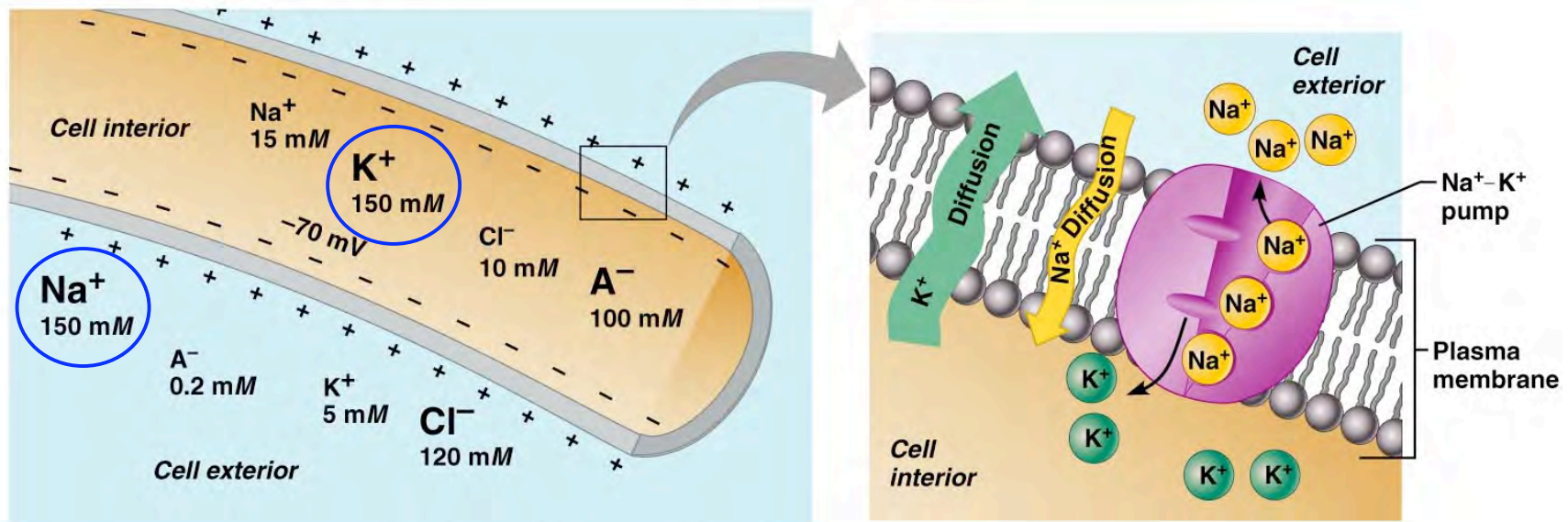


# Skeletal Muscle Physiology

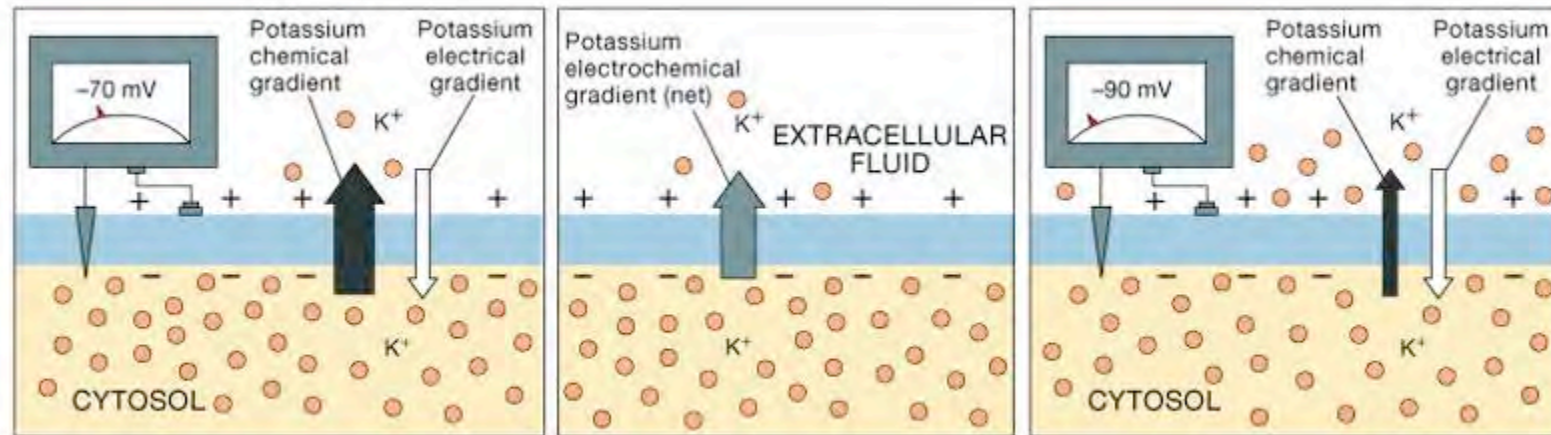
How do contractions occur?  
Remember that muscles are  
**excitable**

# Electrochemical gradient

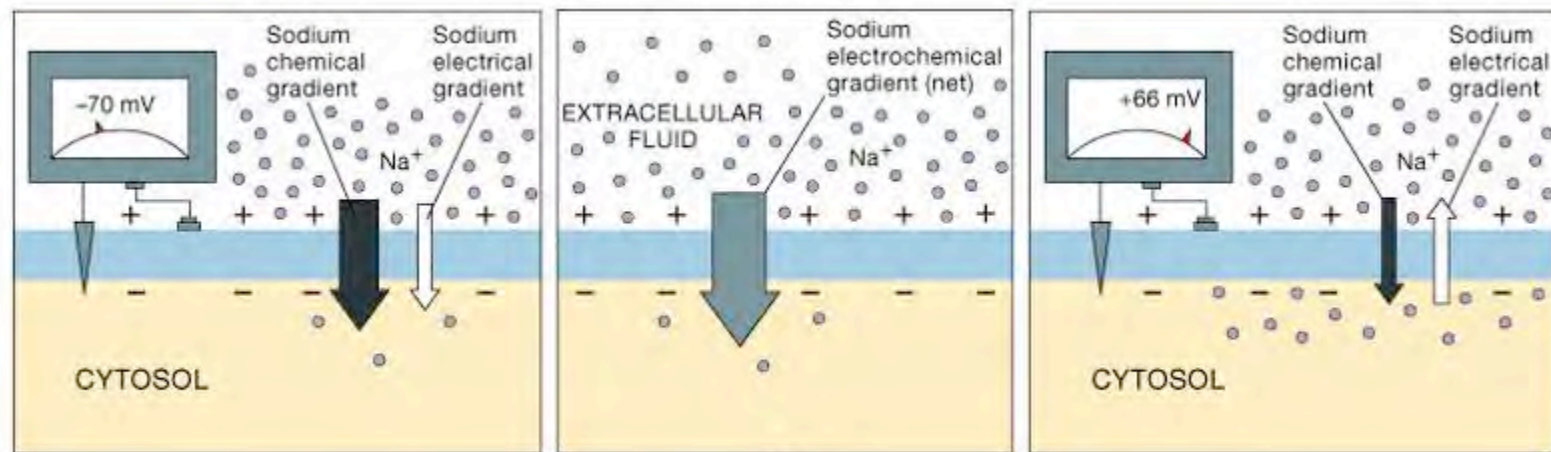
- Both neurons and muscle cells maintain **electrochemical gradients** across their plasma membranes: a charge difference exists, like between poles of a battery.
- **Intracellular fluid is negatively charged**



# Electrochemical gradient



(a)



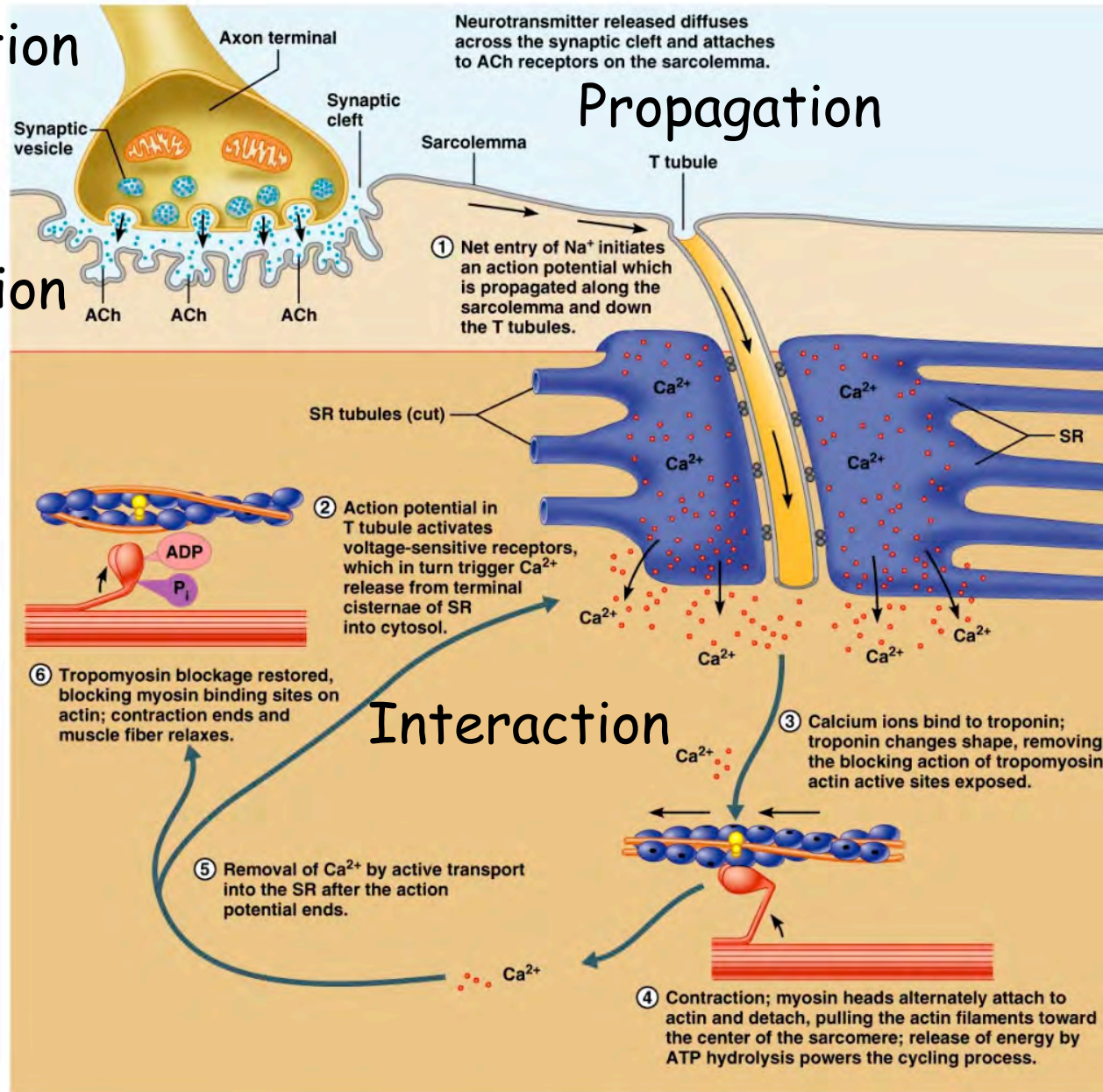
(b)

# How does skeletal muscle contract?:

- Requires a **stimulus** from the **somatic** nervous system to initiate contraction
- Where does the stimulus come from?
- Brain/spinal cord -> Motor neuron -> muscle cell
  - One motor neuron innervates *multiple* muscle cells

# Propagation

# Transduction

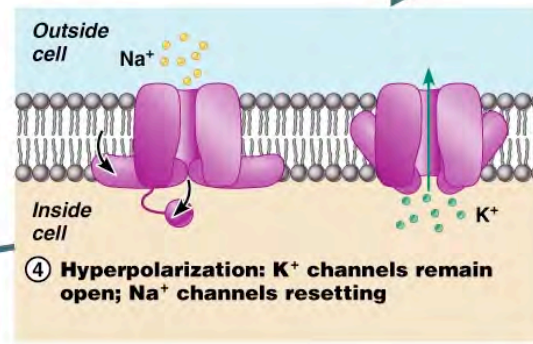
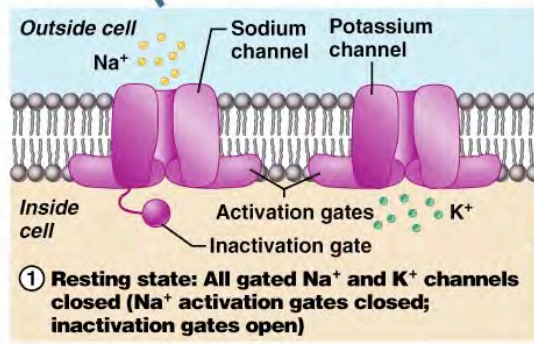
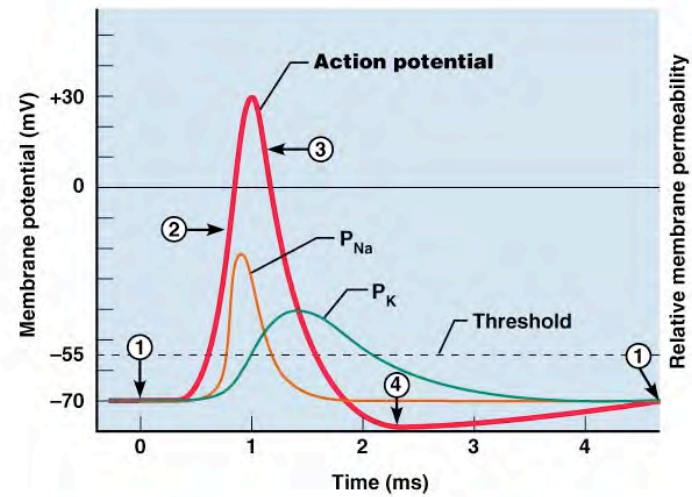
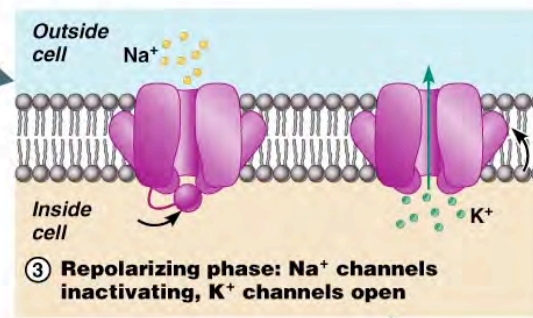
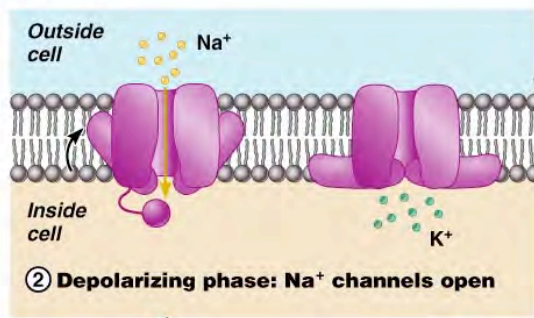


# What do you need to produce a contraction?

1. Must transfer message (**action potential**) from the neuron throughout the muscle cell (via **transverse tubules**)
2. **Myosin** and *actin* filaments must interact
  - $\text{Na}^+$  &  $\text{Ca}^{2+}$
  - Energy to contract
    - ATP

# What is an Action Potential (AP)?

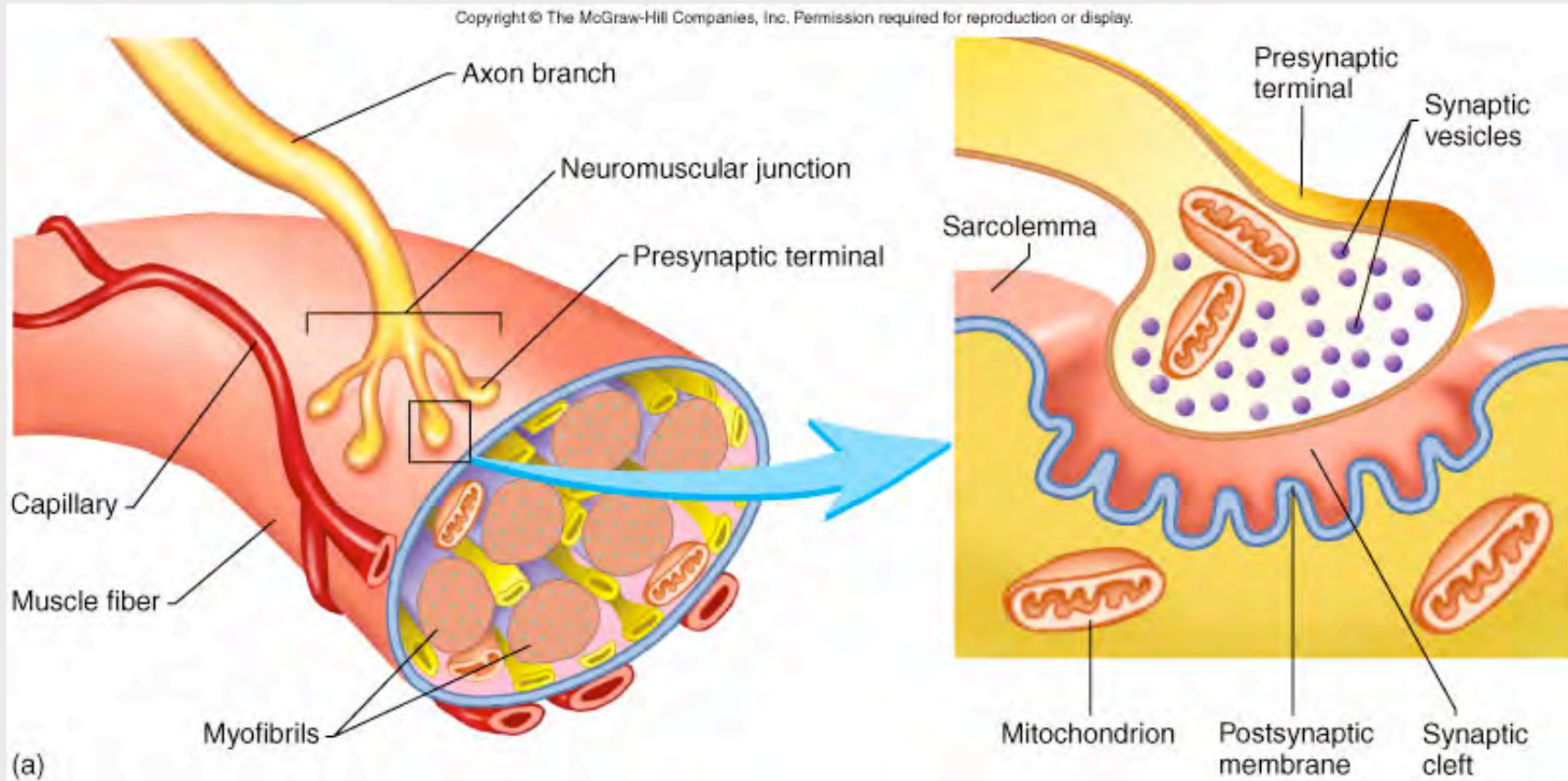
- A propagated change in the *transmembrane potential* of excitable cells
  - This is the message telling the cell to contract!
  - Initiated by a depolarization of cell membrane. Causes an *influx* of  $\text{Na}^+$  ions.





1. Cell @ rest; Gated channels closed
2. Stimulus arrives!  $\text{Na}^+$  channels open &  $\text{Na}^+$  rushes IN; **Depolarization**
3. Slow response  $\text{K}^+$  channels open &  $\text{K}^+$  rushes OUT; **Repolarization**

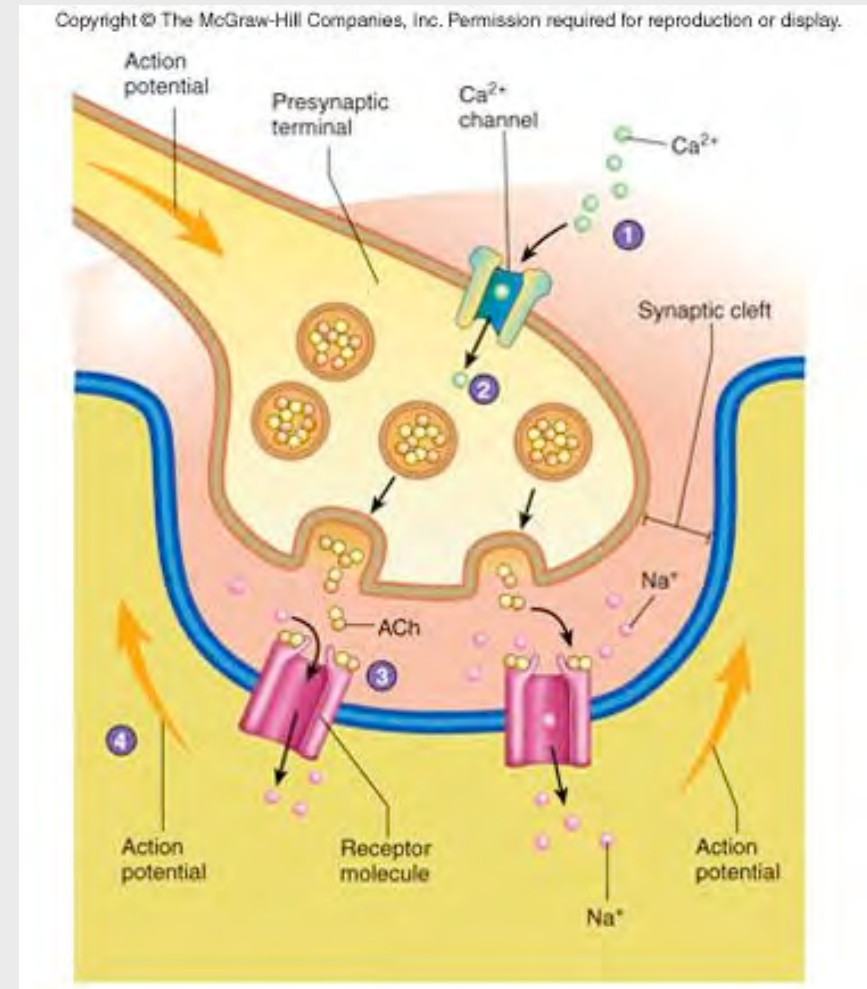
# Connection between nerve & muscle



How is a signal transferred from neuron to muscle cell?

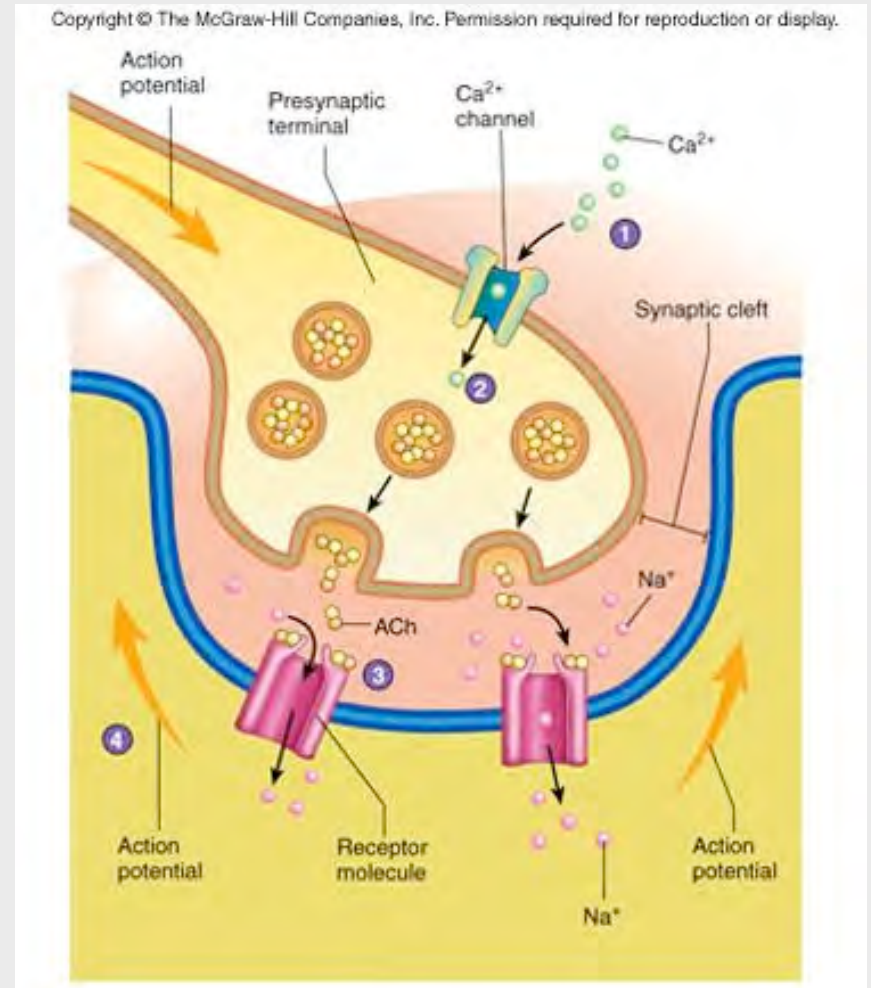
# Signal transduction

1. AP arrives @ presynaptic terminal; causes  $\text{Ca}^{2+}$  channels to open
2.  $\text{Ca}^{2+}$  ions enter & stimulate neurotransmitter release (ACh) from synaptic vesicles into synaptic cleft



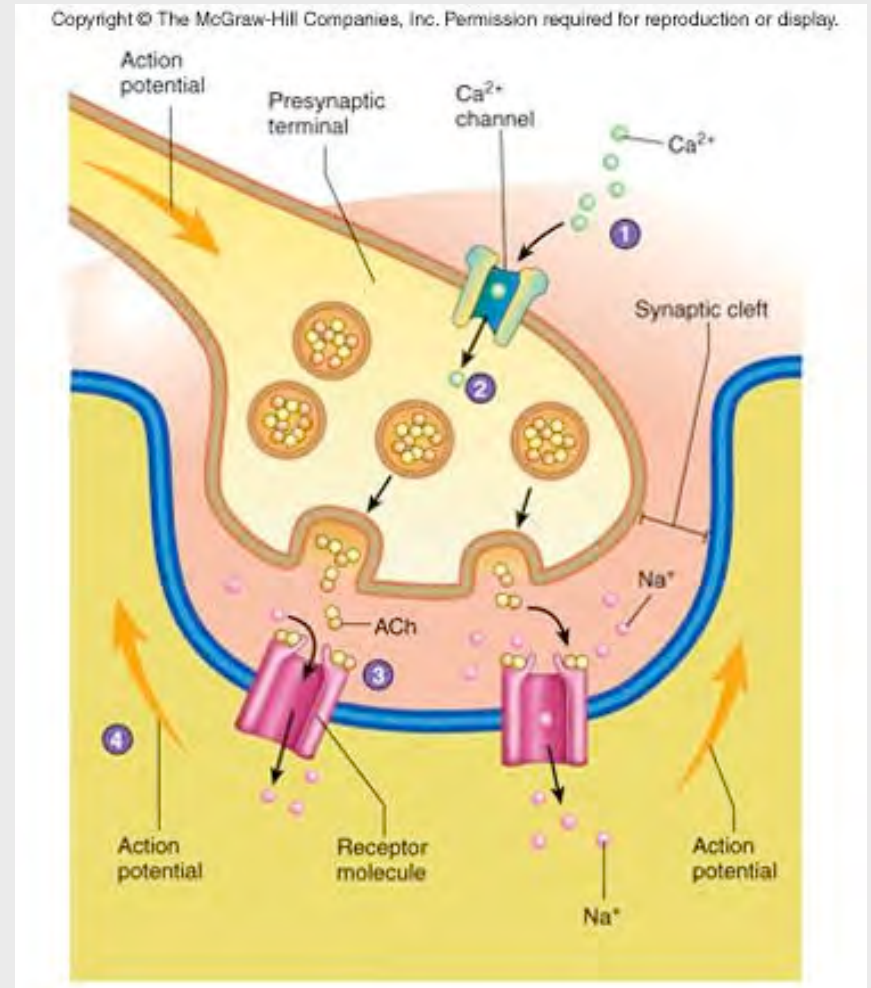
# Signal transduction

3. ACh diffuses across synaptic cleft & binds to ACh receptors on  $\text{Na}^+$  channel proteins in sarcolemma of muscle cell

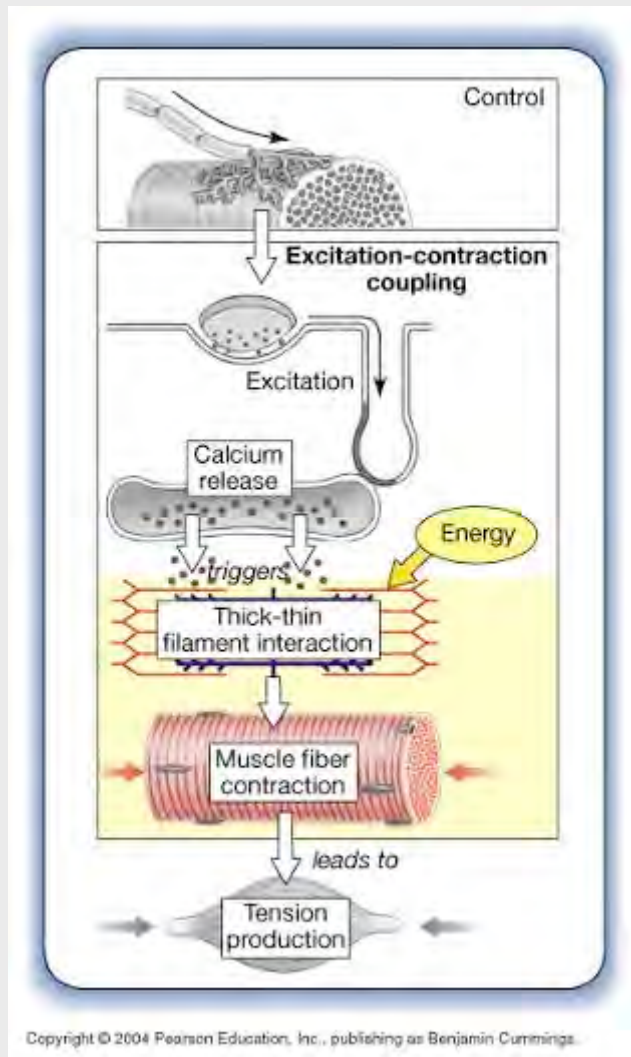


# Signal transduction

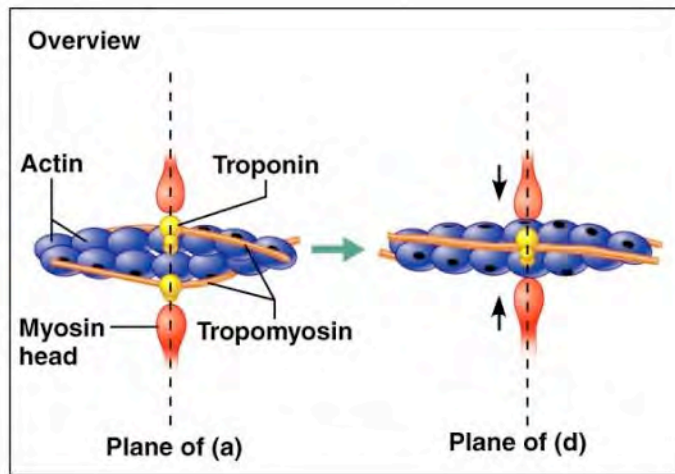
4. Influx of  $\text{Na}^+$  ions results in depolarization of postsynaptic membrane; when "threshold" is reached, postsynaptic (muscle) cell fires an AP



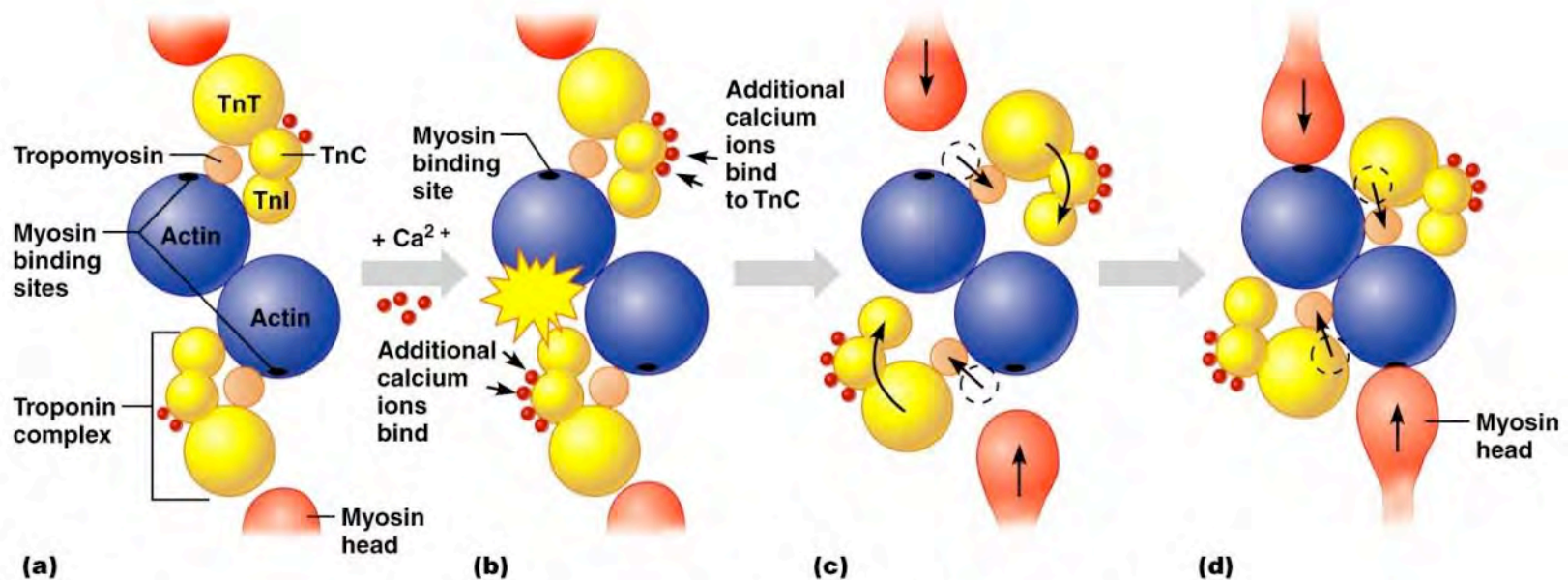
# Ca<sup>2+</sup> ions released

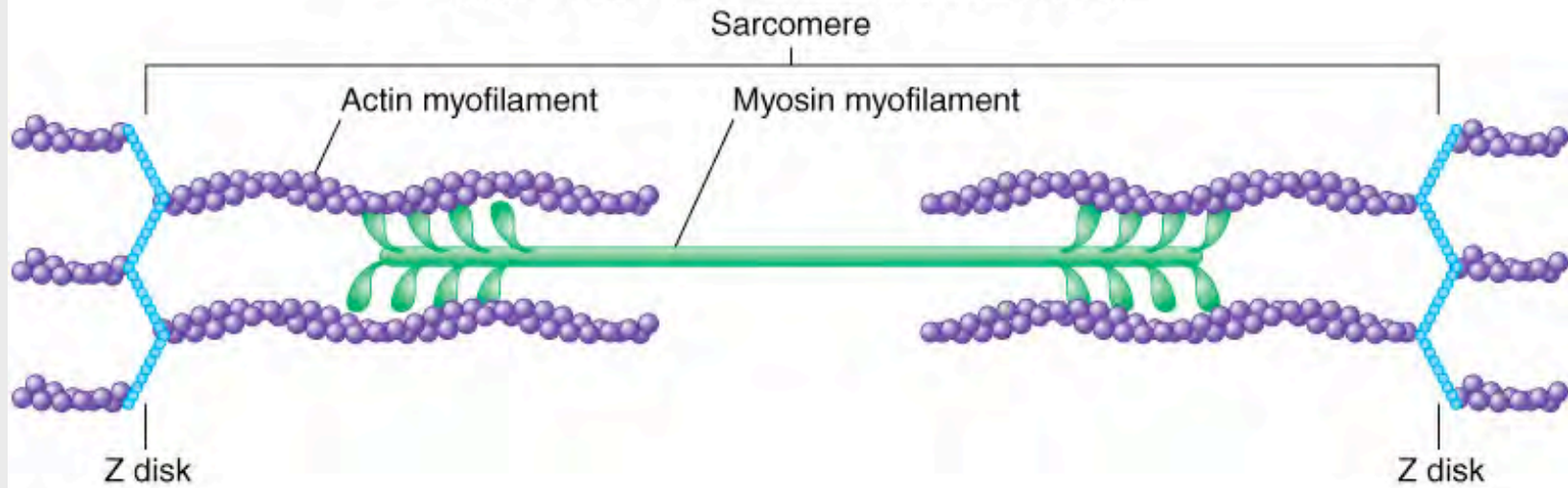


- Ca<sup>2+</sup> binds to troponin of *thin* filaments
- Allows interaction of **thick** and *thin* filaments
- Causing a contraction



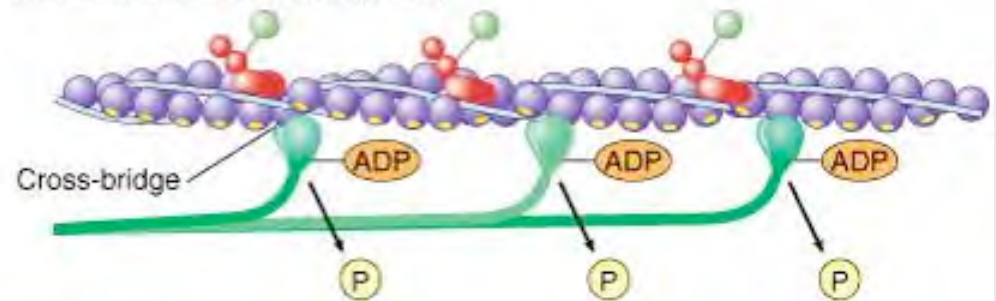
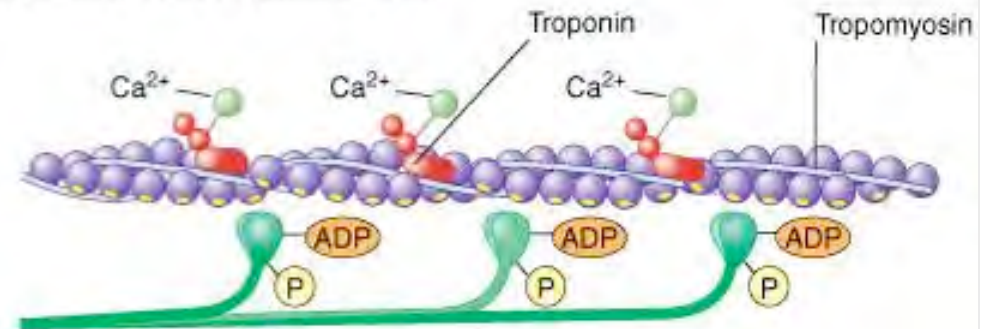
Ca<sup>2+</sup> binds troponin;  
Troponin - tropomyosin moves;  
Exposes active sites;  
Myosin binds to actin





**Exposure of attachment site:**  $Ca^{2+}$  binds to troponin; allows tropomyosin to move, exposing myosin attachment site

**Cross-bridge formation:** Myosin heads attach to actin subunits. P released





**Power Stroke:** Stored E in myosin heads used to pull actin filament toward M line. ADP released from myosin head

**ATP regenerated & attached to myosin head:** Could be new ATP or phosphorylated ADP from previous step

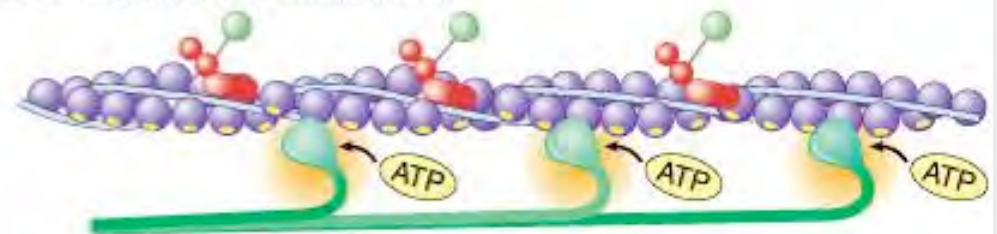
**Cross-bridge release:** ATP broken down to **ADP + P**. Myosin head releases

**Recovery Stroke:** Myosin heads return to resting position. E still stored in myosin head

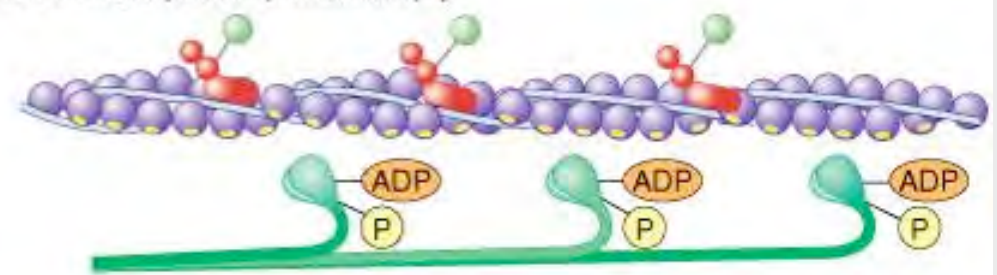
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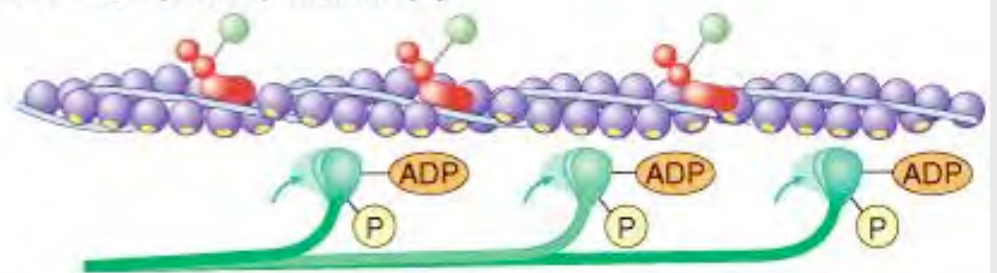
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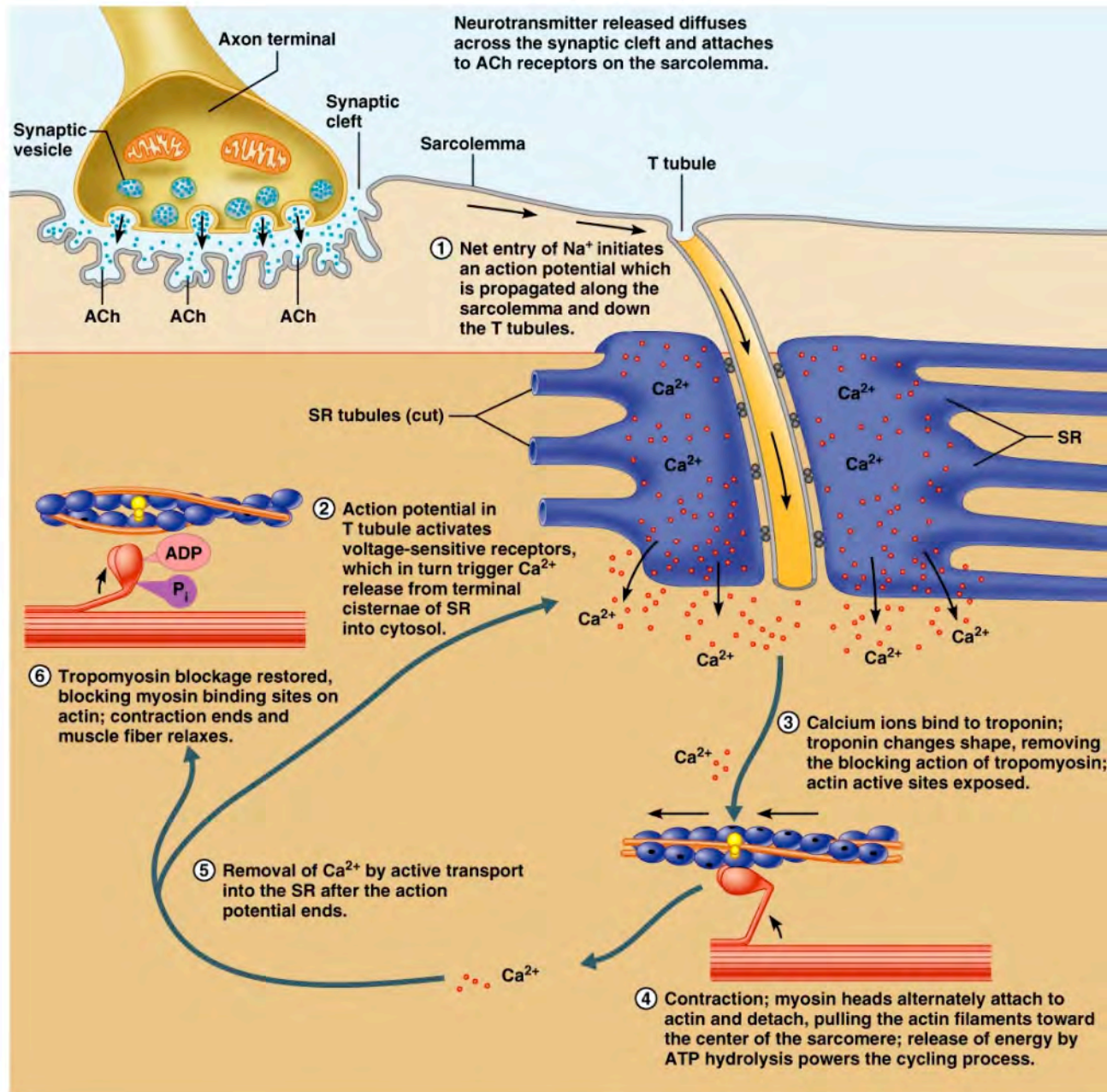


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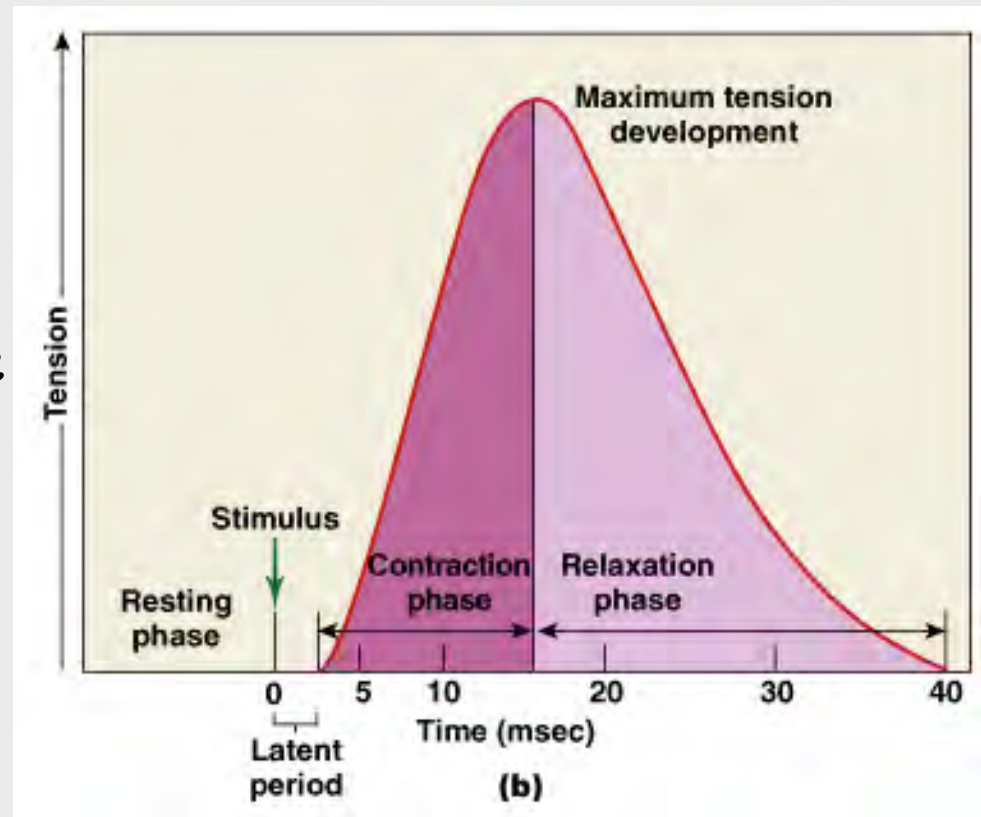


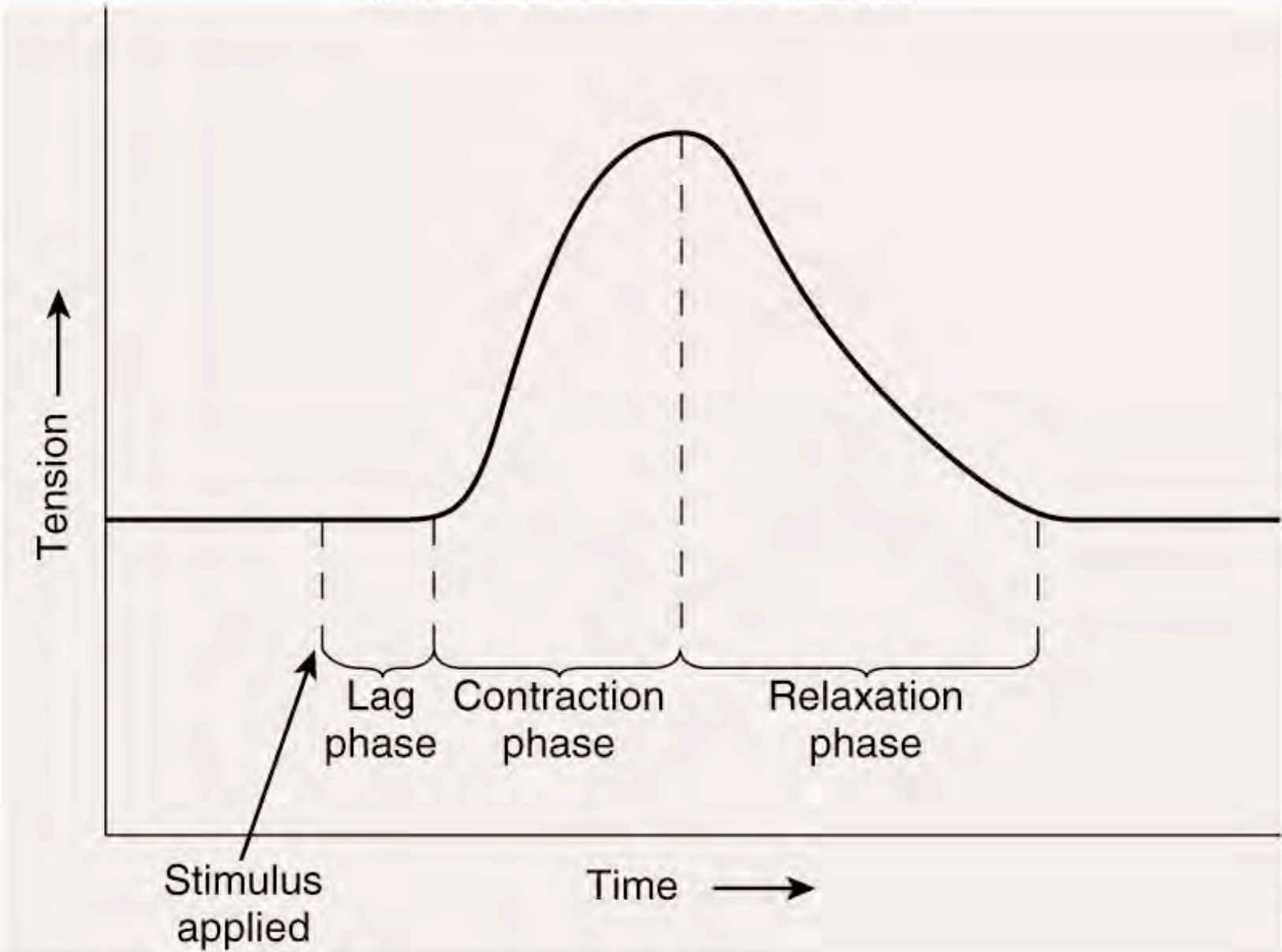
# AP produces Twitch contraction

- We know **single** muscle cells contract when AP arrives
- One single AP stimulus produces a single **Twitch**
  - Twitches produce muscle tension
  - How long does one twitch take?

# Single Contraction = Twitch

- **Three** phases
- Latent: AP reaches sarcolemma; SR releases  $\text{Ca}^{2+}$ ; 2ms
- Contraction: Cross-bridge formation;  $\text{Ca}^{2+}$ , troponin; 15ms
- Relaxation:  $\text{Ca}^{2+}$  uptake; tropomyosin covers actin; 25ms



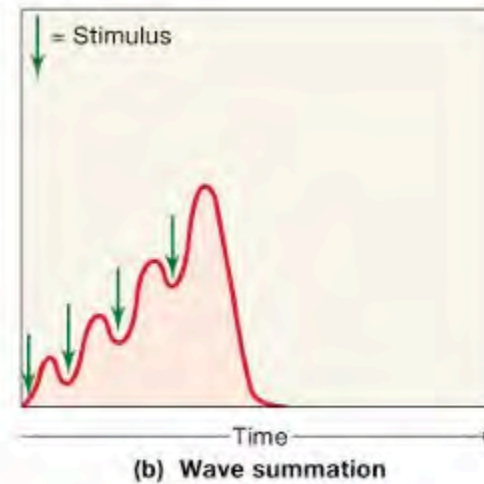
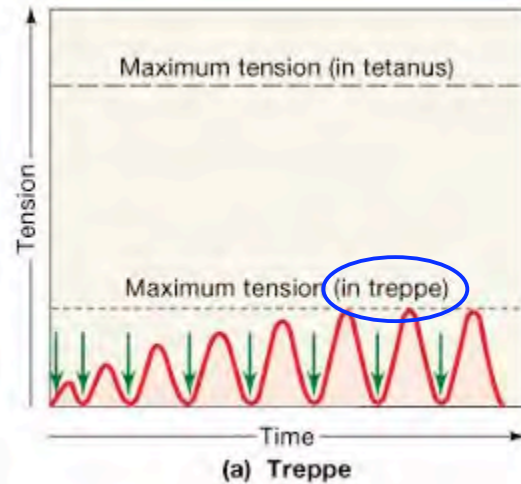


# Recruitment & Summation

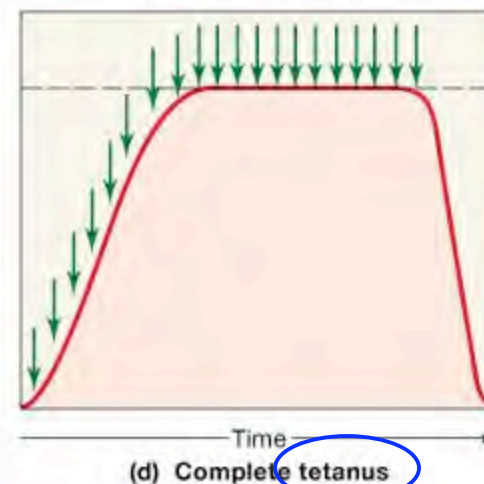
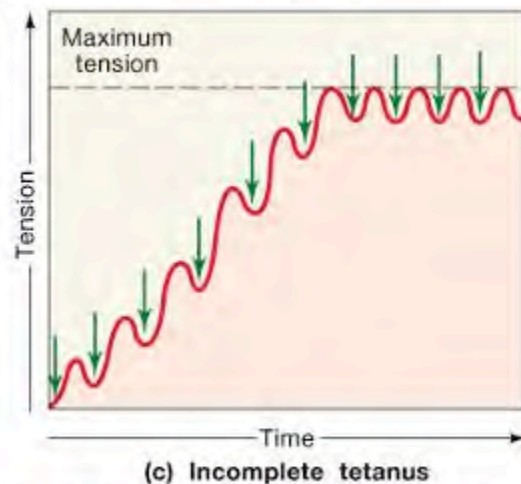
- We know a single AP produces a single **Twitch**
  - Twitches produce muscle tension
- How do twitches achieve **whole** muscle contraction?
- By building **Tension = Force produced by a contracting muscle**
  1. Many motor units are stimulated (**recruitment**)
  2. AP's arrive more frequently (**summation**)

# What happens when AP frequency increases?

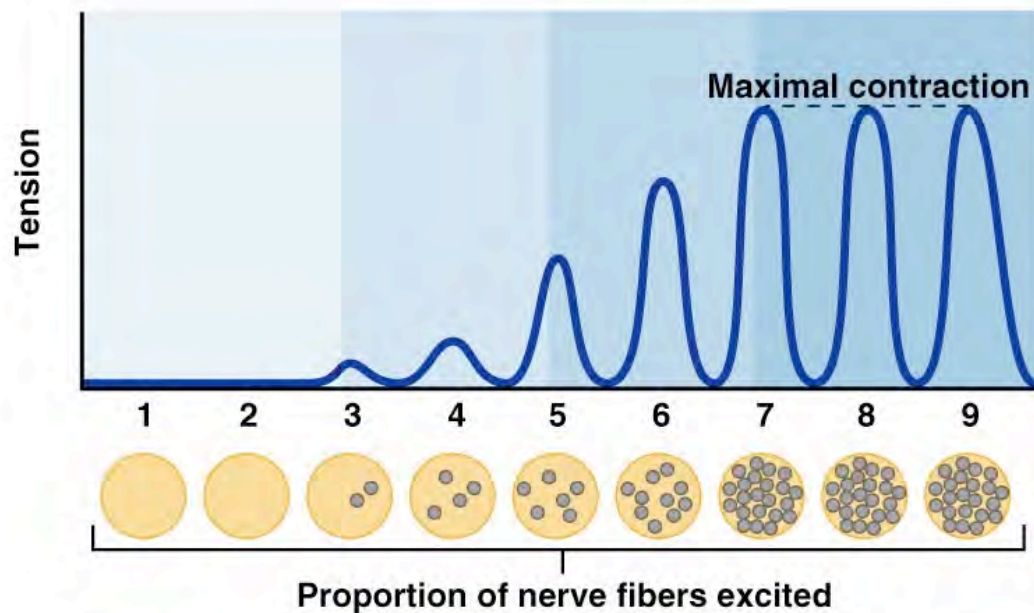
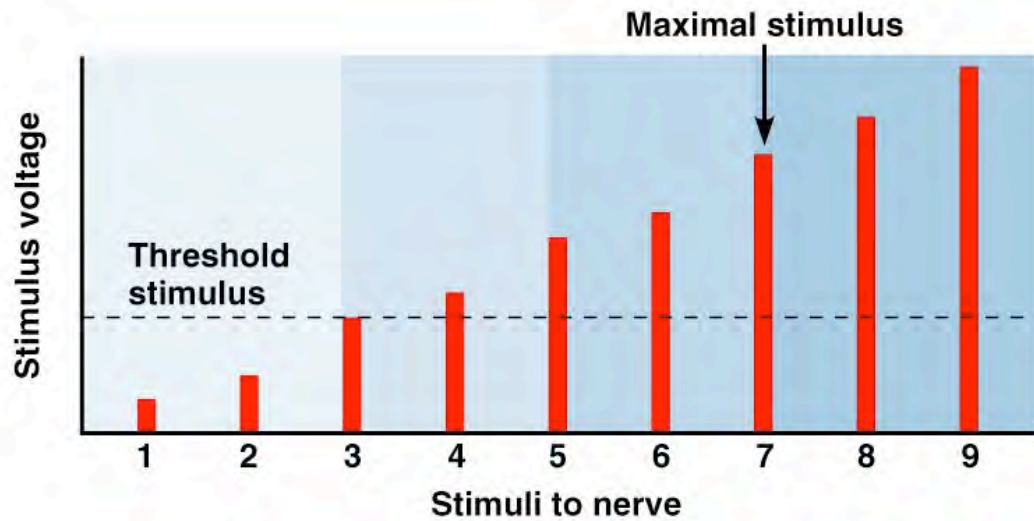
relaxation phase  
Complete



relaxation phase  
Incomplete



relaxation phase  
Eliminated



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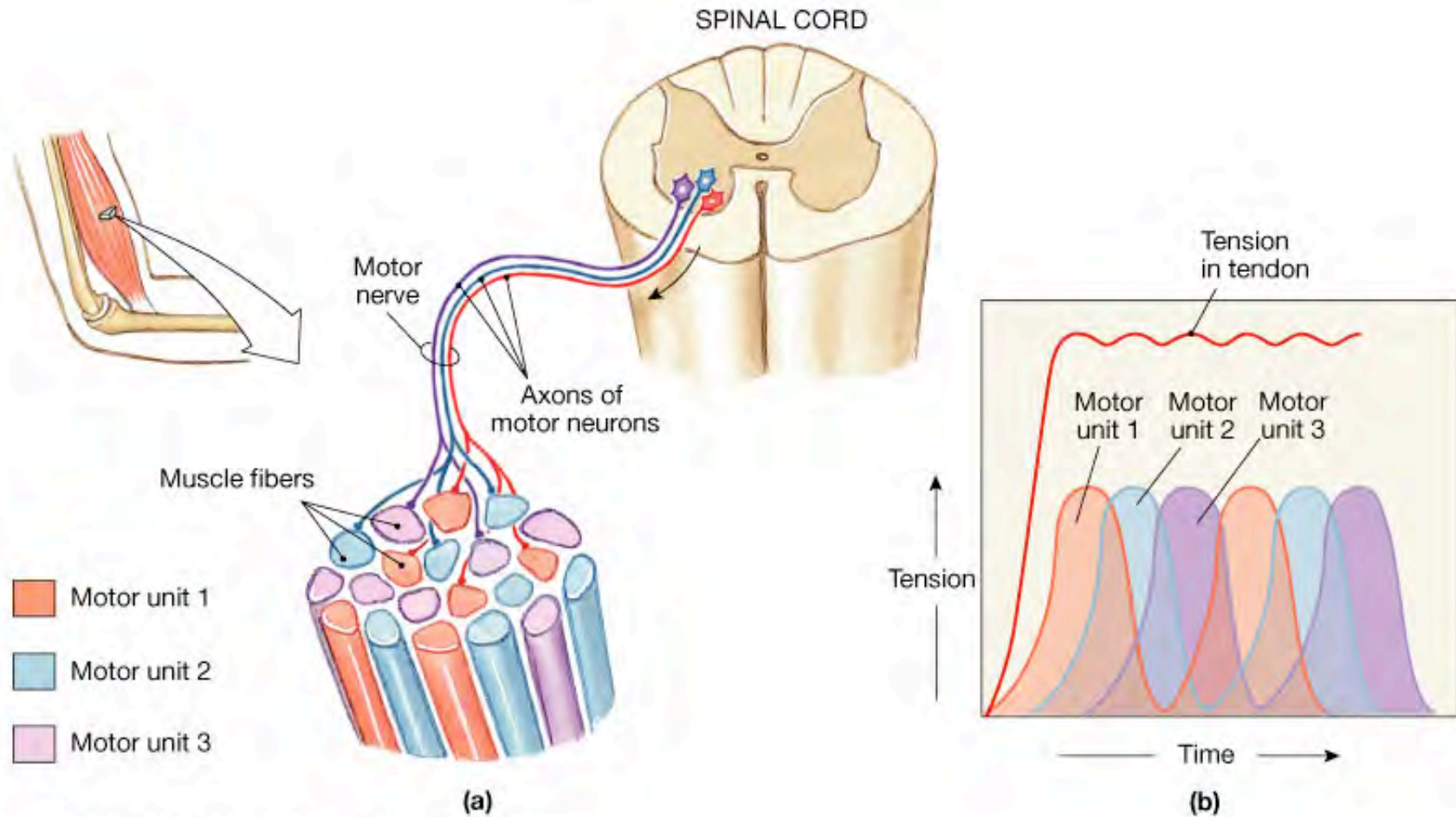
What happens when multiple fibers are stimulated?



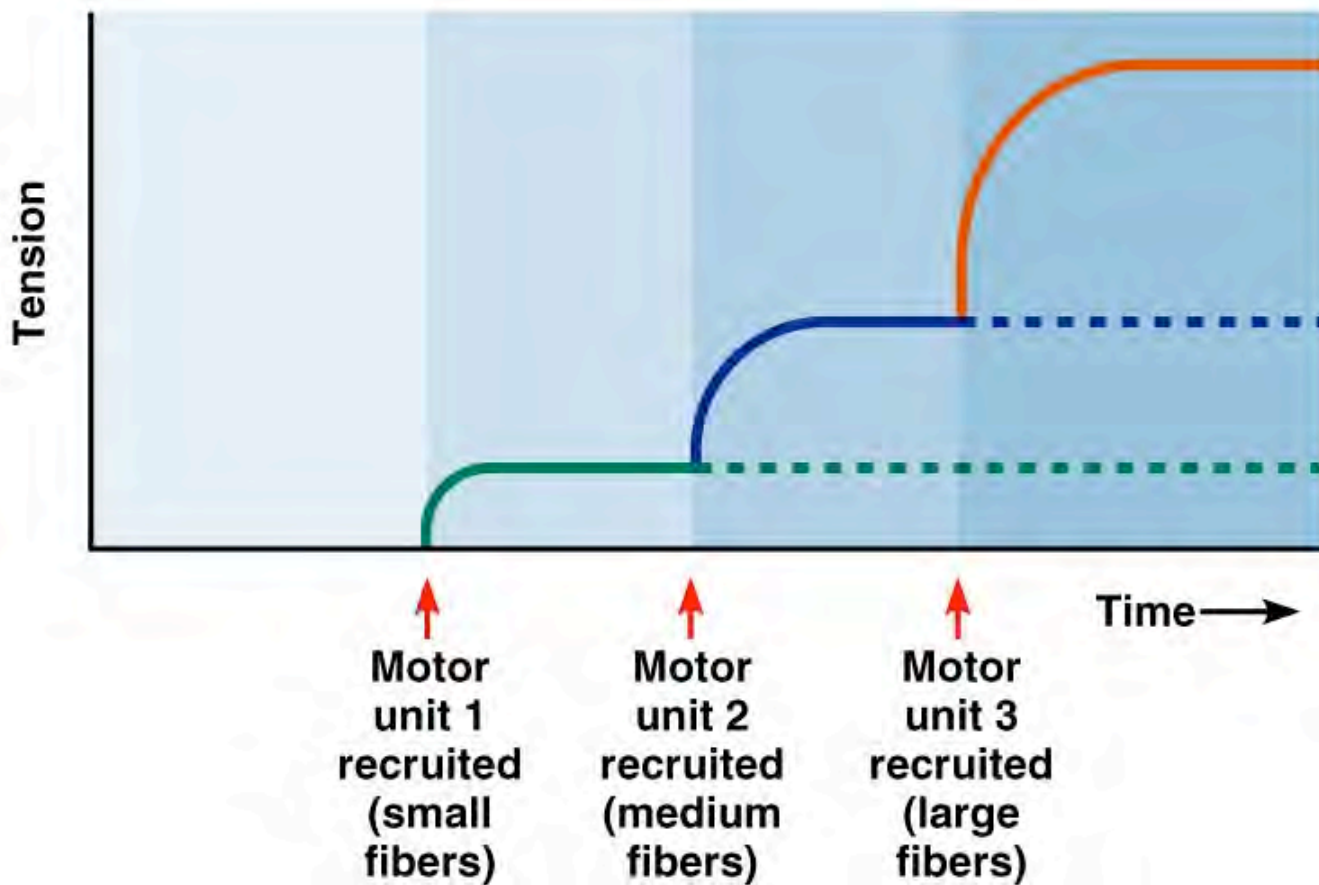
# Motor units control tension

- 1 **motor unit** = all the muscle *fibers* controlled by a **single** motor neuron
- Can the size (of motor units) vary?
  - Yes! Why would it vary?
- Size of the muscle
- Level of control required
  - Muscles of the eye - precise control; 4-6 fibers per unit
  - Muscles of the leg - gross control; 1-2k fibers per unit

# Motor Units



# Motor unit recruitment



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# What ultimately controls muscle tension?

- Presence of  $\text{Ca}^{2+}$  ions
  - More  $\text{Ca}^{2+}$  ions present = more to potentially bind to troponin
  - Stronger contraction (more tension produced)

# Cardiac muscle

- Heart muscle
- Cells directly connected via **intercalated discs** (pores through which ions pass)
  - Allows all connected cells to contract as one
- Cardiac muscle is **autorhythmic** (spontaneous generation of AP)
- Involuntary (influenced by hormones)
- Metabolism is always aerobic

# Smooth muscle

- Less actin & myosin, no sarcomeres
- Contracts slowly
  - No  $O_2$  debt
- Autorhythmic
- Involuntary control