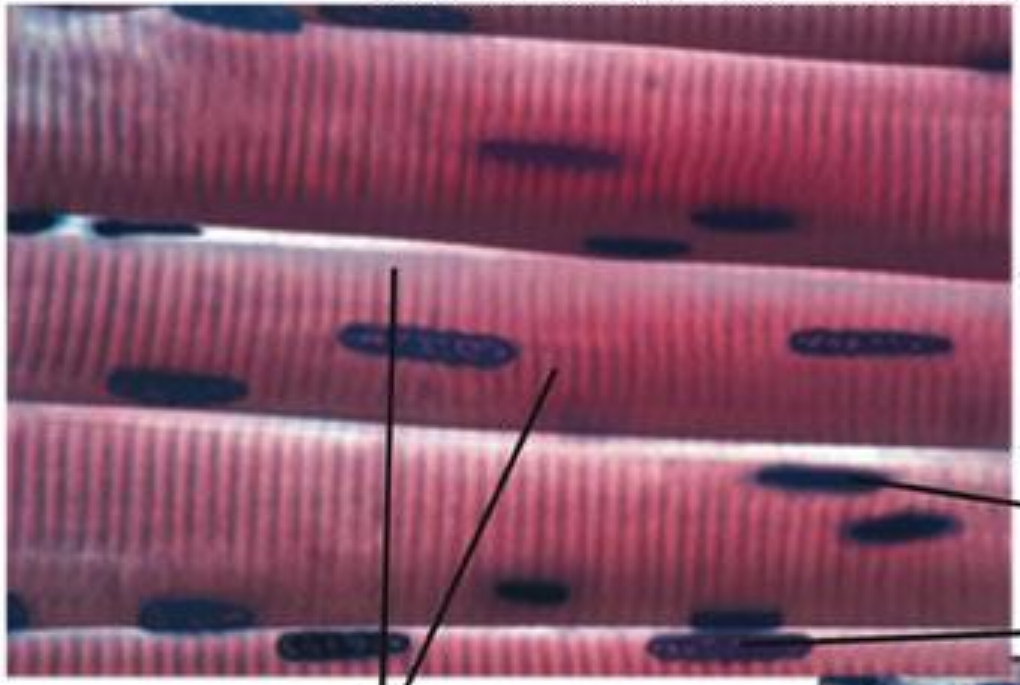
- **Fascia**
  - Surrounds an individual skeletal muscle, separating it from other muscles
  - Fascia may extend beyond the ends of the muscle to become a tendon
  - Fascia may connect muscle to muscle and is called an aponeurosis



Characteristics of Skeletal Muscle Tissue

- **Long, thin contractile fibers that are Striated**
  - **Striations due to arrangement of thick and thin filaments**
- ***Under voluntary control***
- **Attached to the bones of the skeleton by tendons**
- **Allow for movement, facial expressions, breathing, swallowing, writing, talking and singing, posture, heat production, joint stability**

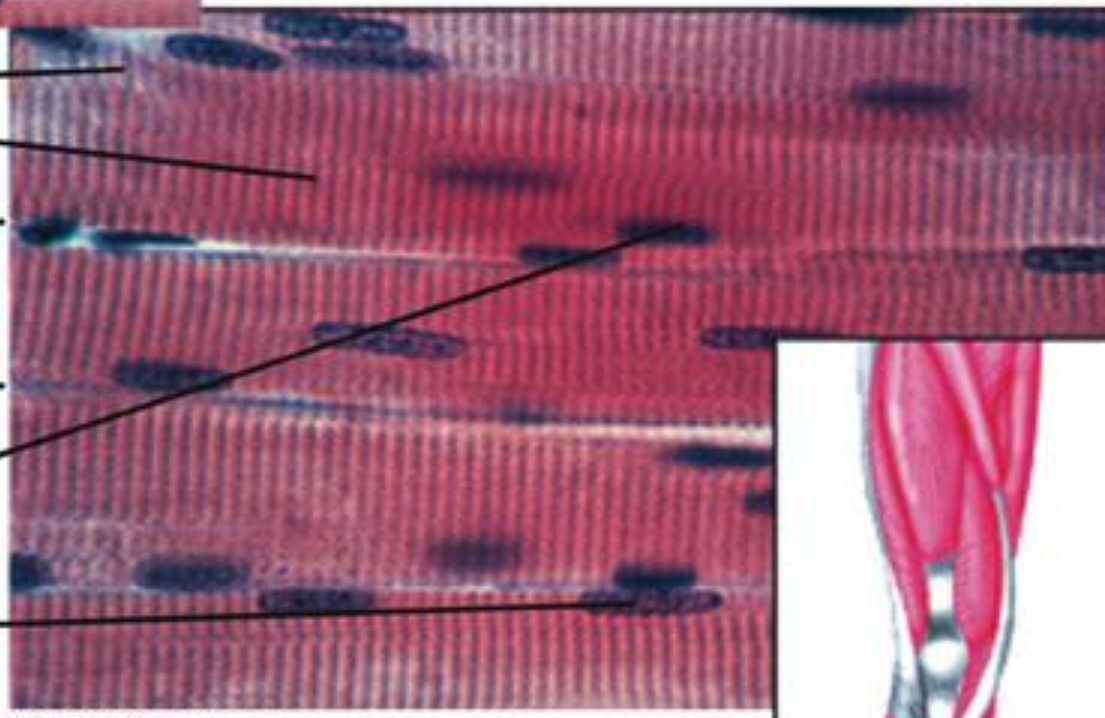
Skeletal Muscle Tissue



Muscle fiber

Nuclei

Striations

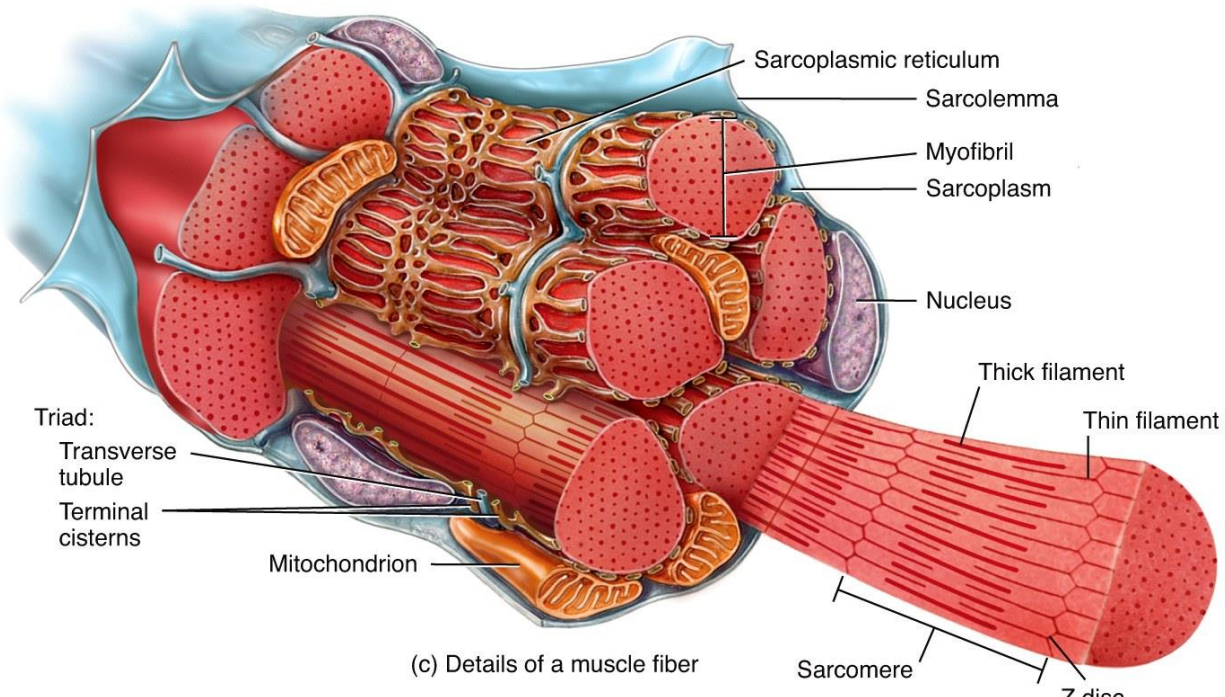


Muscle fiber

Nuclei

Skeletal Muscle Arrangement

- A single muscle cell is a muscle fiber
  - Fibers are made up of myofibrils
  - Myofibrils are made up of thick and thin filaments
- Sarcolemma – muscle cell membrane
- Sarcoplasm
- muscle cell cytoplasm

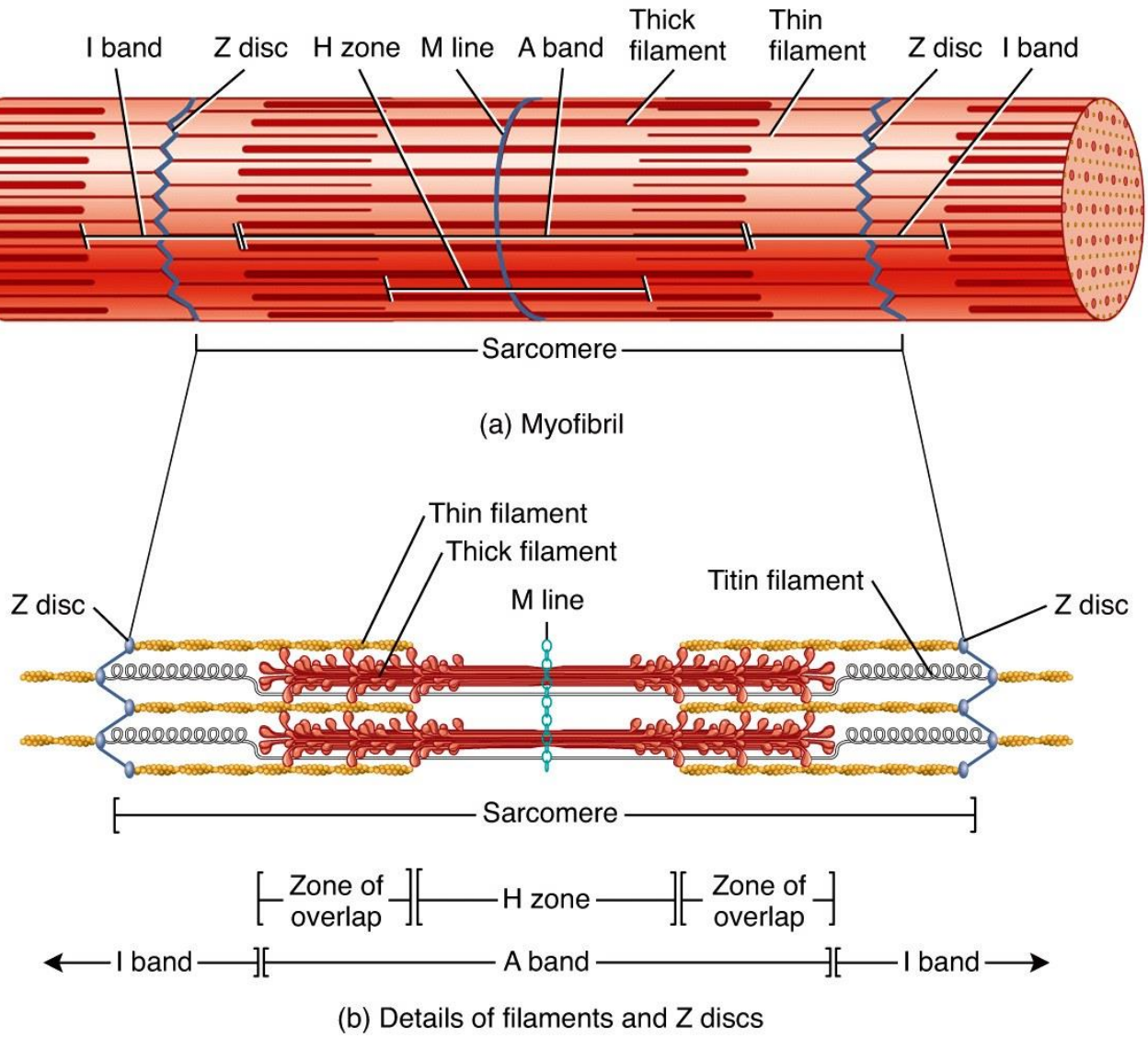


Skeletal Muscle Cells

- **Myofibrils are striated**
  - **Striations due to arrangement of thick and thin filaments**
    - **Seen as alternating areas of light and dark bands**

- **The length of each myofibril is divided into repeating units called sarcomeres**
  - **A sarcomere is the functional unit of skeletal muscle**

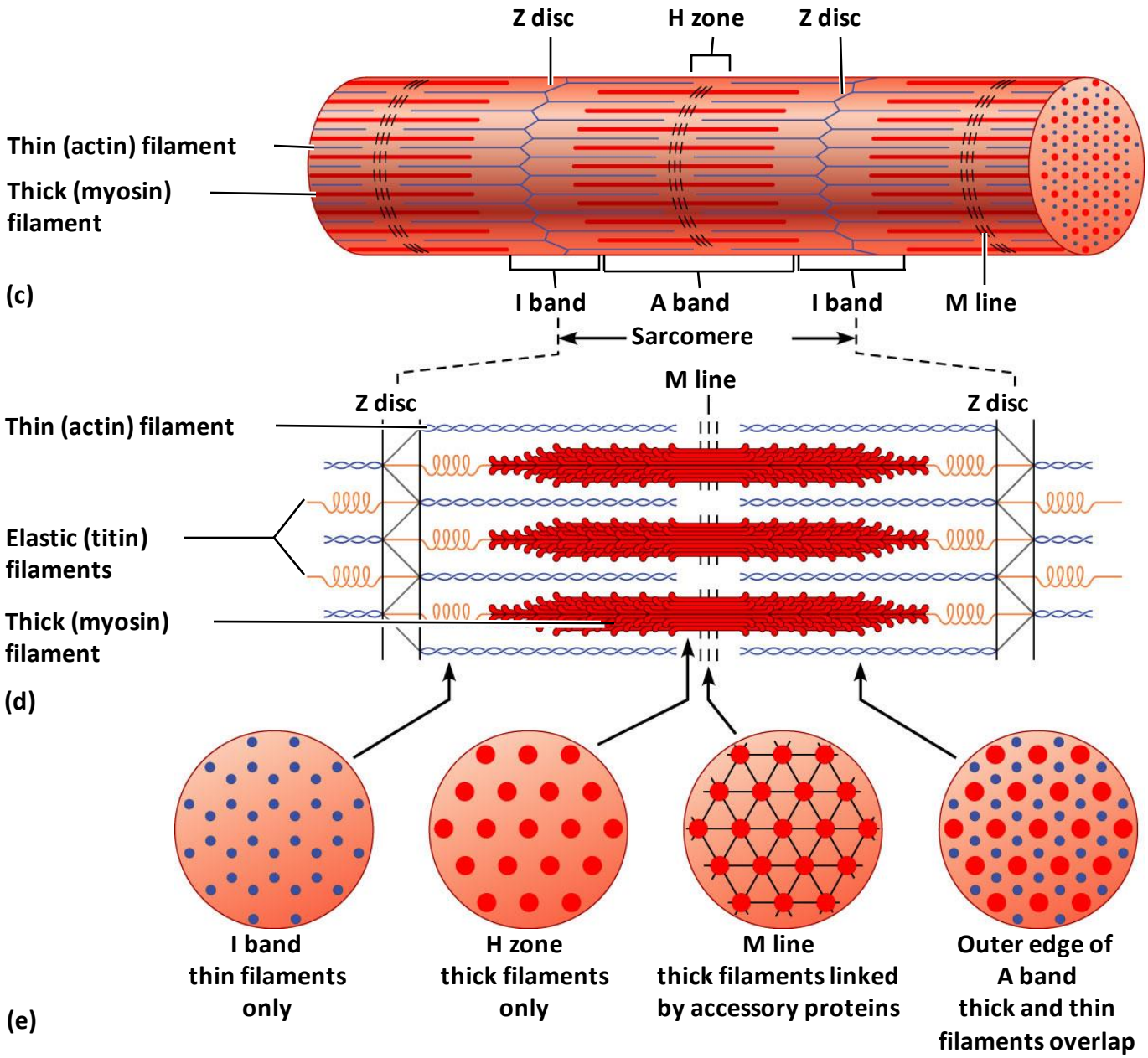
Sarcomere Arrangement



Sarcomere Structure

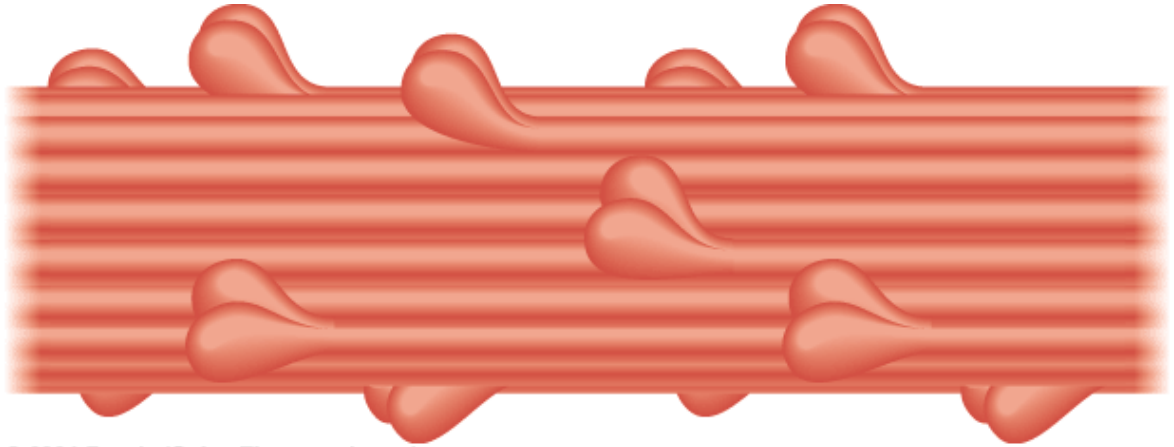
- Sarcomere exists from Z-line to Z-line
- A-Band is dark middle band
  - Overlapping think and thin filaments
- I-Band – ends of A-Band, thin filaments only
- Z-line is in the middle of the I-Band
- Myosin filaments are held to the Z-line by titin proteins

Microscopic anatomy of a skeletal muscle fiber



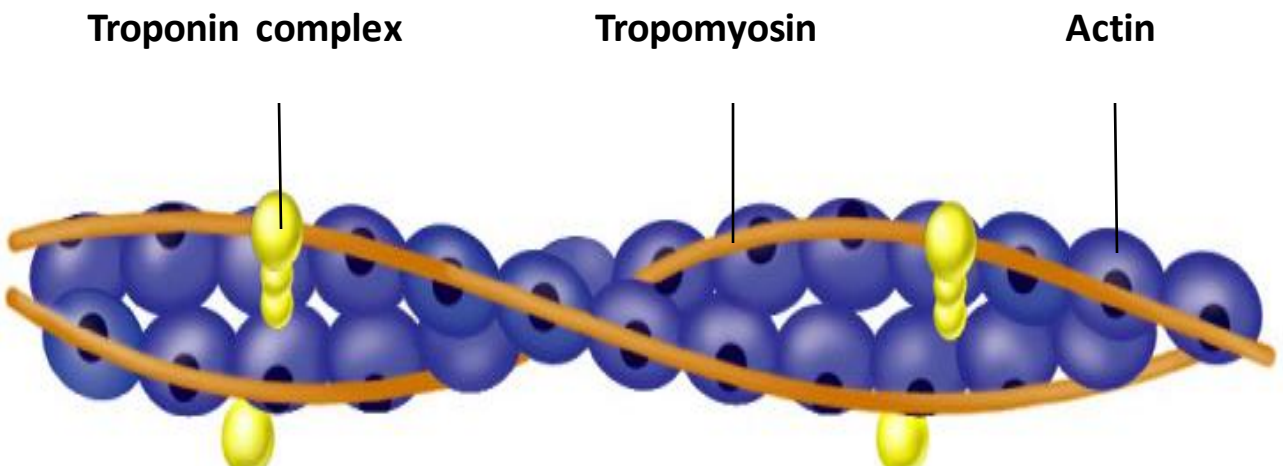
Thick Filament Structure

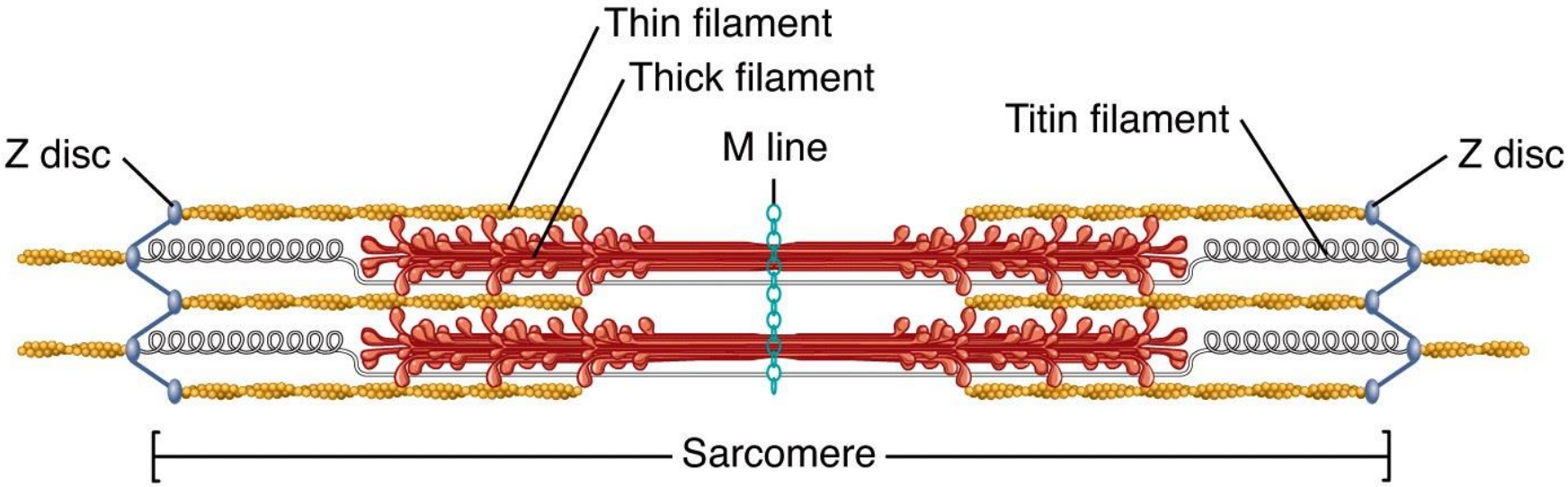
- **Composed of many myosin molecules**
  - **Each myosin molecule has a tail region and 2 globular heads (crossbridges)**



Thin Filament Structure

- Composed of actin protein
  - 2 strands of globular actin molecules twisted into a helix
  - Actin filaments have binding sites for myosin cross bridges
  - Tropomyosin protein spirals around actin helix
  - Troponin protein (3 subunits) is attached to actin and holds tropomyosin in place
    - Call this the troponin-tropomyosin complex



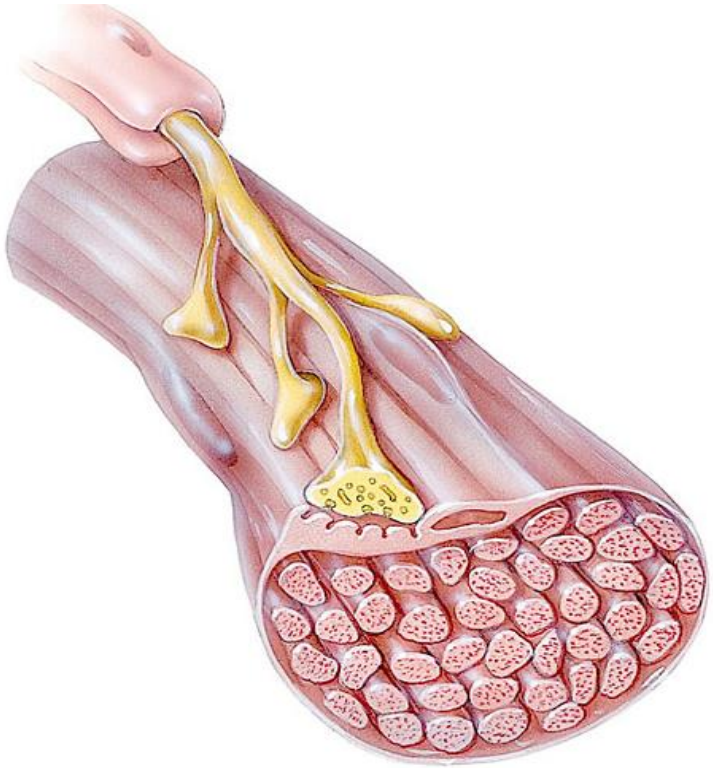

Thin filament
Thick filament
Titin filament
Z disc
M line
Z disc
Sarcomere

Skeletal Muscle Contraction

Motor Neuron

- Nerve cell that innervates skeletal muscle tissue

- Dendrite
  - Receives information
- Axon
  - Transmits information
  - Has vesicles containing neurotransmitter that will stimulate or inhibit muscle contraction
- *Neuromuscular Junction* -Site where branch of motor neuron (motor nerve ending) comes in contact with sarcolemma of skeletal muscle fiber
  - A type of synapse

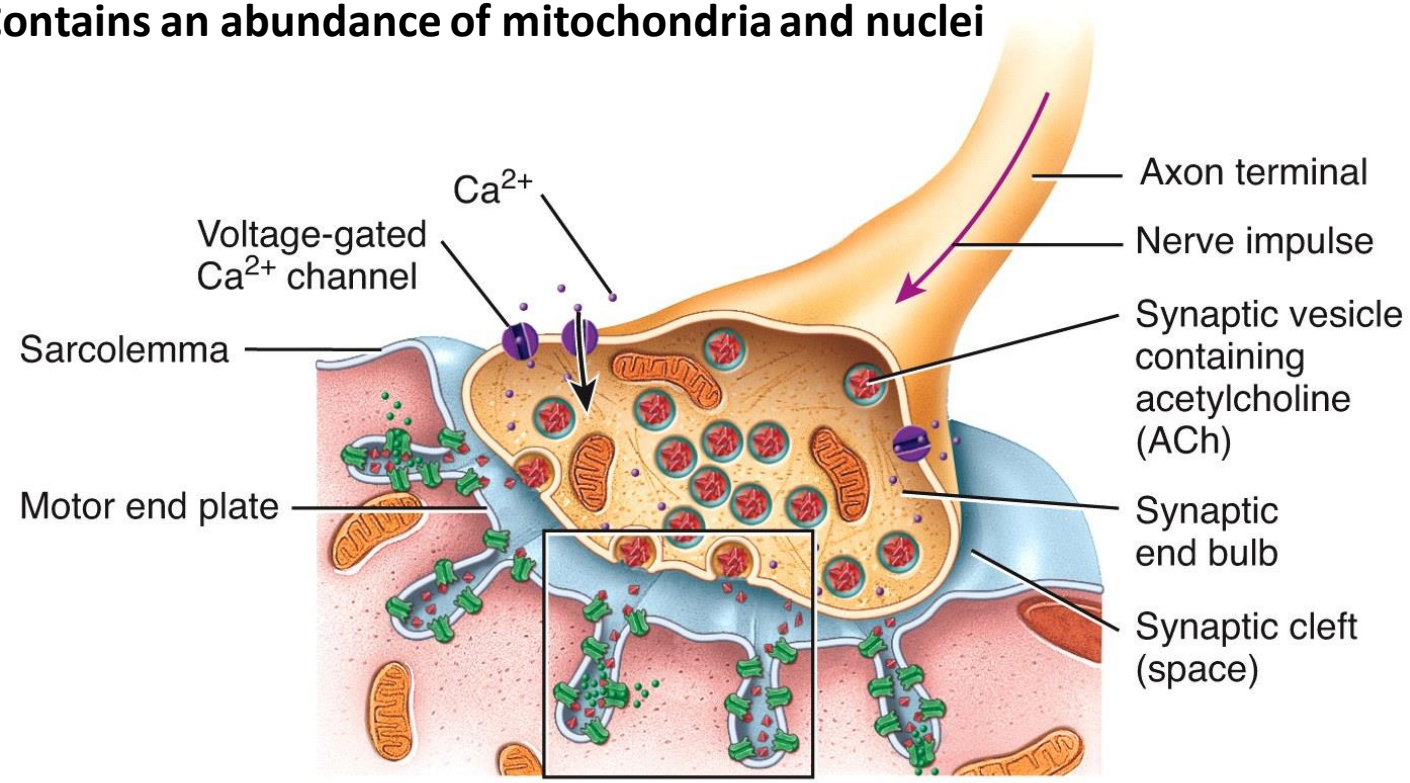


NMJ

Motor end-plate

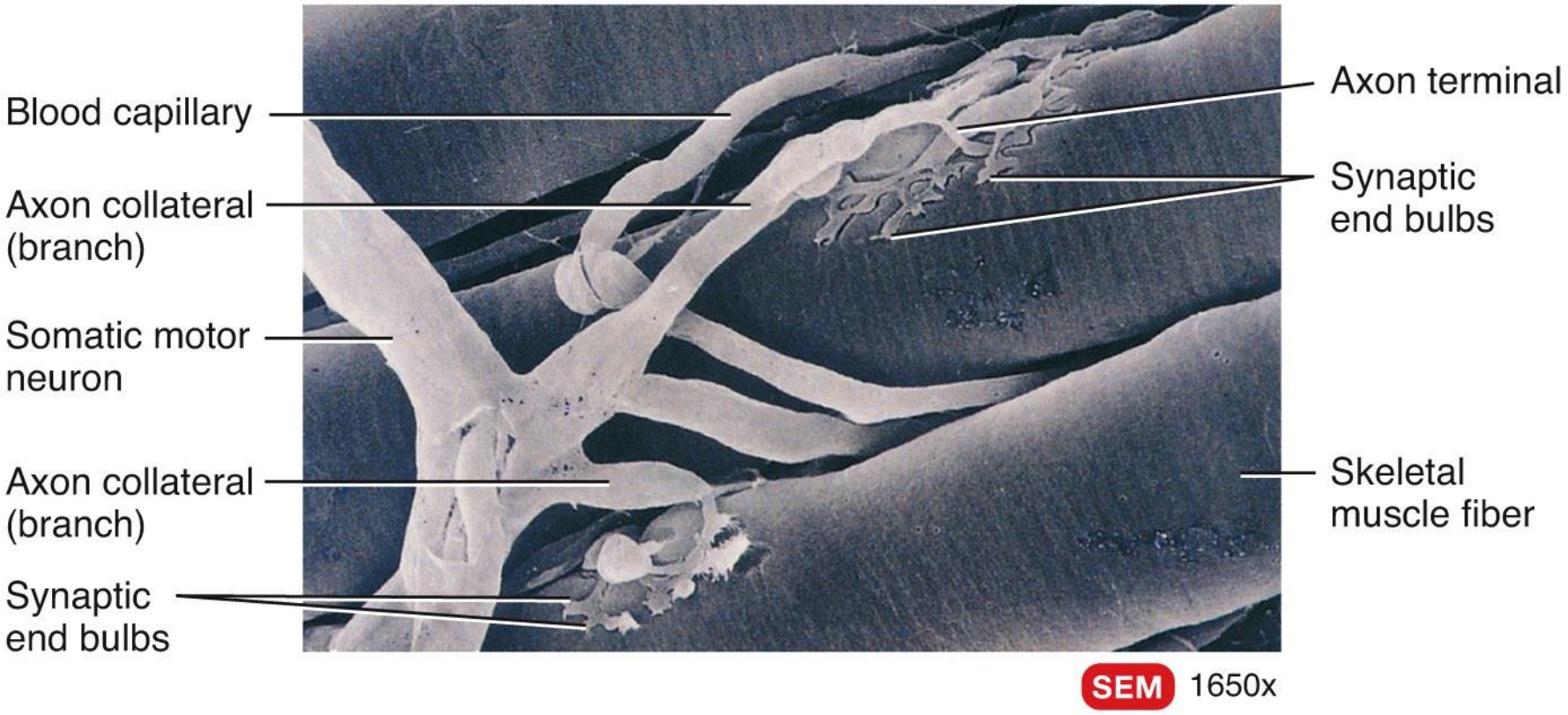
Sarcolemma of muscle fiber directly beneath motor nerve ending

Contains an abundance of mitochondria and nuclei



(b) Enlarged view of the neuromuscular junction

Neuromuscular Junction



Synapse

- ***Junction between the axonal end of one neuron and the dendrite of another neuron OR membrane of another cell type***

- **Synaptic cleft**
  - **Separation that exists between the axonal ending of the motor nerve and the sarcolemma of the muscle cell fiber**

- **The axon ending contains vesicles of neurotransmitter**

Neurotransmitter

- **Chemical substance released from vesicles in the motor nerve ending (axonal ending)**
  - **Acetylcholine (Ach) is the neurotransmitter released by motor neurons**
- **When stimulated by a nerve impulse, Ach is released, travels across the synaptic cleft and binds receptors on the motor end plate**
- **Stimulates contraction**

Sliding Filament Theory

- A sarcomere is the functional unit of skeletal muscle

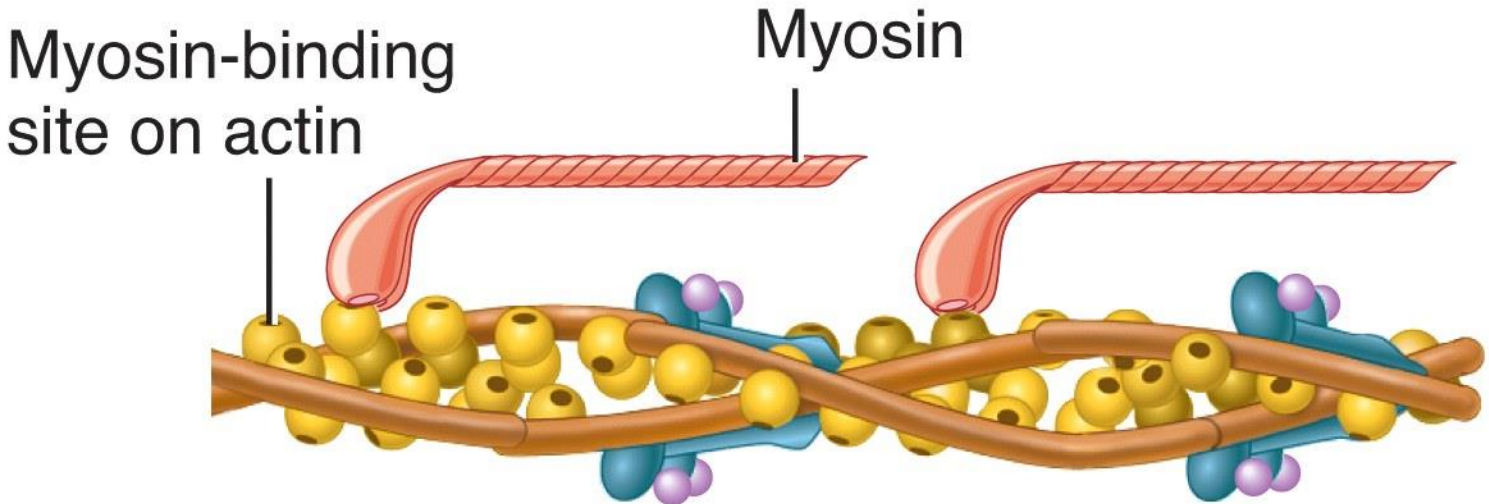
- When a skeletal muscle contracts, sarcomeres shorten

- This is described by the sliding filament theory

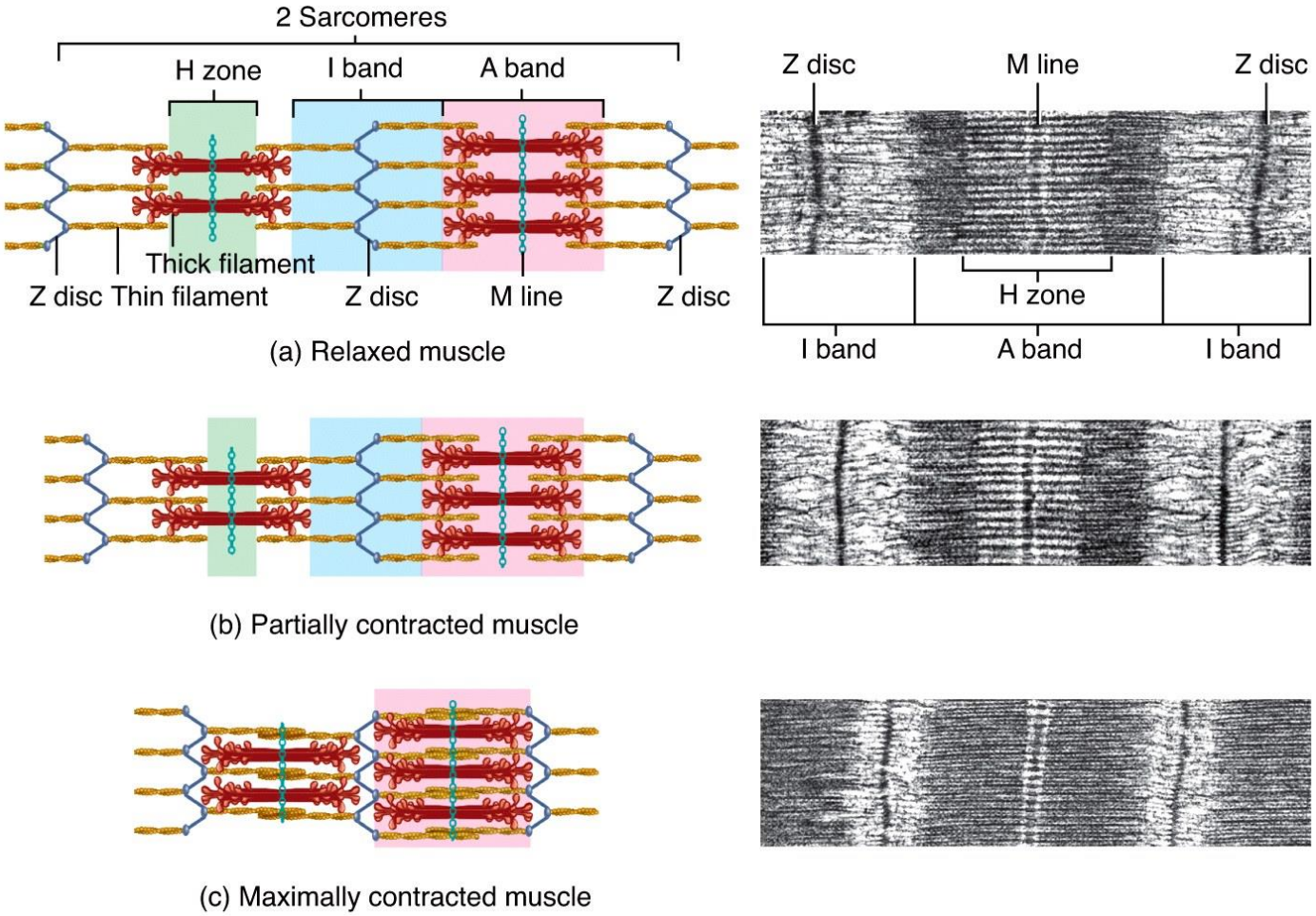
Sliding Filament Theory

- **Sarcomeres shorten because <u>thick and thin filaments slide past one another</u>**

- **Thin filaments move towards the center of the sarcomere from both ends**



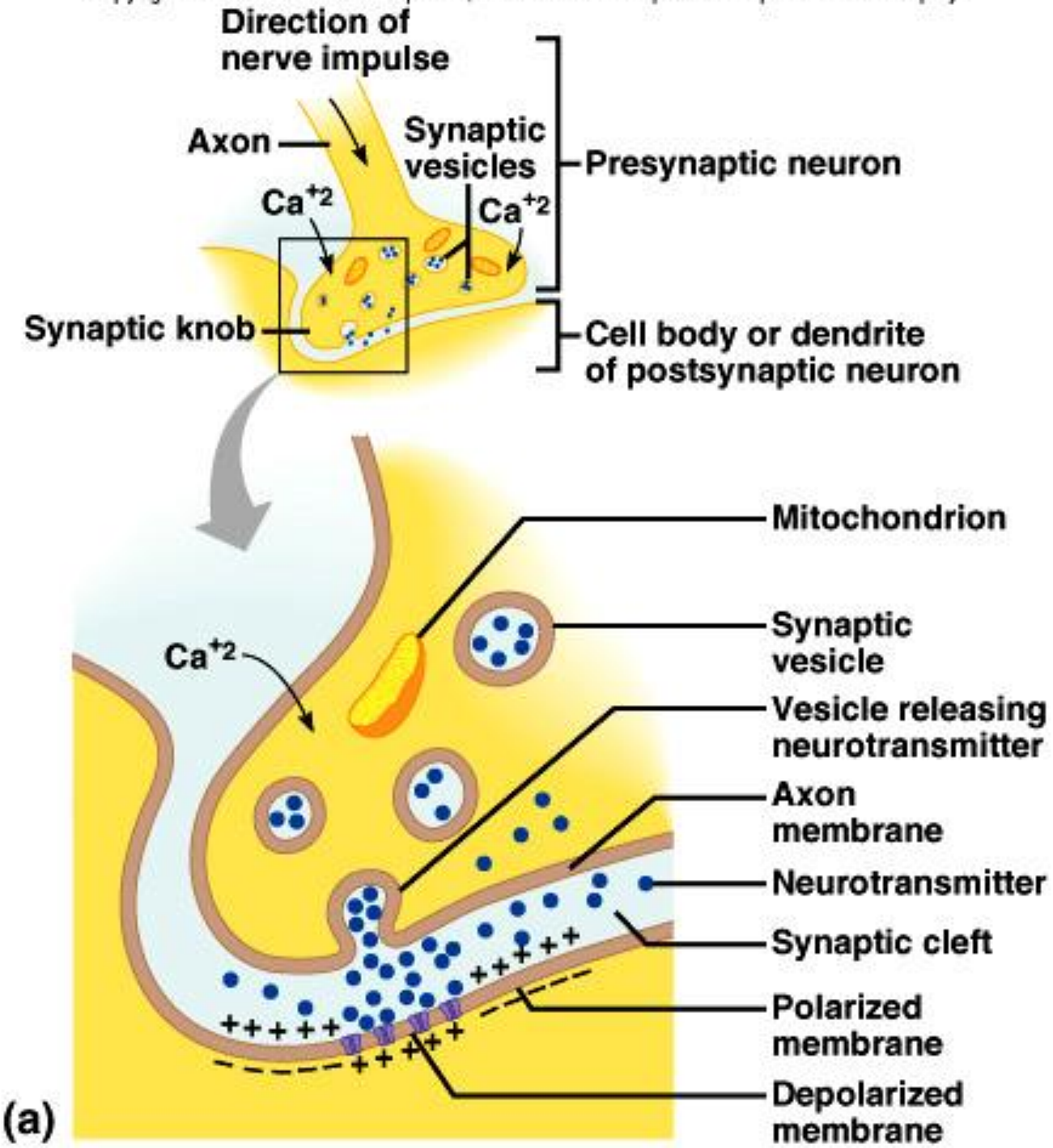
The Sliding-Filament Mechanism



- The “sliding” of actin on myosin (thick filaments on thin filaments) can be broken down into a 4 step process

Physiology of Skeletal Muscle Contraction: Neurotransmitter Release

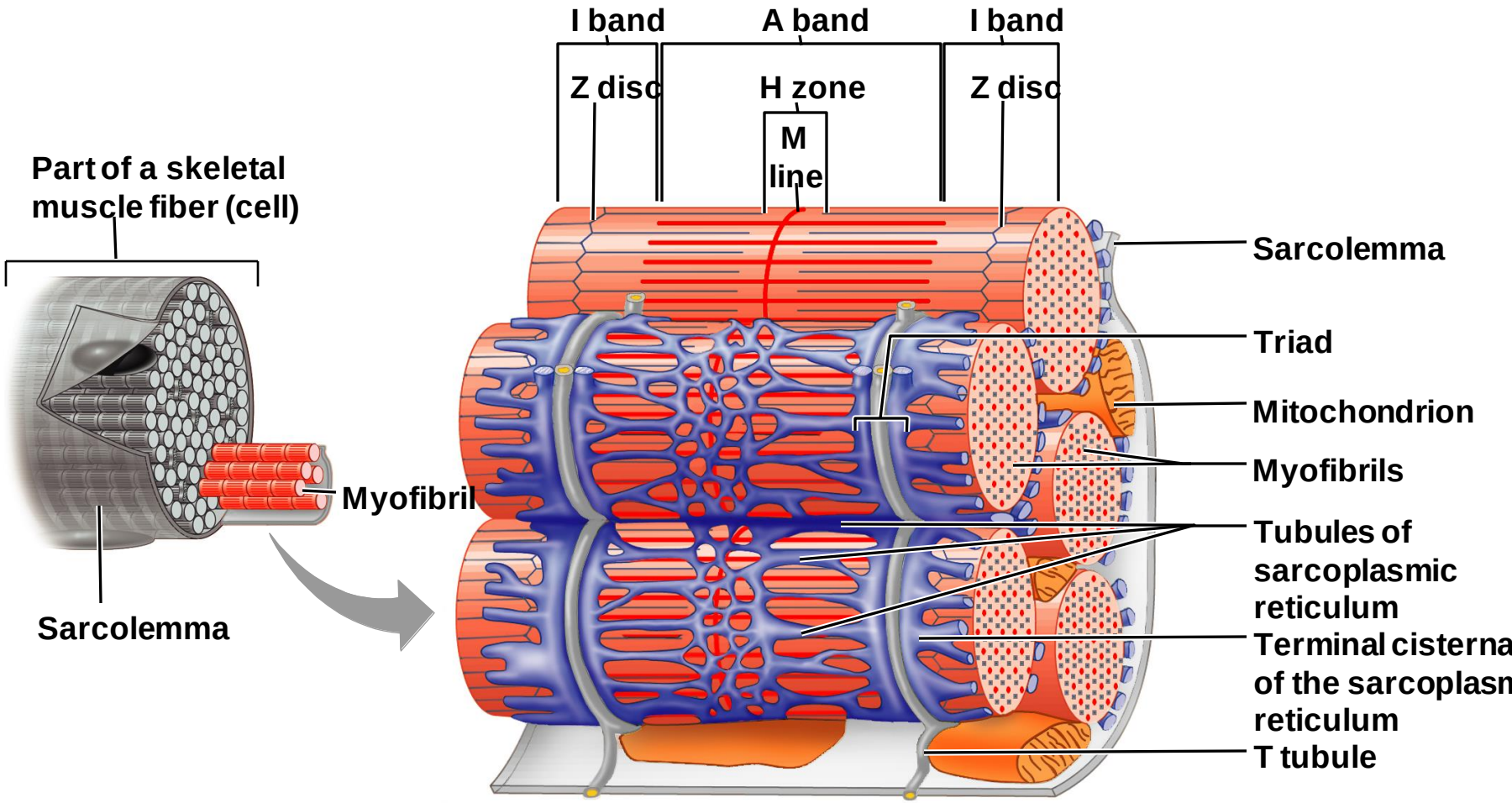
- **Motor impulse is initiated in the brain**
- **Travels through the brain and spinal cord to a motor nerve ending**
- **Motor nerve endings (axons) depolarize**
- **Calcium enters the axonal endings**
- ***Calcium causes the release of acetylcholine into the neuromuscular junction (synaptic cleft)***



Physiology of Skeletal Muscle Contraction: Depolarization

- **ACh binds receptors on motor end plate**
- **Depolarizes skeletal muscle fibers**
  - **Reverses charge of membrane**
- **Impulse travels through transverse tubules to reach all of the muscle fibers**
- ***Muscle depolarization causes release of calcium from the sarcoplasmic reticulum into the sarcoplasm***

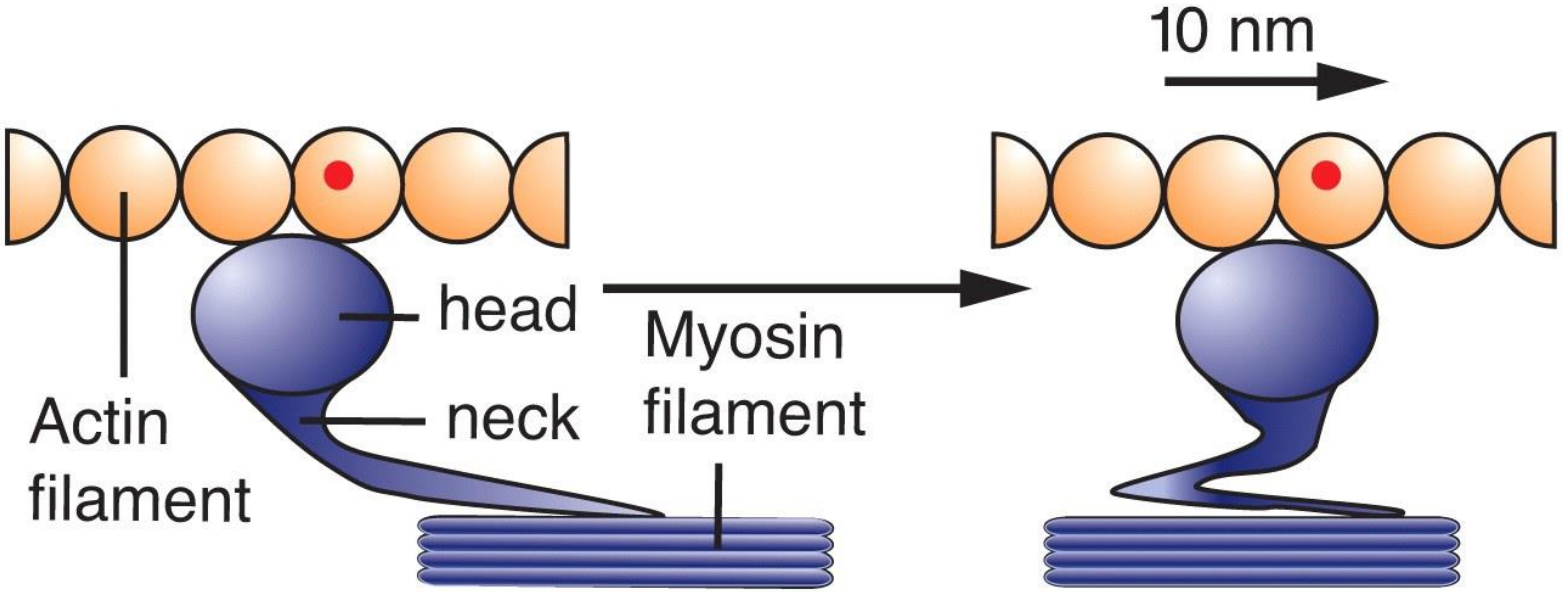
Relationship of the sarcoplasmic reticulum and T tubules to myofibrils of skeletal muscle



Physiology of Skeletal Muscle Contraction: Power Stroke

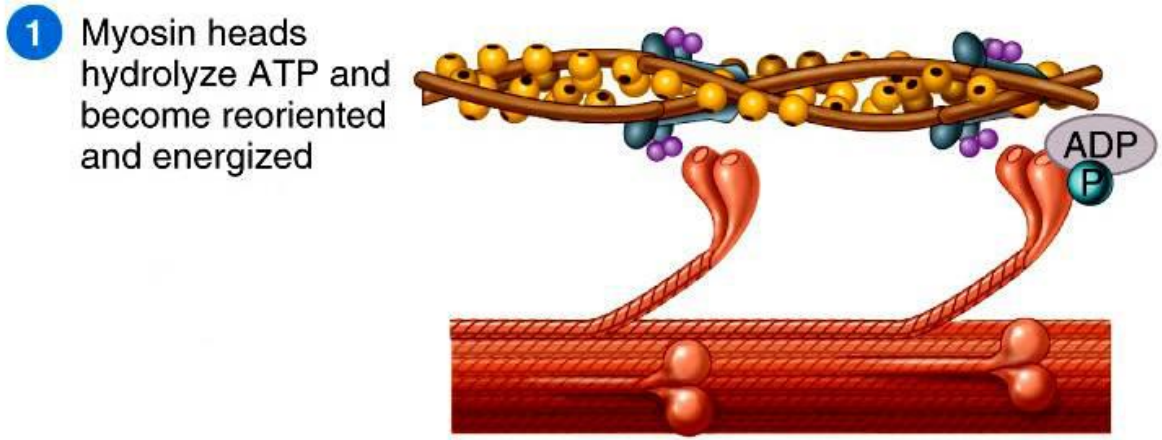
- **Calcium binds troponin (which is attached to tropomyosin**
- ***Moves tropomyosin from the myosin binding sites on actin***
- **Myosin crossbridges (heads) bind to actin**
  - **ATP hydrolysis supplies energy**
- **Actin is pulled inward towards the center of the sarcomere = POWER STROKE**
- **Sarcomeres shorten as muscle contracts**

The Sliding-Filament Mechanism

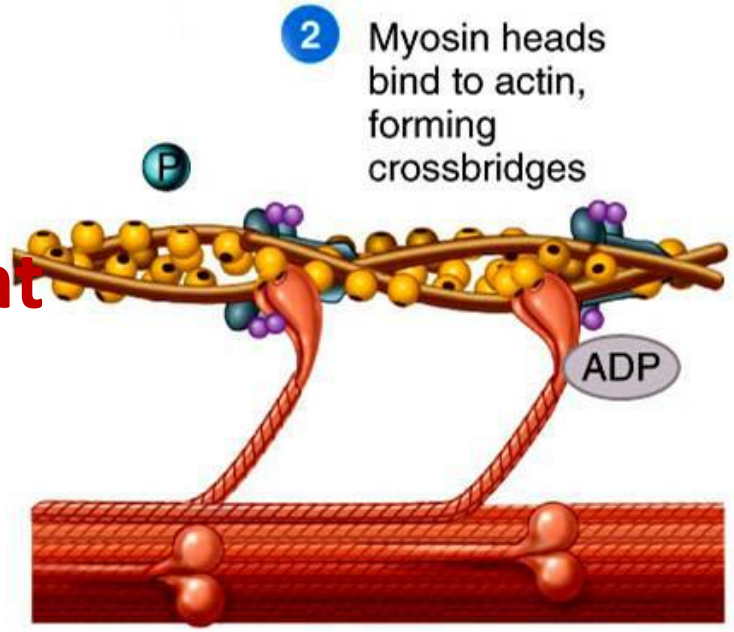


- With exposure of the myosin binding sites on actin (the thin filaments)—in the presence of Ca^{2+} and ATP—the thick and thin filaments "slide" on one another and the sarcomere is shortened

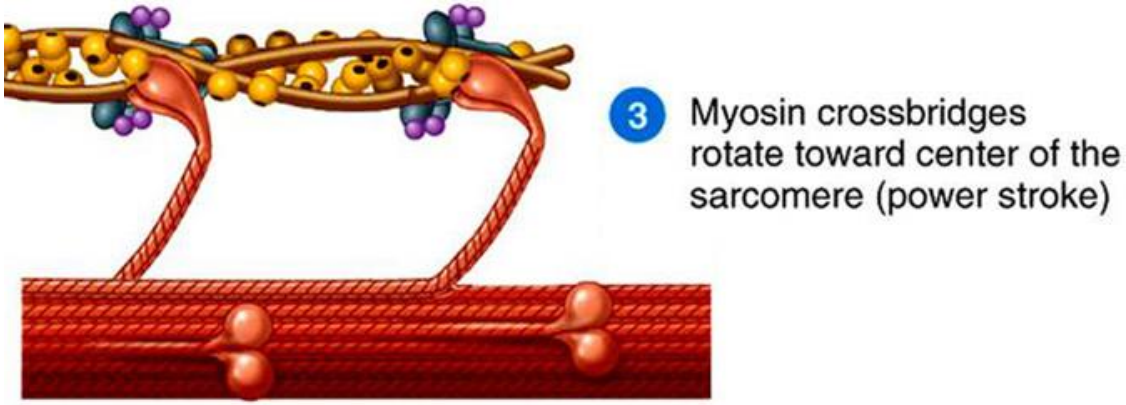
- **Step 1: ATP hydrolysis**



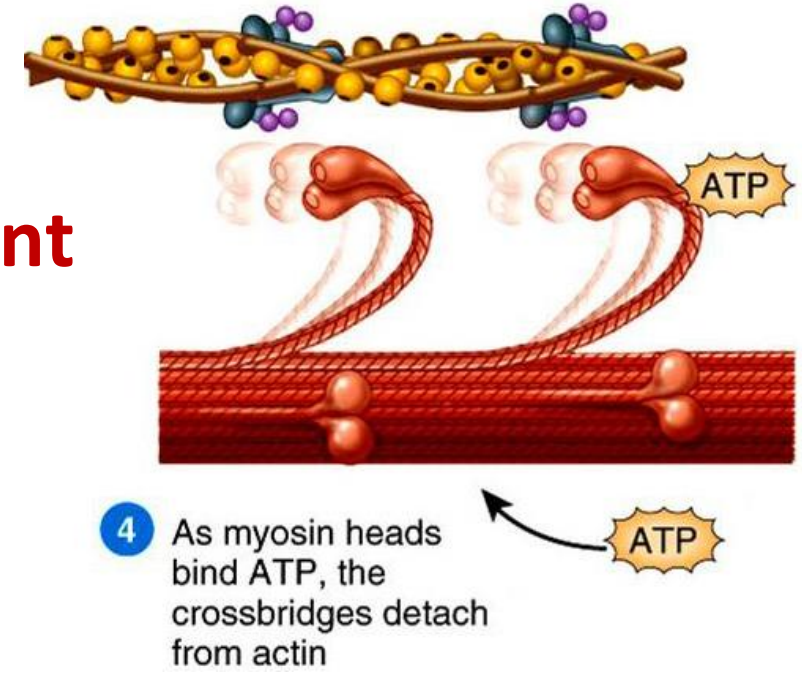
- **Step 2: Attachment**



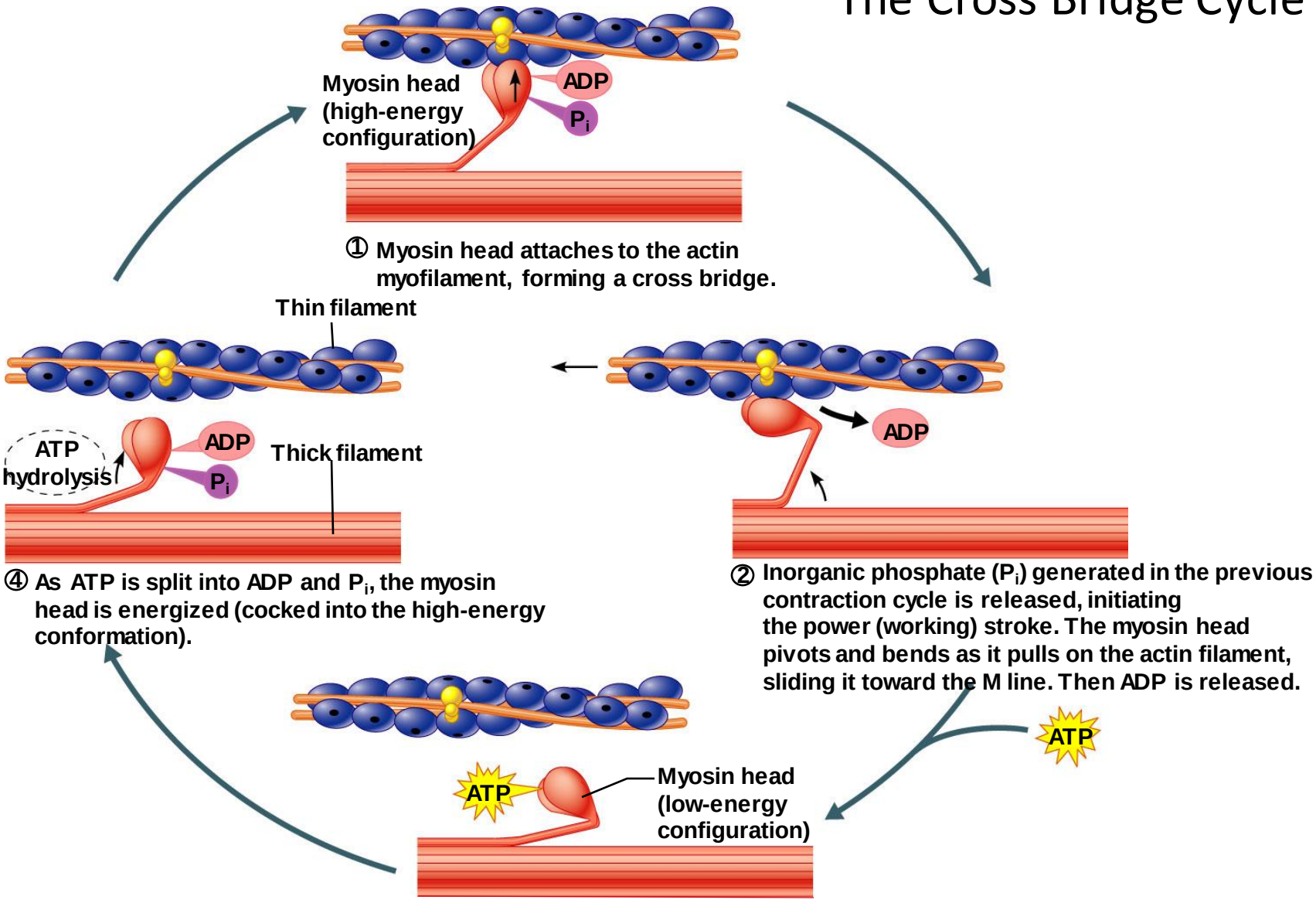
- **Step 3: Power Stroke**



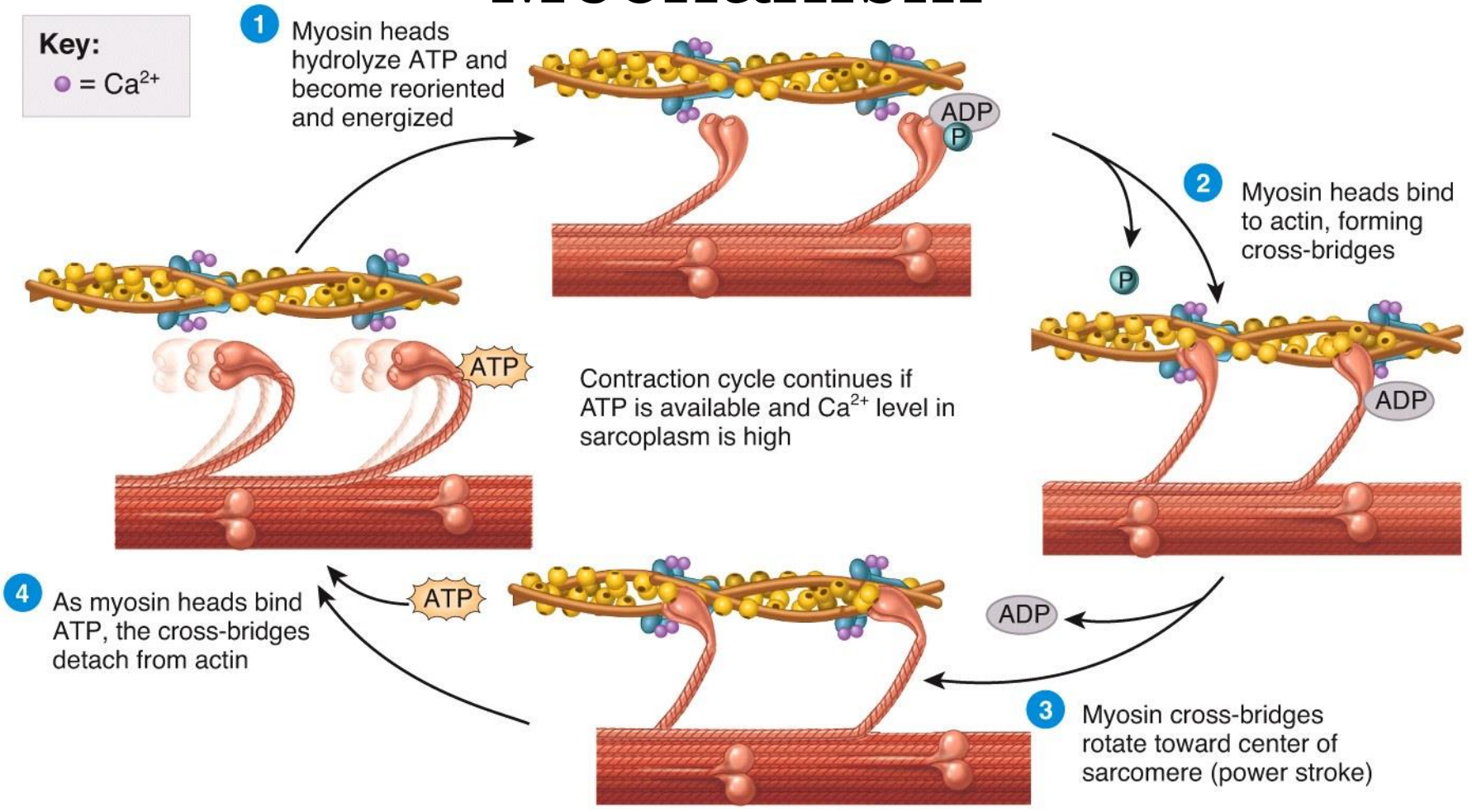
- **Step 4: Detachment**



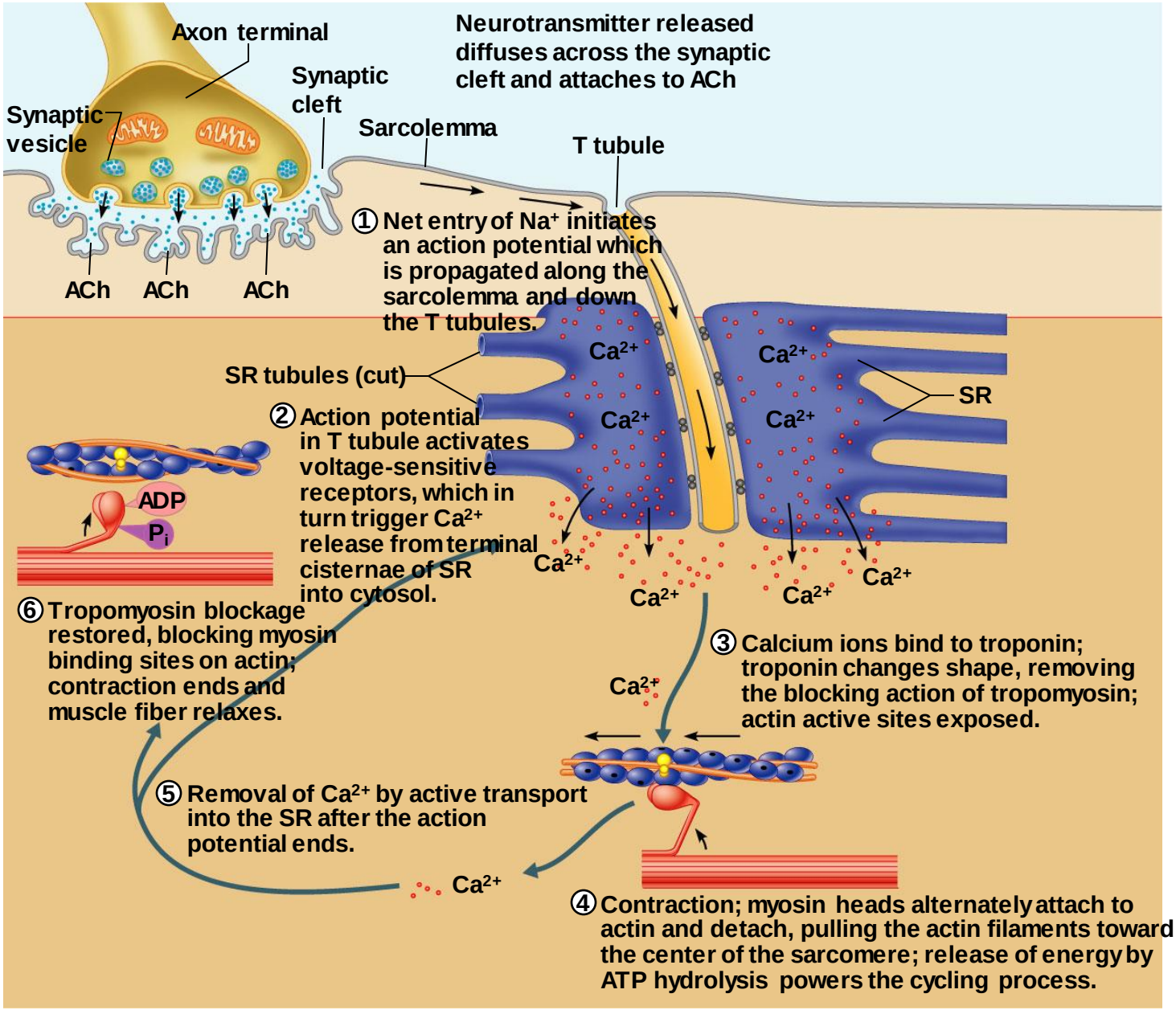
The Cross Bridge Cycle



The Sliding-Filament Mechanism



Excitation-Contraction Coupling



Muscle Relaxation Mechanism

1. Acetylcholinesterase present in the NMJ destroys ACh (preventing continual stimulation)

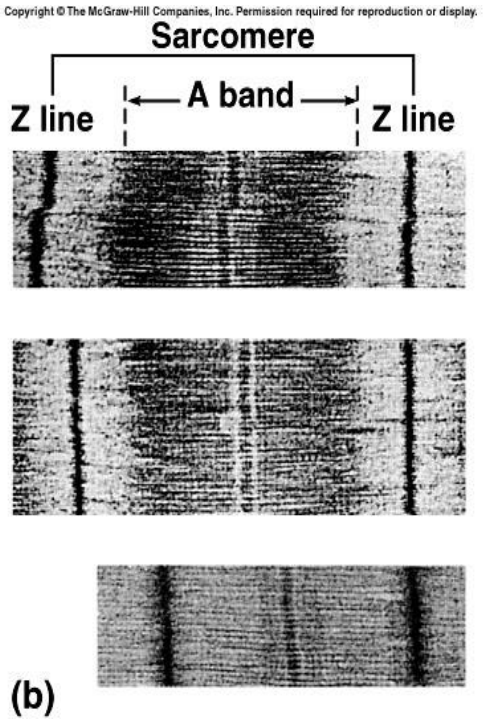
2. Calcium ions are transported from the sarcoplasm back into the SR

3. Linkages between myosin and actin are broken
   - Requires ATP binding

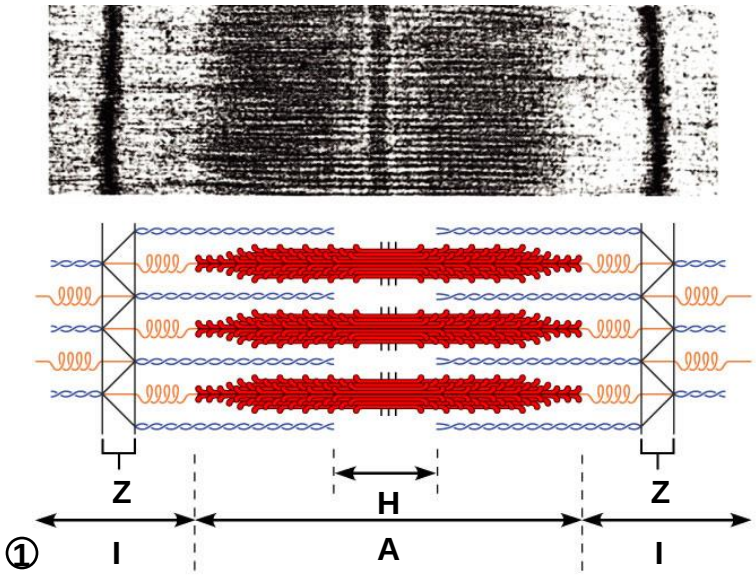
- THEN: The muscle fiber relaxes

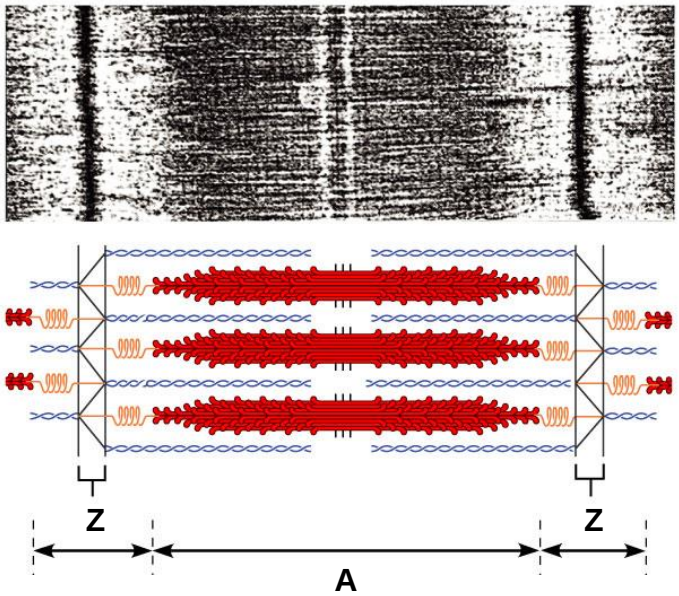
Contraction in the Sarcomere

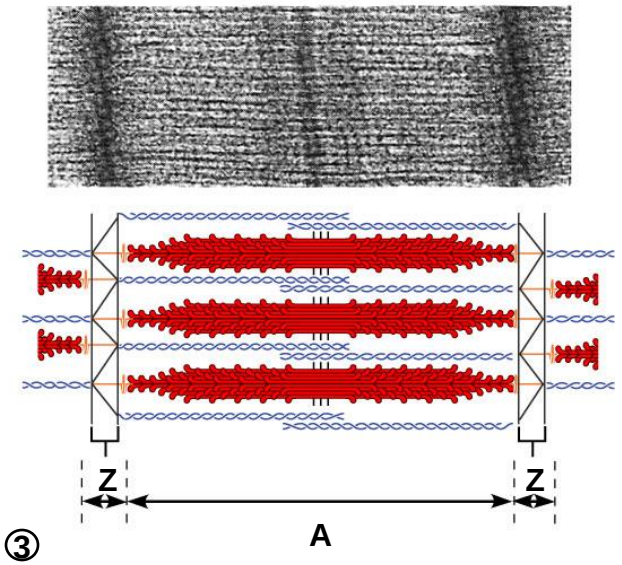
- A band stays the same
- I band gets smaller
- H zone gets smaller
- Sarcomere shortens



Sliding filament model of contraction



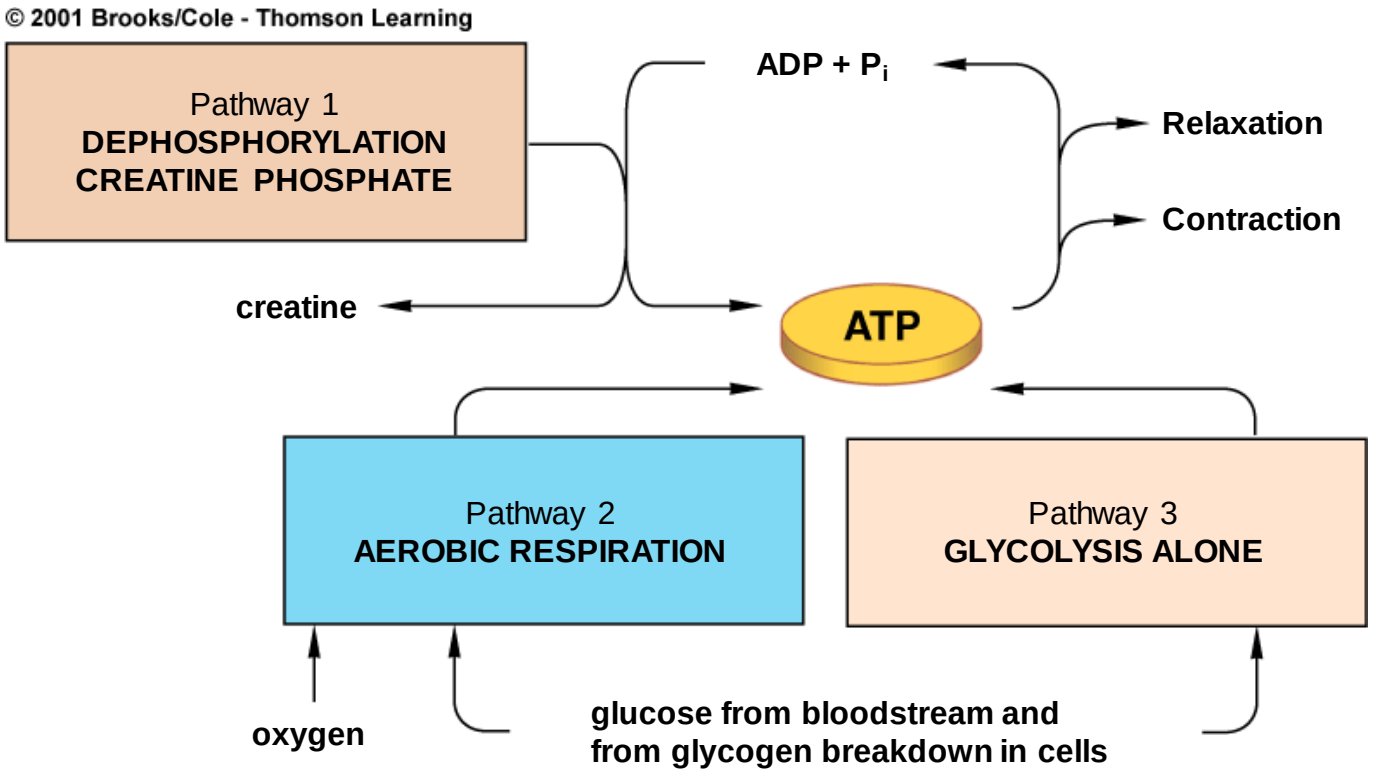




Energy for Contraction

- **Muscle cells require huge amounts of ATP energy to power contraction**
- **The cells have only a very small store of ATP**
- ***Three pathways supply ATP to power muscle contraction***

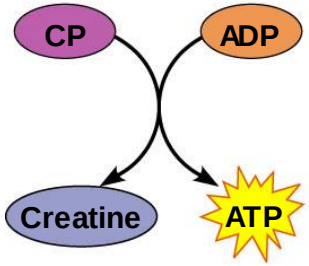
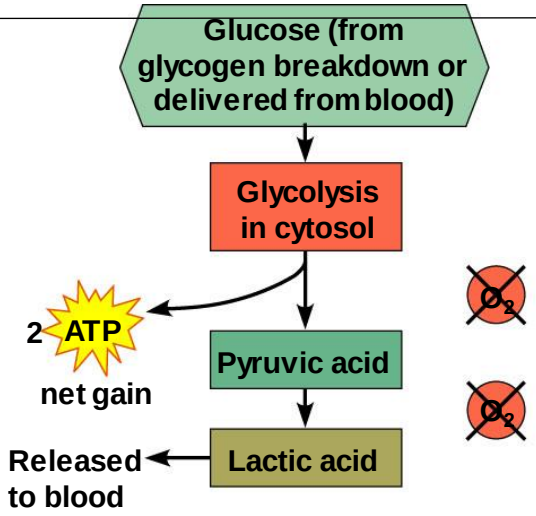
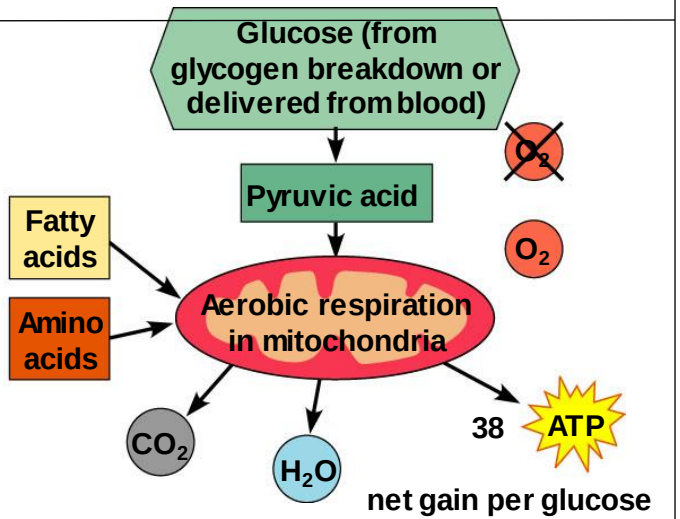
ATP Supply for Contraction



Energy for Contraction

- **ATP initially supplied from cellular respiration**
- **If ATP is abundant, is converted to creatine phosphate and stored in skeletal muscles**
- **When ATP is low, creatine phosphate supplies phosphate to ADP making ATP**
- **CP & ATP stores only good for about a 10 second maximal contraction**
- **ATP must then come from cellular respiration or glycolysis**

Methods of regenerating ATP during muscle activity

		
(a) Direct phosphorylation [coupled reaction of creatine phosphate (CP) and ADP]	(b) Anaerobic mechanism (glycolysis and lactic acid formation)	(c) Aerobic mechanism (aerobic cellular respiration)
Energy source: CP	Energy source: glucose	Energy source: glucose; pyruvic acid; free fatty acids from adipose tissue; amino acids from protein catabolism
Oxygen use: None Products: 1 ATP per CP, creatine Duration of energy provision: 15s	Oxygen use: None Products: 2 ATP per glucose, lactic acid Duration of energy provision: 30–60 s.	Oxygen use: Required Products: 38 ATP per glucose, CO_2, H_2O Duration of energy provision: Hours

Oxygen & Muscle Contraction

- **Myoglobin of muscle (similar to hemoglobin) binds to and stores oxygen**

- **Supplies O_2 needed to make ATP for contraction**

Exercise and Skeletal Muscles

- **Prolonged, moderate exercise**
  - **ATP supplied through cellular respiration**
  - **Once glycogen stores are depleted in muscle, glucose and fatty acid deliveries from blood are used as fuel source**

Exercise and Contraction

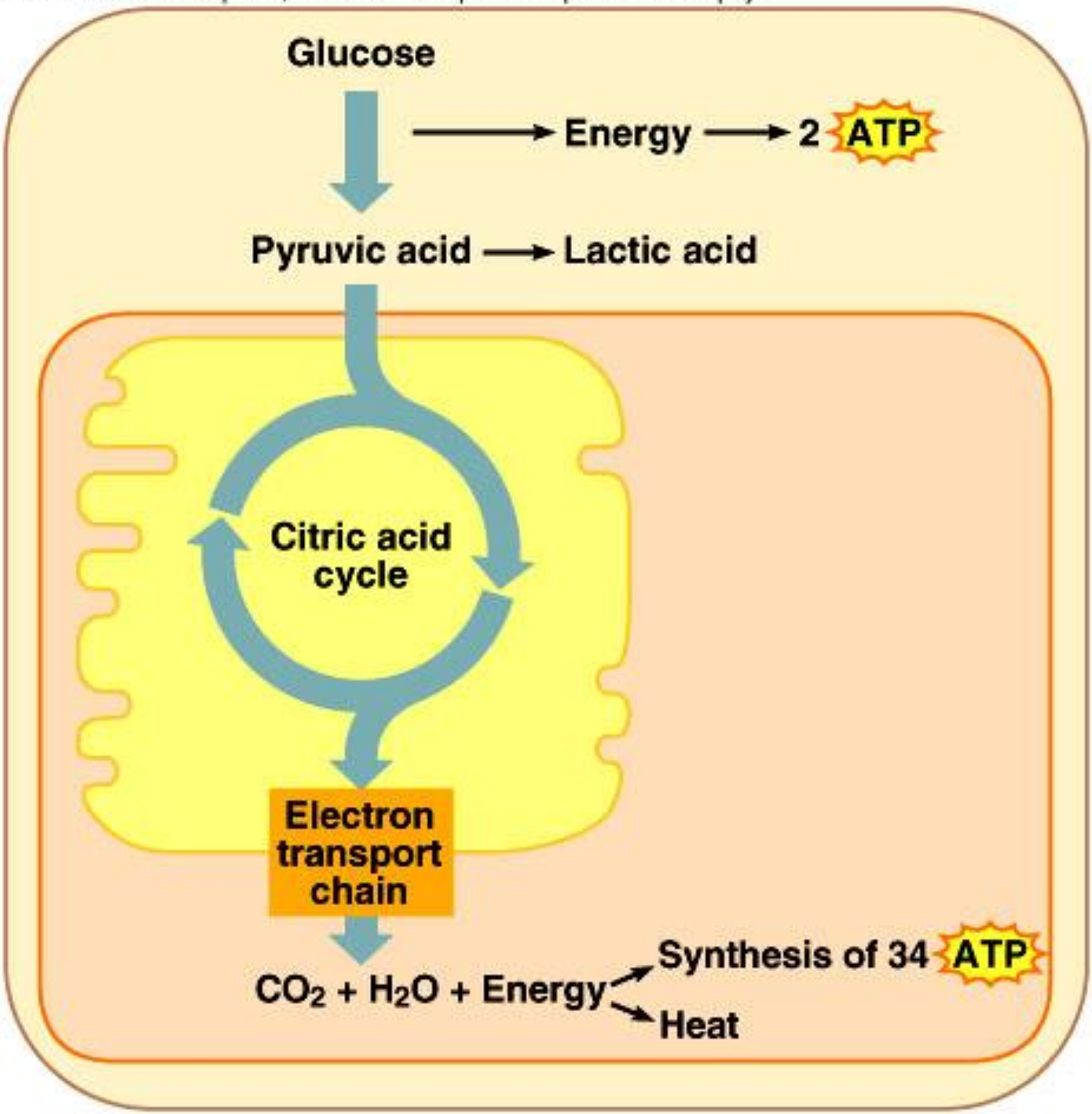
- **In intense strenuous activity, oxygen can be depleted**
- **Why?**
- **Contraction of skeletal muscles decreases blood delivery to muscles**
- **Nutrient and O_2 levels in contracting muscles decrease**

Exercise and Skeletal Muscles

- **Intense, strenuous exercise**
  - **Muscles exceed capacity of respiratory and cardiovascular systems to deliver oxygen for contraction**
  - ***ATP supplied anaerobically through glycolysis***
  - **Pyruvate is converted to lactic acid**
  - **Lactic acid builds up in muscles**
    - **Causes muscles to fatigue**

1 In the absence of sufficient oxygen, glycolysis leads to lactic acid accumulation.

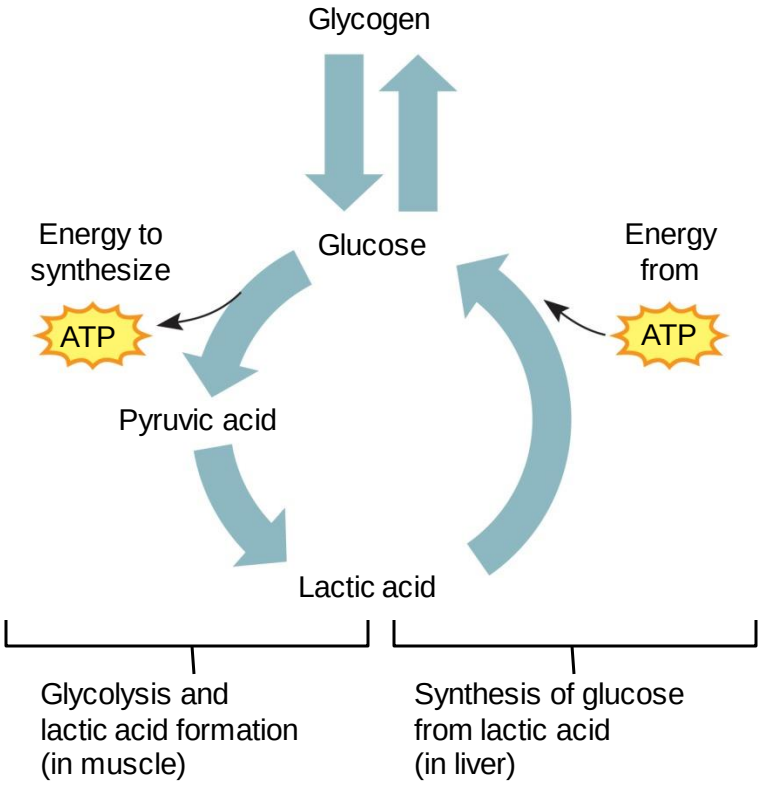
2 Oxygen carried from lungs by hemoglobin in red blood cells is stored in muscle cells by myoglobin and is available to support aerobic respiration.



Oxygen Debt

- *Amount of oxygen needed by liver cells to use the accumulated lactic acid to produce glucose*

- **Oxygen not available**
- **Glycolysis continues**
- **Pyruvic acid converted to lactic acid**
- **Liver converts lactic acid to glucose**
- *Also the amount of oxygen needed to replace O_2 levels in skeletal muscle to pre-exercise levels*



Heat Production

- **Cellular respiration is only about 40% efficient**
- **About 60% of the energy found in a glucose is lost as heat during cellular respiration**
- **Muscle contraction generates heat because muscles use large amounts of nutrients to make ATP, generating large amounts of heat**
- **Heat is used to maintain body temperature**

Glycogenolysis

- Do you remember what glycogen is??????
- Glycogenolysis is the breakdown of glycogen into glucose molecules
- Epinephrine can trigger this pathyway too
- Depends upon the presence of an enzyme – *glycogen phosphorylase*

McArdle's Disease

- *Absence of the muscle glycogen phosphorylase enzyme*
- Individuals must rely on blood-transported fuels
  - Fatty acids, protein, glucose from the liver
  - These reserves take 5-10 minutes to arrive to the mitochondria
- Muscles stop functioning until these fuels arrive
- Autosomal Recessive Disorder

Symptoms of McArdle's Disease

- Premature muscle fatigue and weakness and pain during exercise

- Muscles can become injured during exercise

McArdle's Disease

- What should an individual with McArdle's eat?
- Can they participate in intense strenuous activity?
- Can they participate in Prolonged, moderate exercise?
- Where does their supply of ATP come from?