Sliding Filament Theory

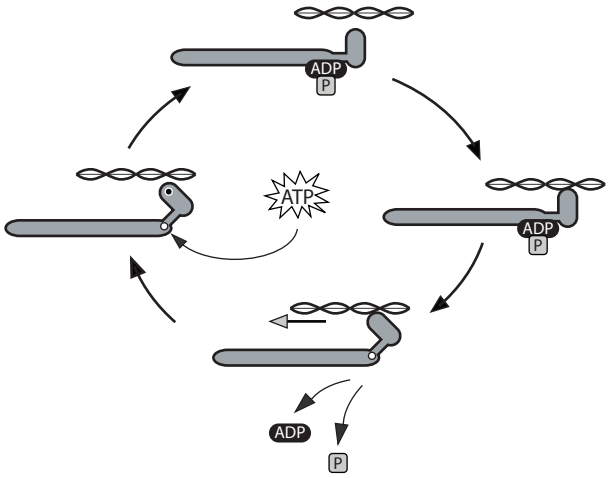
A Pictorial Guide on

Muscle Contraction

and

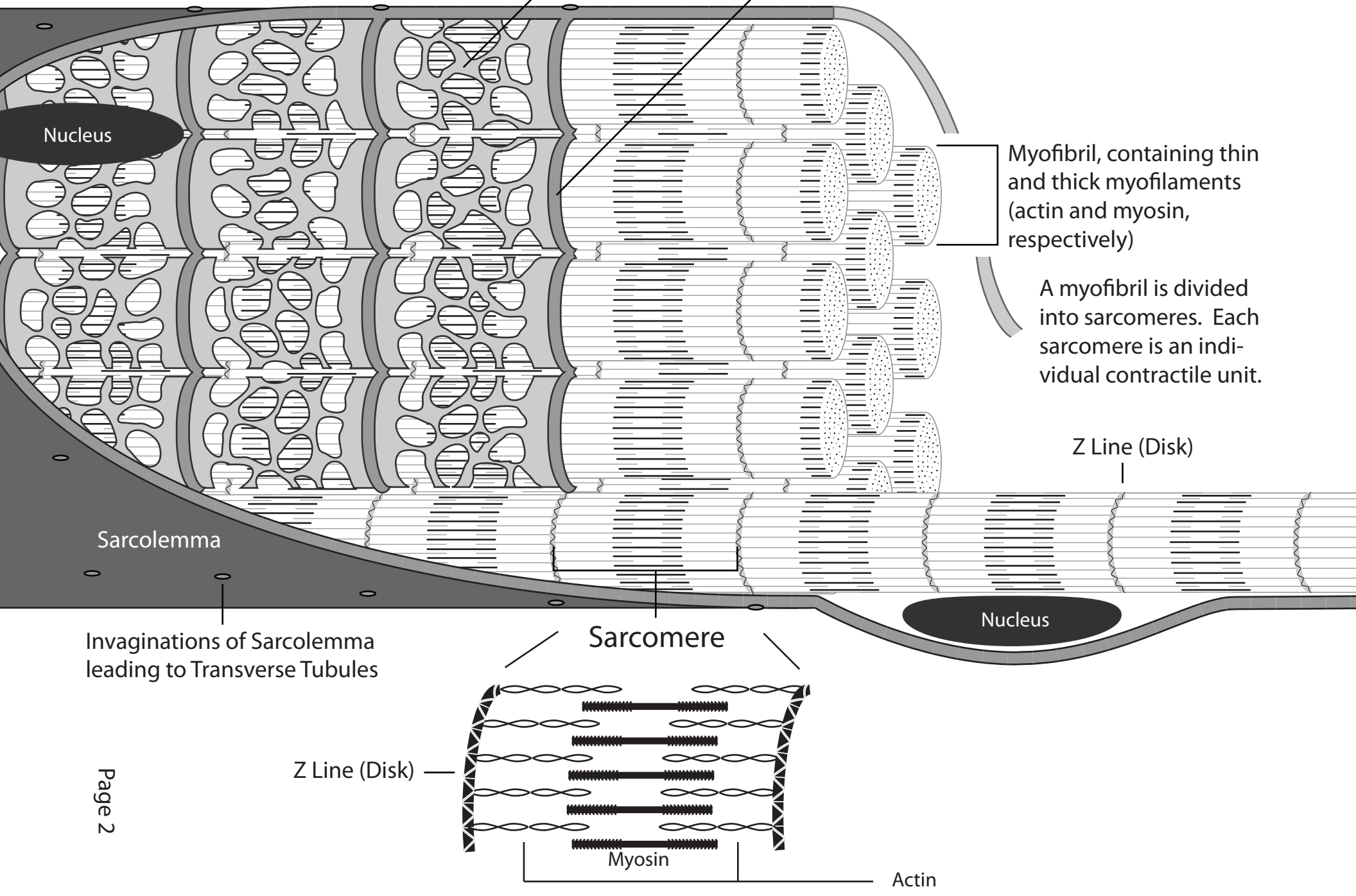
The Neuromuscular Junction

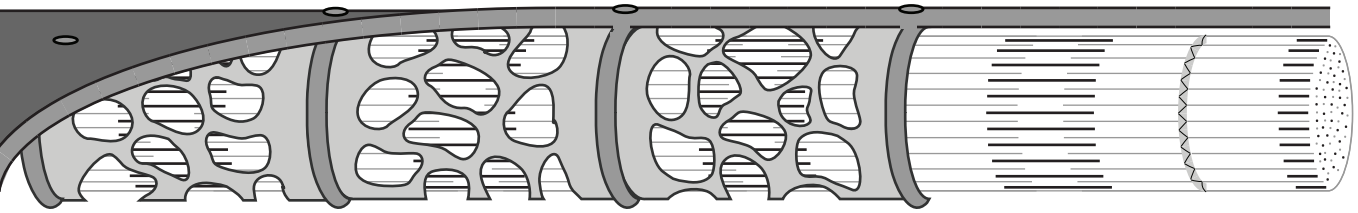
To Accompany Lecture



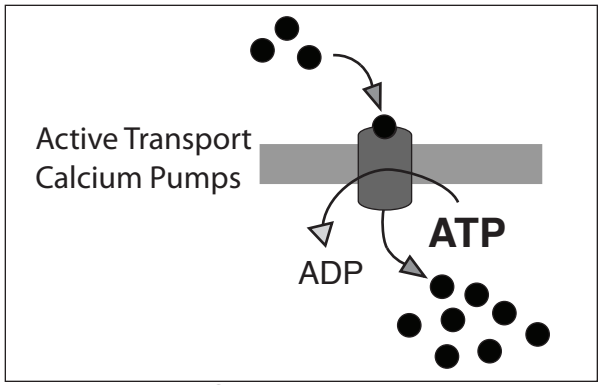
By Noel Ways

Myofiber (Muscle Cell)



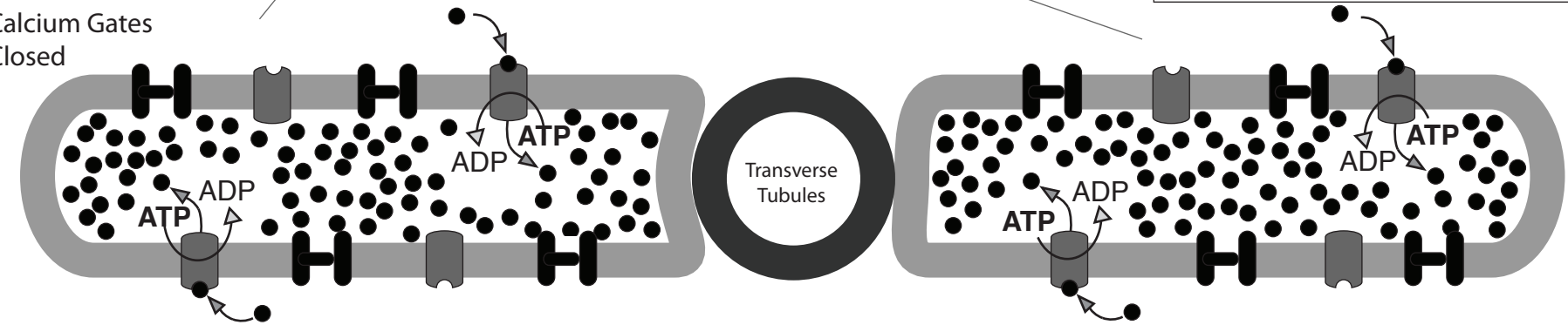


Sarcoplasmic Reticulum



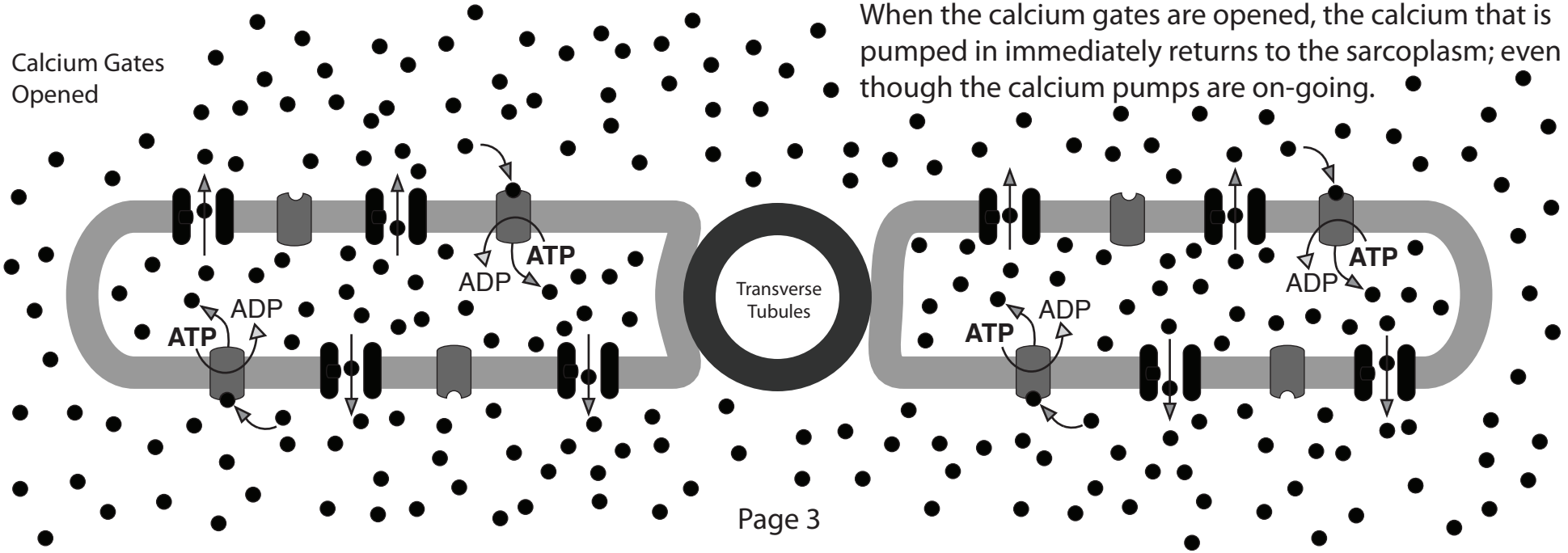
The Sarcoplasmic Reticulum has active transport calcium pumps and calcium gates. When the calcium gates are closed, calcium is sequestered within the sacoplasmic reticulum and it's terminal cisterns.

Calcium Gates
Closed

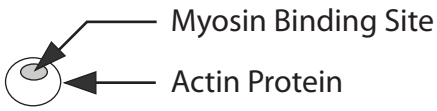


Calcium Gates
Opened

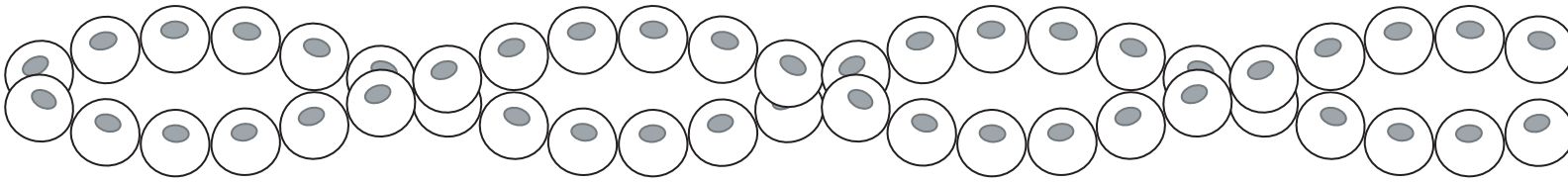
When the calcium gates are opened, the calcium that is pumped in immediately returns to the sarcoplasm; even though the calcium pumps are on-going.



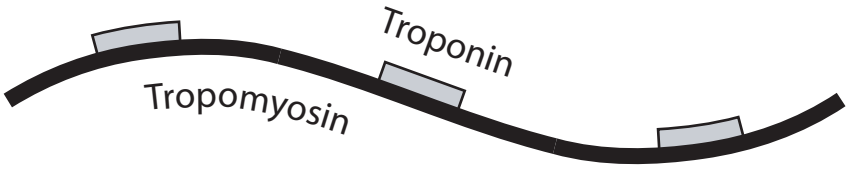
The thin myofilaments are made of the protein actin.
Each actin protein has a myosin binding site.



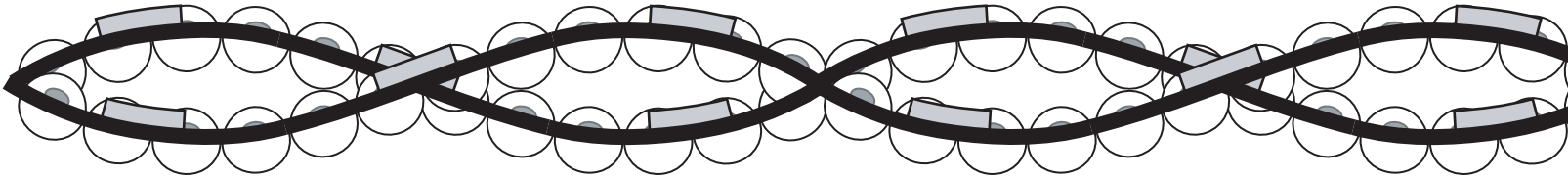
Actin proteins are arrainged in a double helix.



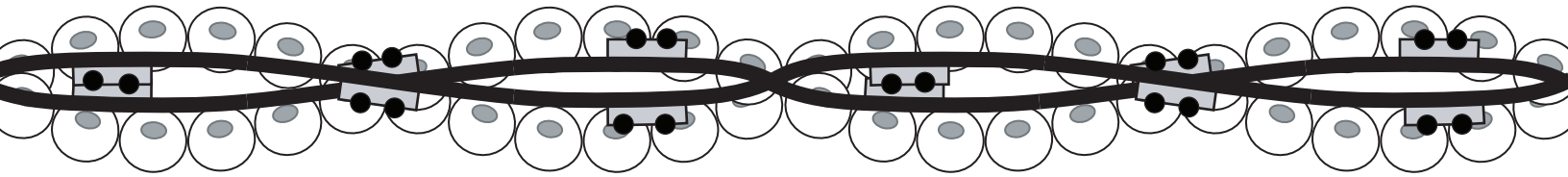
Around the actin double helix is another protein complex called the tropomyosin-tropoin complex.



The tropomyosin-troponin complex has two configurations depending upon weather calcium (●) is bonded to the troponin or not. When calcium is absent the tropomyosin-troponin complex covers the myosin binding sites of the actin.

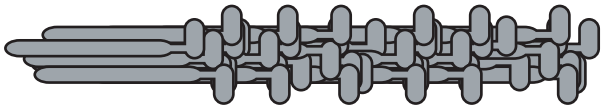


When calcium is present, calcium binds to the troponin causing the tropomyosin-troponin complex to take on a new configuration, whereby the myosin binding sites of the actin are exposed.



A muscle contraction is depended upon the exposure of the myosin binding sites. When the myosin binding sites are hidden by the tropomyosin-troponin complex, a contraction cannot take place. When the myosin binding sites are exposed, a contraction can take place.

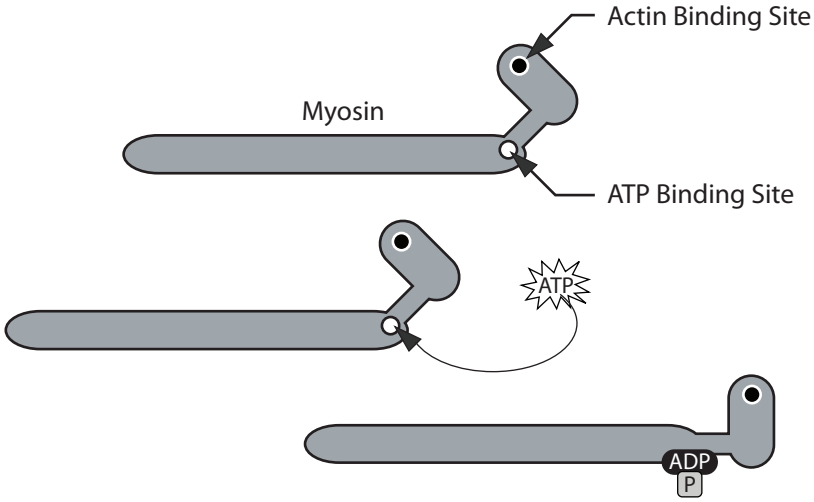
The thick myofilament is made of a protein called myosin ( ). Many myosin myofilaments form a fibril (protein bundle), making the myofilament thick. The fibril is appropriately called a "myofibril".



Each myosin protein has two binding sites:

- Actin Binding Site
- ATP Binding Site

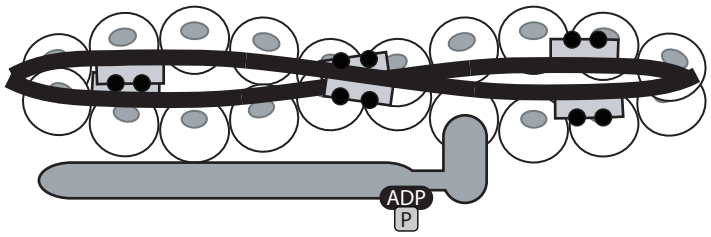
When ATP ( ) binds to the ATP binding site, it splits to ADP and P, thereby releasing energy. The released energy "cocks" the myosin head, and this stored energy is now available for a contraction. Notice the ADP remains attached to the myosin, and will remain so until the myosin head "swivels" during a contraction.



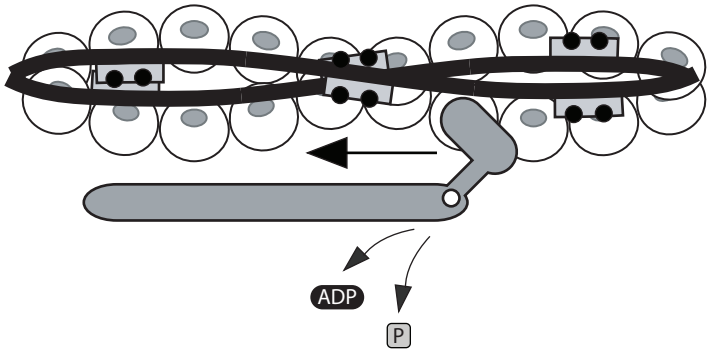
The potential energy stored in the cocked myosin head can be released only if an appropriate trigger is available. The trigger is an exposed myosin binding site on actin.

THE PROCESS:

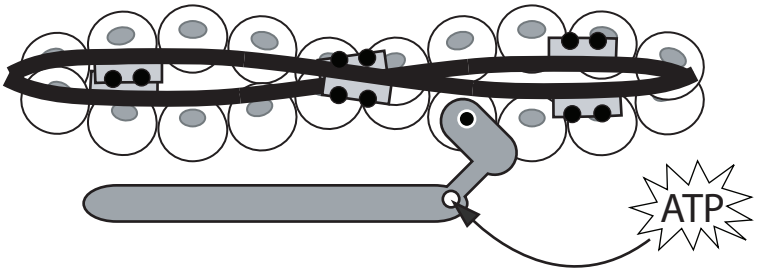
1. Calcium released from the sarcoplasmic reticulum binds to Troponin, and the Tropomyosin-Troponin Complex shifts exposing the myosin binding sites.



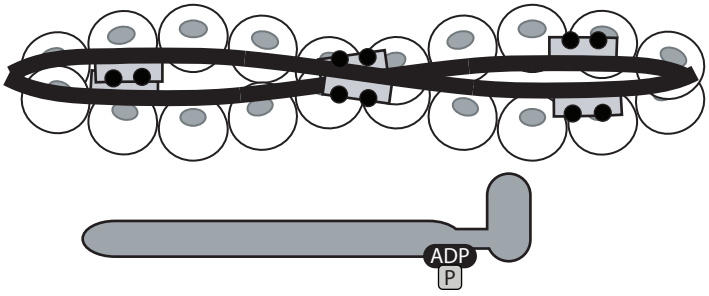
2. The stored energy in the myosin head is released causing the cross-bridge to "swivel". During this process, ADP is released. ATP binding site is again available.



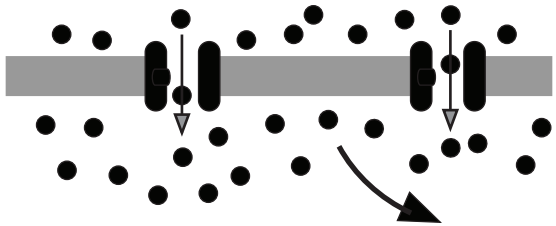
3. ATP binds to the ATP binding site and splits. Energy released both "re-cocks" the cross bridge and causes the myosin to be released from the actin.



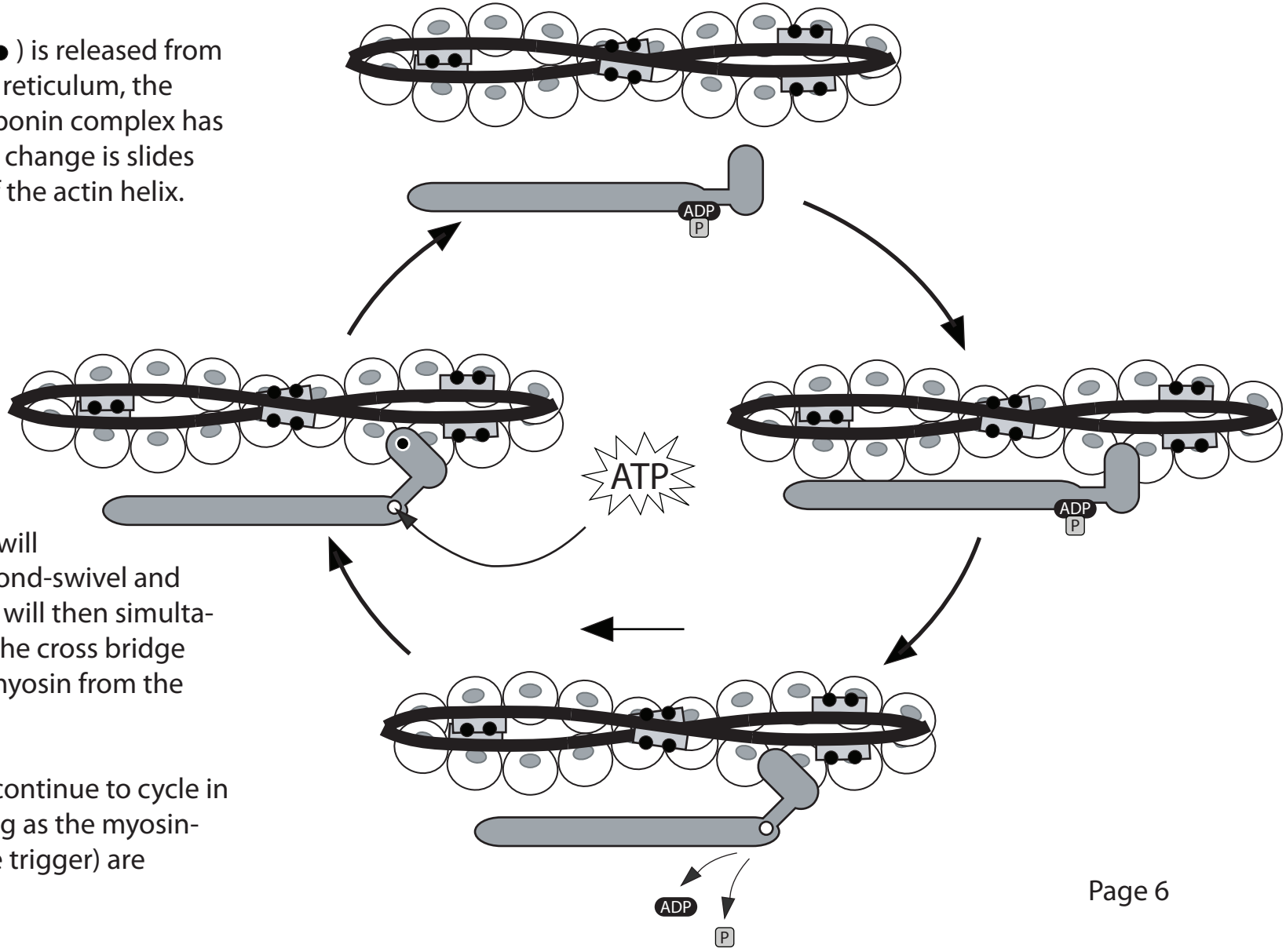
4. Myosin is cocked and can again bind to the actin.



"The Dance"



When calcium (●) is released from the sarcoplasmic reticulum, the tropomyosin-troponin complex has a configurational change is slides into the gutter of the actin helix.

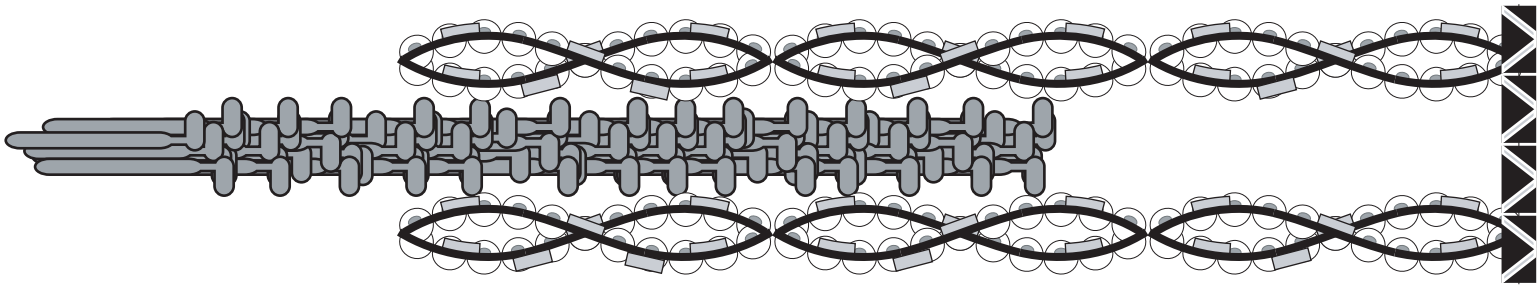


Now the myosin will spontaneously bond-swivel and release ADP. ATP will then simultaneously re-cock the cross bridge and release the myosin from the actin.

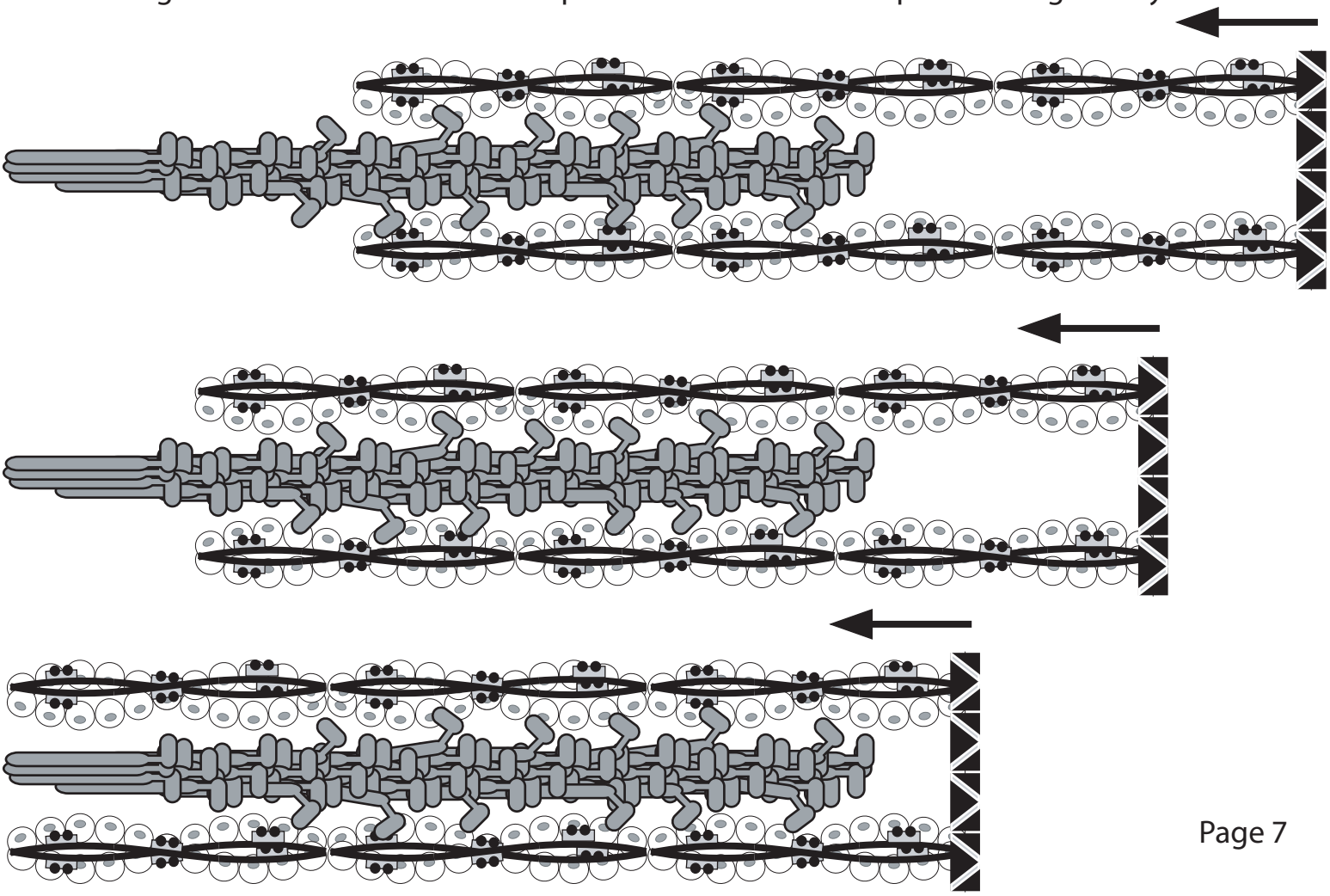
The process will continue to cycle in this manor as long as the myosin-binding sites (the trigger) are exposed.

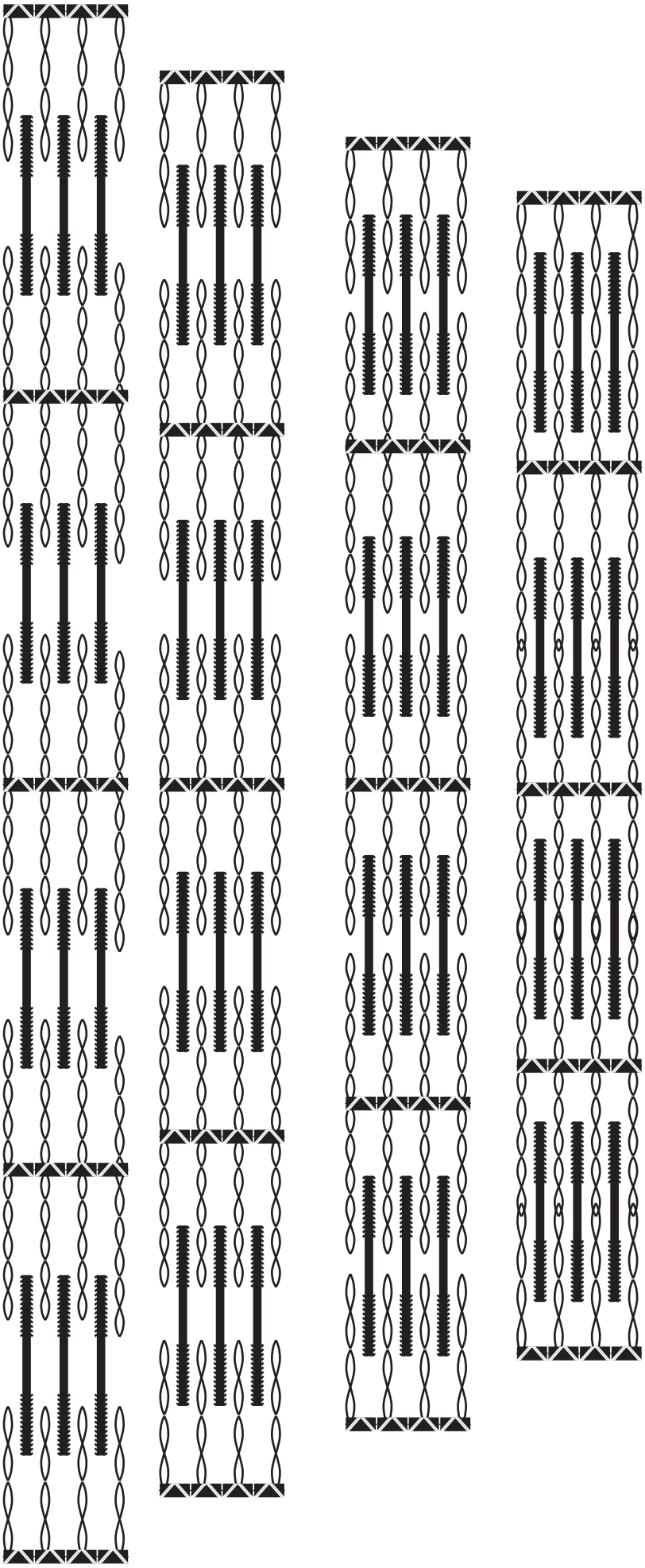
The trigger that releases the energy stored in the myosin head is the myosin binding site on the actin.

When calcium is absent, the tropomyosin-troponin complex covers the trigger - the myosin binding site on the actin. This blockage prevents the myosin and actin from engaging, and therefore the stored energy in the cocked cross bridge is not released.



However when calcium is released from the sarcoplasmic reticulum, calcium diffuses into the sarcoplasm, binds to the troponin and the trypomyosin-troponin complex shift, sliding in the "gutter" of the helix, thereby exposing the myosin bind sites. The mysoin now spontaneously binds - swivels - release ADP - ATP simultaneously "re-cocks" and releases the myosin from the actin. This process will continue as long as long as both calcium and ATP are present. And the actin is pulled along the myosin.



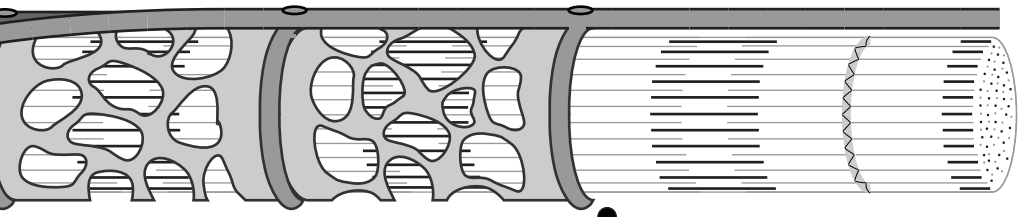


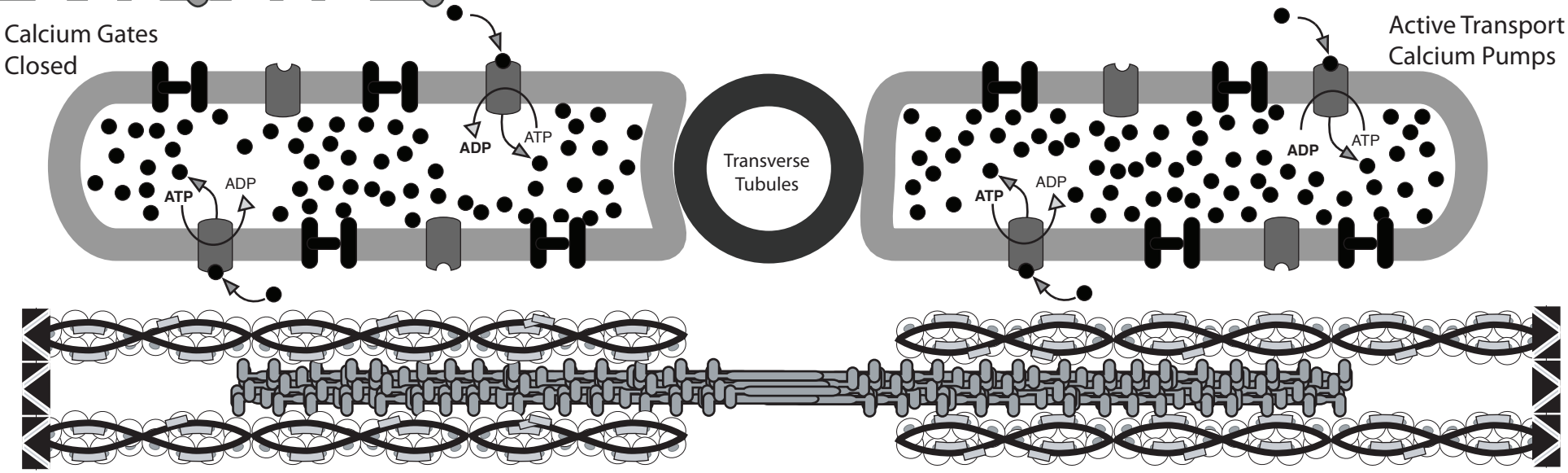
As all the sarcomeres of
all the myofibrils of a muscle
cell contract, then the entire
muscle cell shortens.

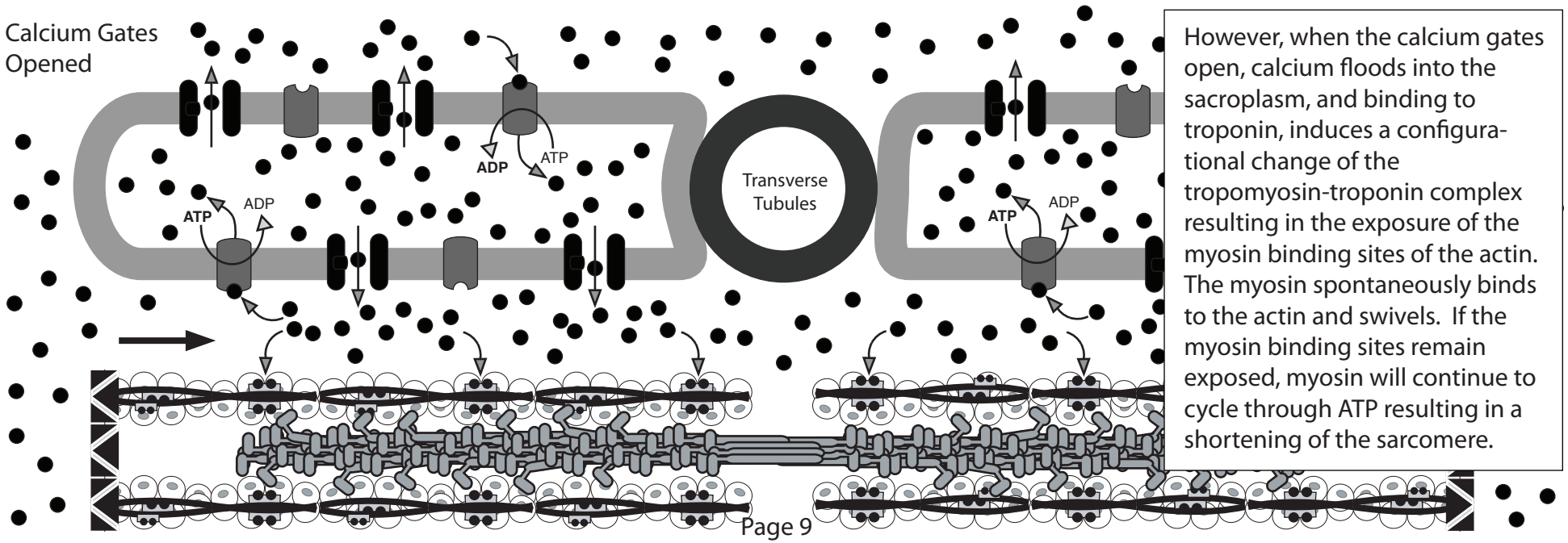
As this process occurs in all
the cells of a muscle,
the muscle contracts!

Calcium and Muscle Contraction

When calcium gates of the sarcoplasmic reticulum closed, calcium is pumped into the membranous folds of the sarcoplasmic reticulum and terminal cisterns. The tropomyosin-troponin covers the myosin binding sites, and myosin can not engage.



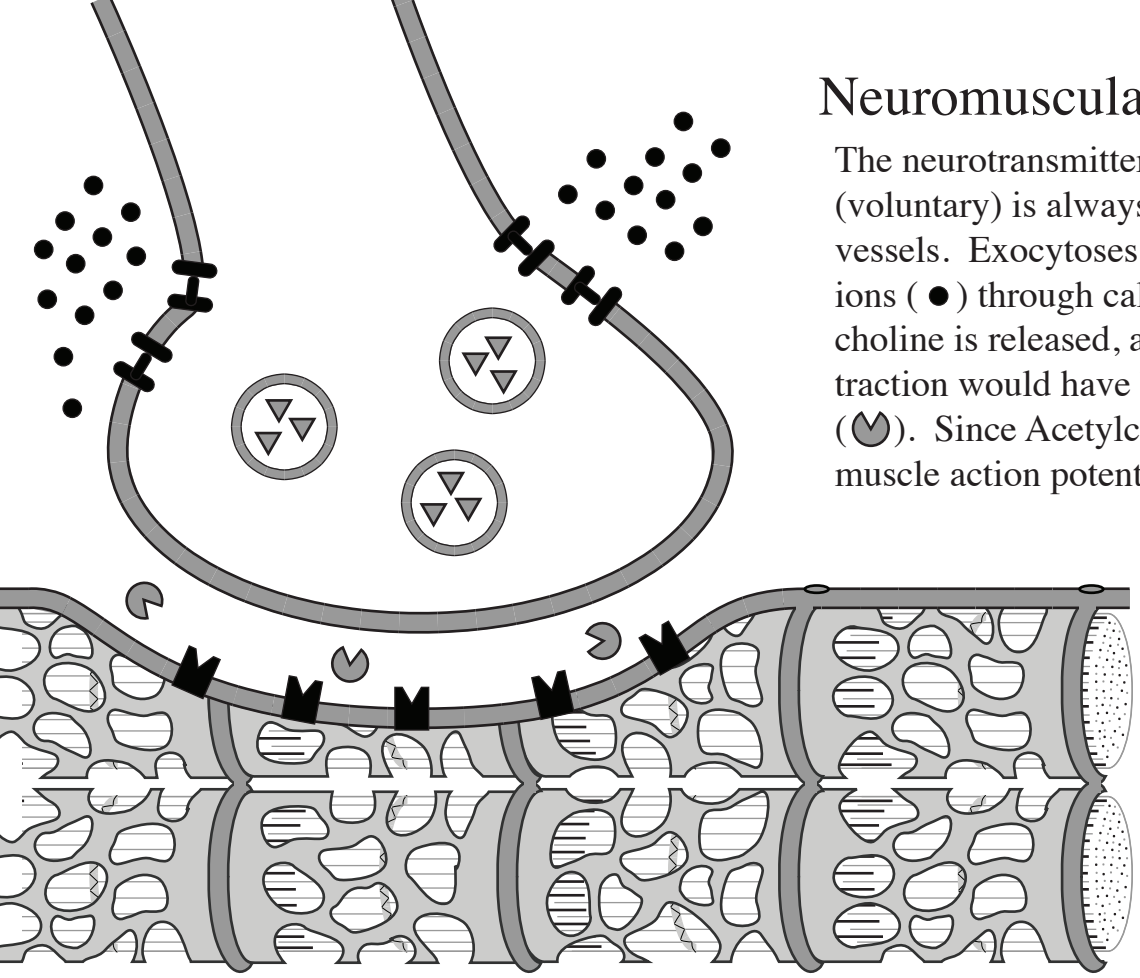


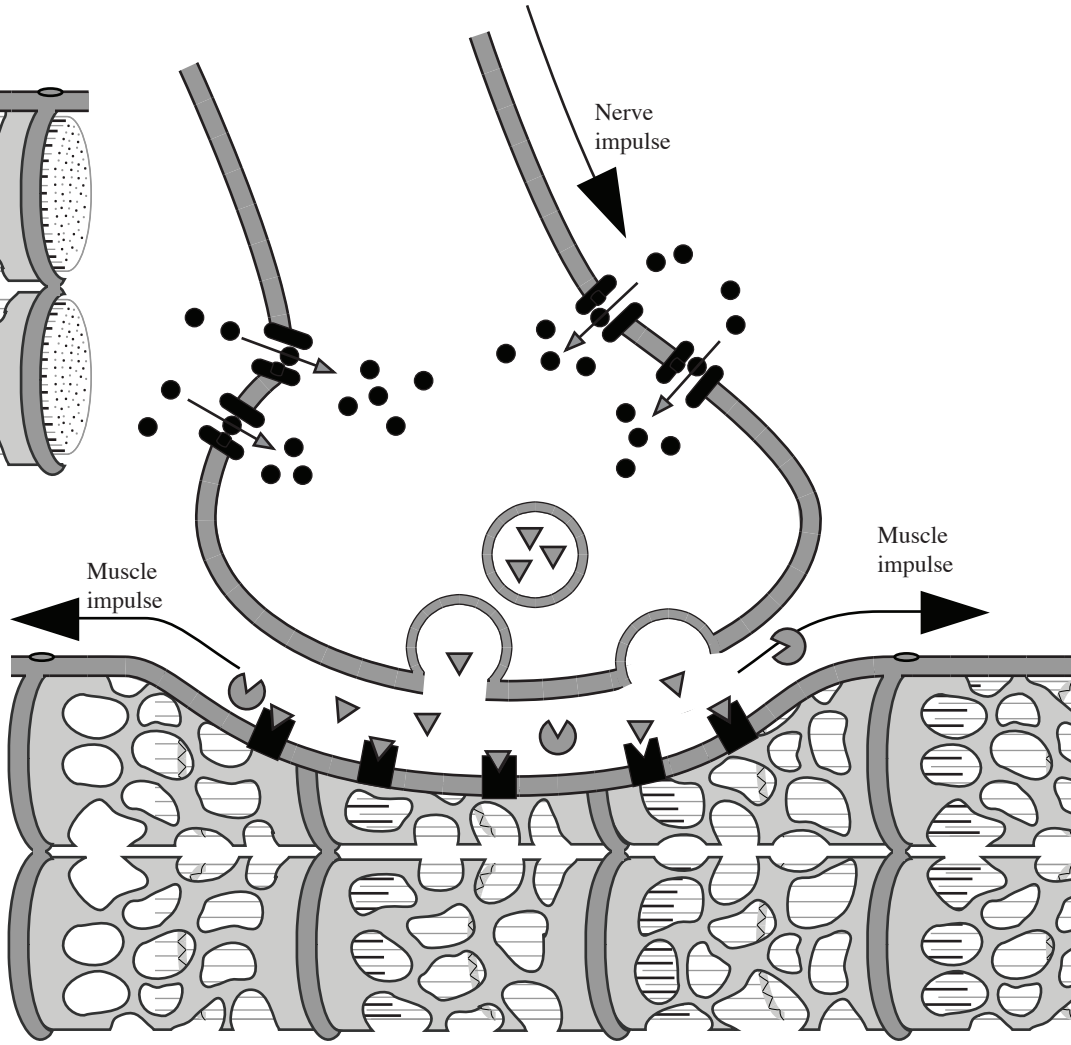


However, when the calcium gates open, calcium floods into the sacroplasm, and binding to troponin, induces a configurational change of the tropomyosin-troponin complex resulting in the exposure of the myosin binding sites of the actin. The myosin spontaneously binds to the actin and swivels. If the myosin binding sites remain exposed, myosin will continue to cycle through ATP resulting in a shortening of the sarcomere.

Neuromuscular Junction

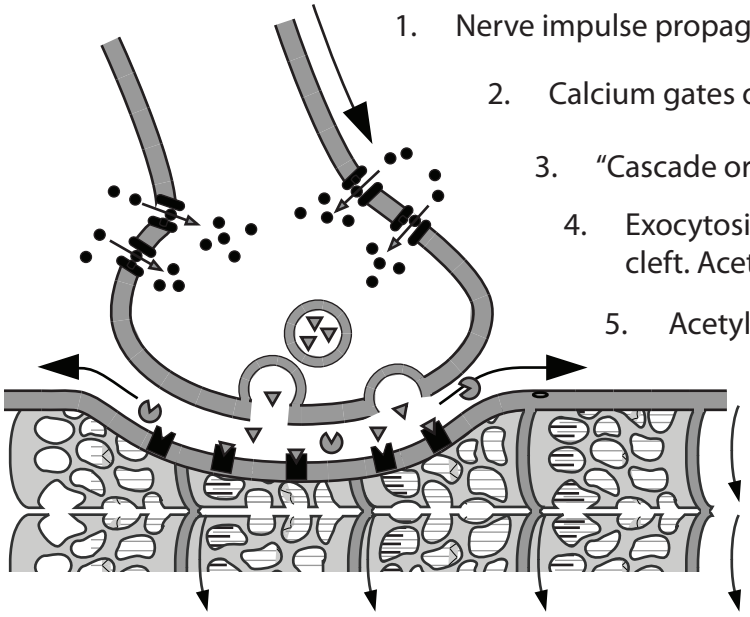
The neurotransmitter at a neuromuscular junction involving skeletal muscle (voluntary) is always Acetylcholine (▽) and is contained within synaptic vessels. Exocytoses of Acetylcholine is triggered by an influx of calcium ions (●) through calcium gates (H). If the gates are closed, no acetylcholine is released, and any neurotransmitter present from a previous contraction would have been destroyed by the enzyme acetylcholinesterase ( ). Since Acetylcholine is not bound to the acetylcholine receptors, a muscle action potential (or impulse) can not be generated.



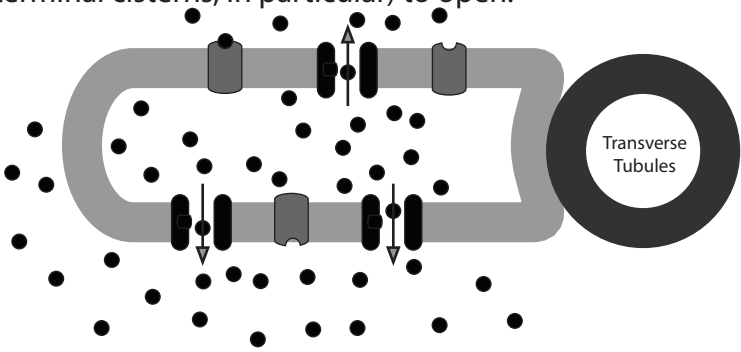


When a nerve impulse comes down a motor neuron and arrives at a synaptic end bulb, calcium gates open resulting in a "cascade of reactions" culminating in the exocytosis of Acetylcholine from the synaptic vesicles into the synaptic cleft. The acetylcholine diffuses across the synaptic cleft and binds to acetylcholine receptors. This initiates a muscle action potential (impulse) across the sarcolemma, which will then dip into the transverse tubules.

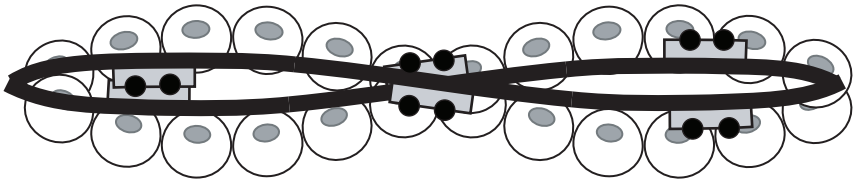
Synthesis "GO"



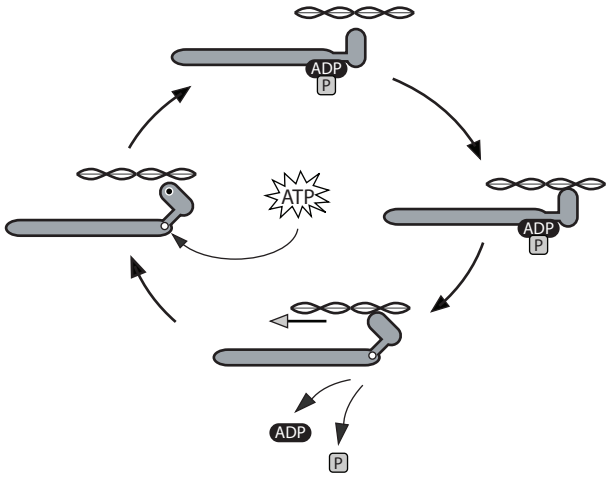
1. Nerve impulse propagation over motor neuron
2. Calcium gates open, clacium enters synaptic end bulb
3. "Cascade or reactions"
4. Exocytosis of Acetylcholine from synaptic vesicles into synaptic cleft. Acetylcholine diffuses across the synaptic cleft.
5. Acetylcholine binds to acetylcholine receptors - generates muscle action potential (impulse) which propagates over sarcolemma.
6. Muscle action potential dips into transverse tubules and causes calcium gates on sarcoplasmic reticulum (terminal cisterns, in particular) to open.



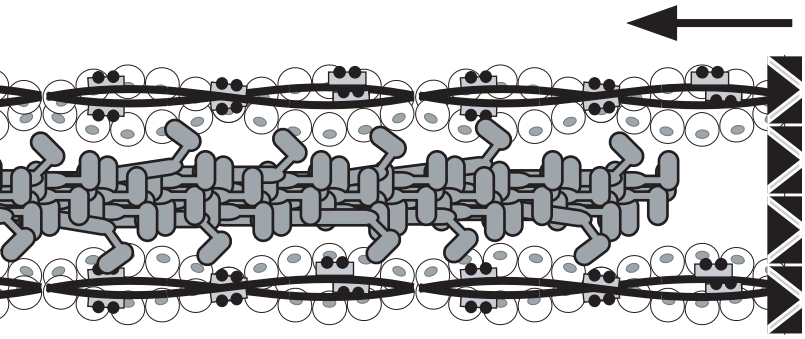
7. Calcium floods into sacroplasm and binds to troponin. Tropomyosin-troponin complex has configurational change, and exposes myosin binding sites on actin.



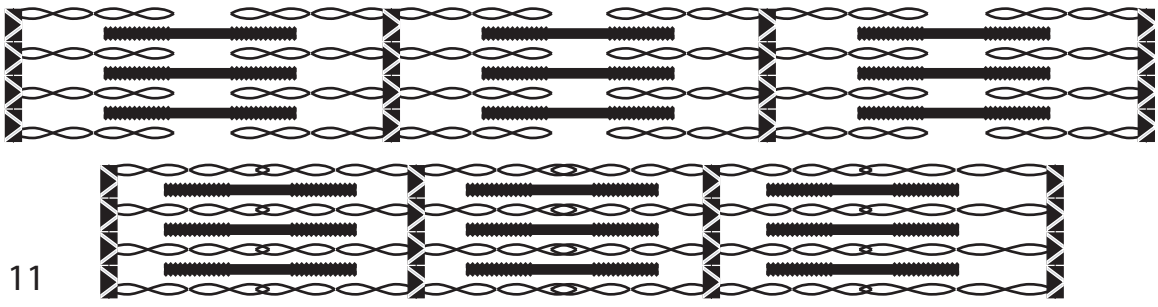
8. The "Dance". Myosin spontaneously binds, swivels, and releases ADP and P. ATP now binds to the vacant ATP binding site. Energy released causes the myosin to "re-cock" and release from the actin. The process repeats.



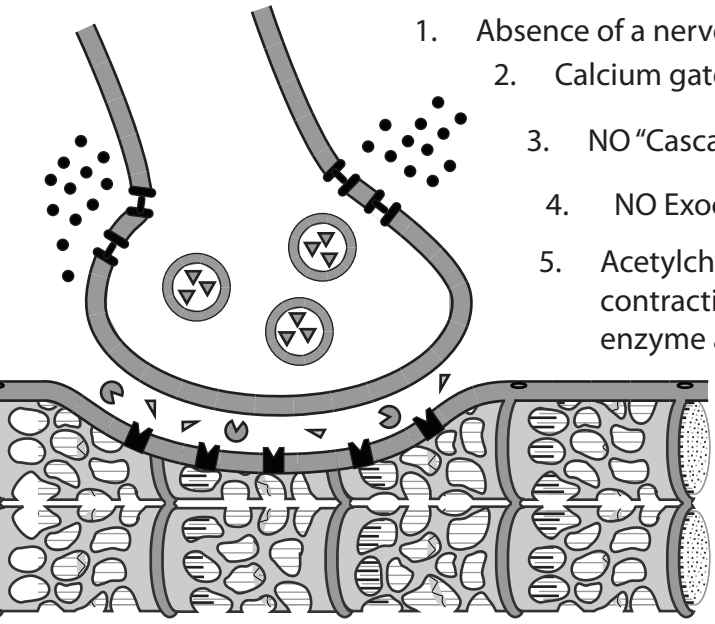
9. As this process repeats itself, and the myosin cycles through ATP, the Z-lines move closer together as actin is pulled alon the myosin.



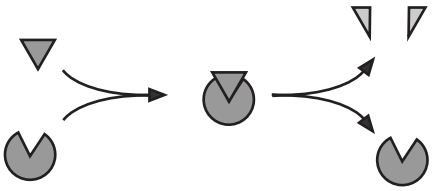
10. As all the sarcomeres do this, the entire myofiber (cell) shortens. As the many myofibers of a muscle do this the muscle contracts.



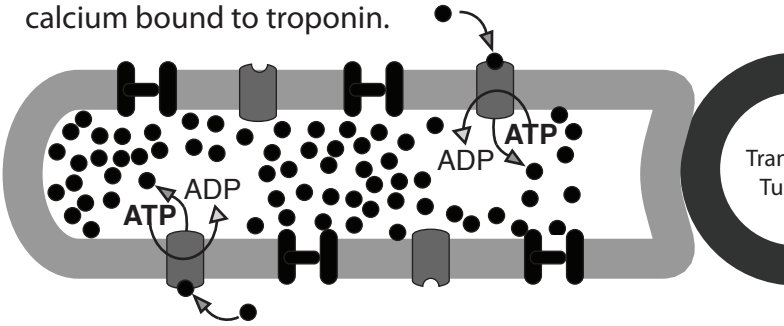
Synthesis "STOP"



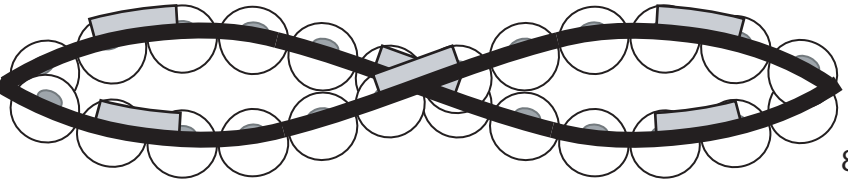
1. Absence of a nerve impulse
2. Calcium gates close
3. NO "Cascade or reactions"
4. NO Exocytosis of Acetylcholine from synaptic vessicles into synaptic cleft
5. Acetylcholine (▽) from previous contraction is destroyed by enzyme acetylcholinesterase (ᔕ) .



6. Muscle action potential is NOT initiated, and calcium gates of the sarcoplasmic reticulum close. Active transport calcium pumps pump calcium back into sarcoplasmic reticulum including calcium bound to troponin.

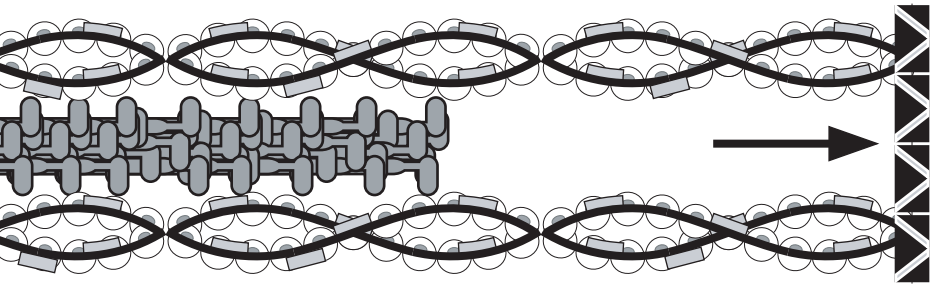


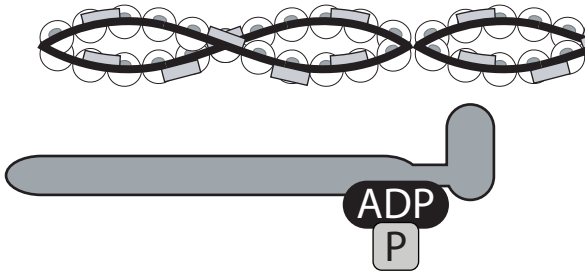
7. Tropomyosin-troponin complex returns to original configuration, covering myosin binding sites of the actin.



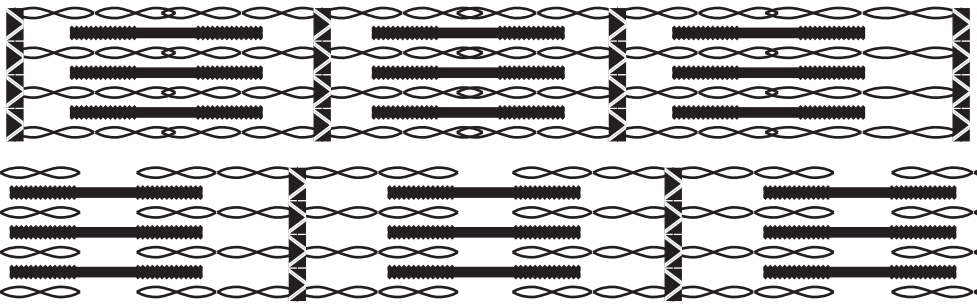
8. Even through the myosin is "cocked, ready to go" (as evidenced by the presence of ADP, the myosin and actin will not engage as the trigger (myosin binding sites) are covered.

9. The muscle now relaxes and actin can move back to original position.





10. As all the sarcomeres disengage, the muscle returns to a relaxed state (until you say "GO" again).



BIBLIOGRAPHY / CREDITS

1. Fundamentals of Anatomy and Physiology, 8th edition; by Martini / Nath

2. Anatomy and Physiology, 6th edition; by Tortora