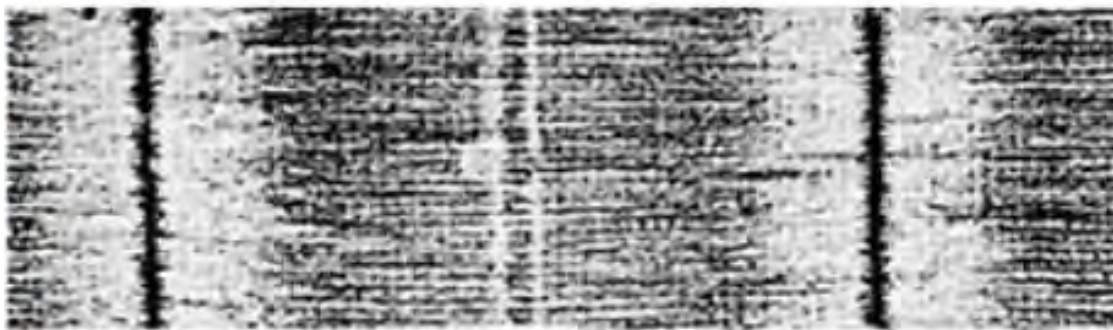
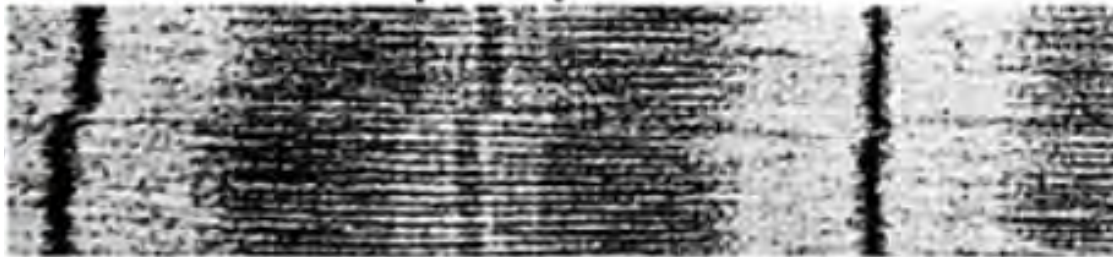
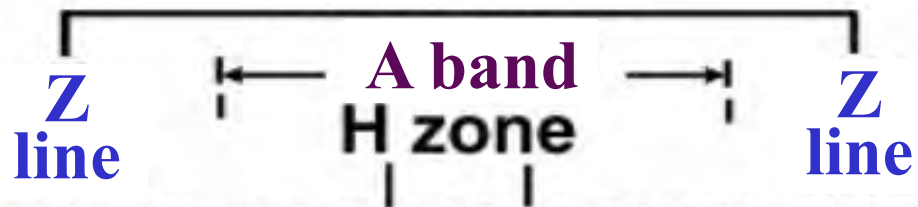


BIO 211:

ANATOMY & PHYSIOLOGY I

Sarcomere



CHAPTER 09

MUSCULAR SYSTEM

Part 1 of 2

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Some illustrations are courtesy of McGraw-Hill.



TABLE 9.2 Muscle Tissue Characteristics

	Skeletal	Smooth	Cardiac
Dimensions			
<i>Length</i>	Up to 30 cm	30-200 μm	50-100 μm
<i>Diameter</i>	10-100 μm	3-6 μm	14 μm
Major location	Skeletal muscles	Walls of hollow organs	Wall of the heart
Major function	Movement of bones at joints; maintenance of posture	Movement of walls of hollow organs; peristalsis	Pumping action of the heart
Cellular characteristics			
<i>Striations</i>	Present	Absent	Present
<i>Nucleus</i>	Multiple nuclei	Single nucleus	Single nucleus
<i>Special features</i>	Transverse tubule system is well developed	Lacks transverse tubules	Transverse tubule system is well developed; intercalated disks separate cells
Mode of control	Voluntary	Involuntary	Involuntary
Contraction characteristics	Contracts and relaxes relatively rapidly	Contracts and relaxes relatively slowly; some types self-exciting; rhythmic	Network of fibers contracts as a unit; self-exciting; rhythmic; remains refractory until contraction ends

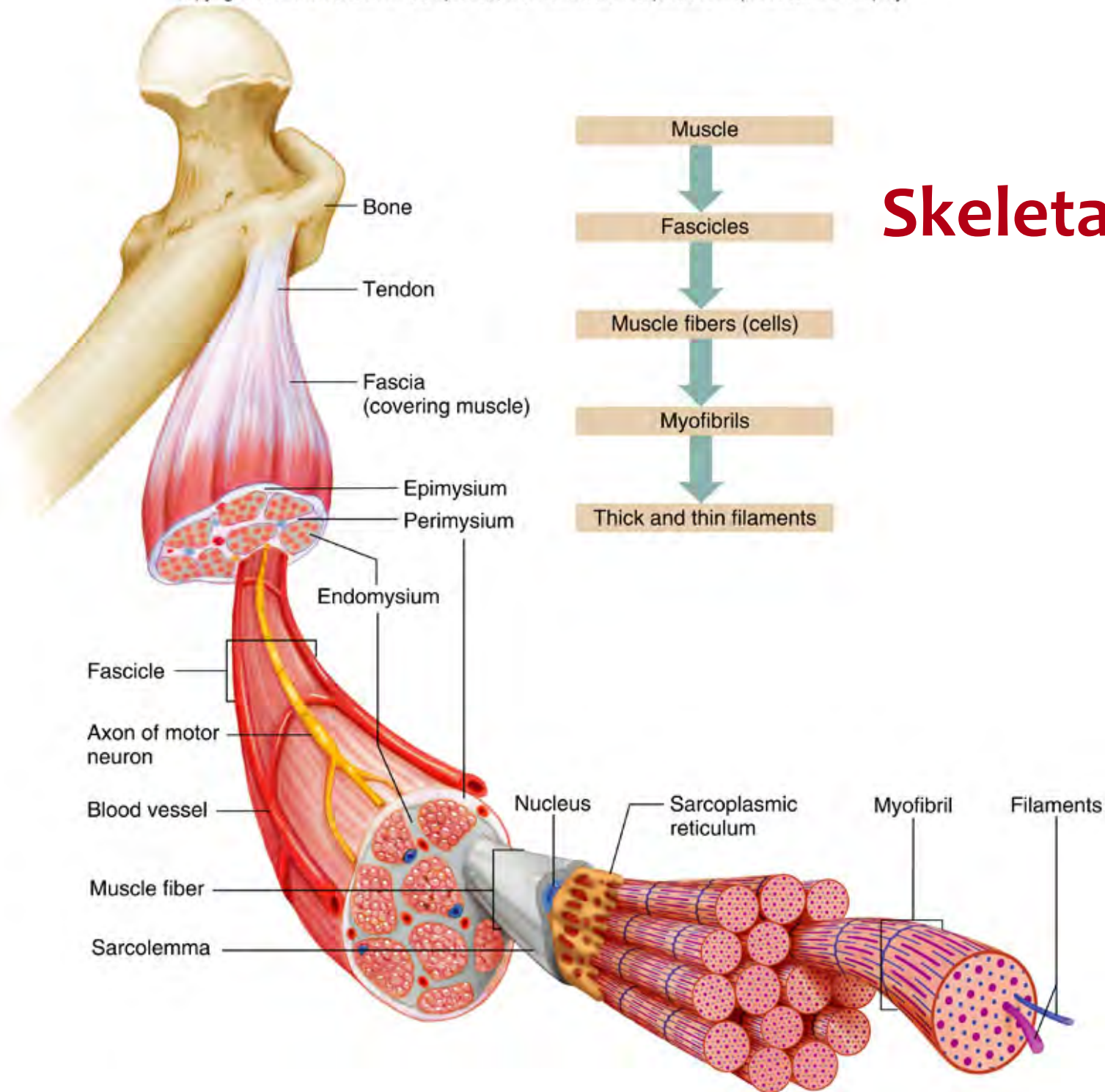
Skeletal Series-Elastic Components

1. The series-elastic components of muscular tissue include the stretchy:
 - a. **endomysium**
 - b. **perimysium**
 - c. **epimysium**

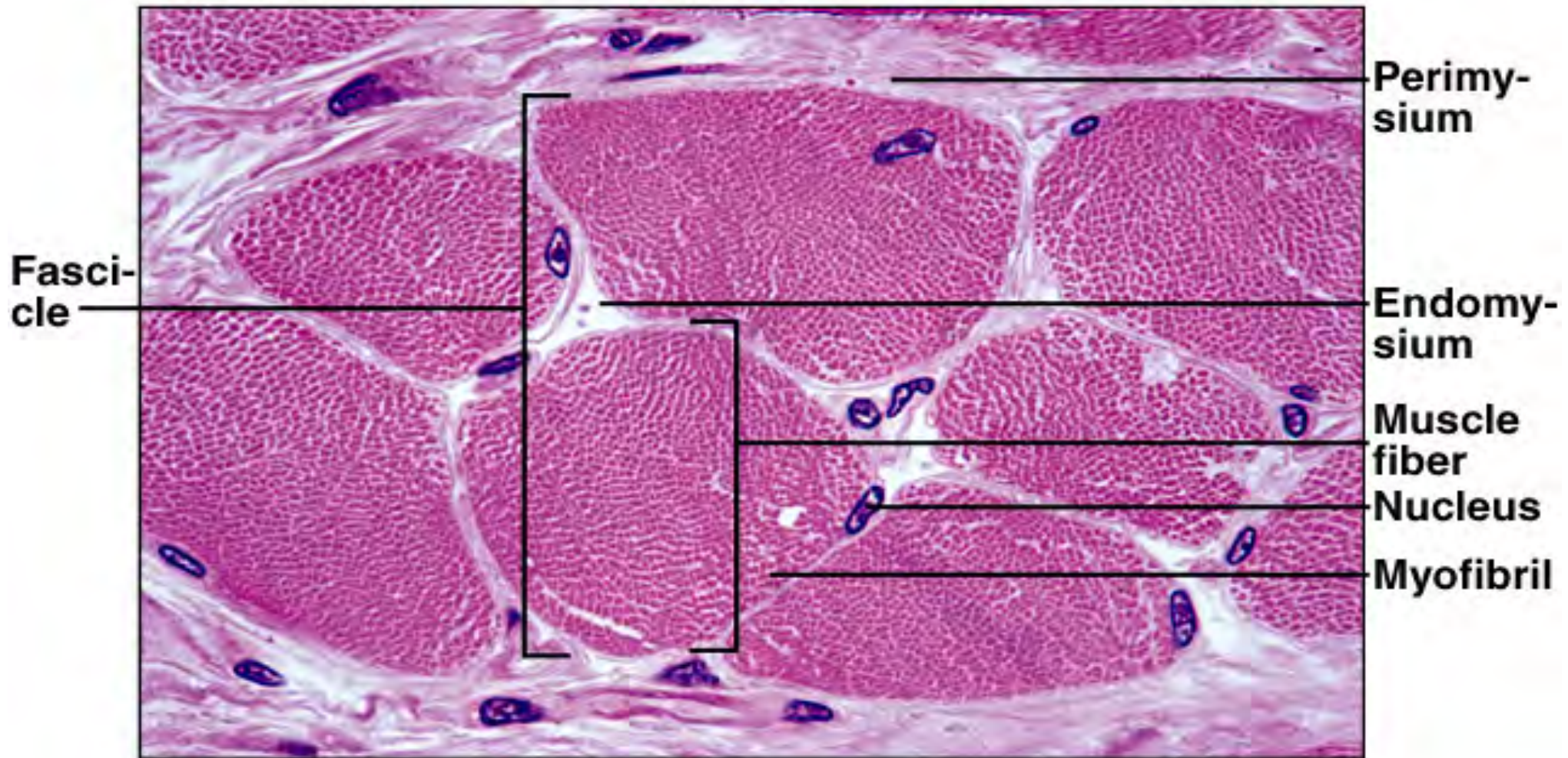
All of the above are not excitable, but do stretch and recoil.

2. During muscle contraction, the muscle generates *internal tension*, followed by external tension that moves the load.

Skeletal Muscle



Fascicle and Perimysium



Skeletal Muscle Cells (fibers)

1. The **plasma membrane** of the muscle fiber is the **sarcolemma**, with characteristic **transverse (T) tubules** which are continuous with the sarcolemma.

The fibers are **multinucleate**.

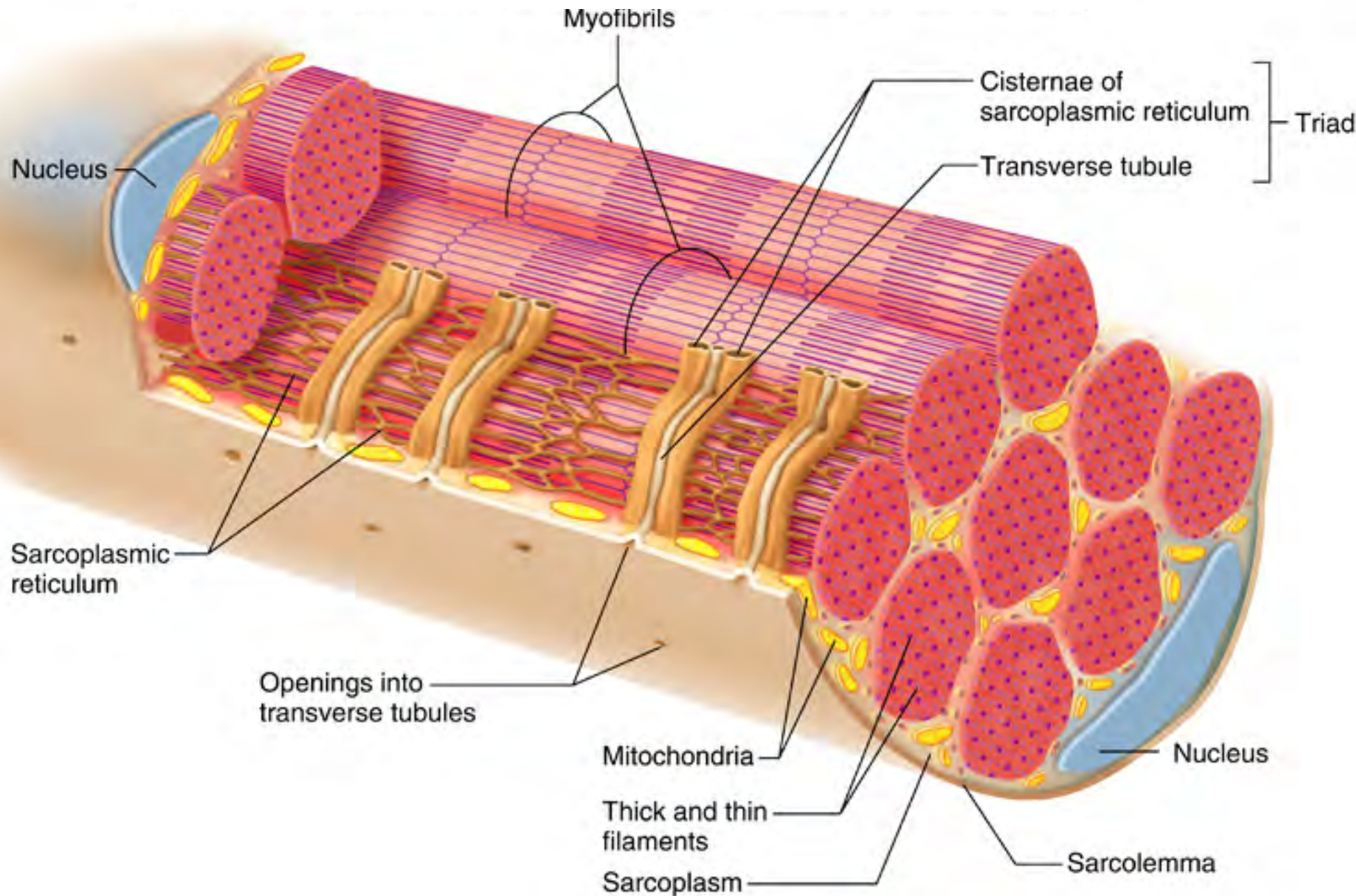
2. The **cytoplasm (sarcoplasm)** contains **myofibrils** made up of **myofilaments**.

3. **Sarcoplasmic reticulum** (a reservoir for **calcium**) joins with **T tubules** to form **terminal cisternae**.

4. The sarcoplasm contains abundant **glycogen** and **myoglobin**.

Triad:
A T tubule with terminal cisternae on each side

Sarcoplasm Contents

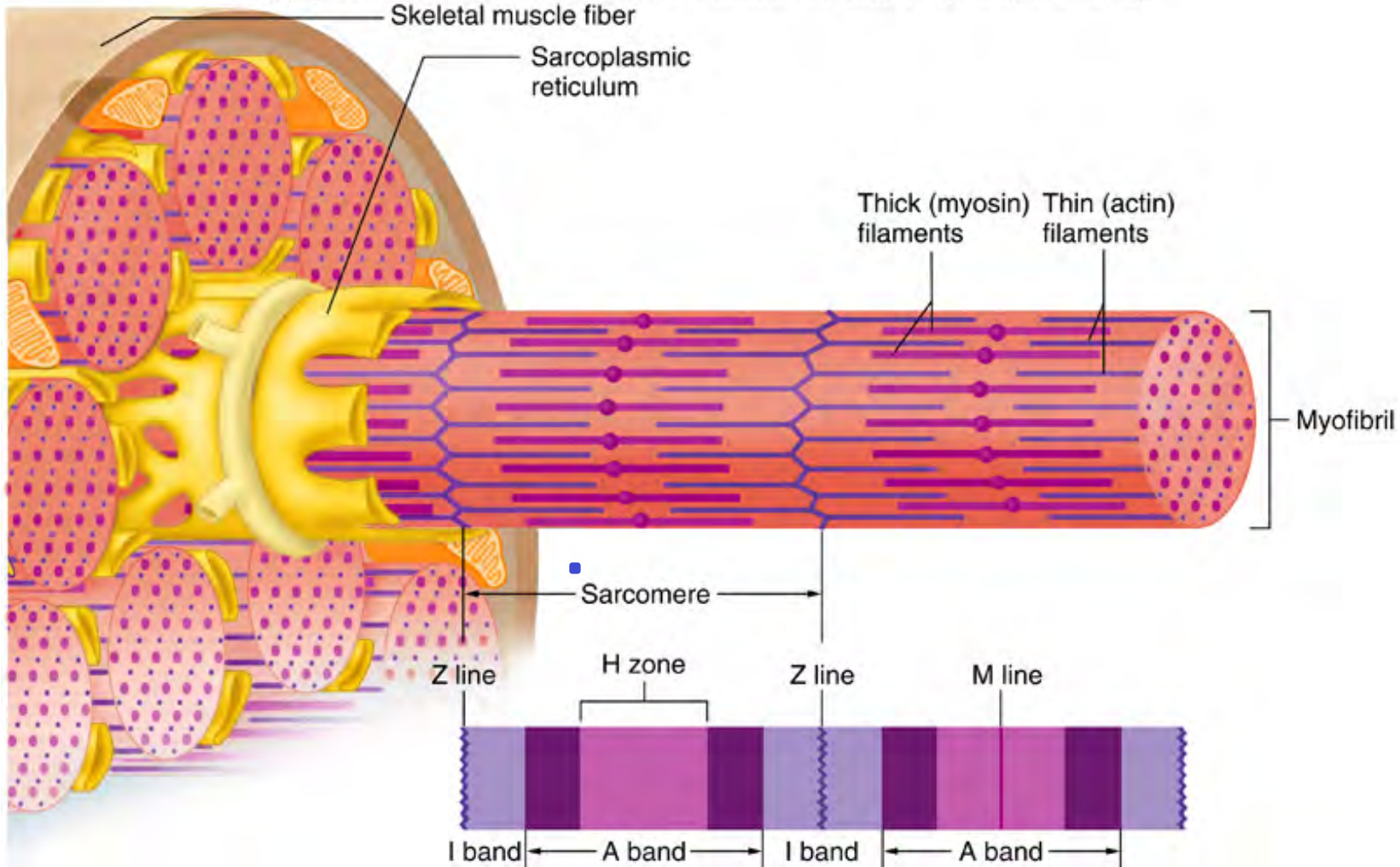


MYOFILAMENTS (within the myofibrils)

1. **Myofilaments** are central to muscle contraction.
Two kinds exist:
 - a. **Thick myofilaments** are made of myosin, shaped somewhat like a **golf club**.
 - b. The **thin myofilaments** are made up of fibrous actin with bead-like subunits of globular actin, each of which has an **active site** that can *bind with the head of a myosin molecule*.
2. Within the fibrous actin lies another protein called **tropomyosin** which itself has smaller proteins called **troponin**.

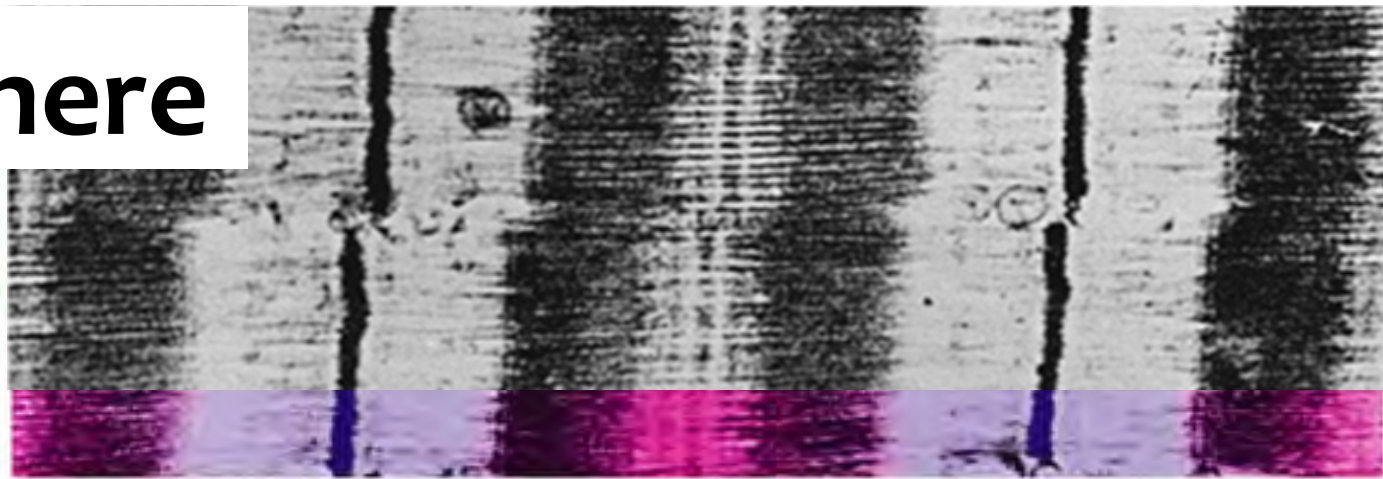
Later:
**Sliding
Filament
Theory**

Tropomyosin and troponin are the **regulatory proteins** of muscle contraction.

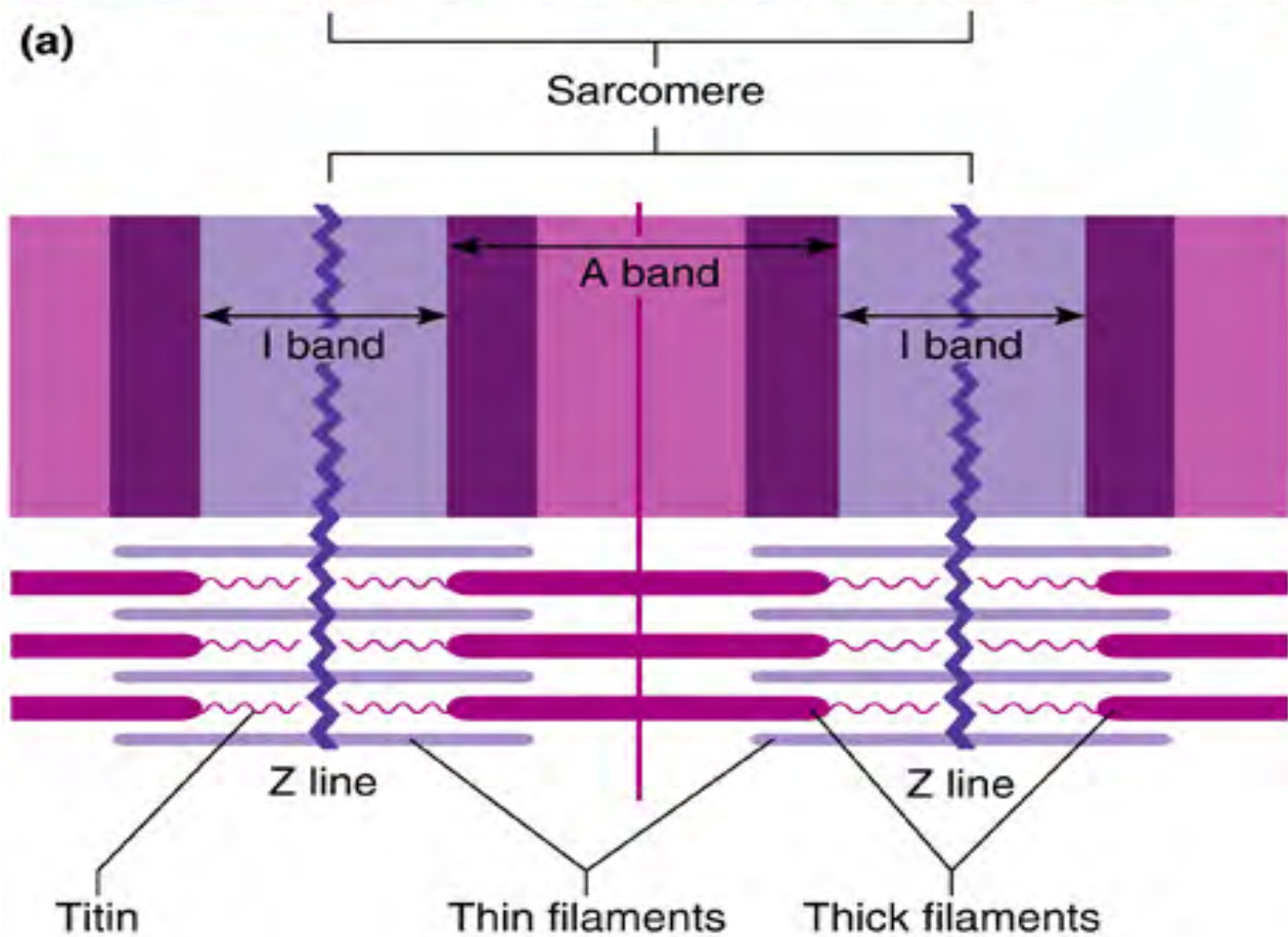


1. Striated muscle has ***dark A bands (thick filaments)*** alternating with lighter ***I bands***. In the middle of the ***A band*** there is a lighter region called the ***H band***, into which thin filaments do not extend.
2. Each I band has a narrow dark line called the ***Z line*** or disc.
3. Each segment of myofibril from one Z disc to the next is the ***sarcomere***, the ***unit of contraction of a muscle fiber***.

Sarcomere



(a)



MOTOR NEURONS and MOTOR UNITS

Remember "SAME" sensory = afferent
motor = efferent

1. MOTOR NEURONS

- a. Skeletal muscle is innervated by somatic motor neurons.
- b. *Each* muscle fiber is supplied by *only* one *motor nerve fiber*.

2. MOTOR UNIT =

one nerve fiber + all the muscle fibers it innervates

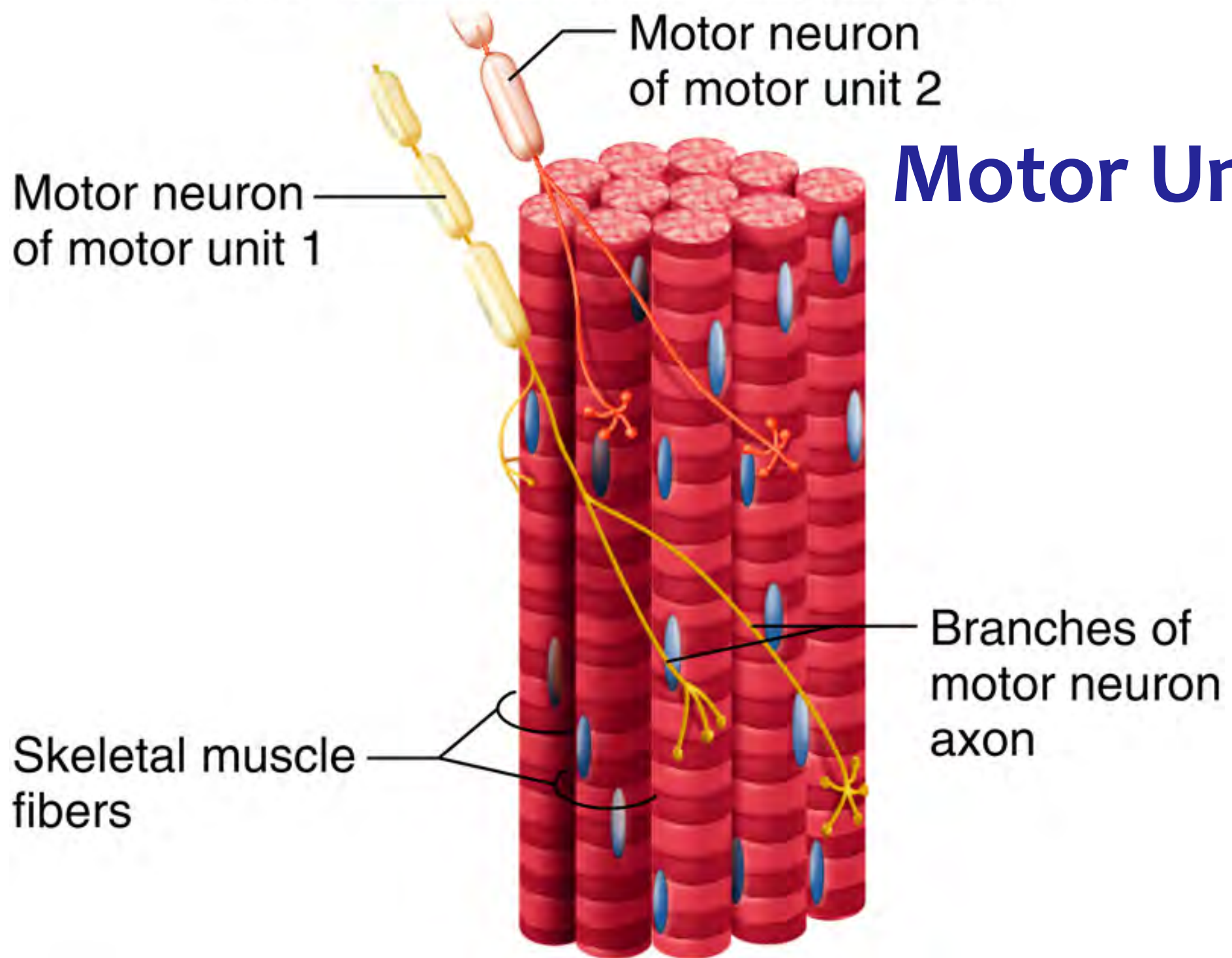
- a. behaves as a single unit; contracts as one.
- b. vary in size: **Which of the following would you think has more fine control ???**

Eye (23 muscle fibers/motor unit)

Thigh (500 - 1,000 muscle fibers/motor unit)

3. Multiple motor units within a muscle are able to work "in shifts."

Motor Units



The NEUROMUSCULAR JUNCTION

1. **Synapse:** contact point between a neuron and its target cell. When the target cell is a muscle cell, the synapse is called a **neuromuscular junction**.

2. At the neuromuscular junction, the neurons expands into a **synaptic knob**.

Motor end plate: muscle cell receives the neuronal message

Synaptic cleft: a **tiny gap** between the two cells.

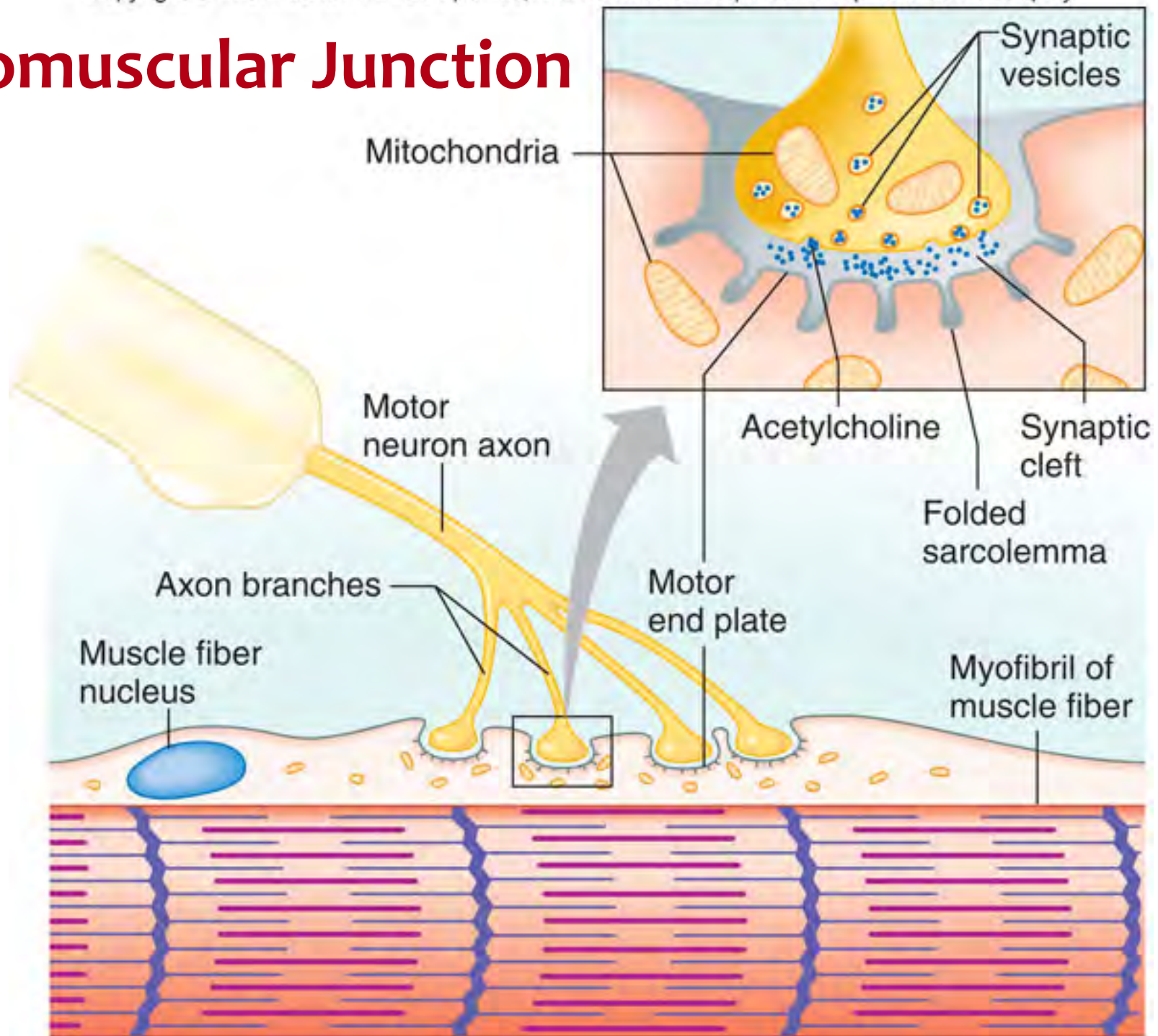
3. A nervous **impulse** traveling down the neuron triggers the release of **neurotransmitter** from **synaptic vesicles** in the **synaptic knob**.

The neurotransmitter is always **acetylcholine (ACh)** *at a neuromuscular junction*.

4. **ACh receptors** are present in the **motor end plate** within infoldings called **junctional folds**.

Also: acetylcholinesterase breaks down ACh after stimulation.

Neuromuscular Junction

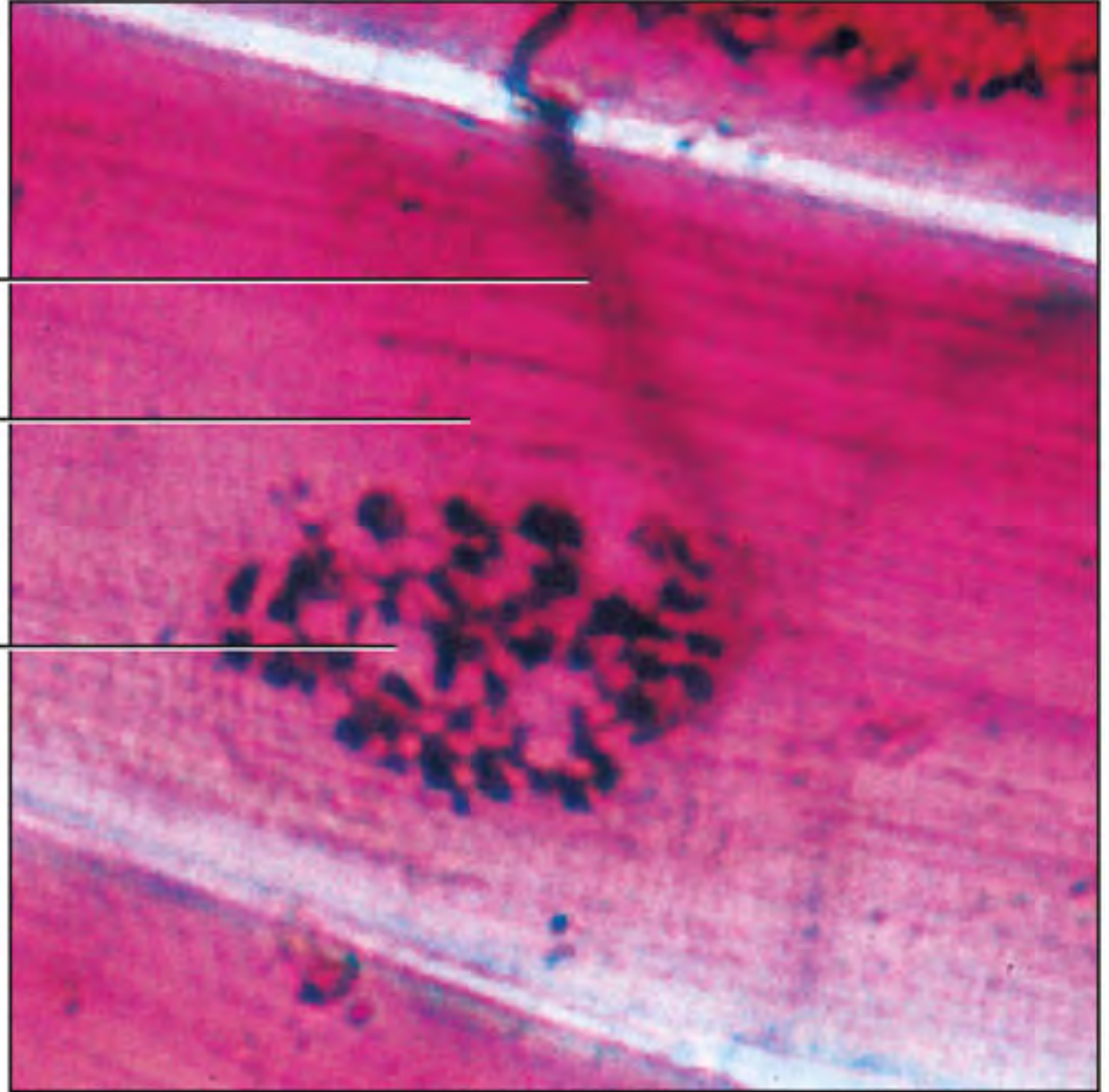


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Motor neuron axon

Muscle fiber

Neuromuscular junction



Neuromuscular Junction

MEMBRANE POTENTIALS

1. Muscles fibers and neurons are *electrically excitable*; plasma membranes show **voltage changes** after stimulation.
2. Electrophysiology:
The study of the electrical activity in cells.
3. **Electric potential** (in volts, V) is potential energy that results from a **polarized state**.
A cell can be **polarized** and exhibit a **resting membrane potential (RMP)**.
4. **RMP** is measured in mV, and is determined by:
 - 1) **diffusion** of ions down their concentrations gradients
 - 2) **selective permeability** of the plasma membrane
 - 3) **electrostatic attraction**

MEMBRANE POTENTIALS

5. **NORMALLY:**

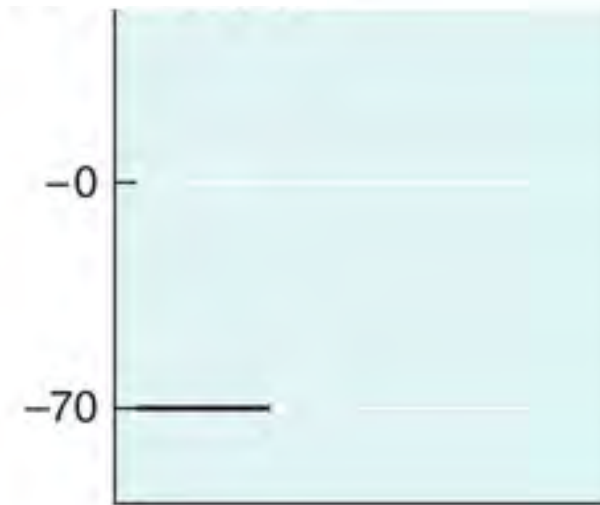
The RMP is maintained by the **sodium-potassium pump**, which **removes three sodium ions from the cell** for every **two potassium ions it brings in**, and therefore has the net effect of contributing to the **negative intracellular charge**.

6. **DURING NERVE or MUSCLE CELL STIMULATION:**

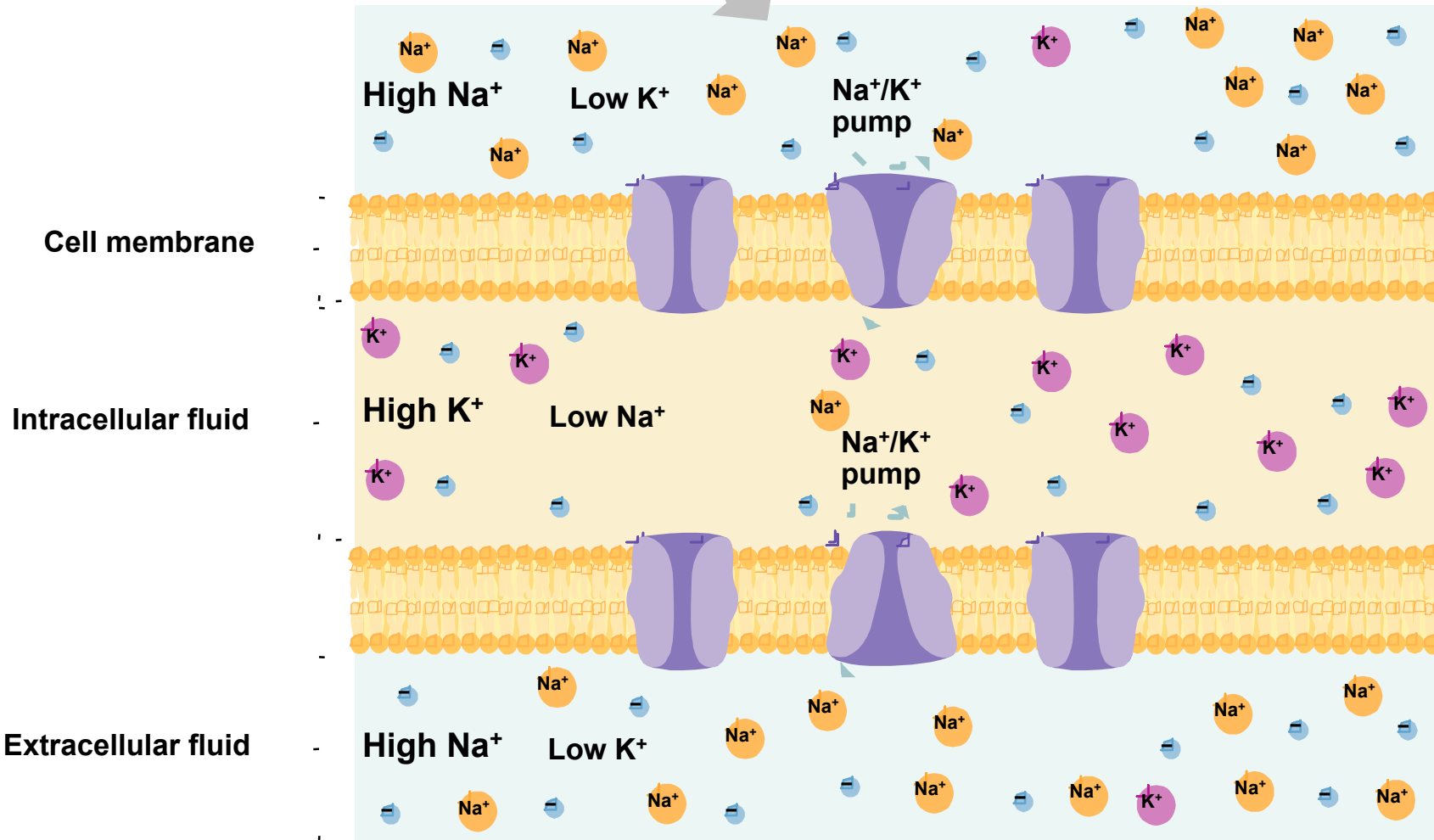
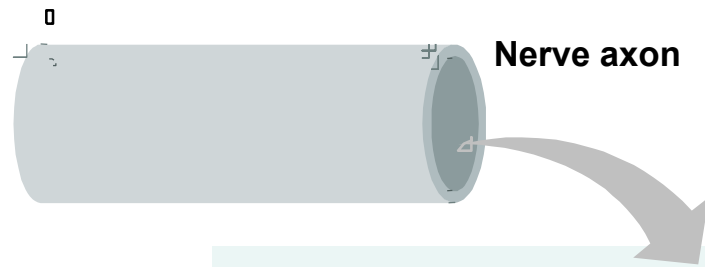
When a nerve or muscle cell is stimulated, **ion gates** in the membrane open, **sodium ions rush in**, and **potassium ions rush out**, resulting in **changes** in membrane voltage called an **action potential**.

To be reviewed during the Nervous System Lectures

Resting Membrane Potential



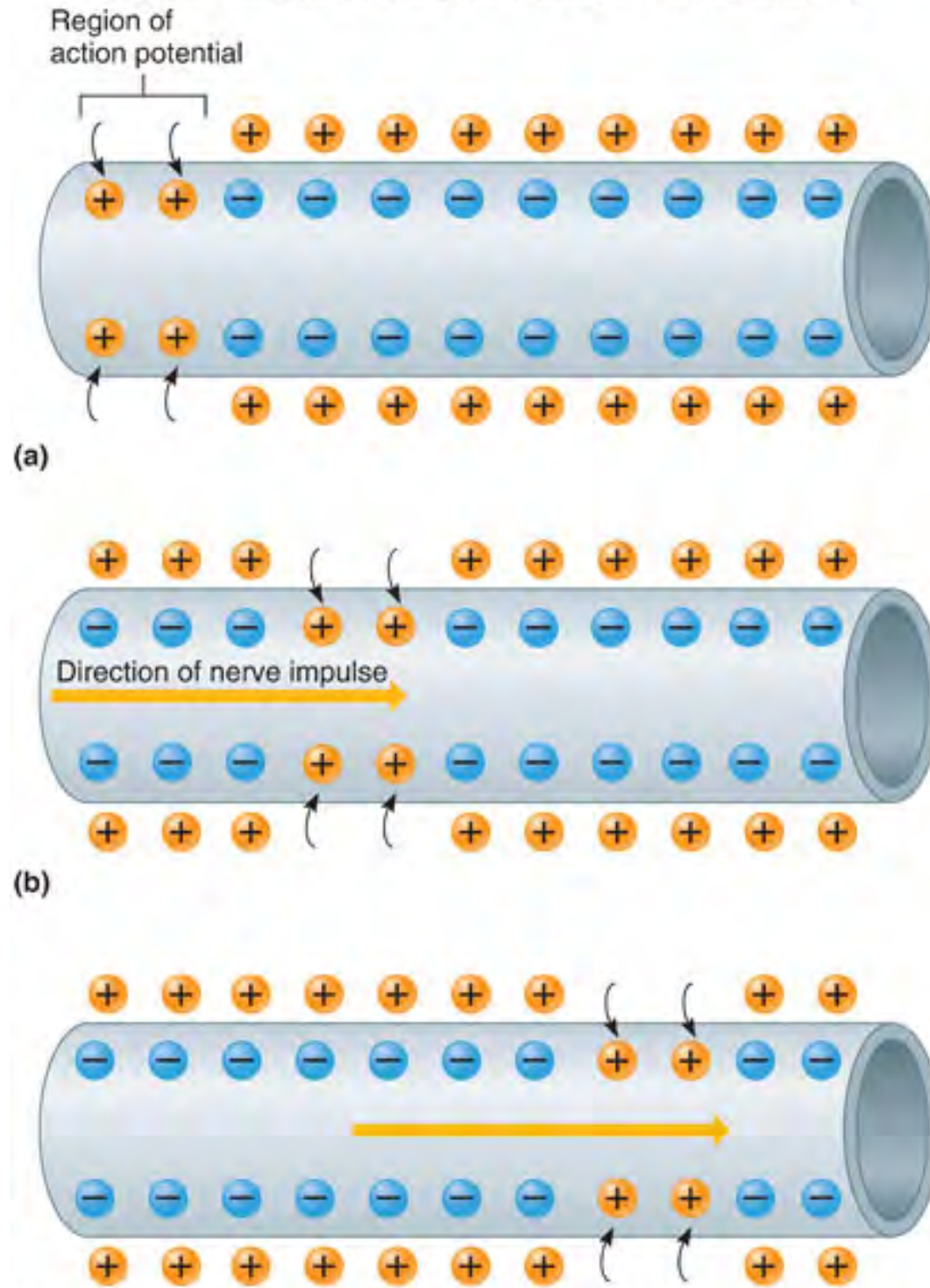
Resting Membrane Potential-Active Transport



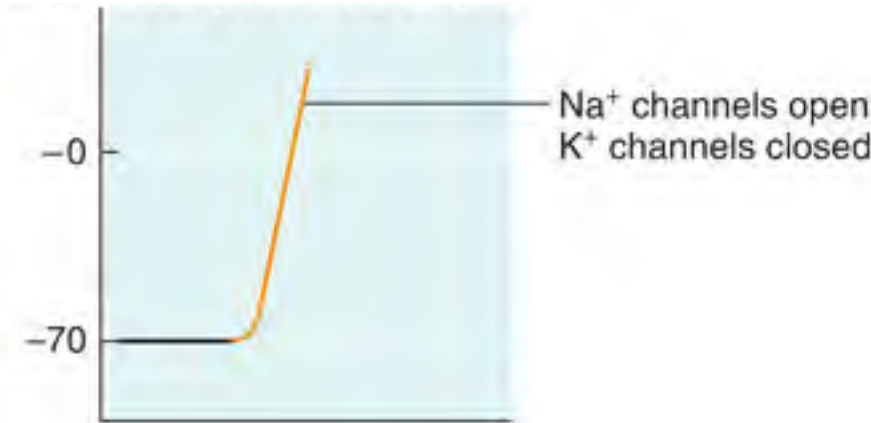
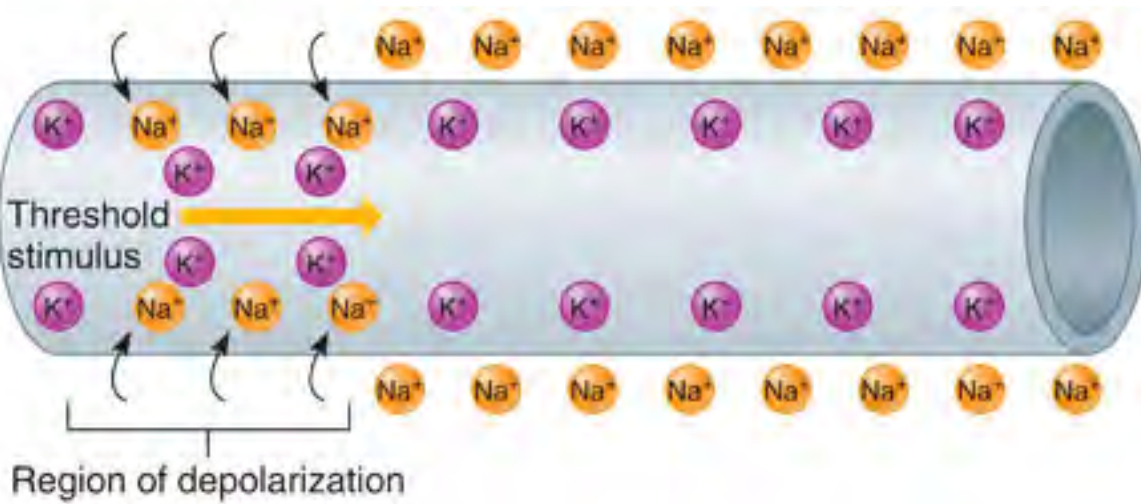
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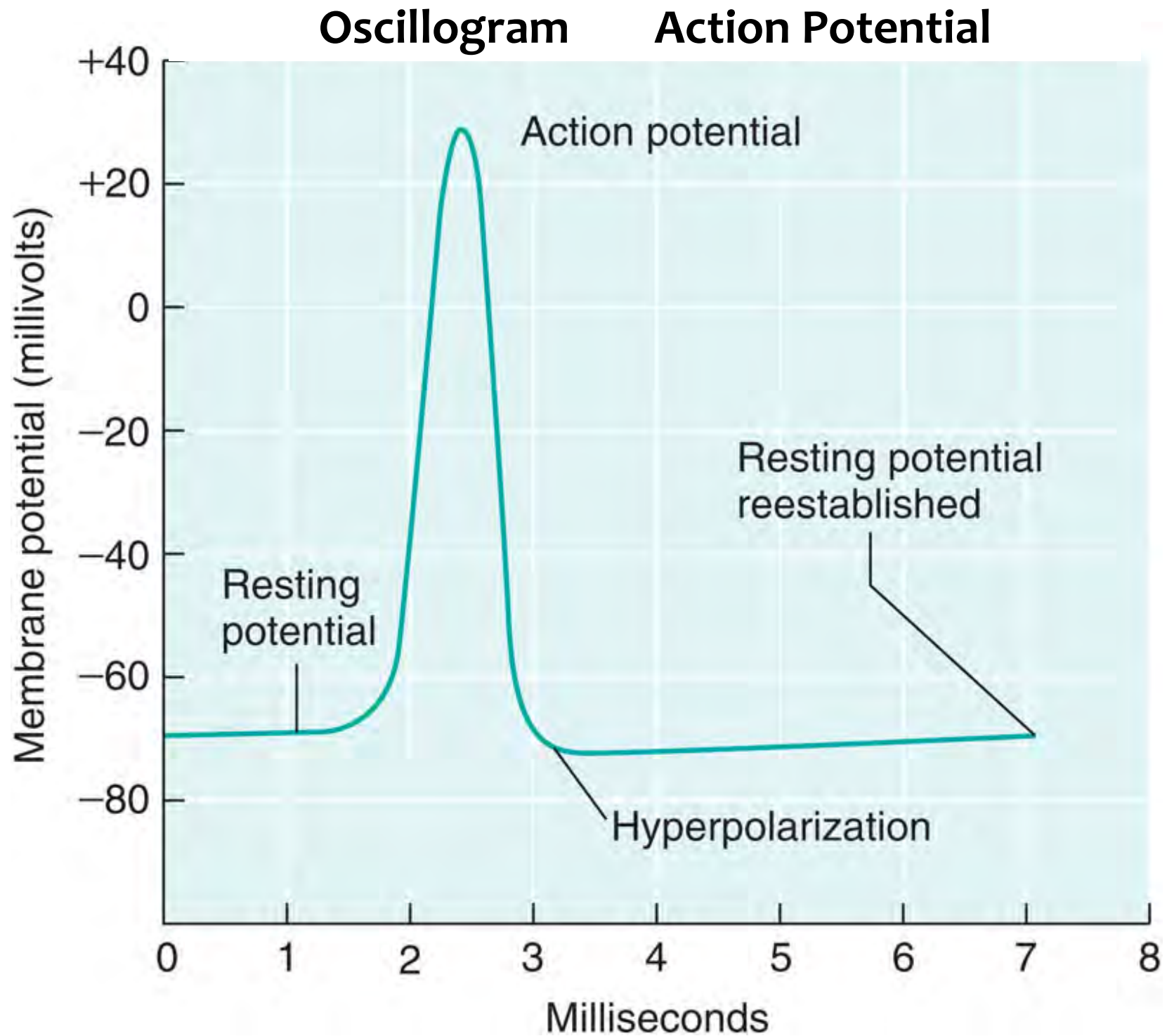
Nerve Impulse

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Depolarized Membrane





Muscular Contraction and Relaxation

Muscle Fiber Contraction

1. The distal end of a motor neuron releases acetylcholine.
2. Acetylcholine diffuses across the gap at the neuromuscular junction.
3. The sarcolemma is stimulated, and a muscle impulse travels over the surface of the muscle fiber and deep into the fiber through the transverse tubules and reaches the sarcoplasmic reticulum.
4. Calcium ions diffuse from the sarcoplasmic reticulum into the sarcoplasm and bind to troponin molecules.
5. Tropomyosin molecules move and expose specific sites on actin filaments.
6. Actin and myosin filaments form linkages.
7. Actin filaments are pulled inward by myosin cross-bridges.
8. Muscle fiber shortens as a contraction occurs.

Muscle Fiber Relaxation

1. Acetylcholinesterase decomposes acetylcholine, and the muscle fiber membrane is no longer stimulated.
2. Calcium ions are actively transported into the sarcoplasmic reticulum.
3. ATP causes linkages between actin and myosin filaments to break without ATP breakdown.
4. Cross-bridges recock.
5. Troponin and tropomyosin molecules inhibit the interaction between myosin and actin filaments.
6. Muscle fiber remains relaxed, yet ready until stimulated again.

CONTRACTION and RELAXATION of Muscle Fibers (cells)

EXCITATION

1. During excitation, action potentials **in the nerve fiber** *give rise* to action potentials in the **muscle fiber**.
2. **Action potentials in the synaptic knob** trigger the **release of ACh from synaptic vesicles**.
ACh is released to the synaptic cleft; detected by the **gated ion channels in the motor end plate**.
3. **Sodium ions rush into** the muscle cell which quickly **reverses polarity** for a section of its cell membrane. As **potassium ions rush out of** the membrane, **polarity is reestablished**. This *rapid change in polarity at the motor end plate* is called **end-plate potential (EPP)**.

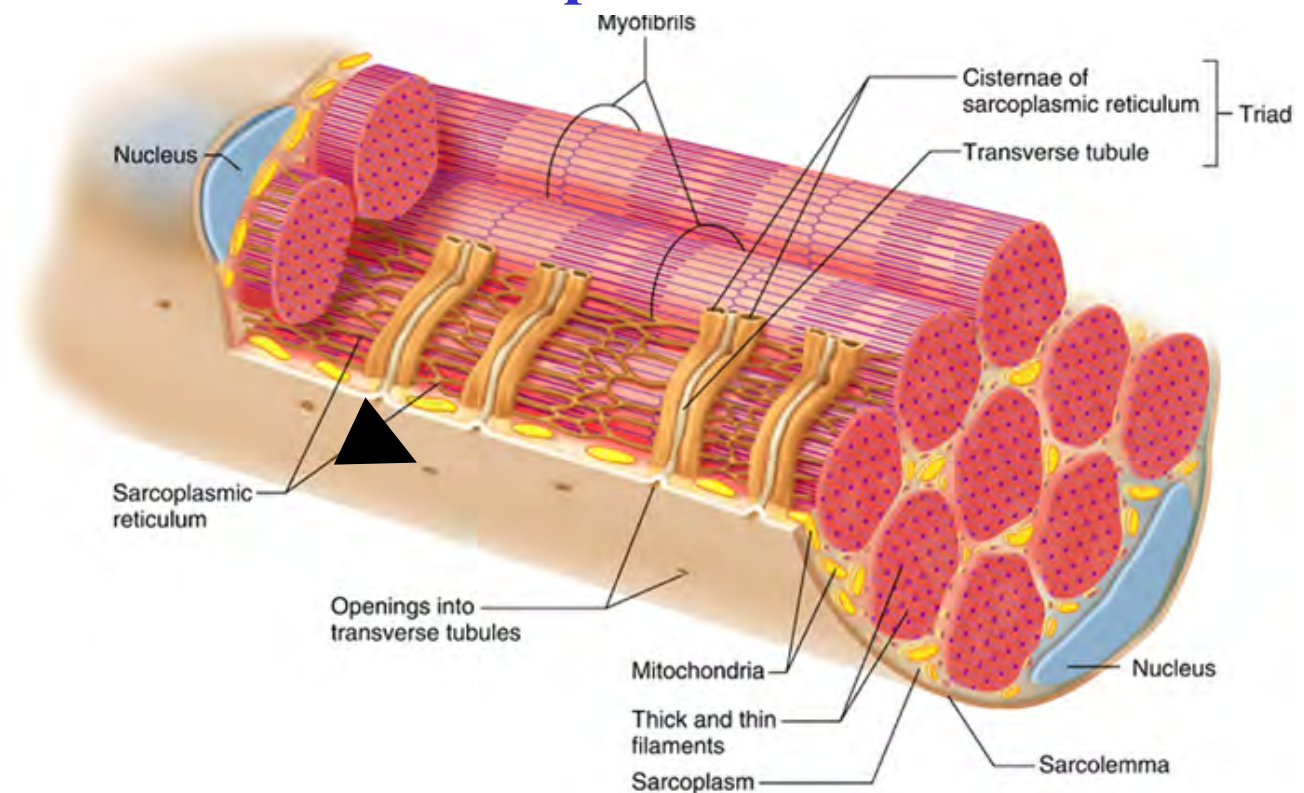
CONTRACTION and RELAXATION

of Muscle Fibers (cells)

EXCITATION cont.

4. The EPP triggers the **opening of sodium and potassium channels** adjacent to the **motor end plate**-**action potentials** radiate from the plate *in all directions*.
5. The wave of action potential reaches the **T tubules** and and **terminal cisternae** of the **sarcoplasmic reticulum**.

□ T - tubule
opening



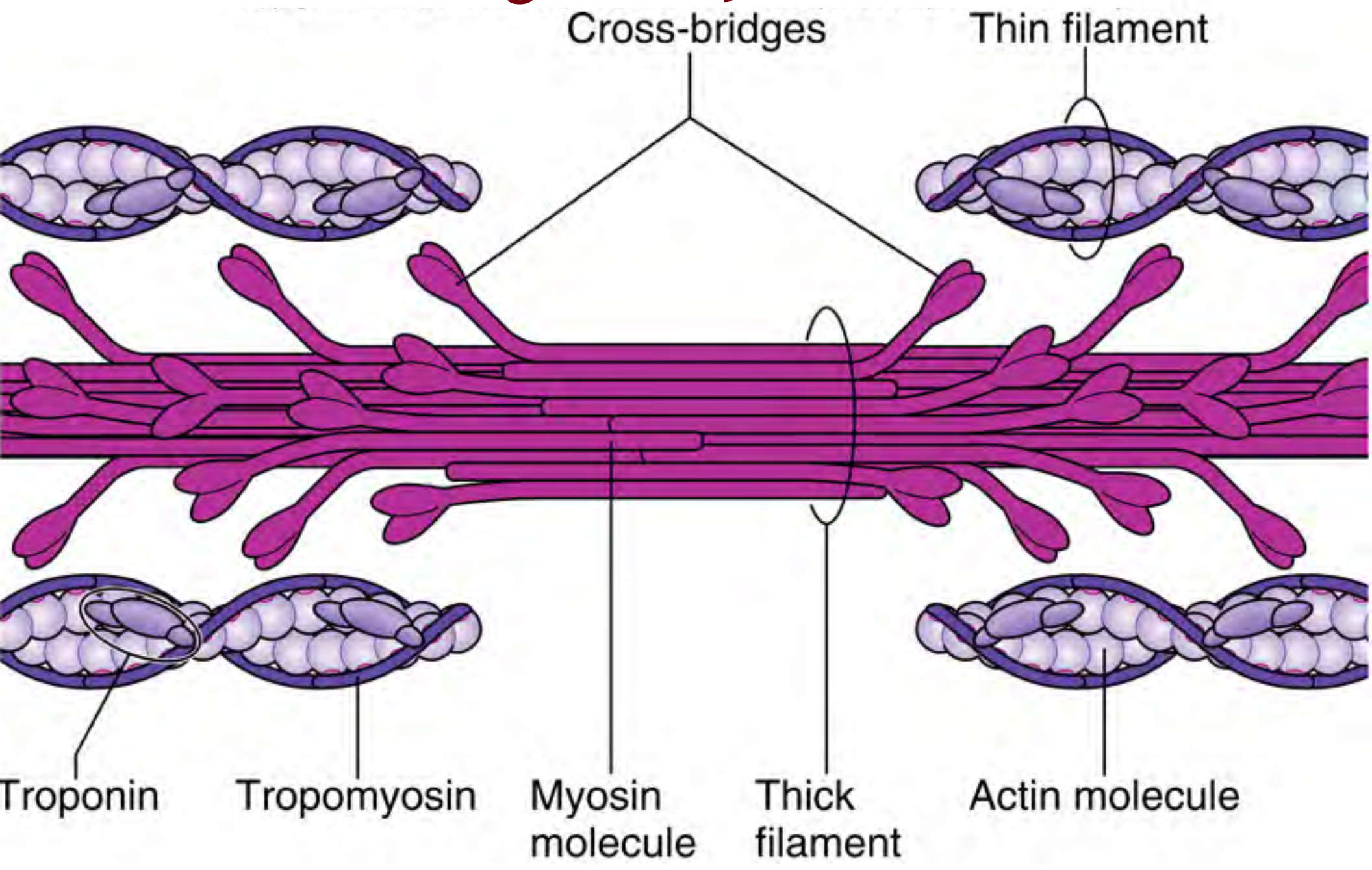
CONTRACTION and RELAXATION

of Muscle Fibers (cells)

EXCITATION Contraction Coupling

1. During excitation-contraction coupling, action potentials in the muscle fiber lead to activation of the myofilaments.
2. After the **action potential** reaches the sarcoplasmic reticulum, it releases a **flood of calcium ions** into the cytosol.
3. **Calcium ions** bind to the **troponin C** of the thin myofilaments, causing the troponin-tropomyosin complex to *shift aside*, exposing the **active sites on the actin filament**.
4. The **heads of the myosin filaments** can now bind to these **active sites** and initiate **contraction**.

Cross-bridges of Myosin Molecules



CONTRACTION and RELAXATION

of Muscle Fibers (cells)

Contraction

1. During the **contraction phase**, **sliding of the thin myofilaments past the thick ones causes the muscle fiber to shorten.**
2. The **Sliding Filament Theory** suggests that **thin filaments slide over thick ones, causing sarcomeres to shorten.**
3. The **head of each myosin molecule** contains **myosin ATPase** that releases energy from ATP. In preparation for action, the **myosin binds and hydrolyses an ATP molecule**, and is now in the **"cocked" position.**

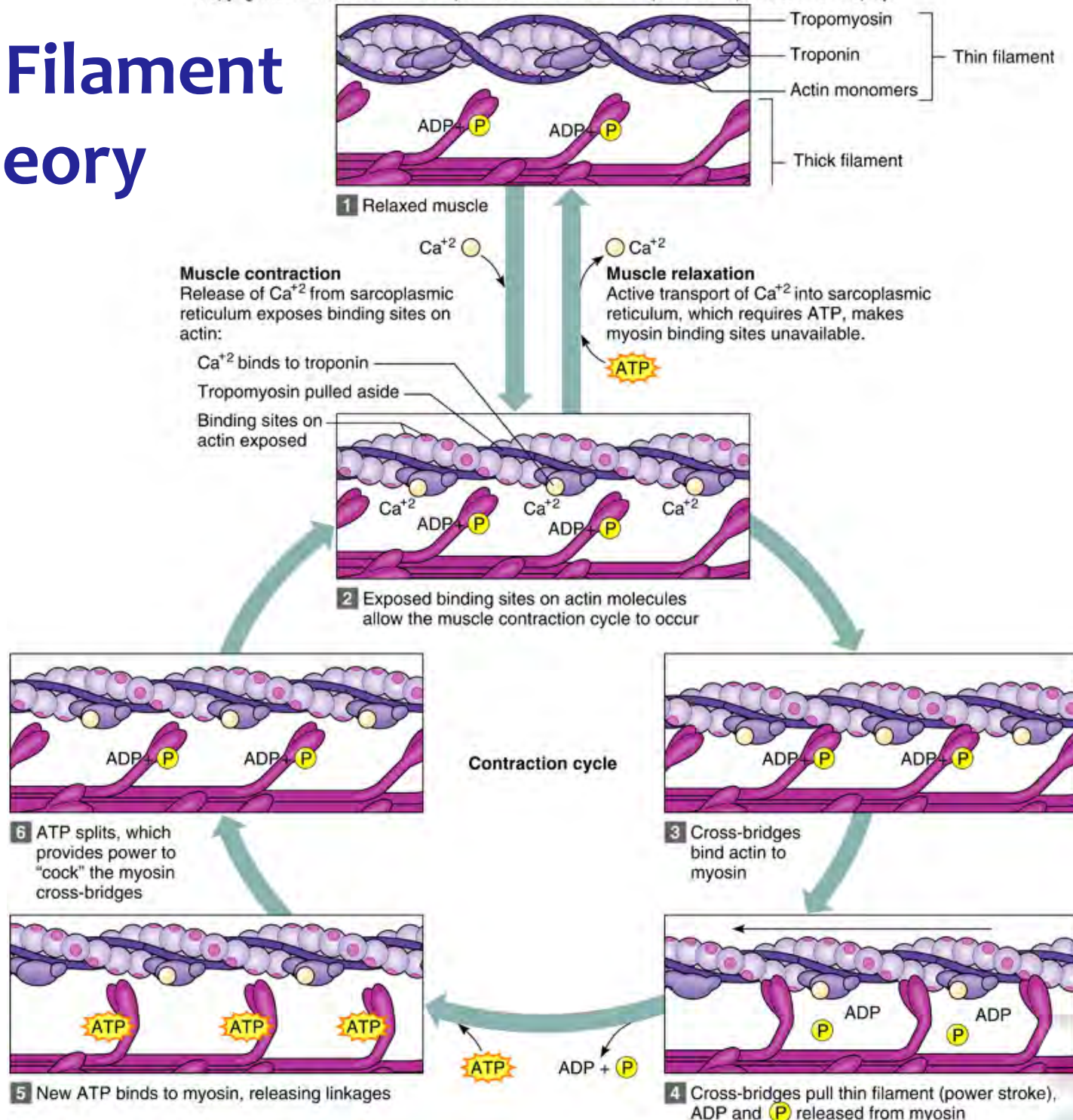
CONTRACTION and RELAXATION

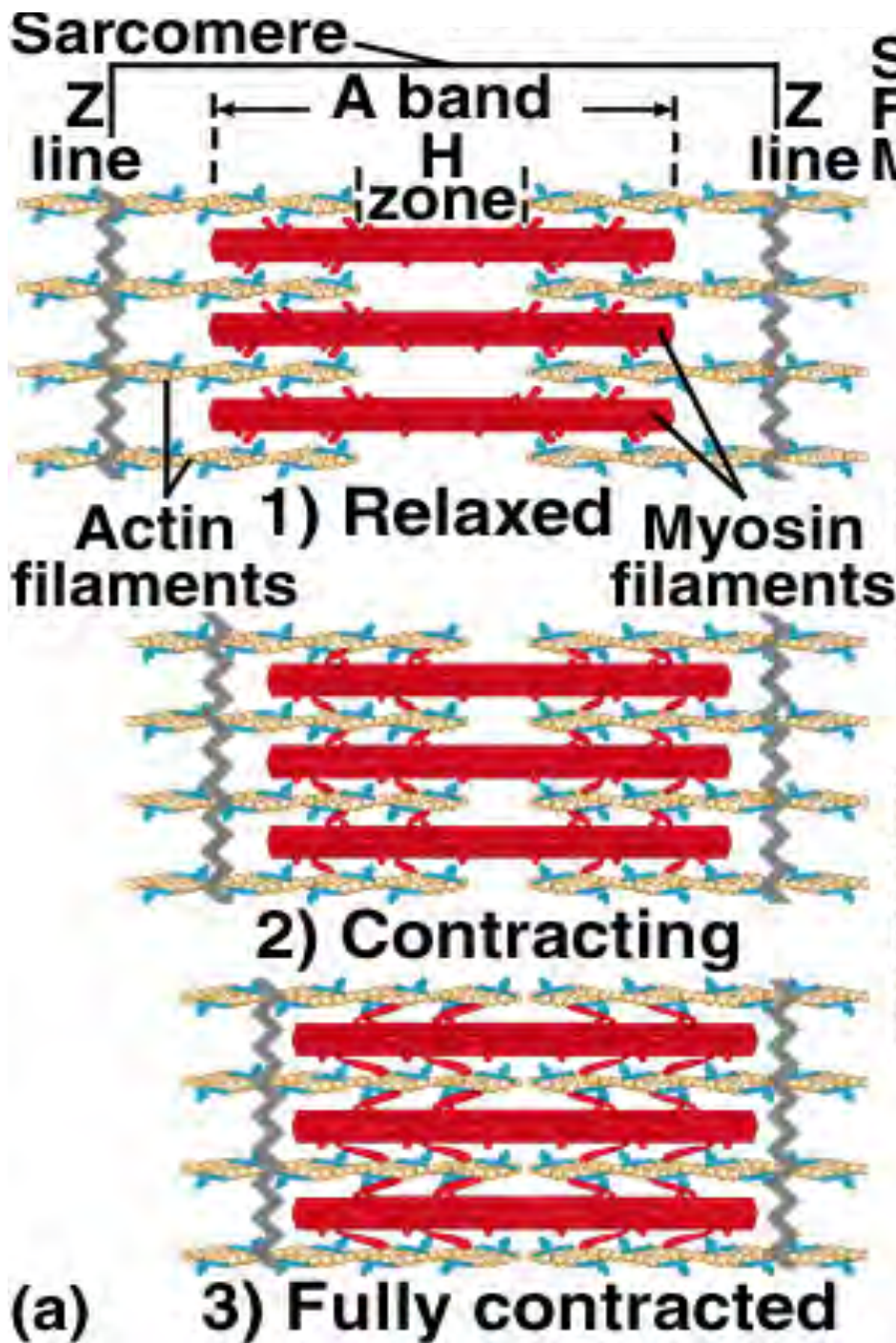
of Muscle Fibers (cells)

Contraction

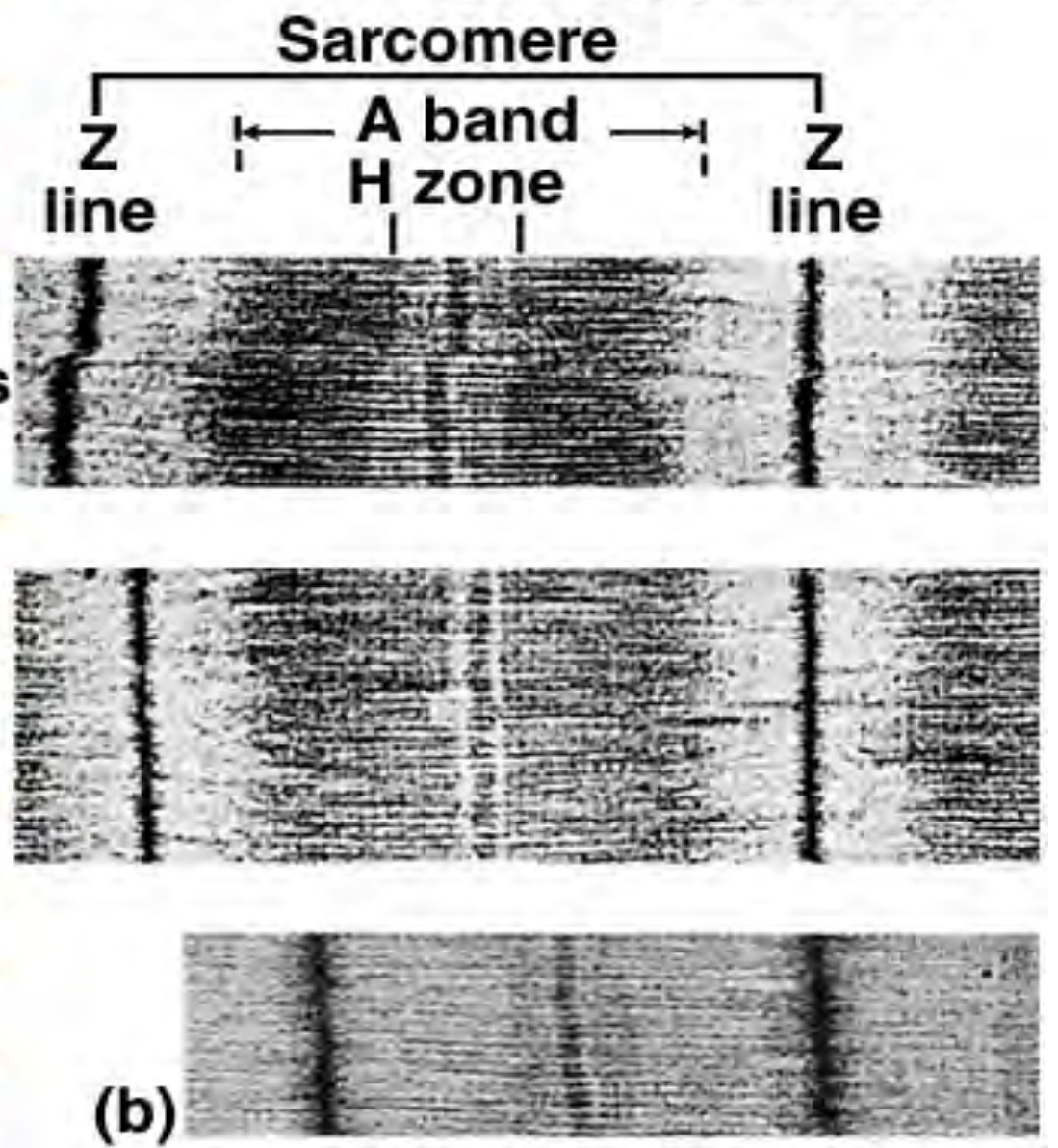
4. When the **active sites on the actin filament are exposed**, the **myosin head contacts the active site**, **releases energy**, and performs a **power stroke**.
5. At the end of a power stroke, **myosin binds to a new ATP**, releases the actin, and returns to its original position in a **recovery stroke**.
Many myosin heads pull on the actin at all times, so the actin does not slip back into its original position.
6. The cycle of power stroke and recovery is repeated many times during muscle contraction.

Sliding Filament Theory





SLIDING FILAMENT MODEL Skeletal Muscle Contraction



CONTRACTION and RELAXATION

of Muscle Fibers (cells)

Length - Tension relationship and Tonus

Muscle are always in a limited state of contraction- even when at rest!

1. Muscle fibers exhibit a **length-tonus relationship**: the tension generated by contraction *depends on how stretched (relaxed) or contracted the fiber was to begin with.*
2. *If the muscle is **already mostly contracted***, stimulation will cause a **weak contraction**.
3. *Conversely, if the muscle is **overly stretched***, **little overlap exists between actin and myosin filaments**, and contraction can damage the muscle.

CONTRACTION and RELAXATION of Muscle Fibers (cells)

Relaxation

1. *When nervous stimulation ceases, the muscle relaxes.*
2. **Acetylcholinesterase** breaks down ACh so the muscle stops generating its action potentials.
3. **Calcium** is carried back to the sarcoplasmic reticulum by **active transport** and a protein: **calsequestrin**.