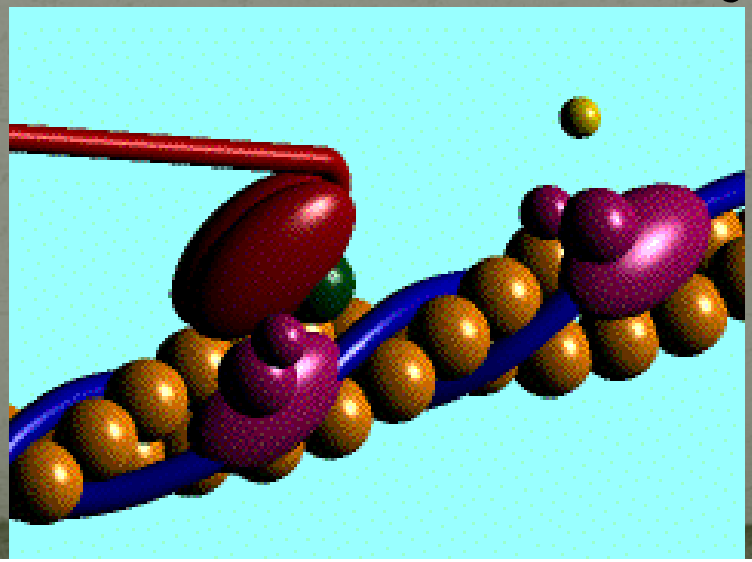
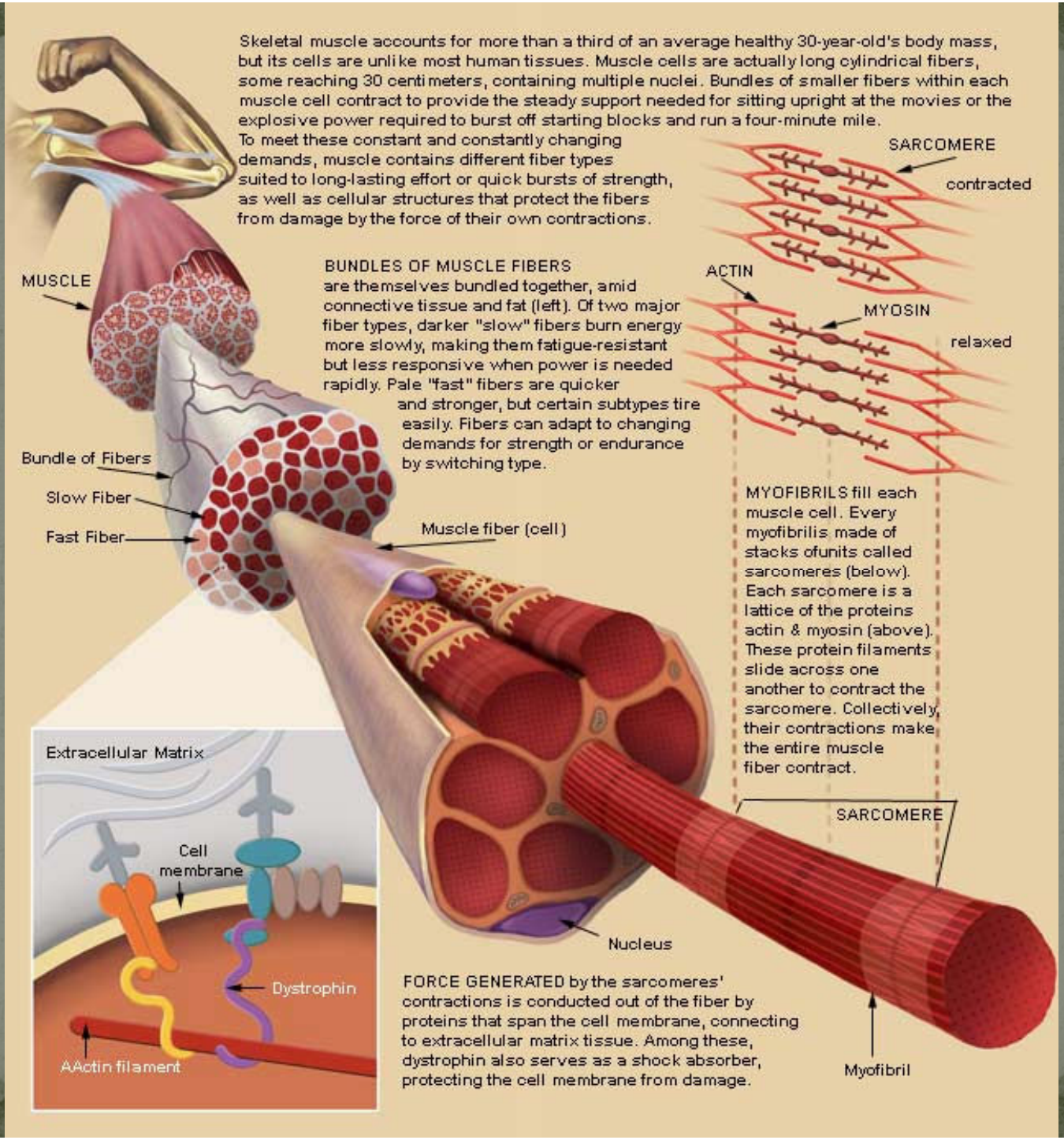
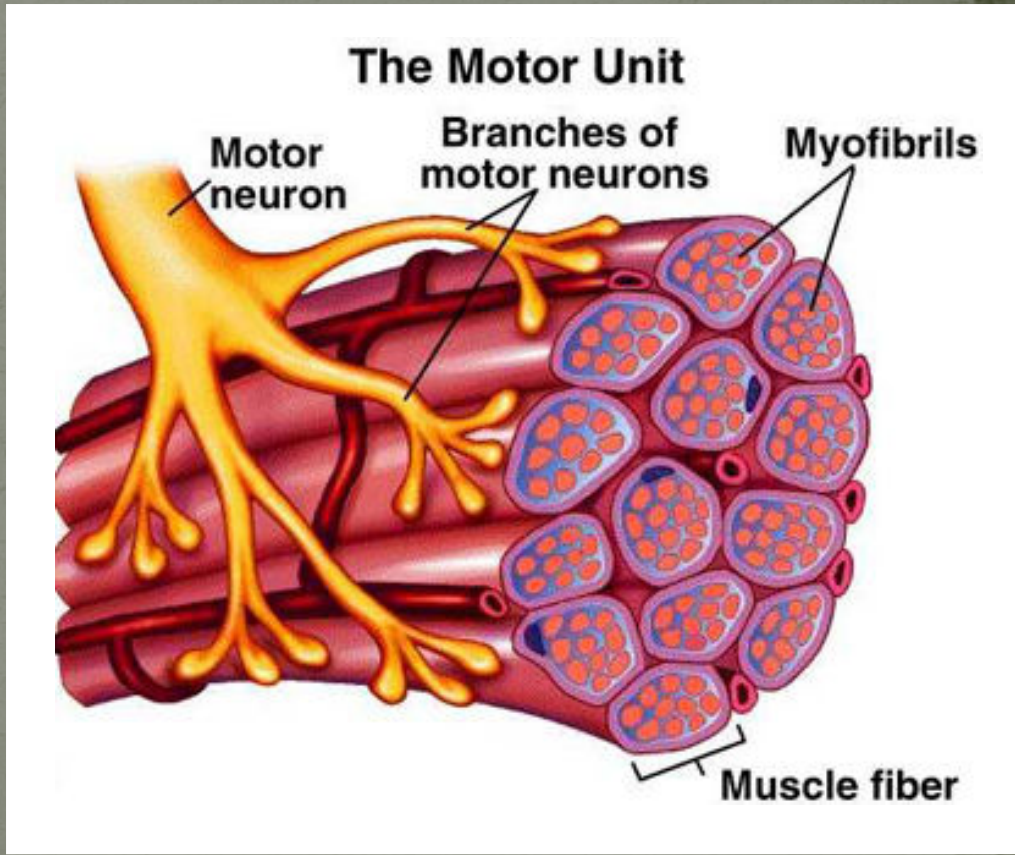
Muscle Contraction



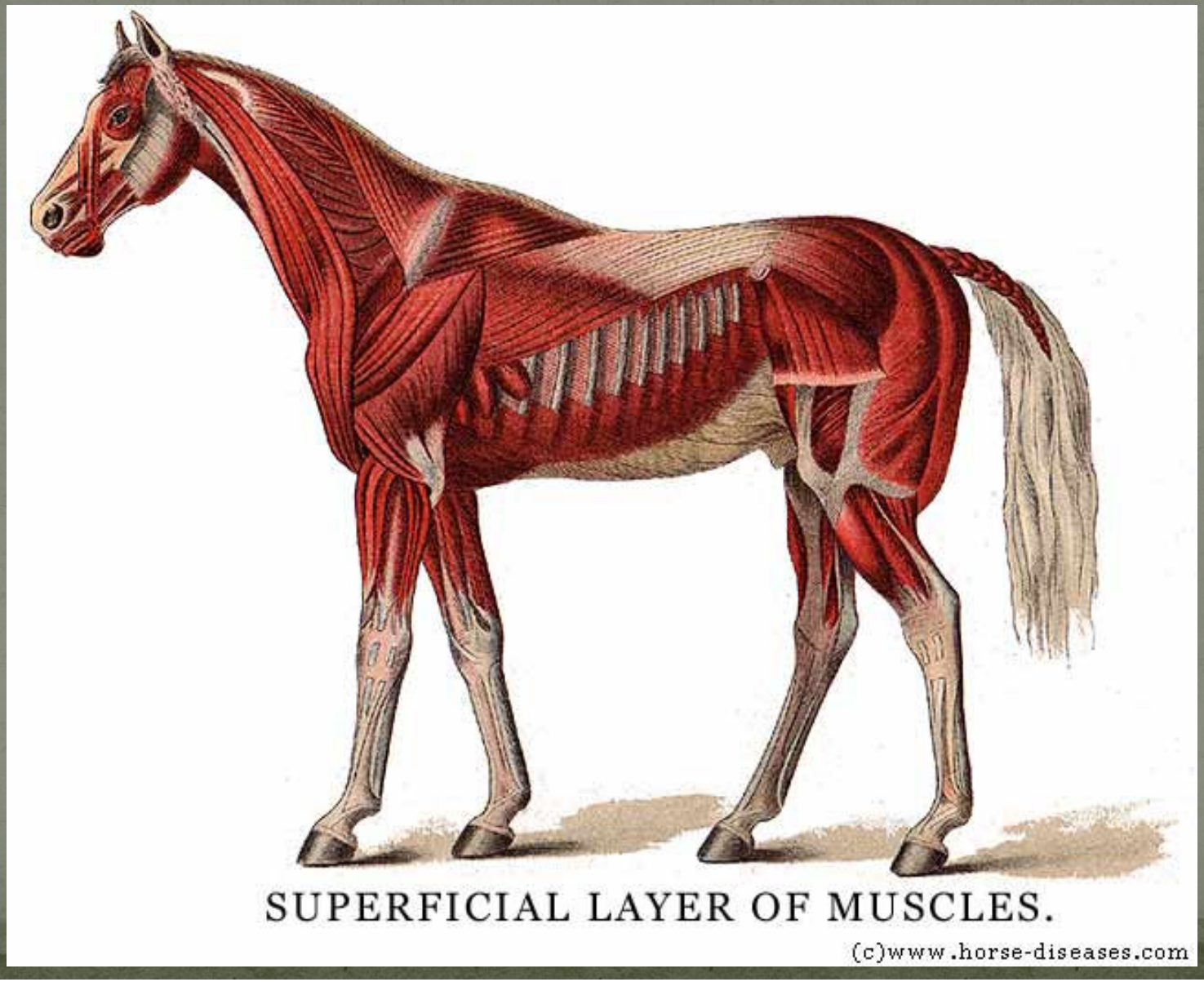

Skeletal muscle accounts for more than a third of an average healthy 30-year-old's body mass, but its cells are unlike most human tissues. Muscle cells are actually long cylindrical fibers, some reaching 30 centimeters, containing multiple nuclei. Bundles of smaller fibers within each muscle cell contract to provide the steady support needed for sitting upright at the movies or the explosive power required to burst off starting blocks and run a four-minute mile.
To meet these constant and constantly changing demands, muscle contains different fiber types suited to long-lasting effort or quick bursts of strength, as well as cellular structures that protect the fibers from damage by the force of their own contractions.
SARCOMERE
contracted
ACTIN
MYOSIN
relaxed
MUSCLE
BUNDLES OF MUSCLE FIBERS are themselves bundled together, amid connective tissue and fat (left). Of two major fiber types, darker "slow" fibers burn energy more slowly, making them fatigue-resistant but less responsive when power is needed rapidly. Pale "fast" fibers are quicker and stronger, but certain subtypes tire easily. Fibers can adapt to changing demands for strength or endurance by switching type.
Bundle of Fibers
Slow Fiber
Fast Fiber
Muscle fiber (cell)
MYOFIBRILS fill each muscle cell. Every myofibrilis made of stacks ofunits called sarcomeres (below). Each sarcomere is a lattice of the proteins actin & myosin (above). These protein filaments slide across one another to contract the sarcomere. Collectively, their contractions make the entire muscle fiber contract.
Extracellular Matrix
Cell membrane
Dystrophin
AActin filament
SARCOMERE
Nucleus
FORCE GENERATED by the sarcomeres' contractions is conducted out of the fiber by proteins that span the cell membrane, connecting to extracellular matrix tissue. Among these, dystrophin also serves as a shock absorber, protecting the cell membrane from damage.
Myofibril

Levels of Muscle Structure

- Muscle
- Muscle Bundle
- Muscle Fiber (myofiber)
- Myofibrils
- Myofilaments



Muscle



Muscle Bundle

- Contains 10-20 myofibers
- Encased by perimysium
- Can see with the naked eye

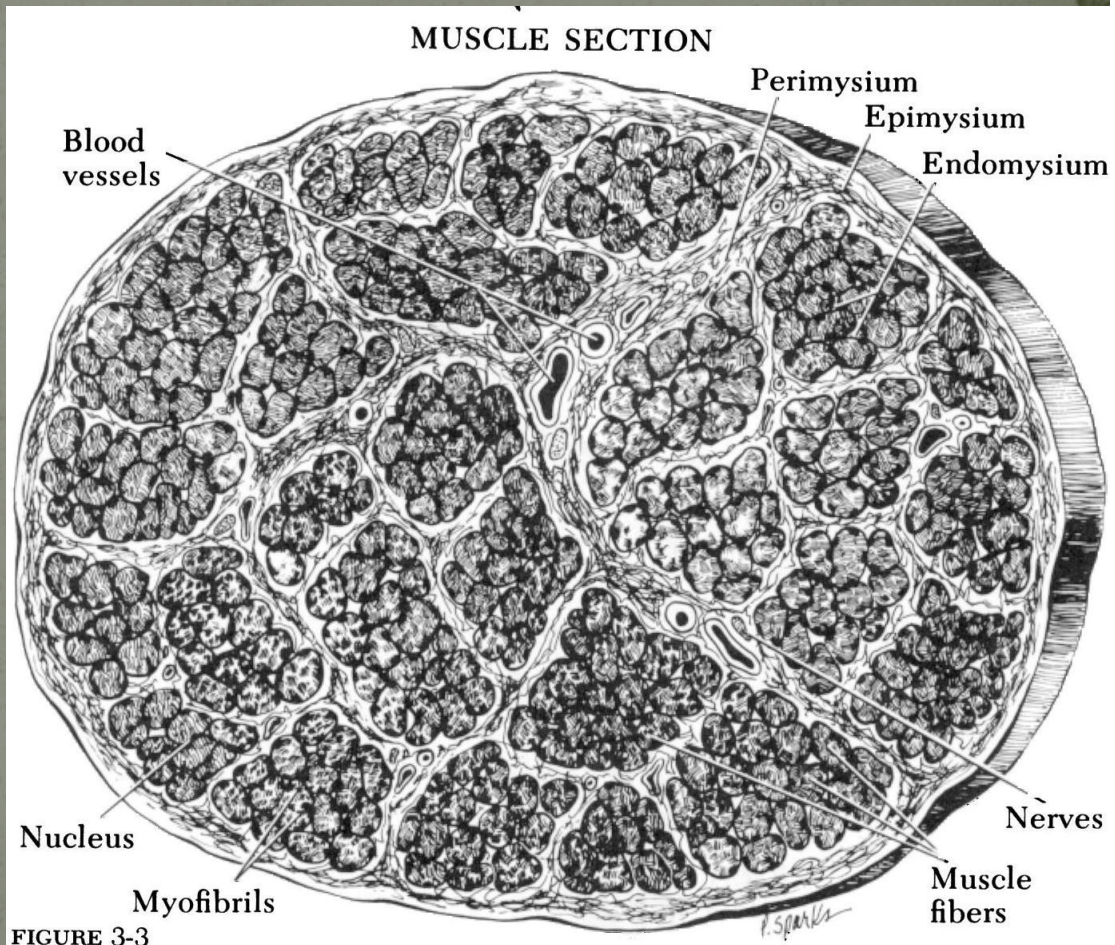


FIGURE 3-3
Drawing of a skeletal muscle in cross section showing muscle fibers, bundle arrangement, pervading connective tissues, nerves, and blood vessels. [Modified from J. E. Crouch, *Functional Human Anatomy*, 2nd ed. 1972. Lea & Febiger, Philadelphia.]

Myofiber (Muscle fiber)

- Individual muscle cell
- Multinucleated
- Encased by endomysium
- Cell wall: sarcolemma

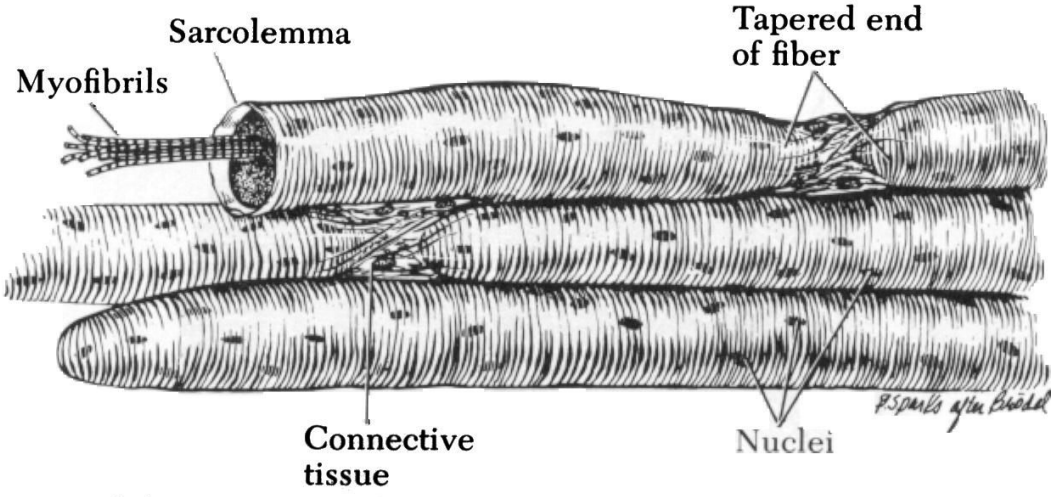


FIGURE 3-4
Drawing of skeletal muscle fibers showing structural features, and their longitudinal orientation. [After M. Brödel, Johns Hopkins Hosp. Bull. 61:295, 1937; © The Johns Hopkins University Press.]

Myofibrils

- Embedded in sarcoplasm
- Mitochondria located between myofibrils

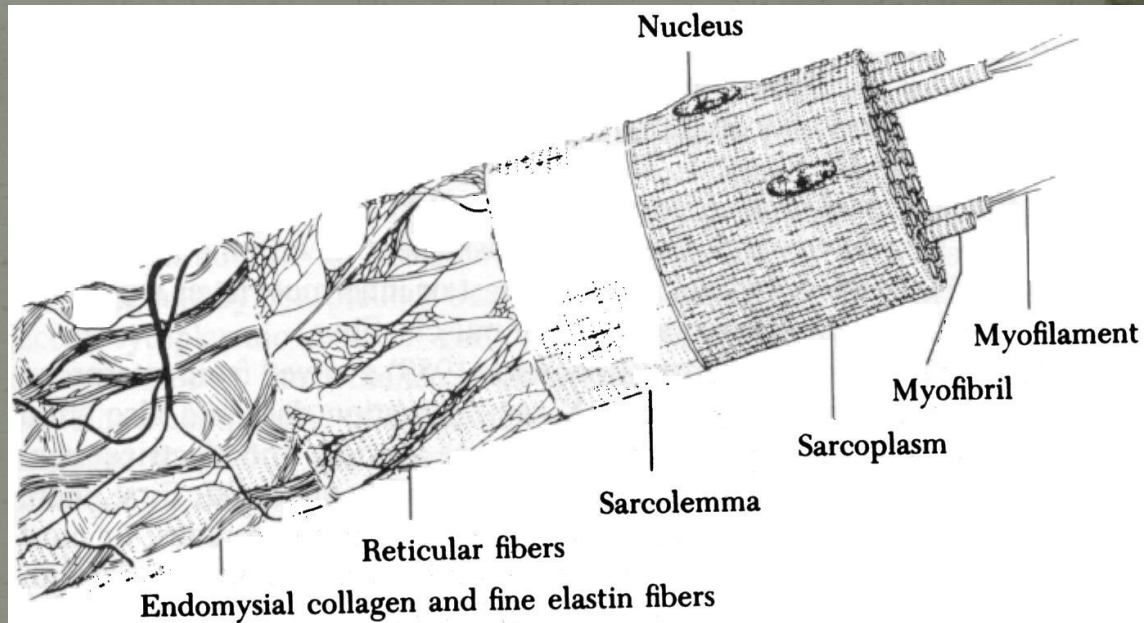
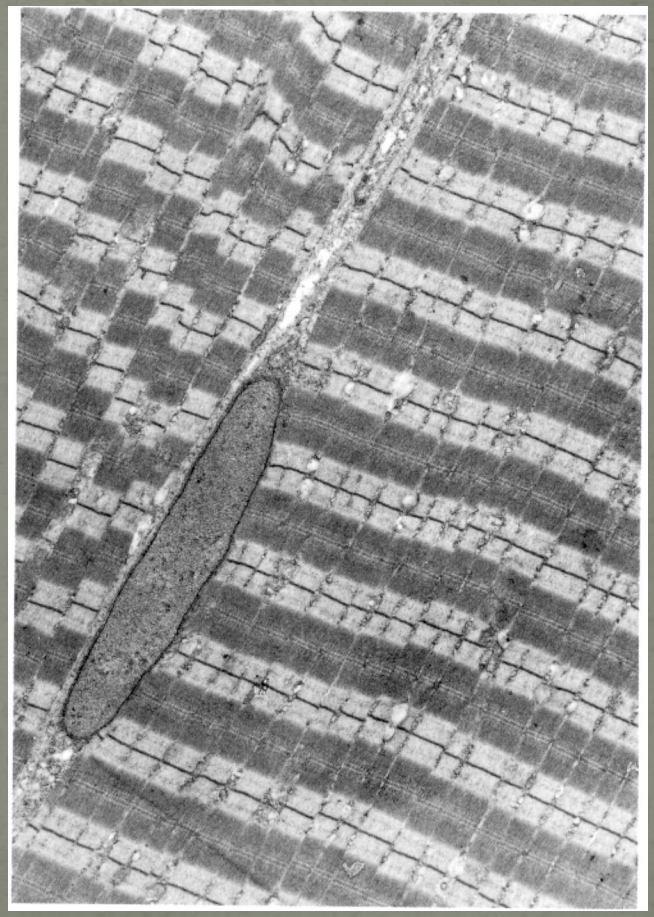
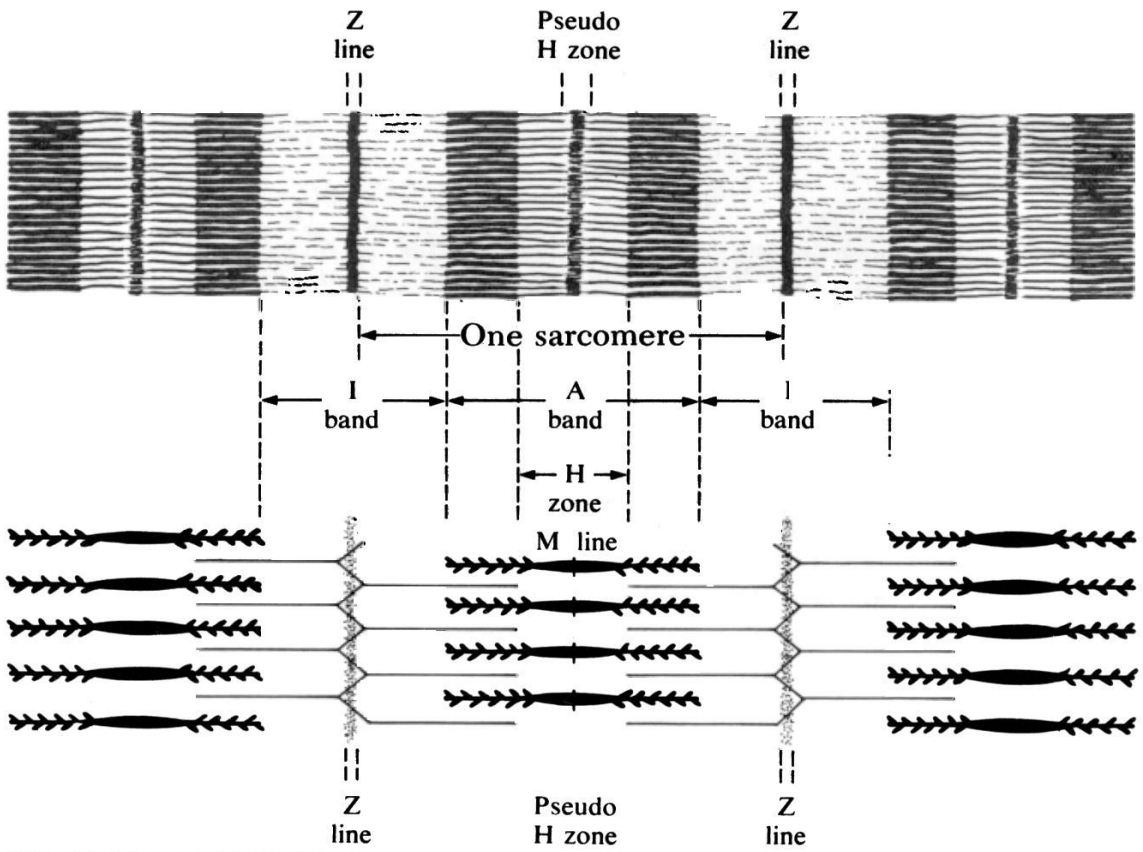


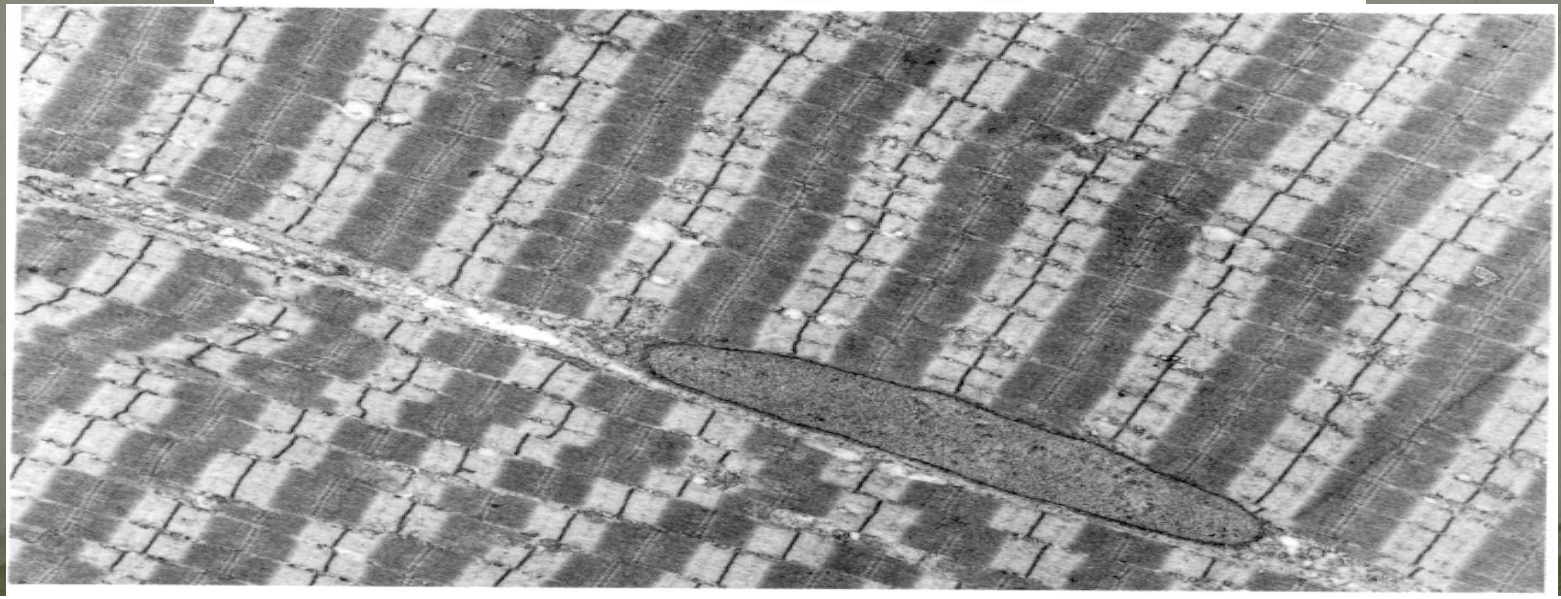
FIG. 2.9. DIAGRAMMATIC SKETCH OF A MUSCLE FIBER

Myofibrils

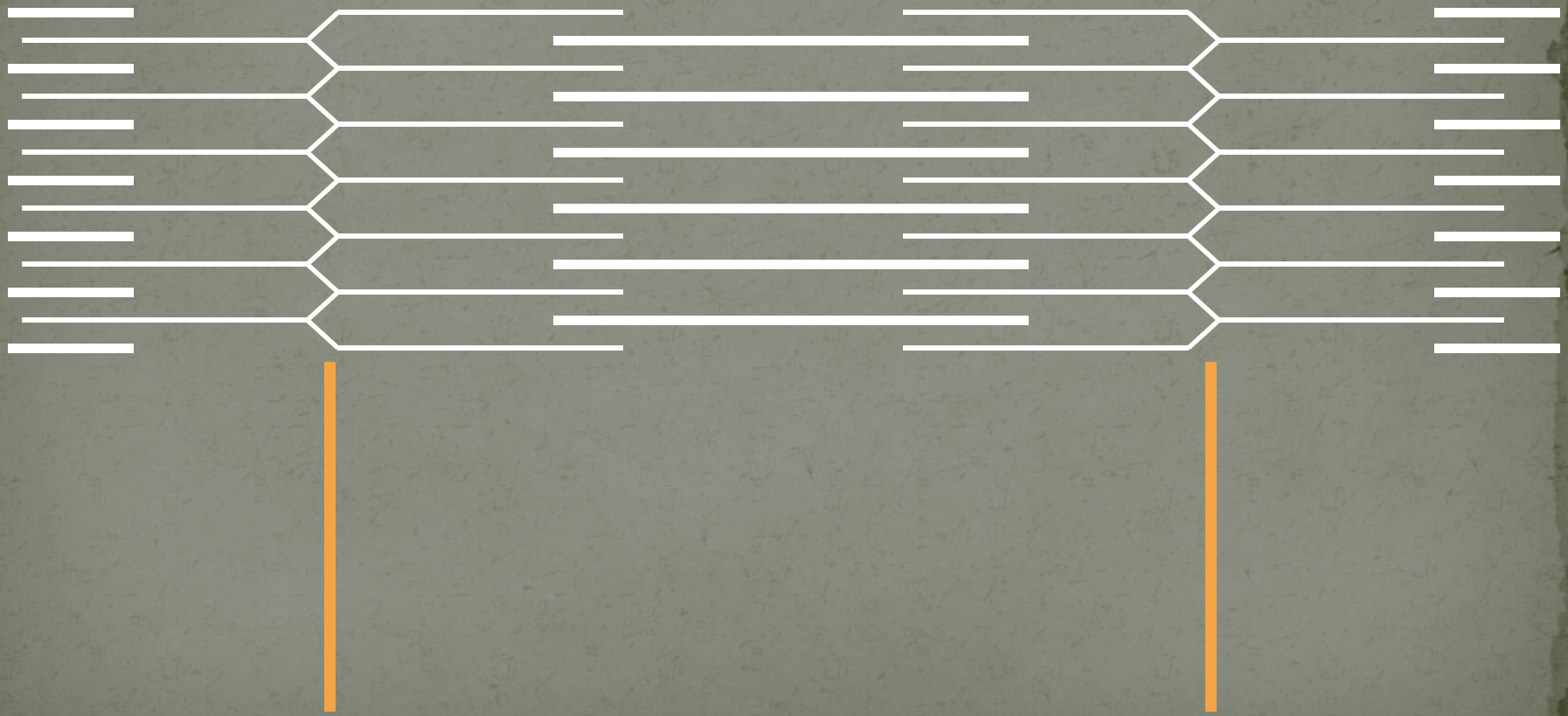
- Comprised of repeating units: sarcomeres
  - A band
  - I band
  - Z disk
  - H zone
  - Pseudo-H zone



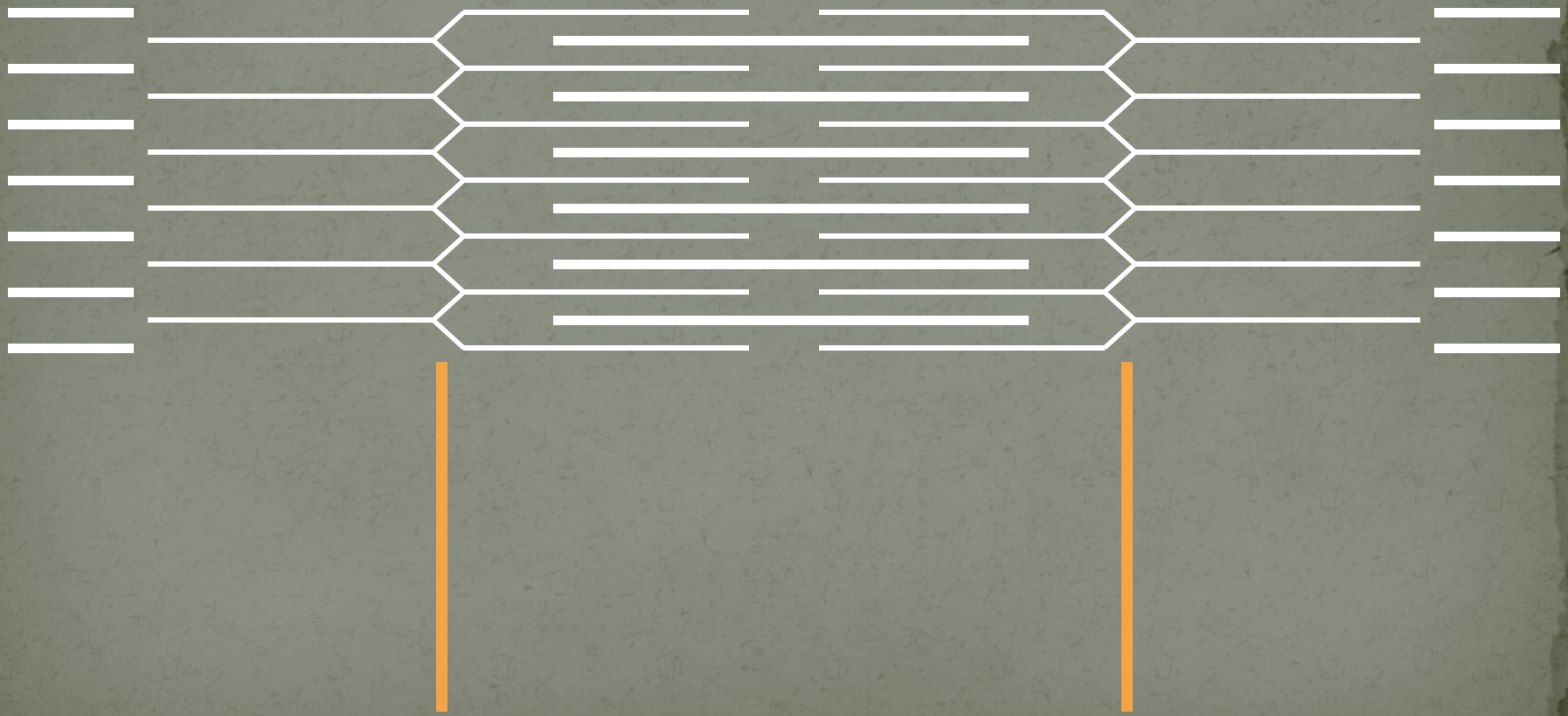

Z line
Pseudo H zone
Z line
One sarcomere
I band
A band
I band
H zone
M line
Z line
Pseudo H zone
Z line



Sarcomere

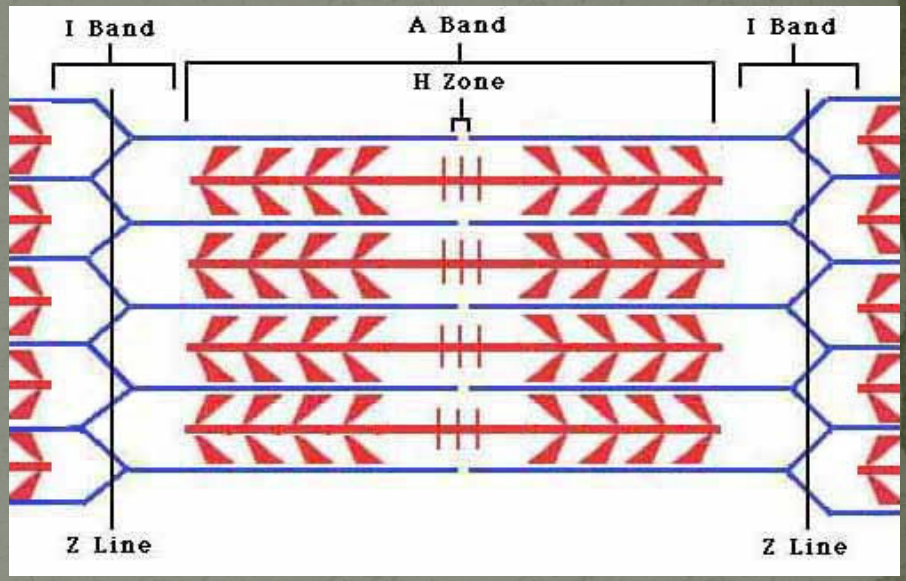


Sarcomere



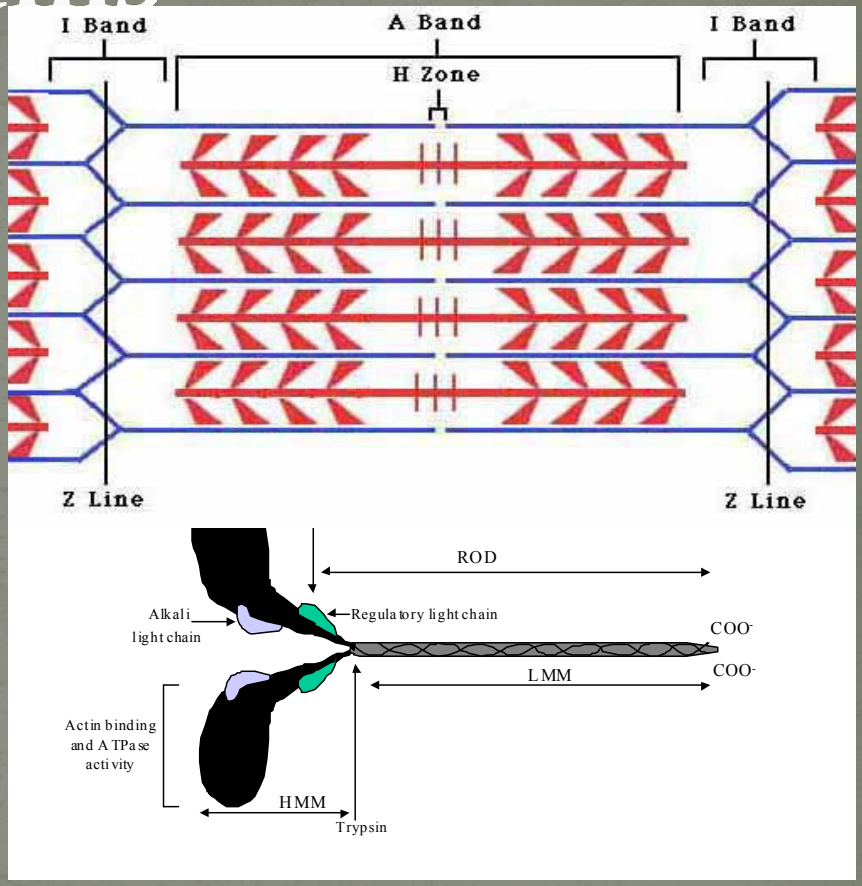
Myofilaments

- Contractile Proteins
  - Myosin
  - Actin
- Regulatory Proteins
  - Tropomyosin
  - Troponin
- Structural Proteins
  - Z – Line Proteins



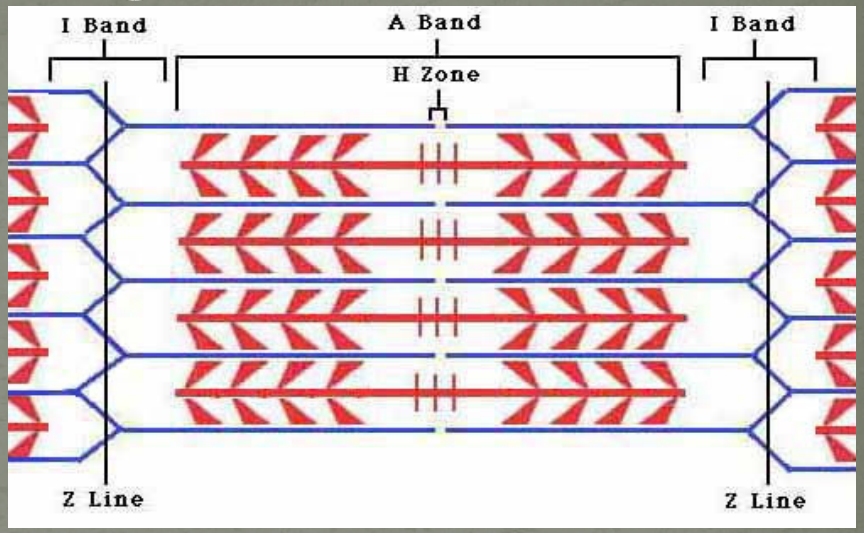
Contractile Proteins

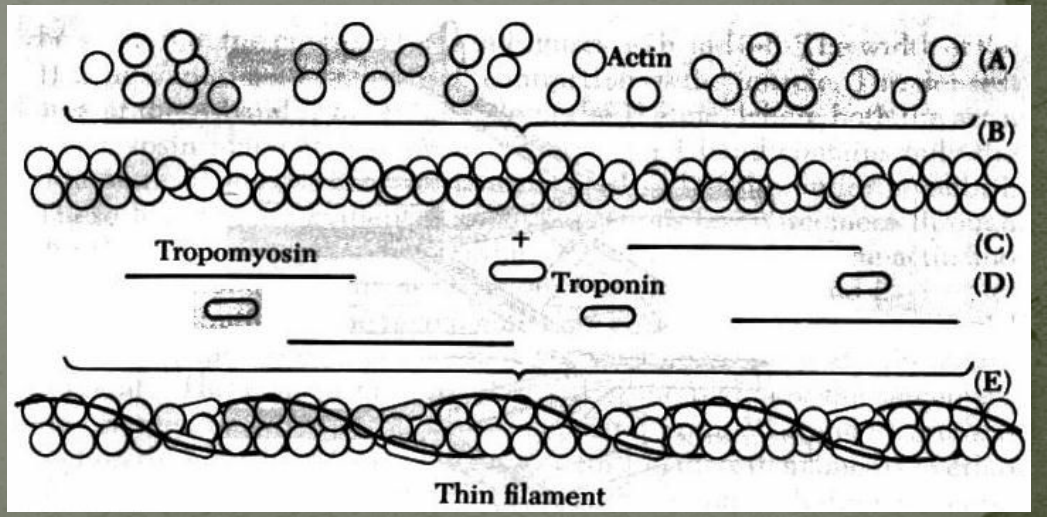
- Myosin
  - 70 – 80% of the total protein
  - Thick filament
  - Burns the ATP for muscle contraction
  - Myosin head moves back and forth to perform a muscle contraction



Contractile Proteins

- Actin
  - 20% of the myofibrillar protein
  - Thin Filament
  - Globular protein (G-protein)
  - Arranged like a twisted pearl necklace (F-protein)
  - Myosin head attaches to the Actin





Regulatory Proteins

- Regulate contraction and the speed of contraction
- Tropomyosin
- Troponin

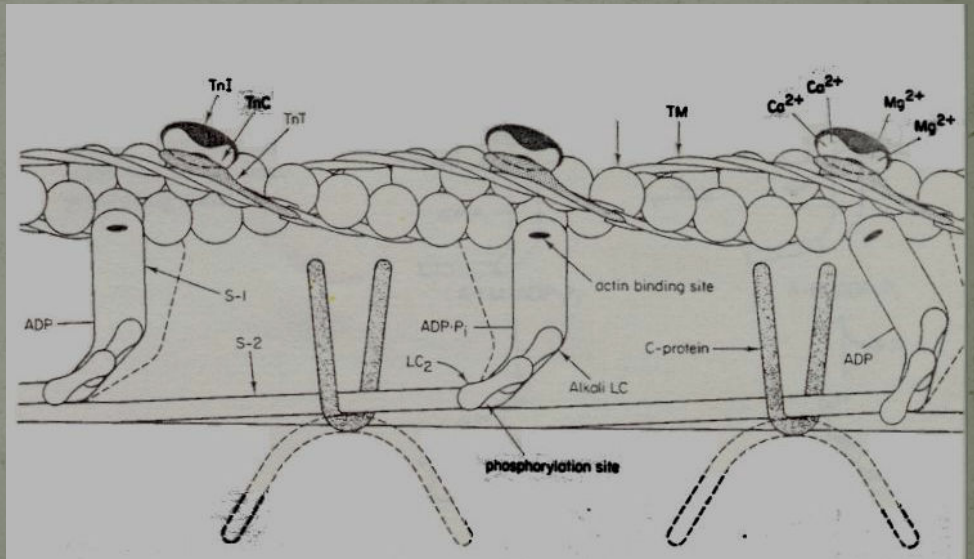
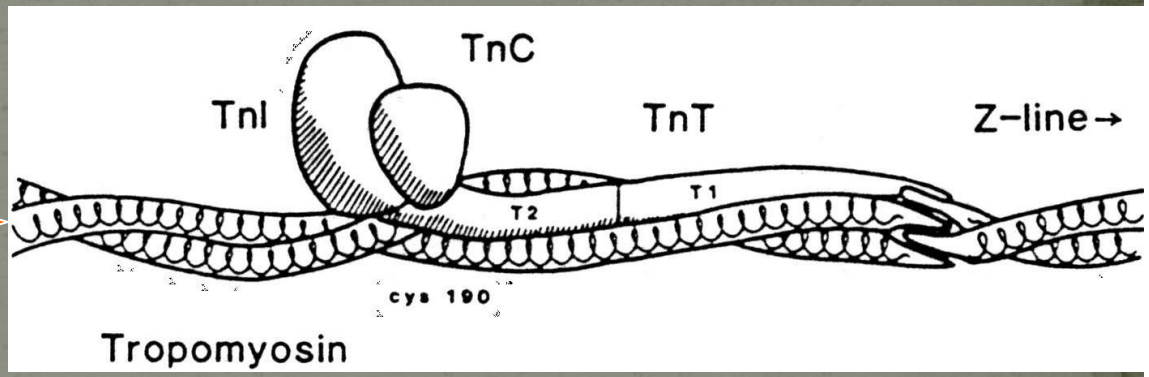
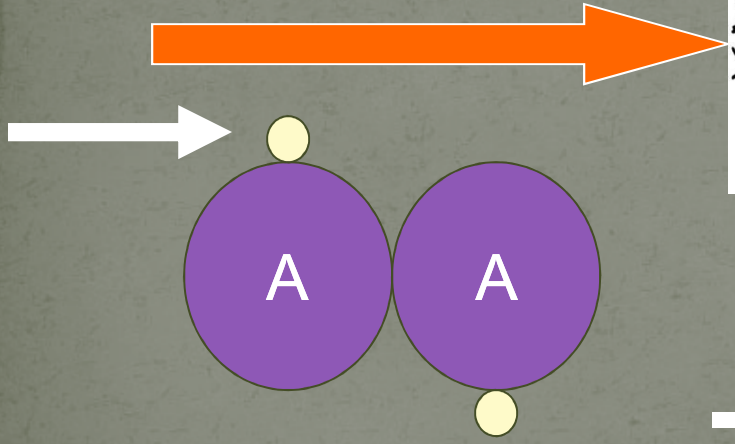


Fig. 2. Schematic diagram of thick and thin filaments drawn approximately to scale. A, Actin; Tm, tropomyosin; Tn, troponin; LC, light chain (LC_2 is also called the 20 kDa LC, the P-light chain, regulatory LC, or DTNB LC; the alkali LCs are also called "essential" LCs). C-protein is drawn in two different configurations since its position in the thick filament is not known (see Solaro 1986)

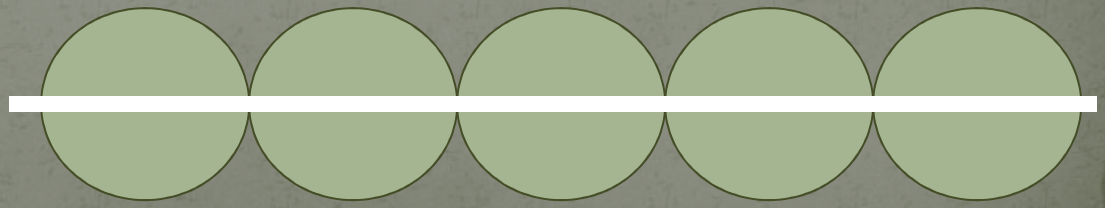
Regulatory Proteins

- Tropomyosin
  - Thin protein that lays around the Actin proteins





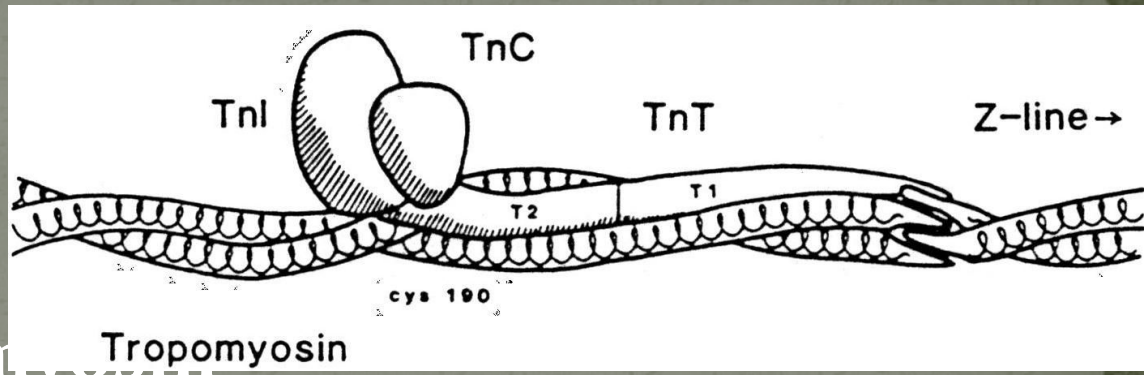
End View



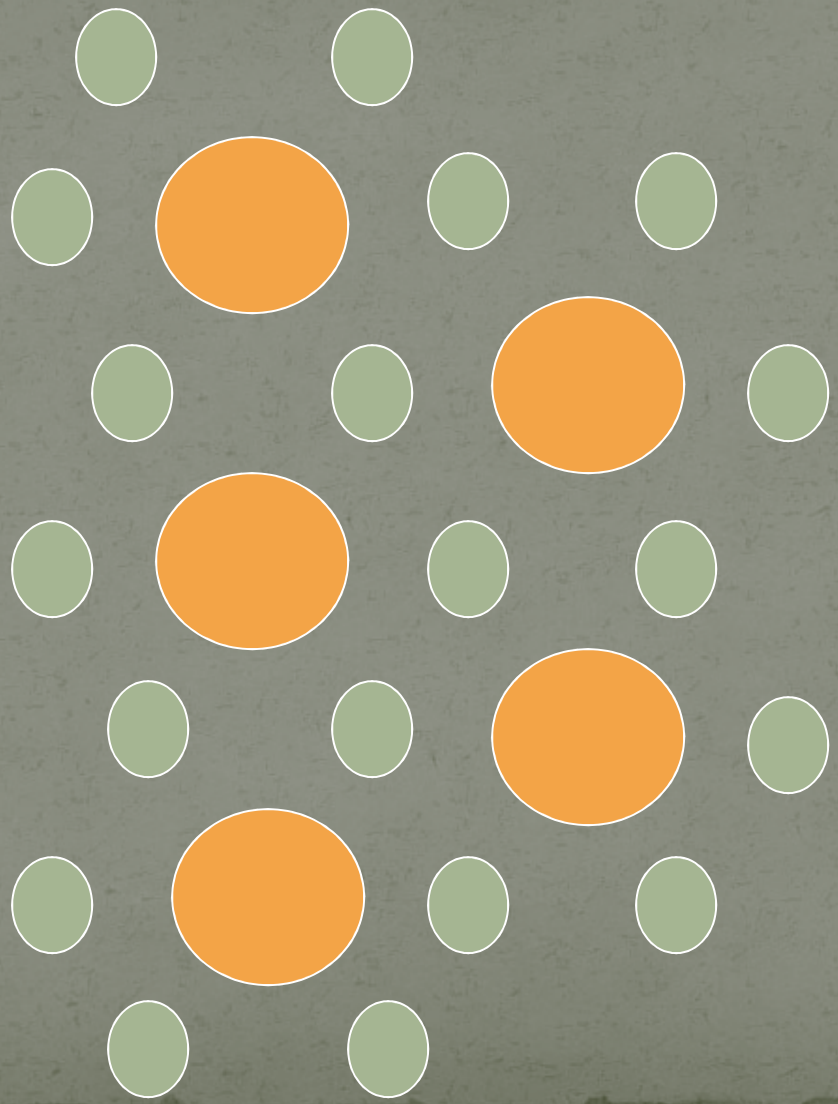
Top View

Regulatory Proteins

- Troponin
- 3 Subunits
  - TnT
    - Binds tropomyosin
  - TnI
    - Inhibitory subunit
  - TnC
    - Ca^{2+} binding subunit



3 Dimensional



How does all this fit together?

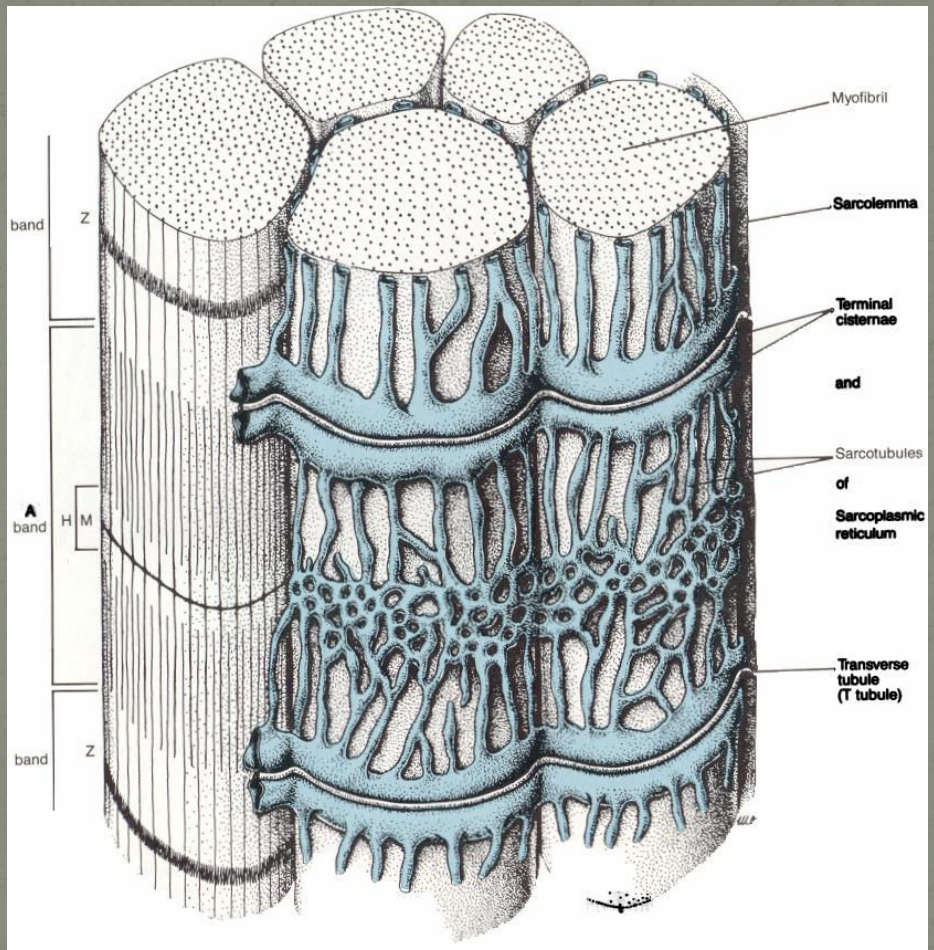
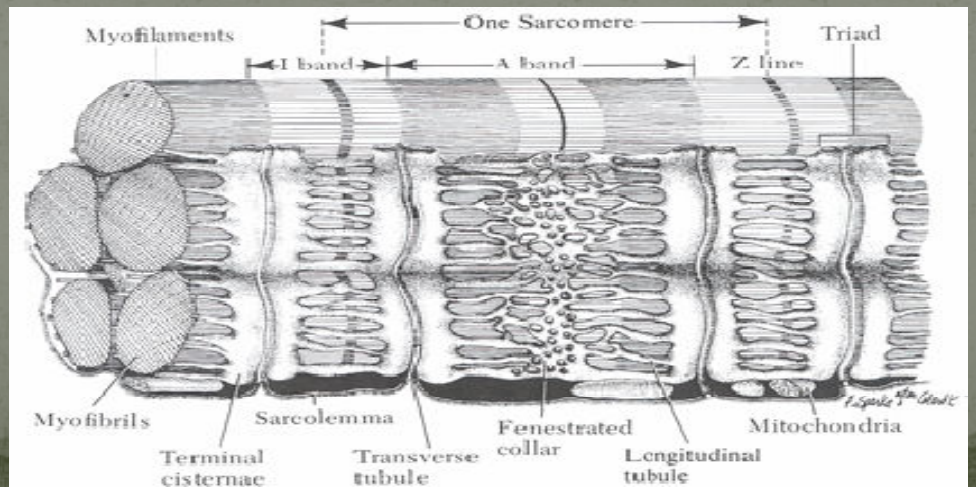


Fig. 15-16. Diagram of part of a mammalian skeletal muscle fiber, illustrating the sarcoplasmic reticulum surrounding its myofibrils. In mammalian skeletal muscle, two transverse (*T*) tubules supply a sarcomere. Each T tubule is situated at the junction between an A and an I band, where it is associated with two terminal cisternae of sarcoplasmic reticulum. Terminal cisternae connect with sarcotubules located around the A band, and these anastomose to form a network in the central region of the A band. The triple structure seen in cross section where terminal cisternae from adjacent sarcomeres flank a transverse tubule is called a triad. (Courtesy of C. P. Leblond)

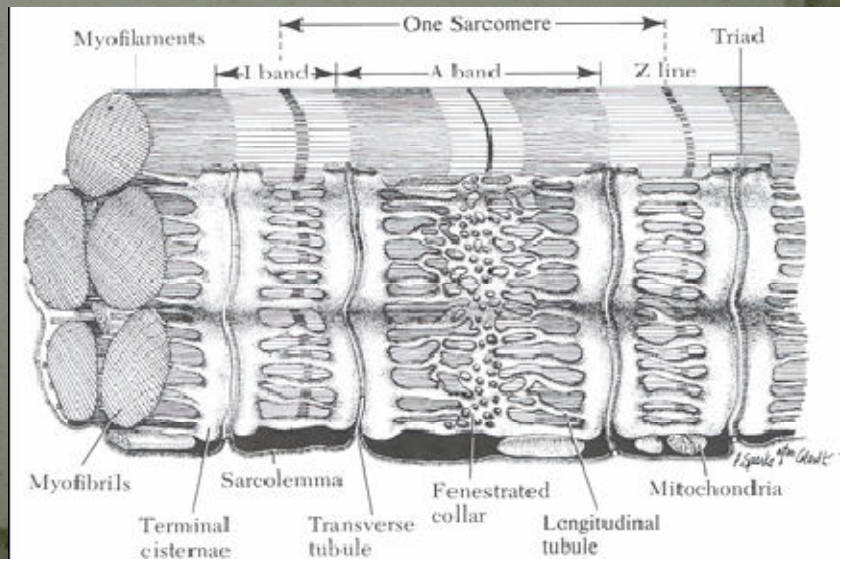
More Structural Stuff

- Sarcolemma – membrane around the myofibril; sits just under the endomysium
- Sarcoplasmic Reticulum
- T – tubules or Transverse Tubules
- Terminal Cisternae



More Structural Stuff

- Sarcoplasmic Reticulum
  - Surrounds each myofibril
  - Stores Calcium, needed for contraction
- T – tubules and Terminal Cisternae transport Ca to cytosol & transmit nerve impulse



We've laid the ground work, let's talk about muscle contraction

"Sliding Rod Theory" Hanson and Huxley 1955; Huxley 1965, 1972; Huxley and Hanson, 1960

Muscle Contraction

- A signal travels down a nerve
- Attached to individual muscle cells
- The signal is passed on to the Sarcolemma
- The Sarcolemma depolarizes

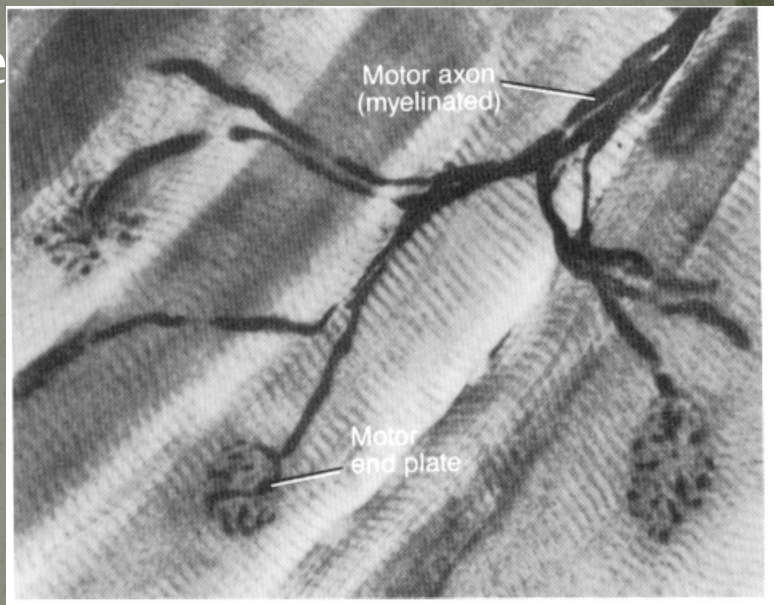
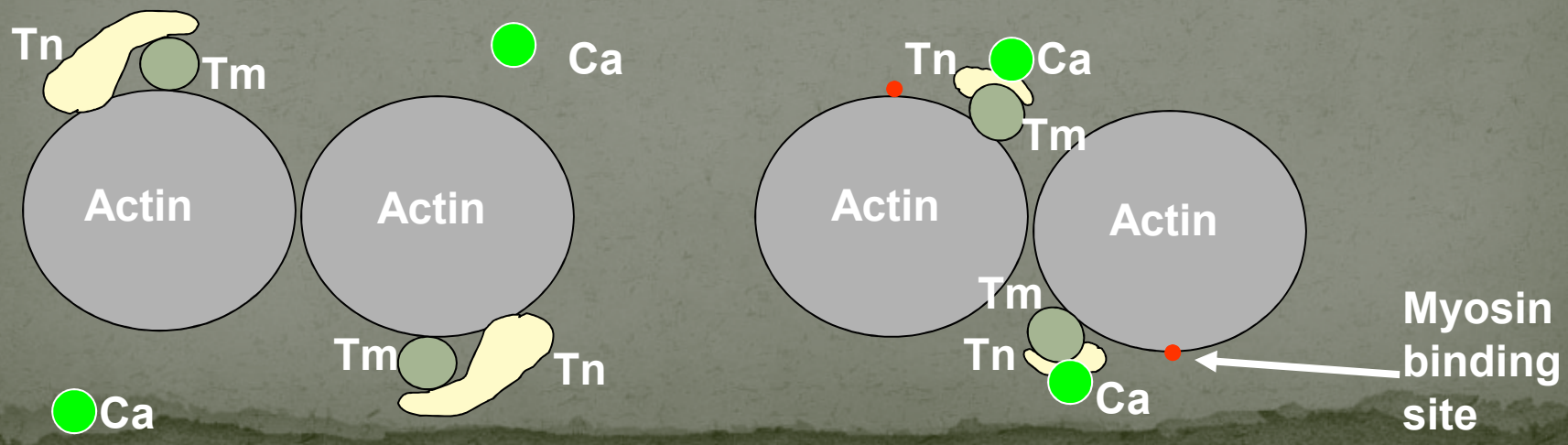


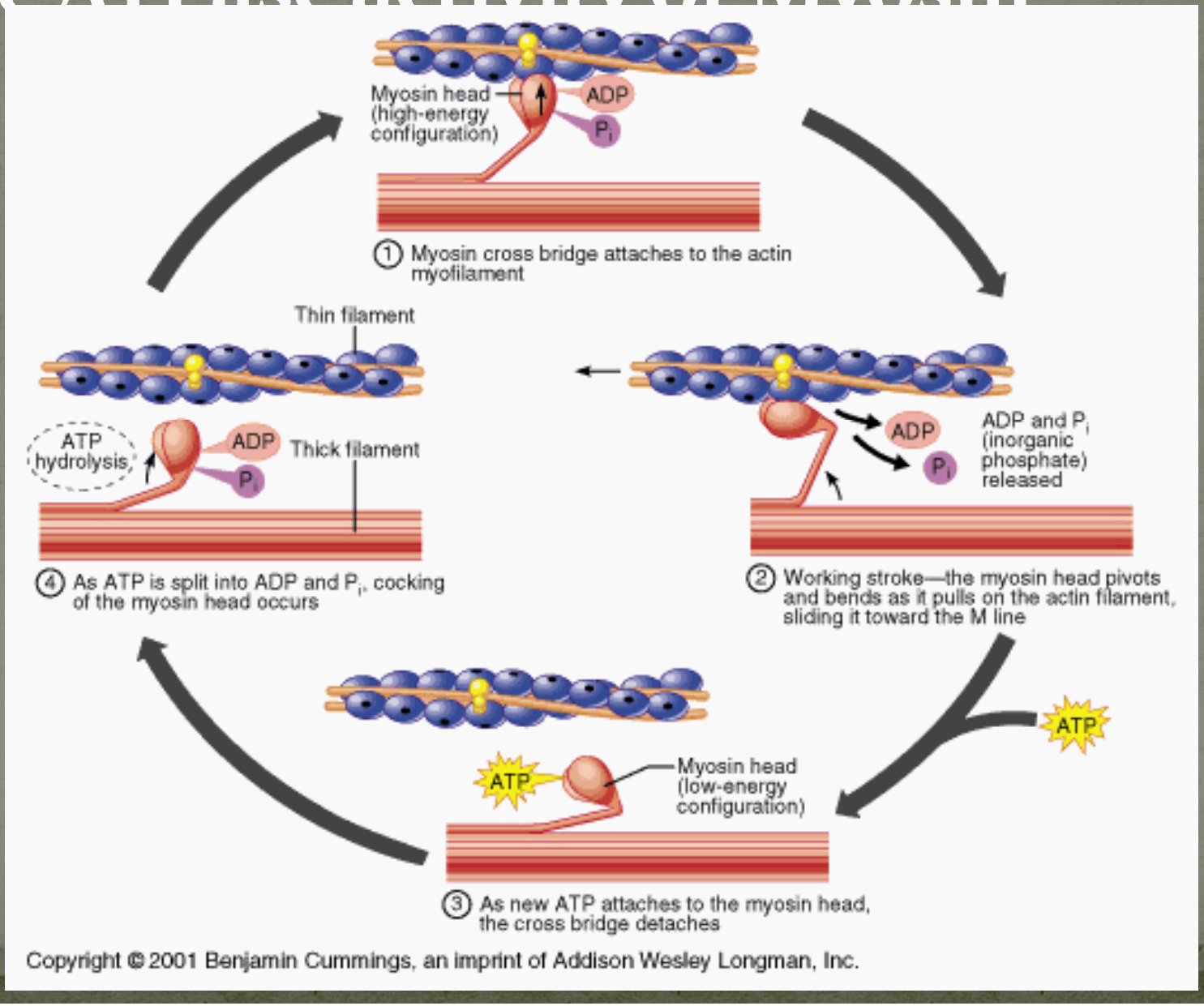
Fig. 15-12. Photomicrograph showing the motor end plates on skeletal muscle fibers (stained with gold chloride).

Muscle Contraction

- The depolarization causes the SR to release Ca into the cytosol
- The Ca will bind with troponin (Tn)
- This causes a shift in the troponin tropomyosin (Tm) complex

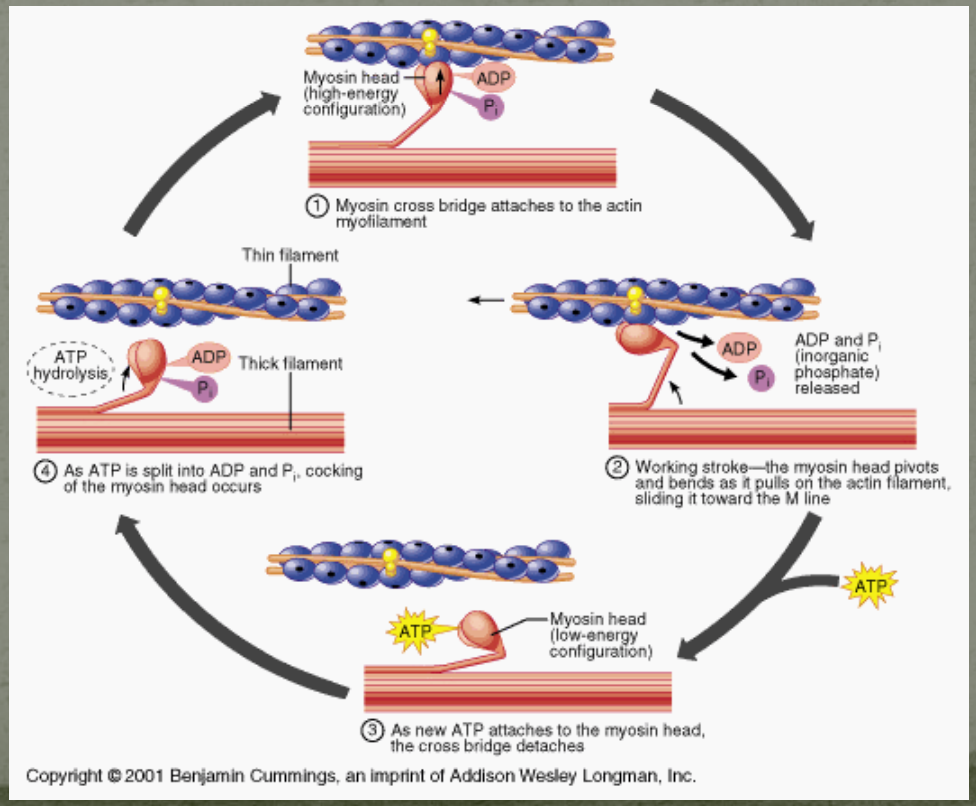


The ATPase activity of Myosin



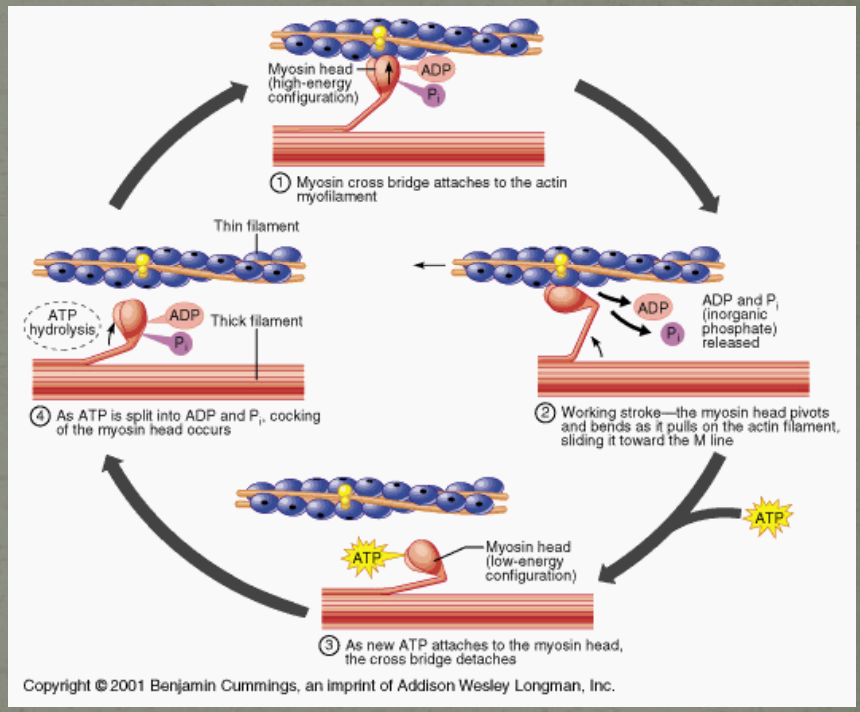
The ATPase activity of Myosin

- ATP (Adenosine Triphosphate) bind to the Myosin head
- ATP hydrolysis to ADP + Pi "cocks" the Myosin head



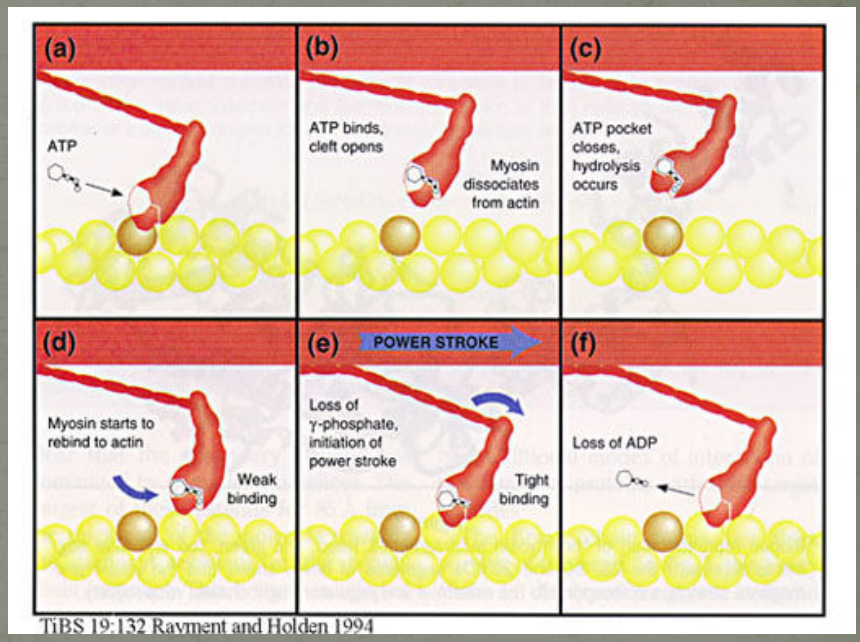
The ATPase activity of Myosin

- The Myosin head attaches to the exposed binding site on Actin
- Weak bond
- Pi leaves the Myosin head causing the "Power Stroke"
- ADP is released causing a strong Myosin – Actin bond



The ATPase activity of Myosin

- ATP re-attaches to the Myosin head causing the head to release from the Myosin – Actin binding site



TiBS 19:132 Rayment and Holden 1994

Let's put it all together

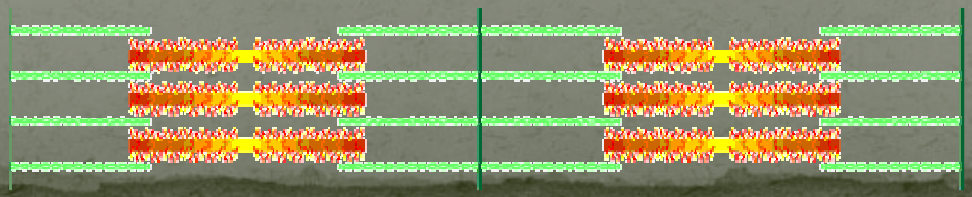
- 1.) An impulse travels down a nerve to a muscle cell
- 2.) The nerve impulse is transferred to the Sarcolemma of a muscle cell
- 3.) The Sarcolemma depolarized causing the Sarcoplasmic Reticulum to release Ca into the cytosol of the cell

Let's put it all together

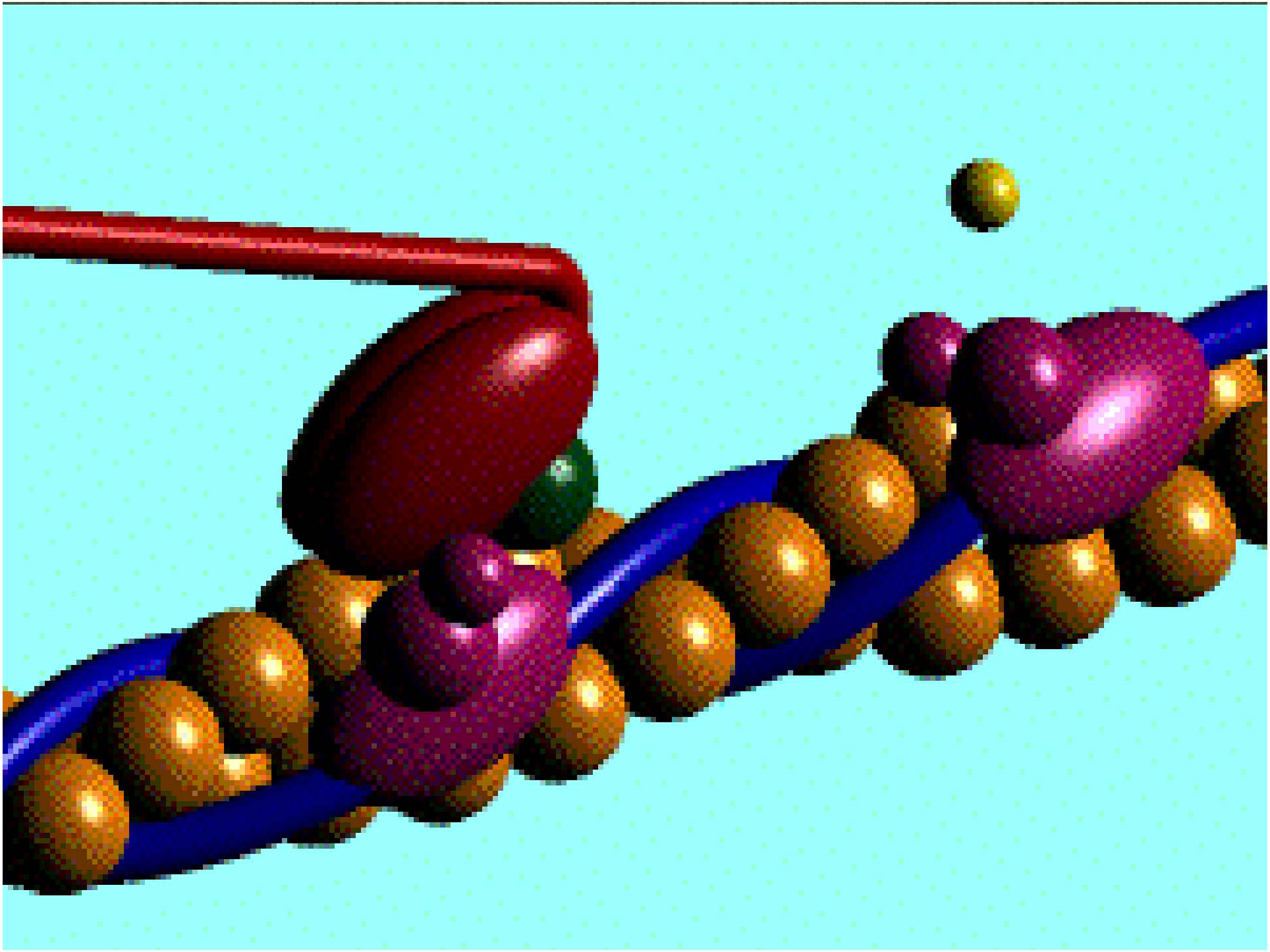
- 4.) The Ca binds to Troponin on the Troponin – Tropomyosin complex
- 5.) The Tn – Tm complex shifts to the grove of the Actin exposing the Actin – Myosin binding site
- 6.) ATP has bound with the Myosin head releasing it from the previous contraction

Let's put it all together

- 7.) Myosin hydrolyzes the ATP to ADP + Pi, "cocking" the Myosin head
- 8.) Myosin attaches to Actin forming a weak bond
- 9.) Pi is released causing the "power stroke"
- 10.) ADP is released forming a tight rigor bond of Actin and Myosin



http://www.tvermilye.com/pmwiki/pmwiki.php?n=Animation.Video12



What makes these guys so strong?

What makes those guys strong is the same that makes him strong!

Or, Who's Stronger??

See ya this afternoon