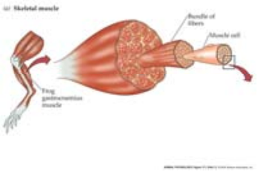
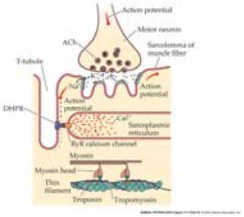
Muscle and Movement

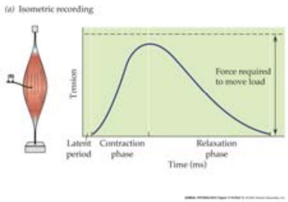
The organization of skeletal muscles



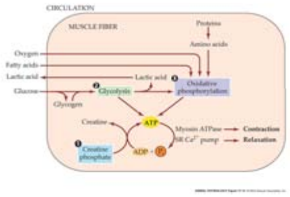
Excitation–contraction coupling



Whole Skeletal Muscles contractions



Muscle Energetics



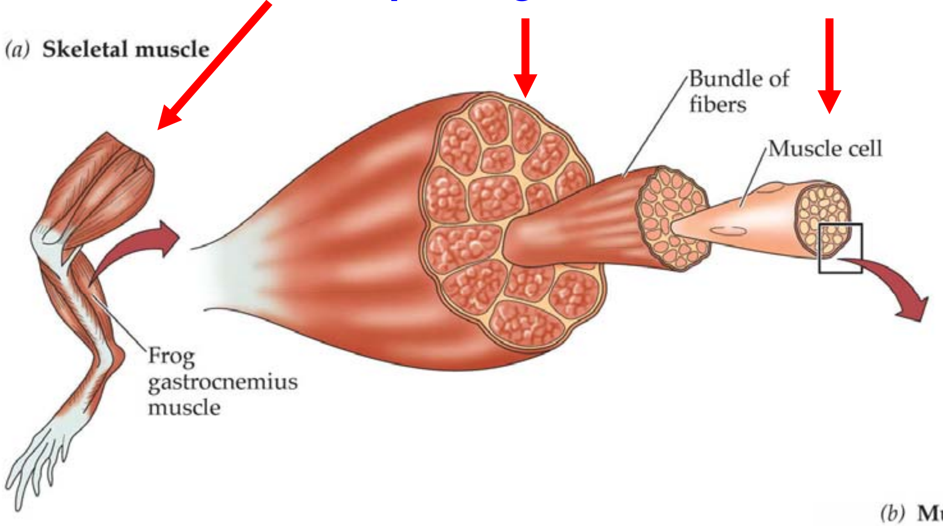
The molecular bases of movement

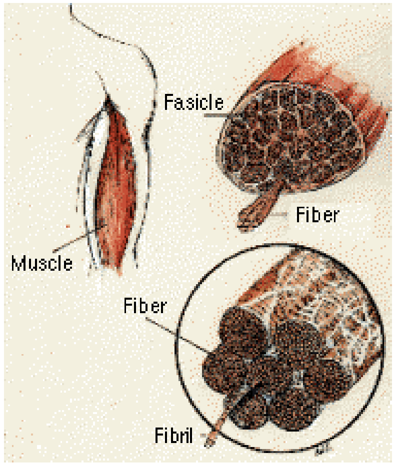
Muscular cells use molecular motors (myosin)
To transform chemical energy (ATP) into mechanical energy
(movement, tension)

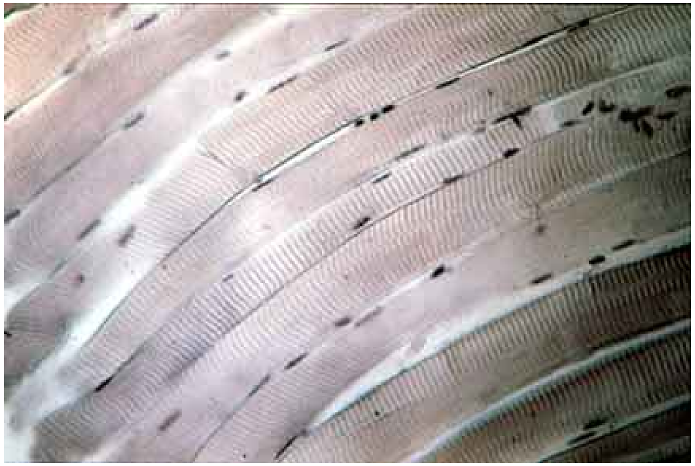
Contractile proteins

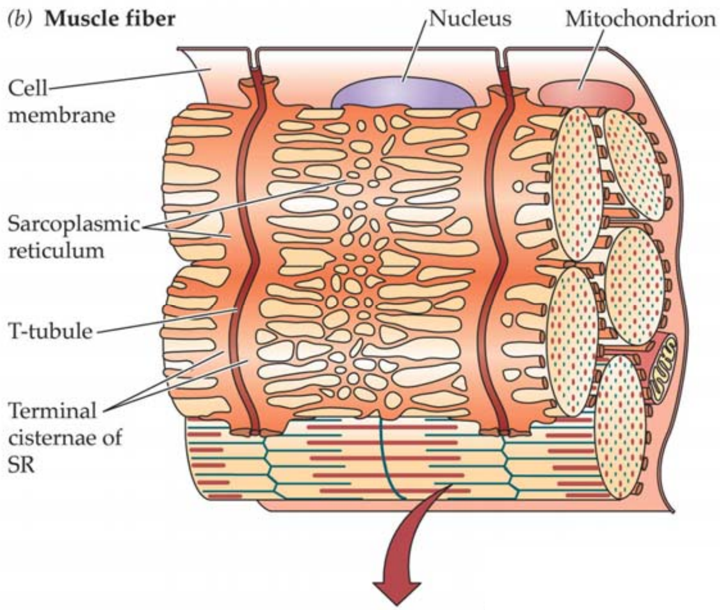
The organization of skeletal muscles

Muscle --- package of fibers----muscle cell (fiber)





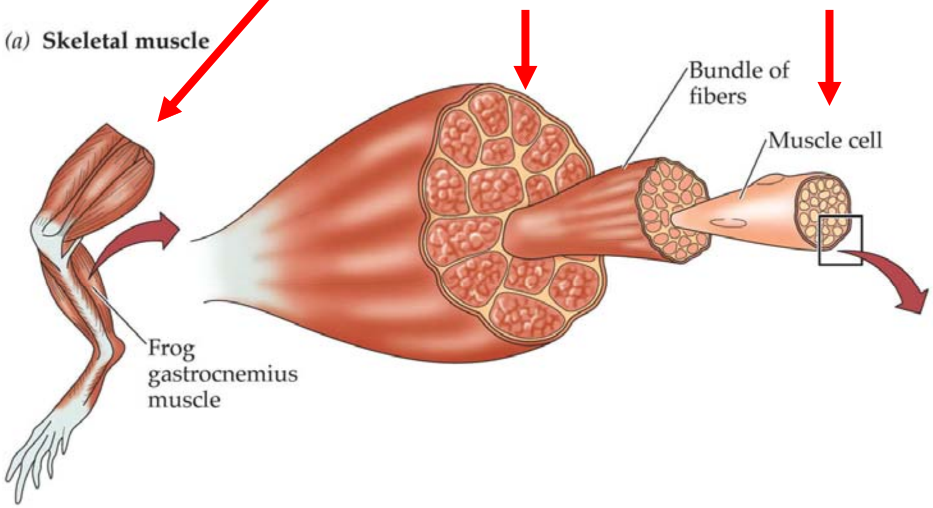


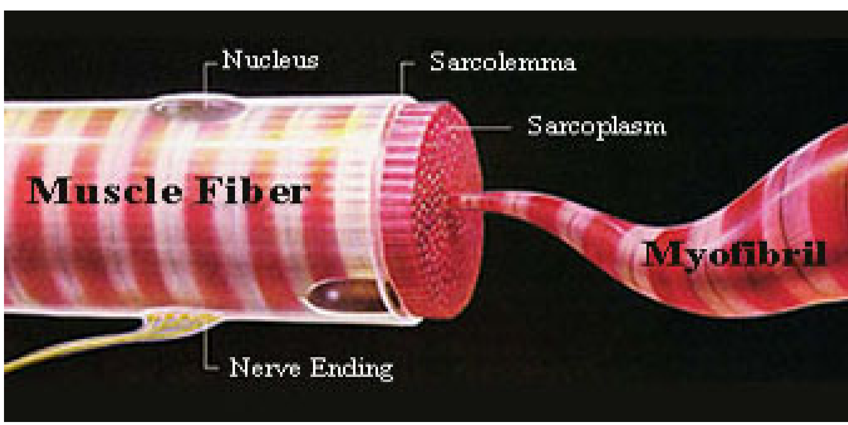


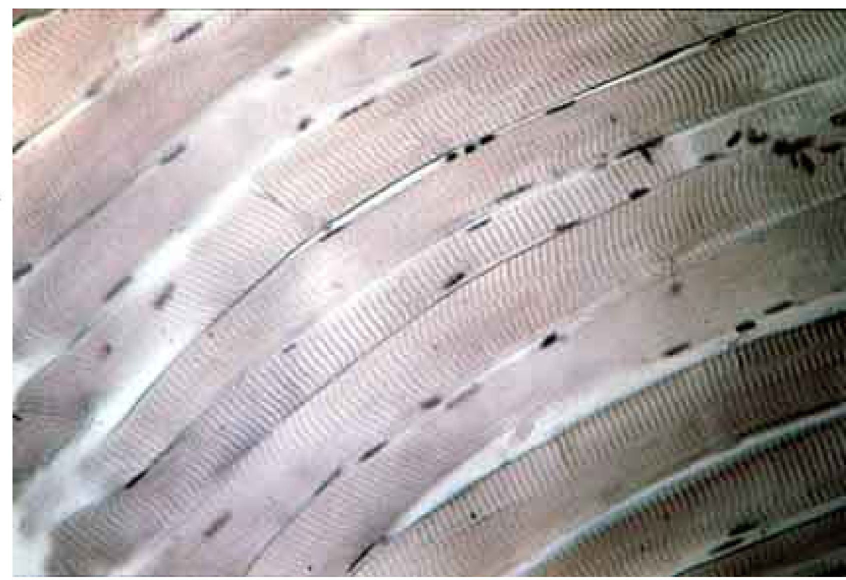
muscle cell -- Myofibril

The organization of skeletal muscles

Muscle --- package of fibers----muscle cell (fiber)

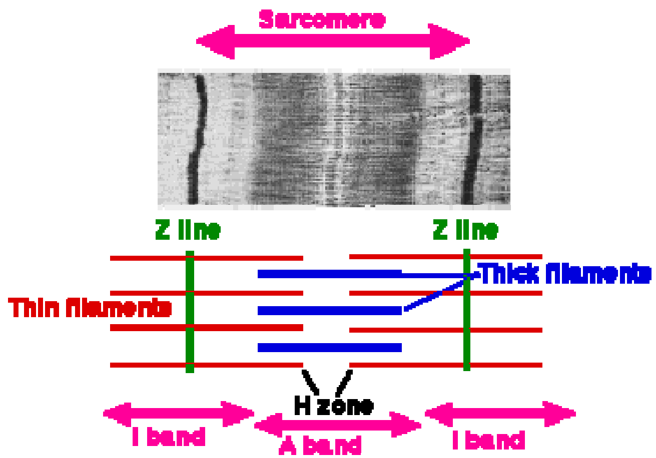


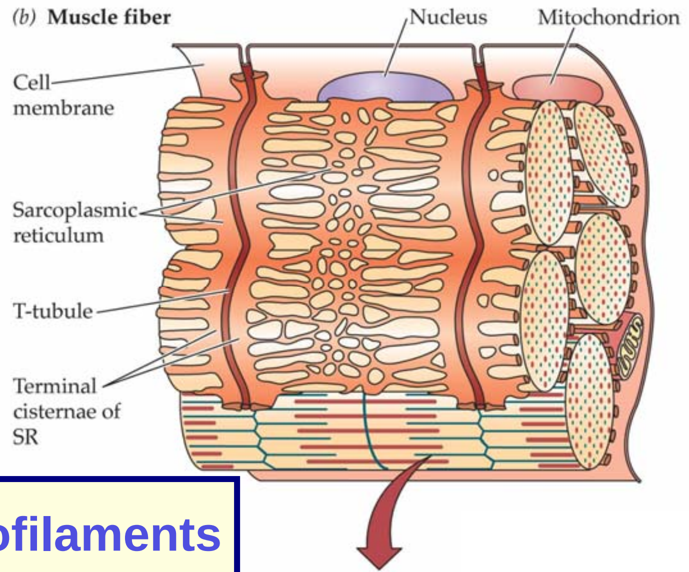




muscle cell -- Myofibril

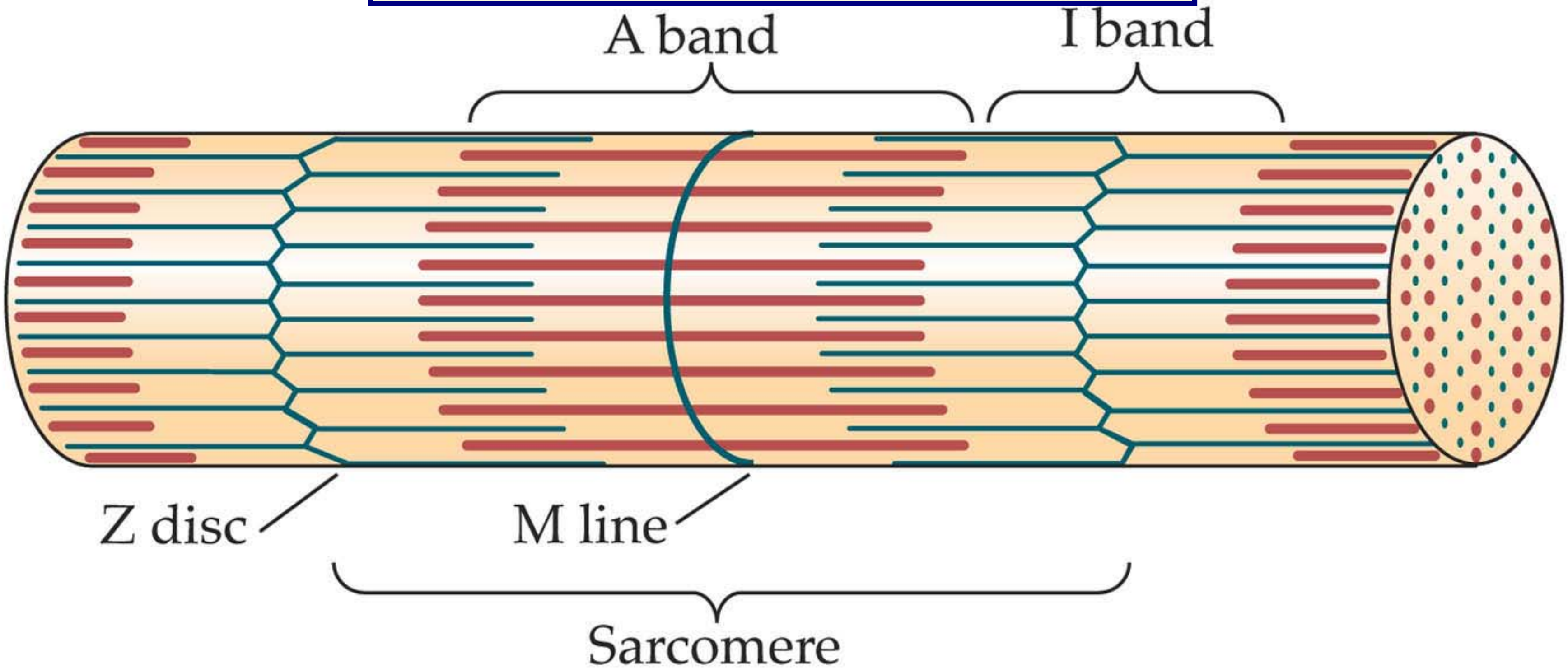
The organization of skeletal muscles





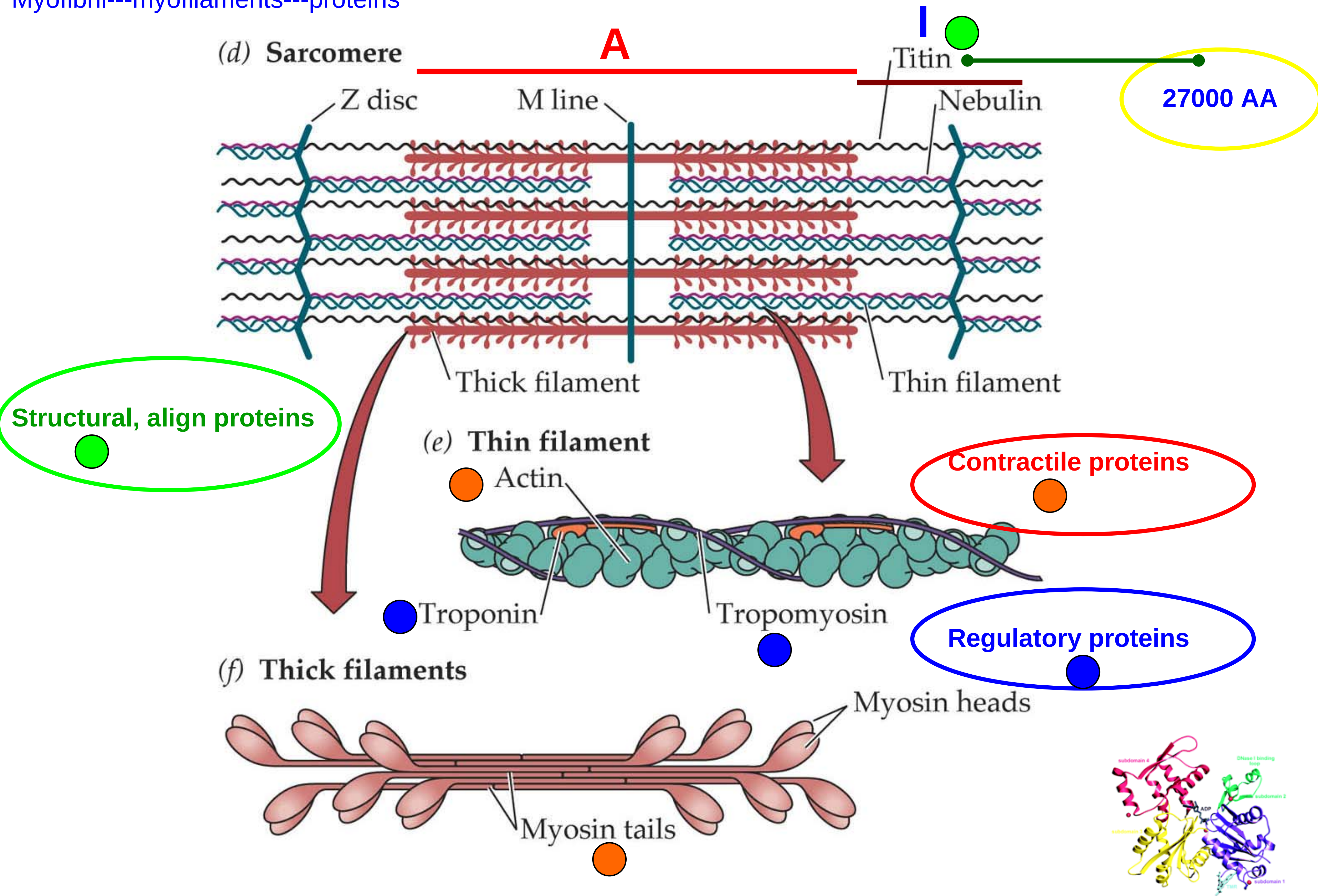
Muscle cell – Myofibril --Myofilaments

(c) **Myofibril**



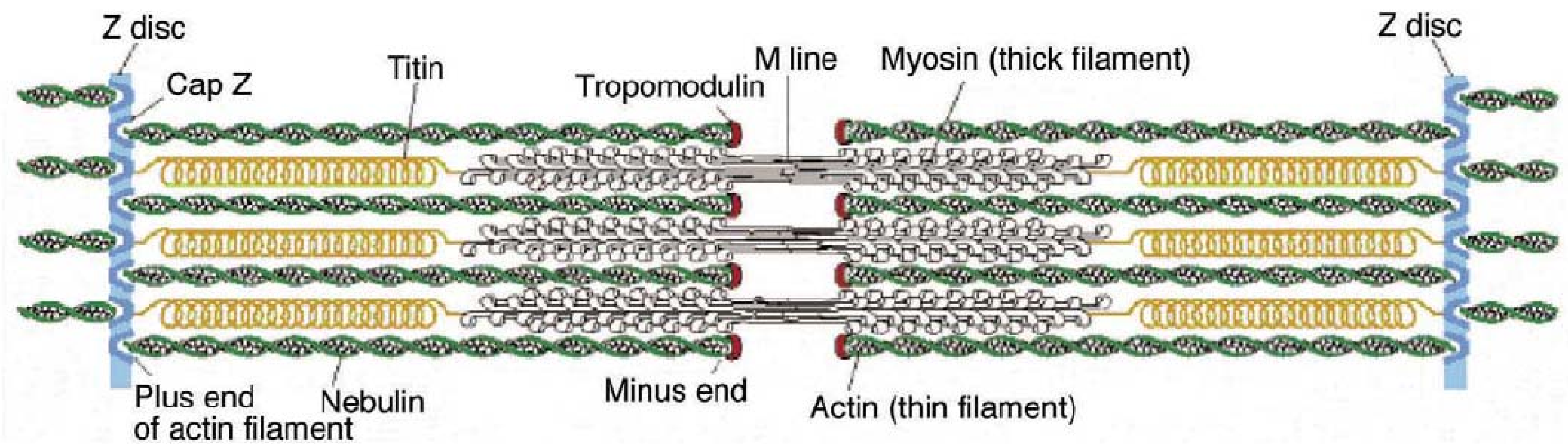
The filaments are polarized polymers of individual protein molecules

Myofibril---myofilaments---proteins



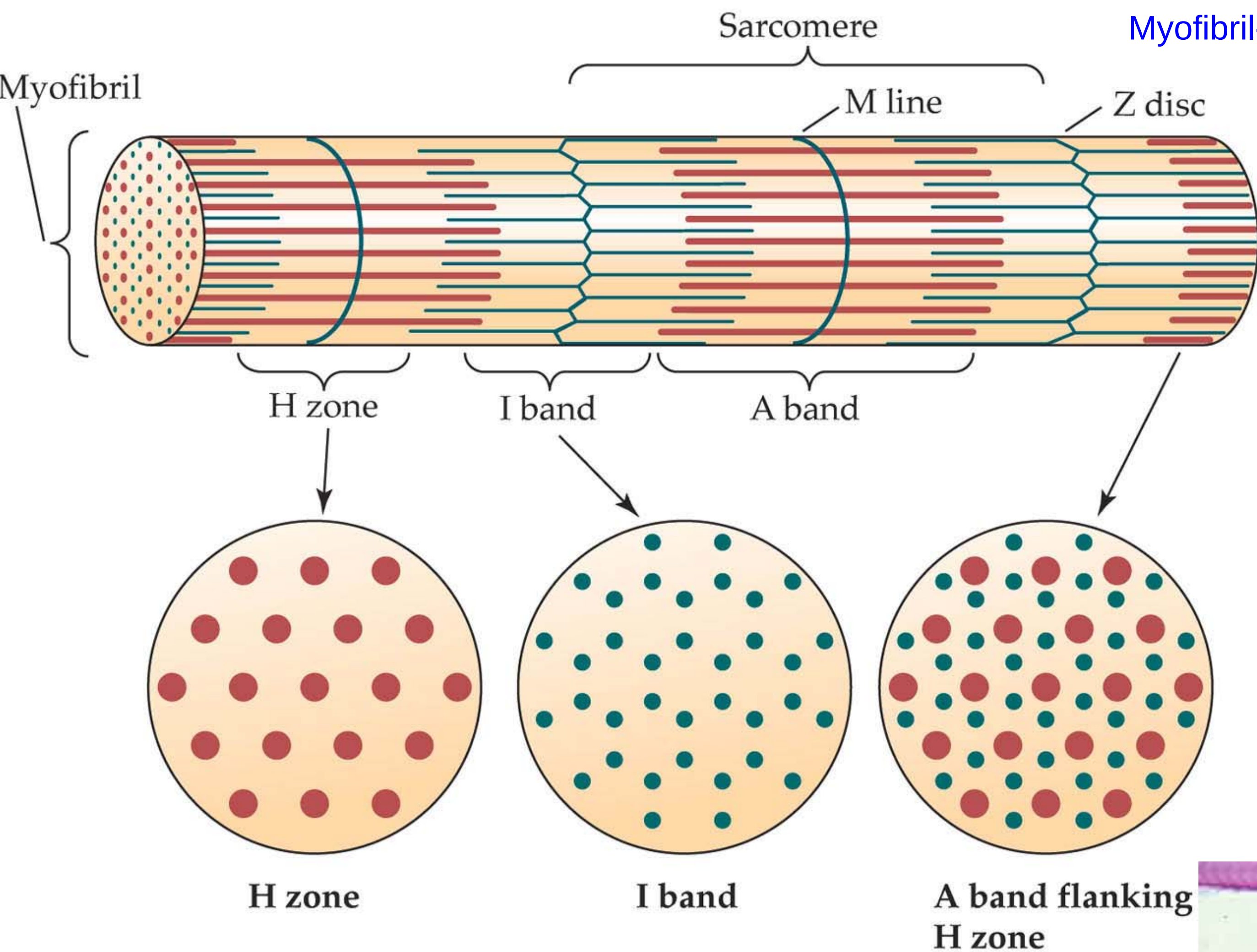
The filaments are **polarized** polymers of individual protein molecules

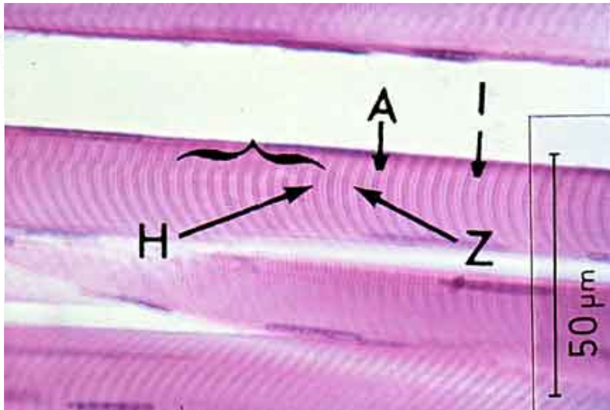
Myofibril---myofilaments---proteins



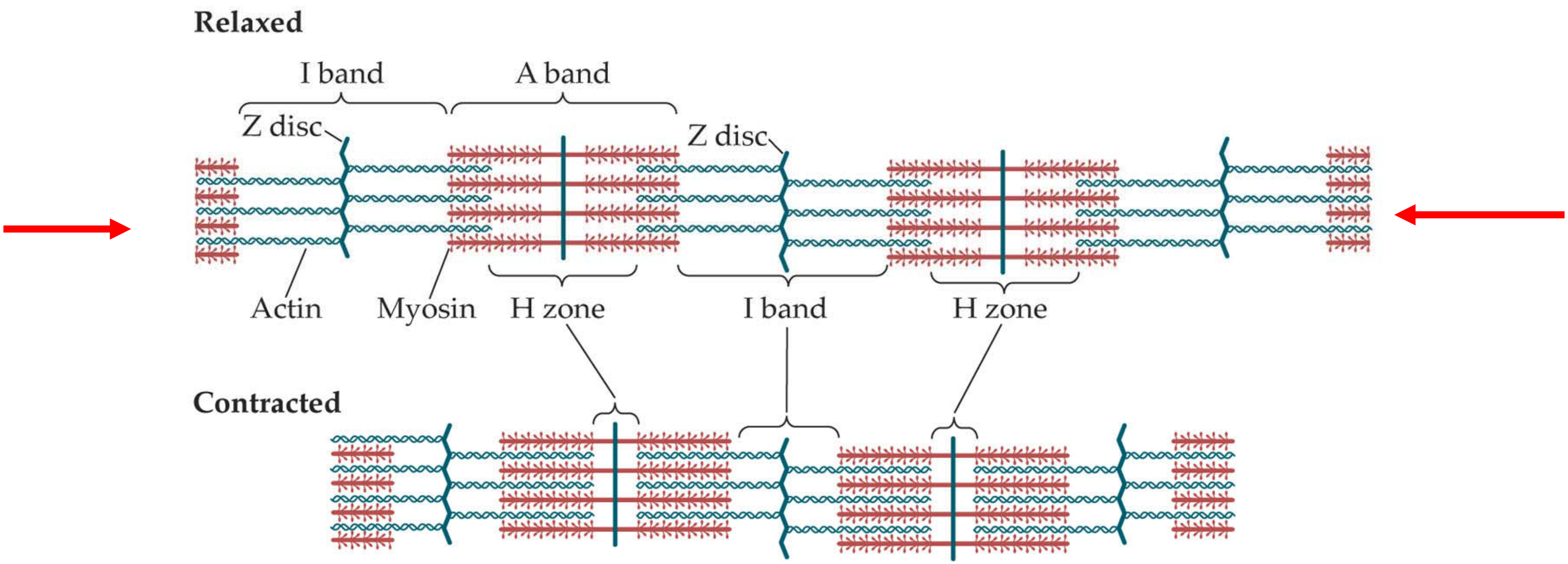
The arrangement of thick (myosin) and thin (actin) myofilaments in a sarcomere

Myofibril---myofilaments---proteins

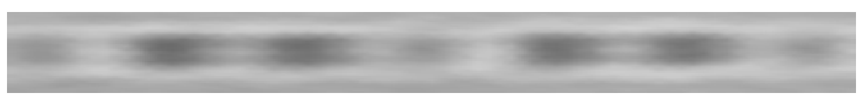


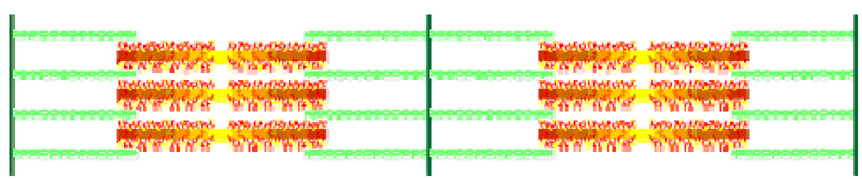


Muscle contraction produced by sliding filaments (<u>sliding-filament theory</u>)



Bands I and H shorten

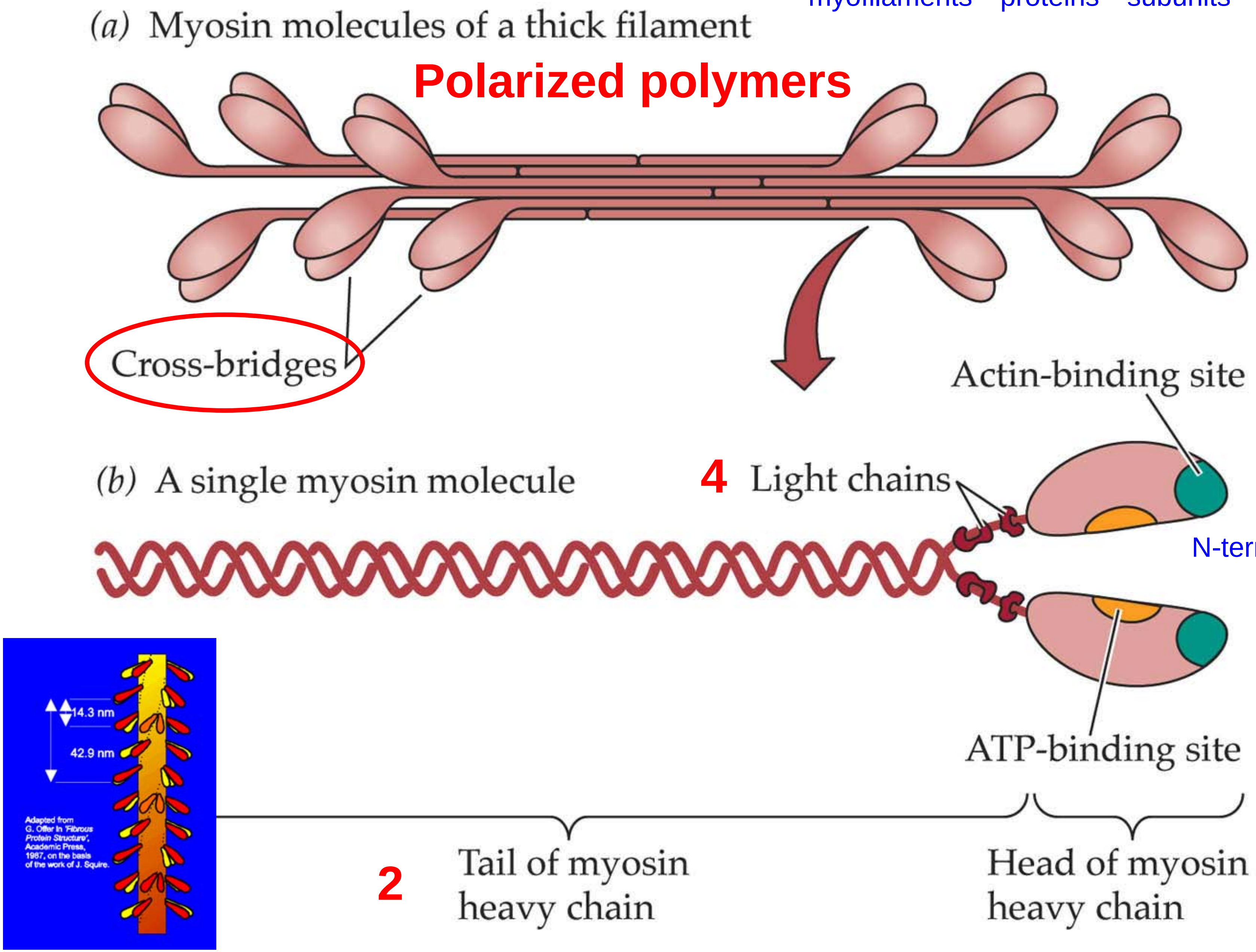




Sarcomere

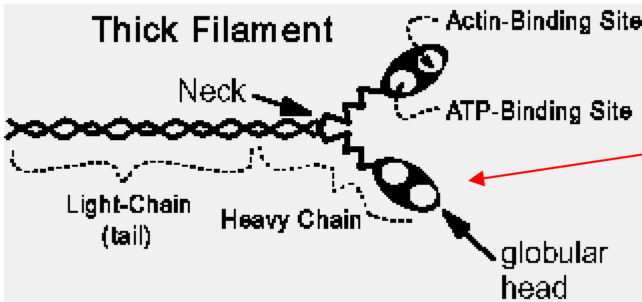
Myosin molecules form the thick filament

myofilaments---proteins---subunits



Myosin molecules form the thick filament

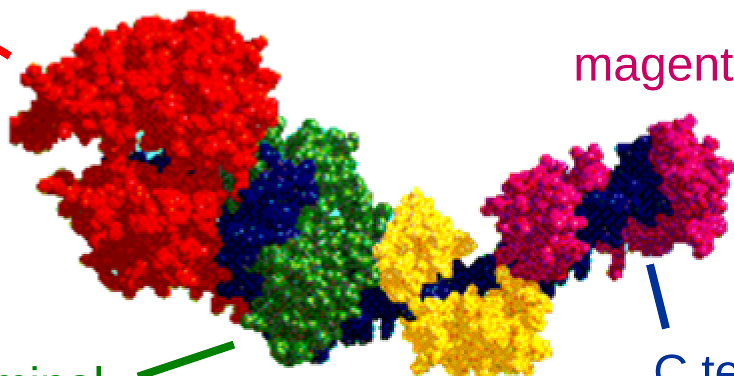
Hexamer: two heavy chains and four light chains.
Molecular weight of 520 kD



heavy chains have a globular head at the N-terminal

actin binding site and the nucleotide binding site (red)

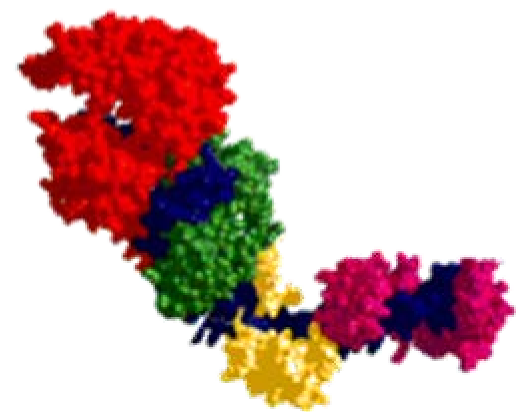
magenta region is the regulatory light chain



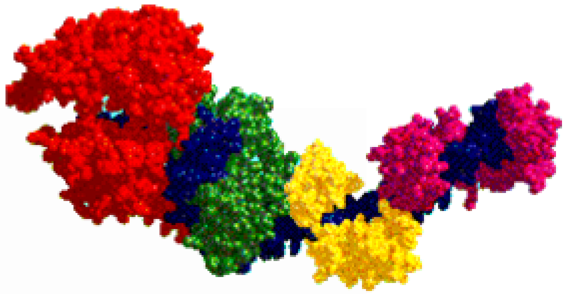
N terminal

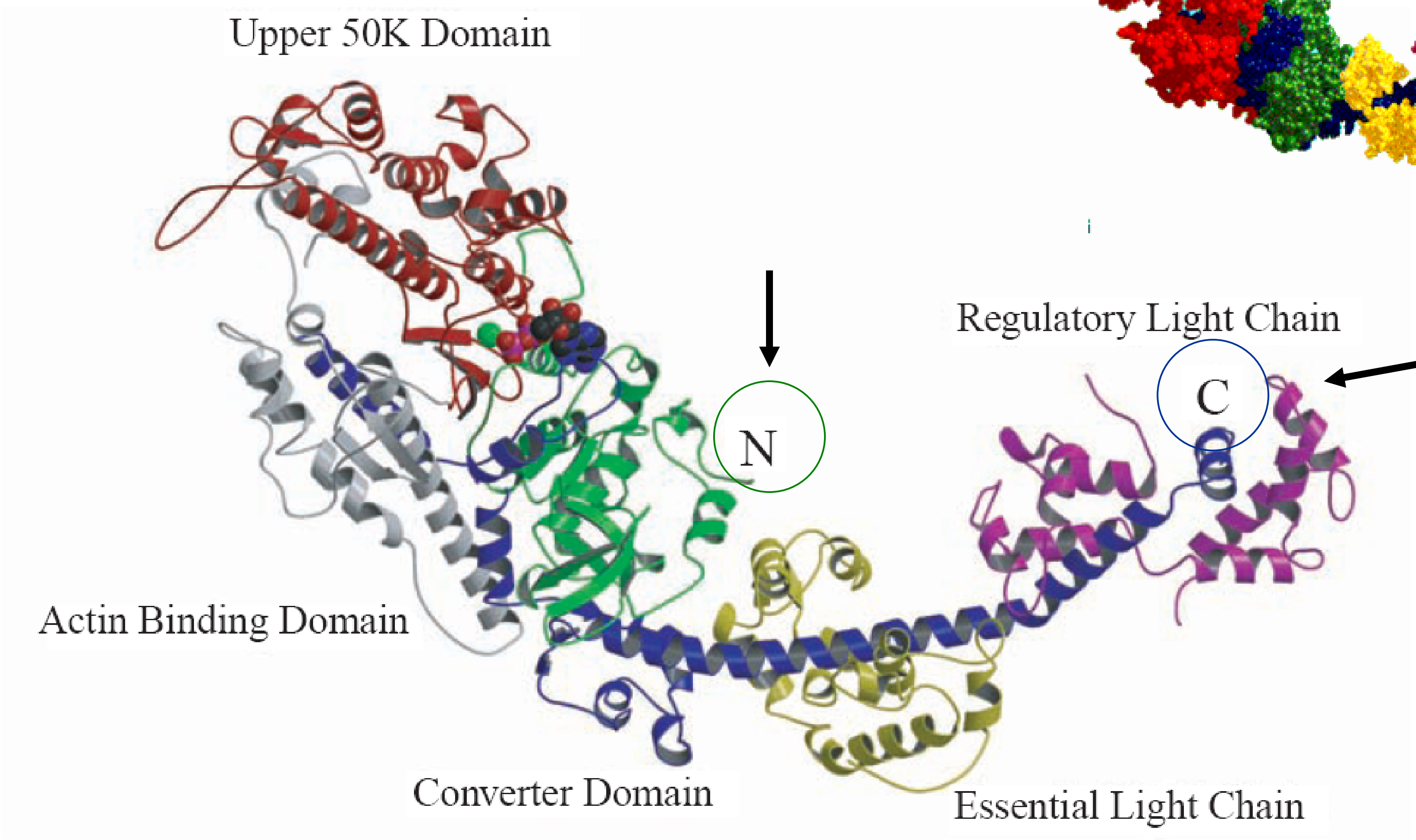
C terminal

essential light chain is yellow

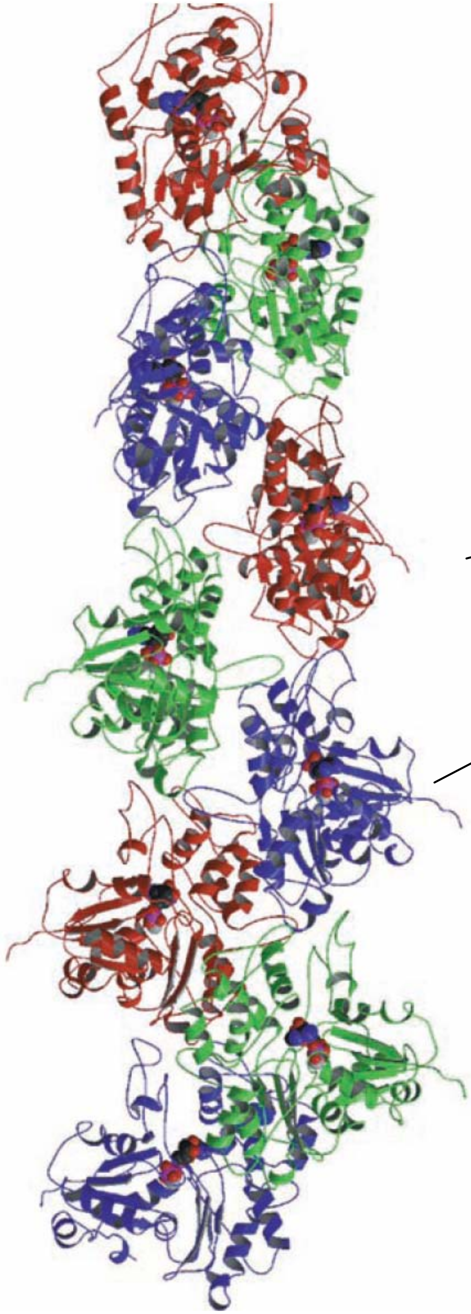


Myosin molecules form the thick filament



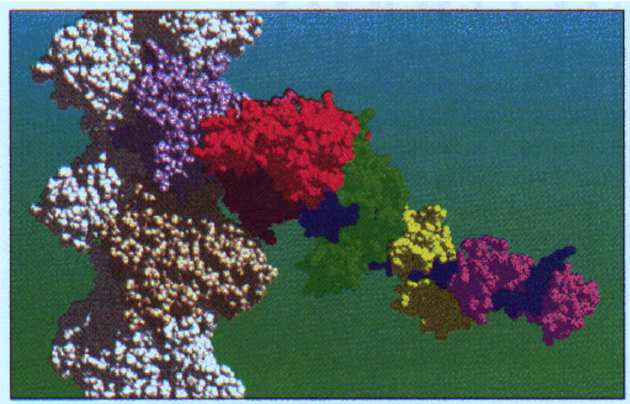


Actin molecules form the thin filament

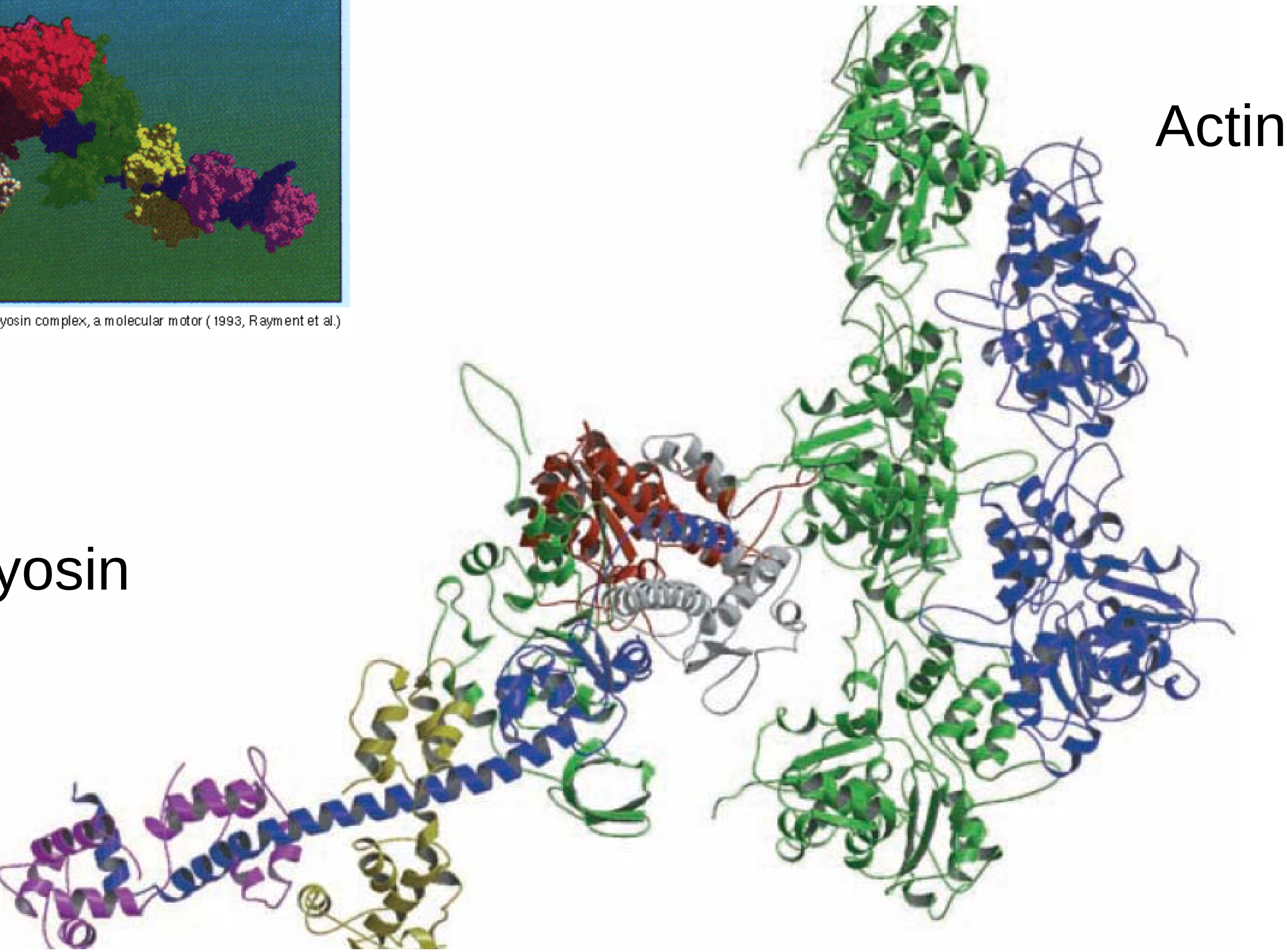


F actin has 13 actin monomer molecules

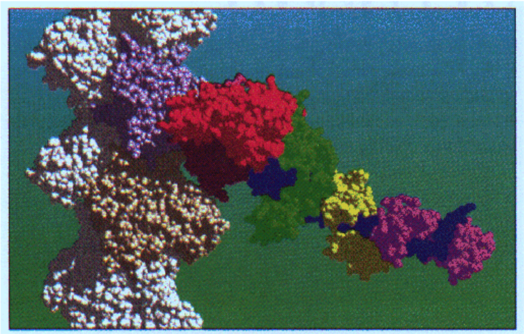
Interaction thin and thick filaments



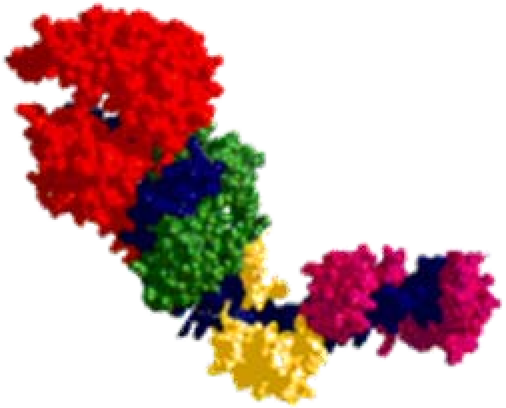
The actomyosin complex, a molecular motor (1993, Rayment et al.)

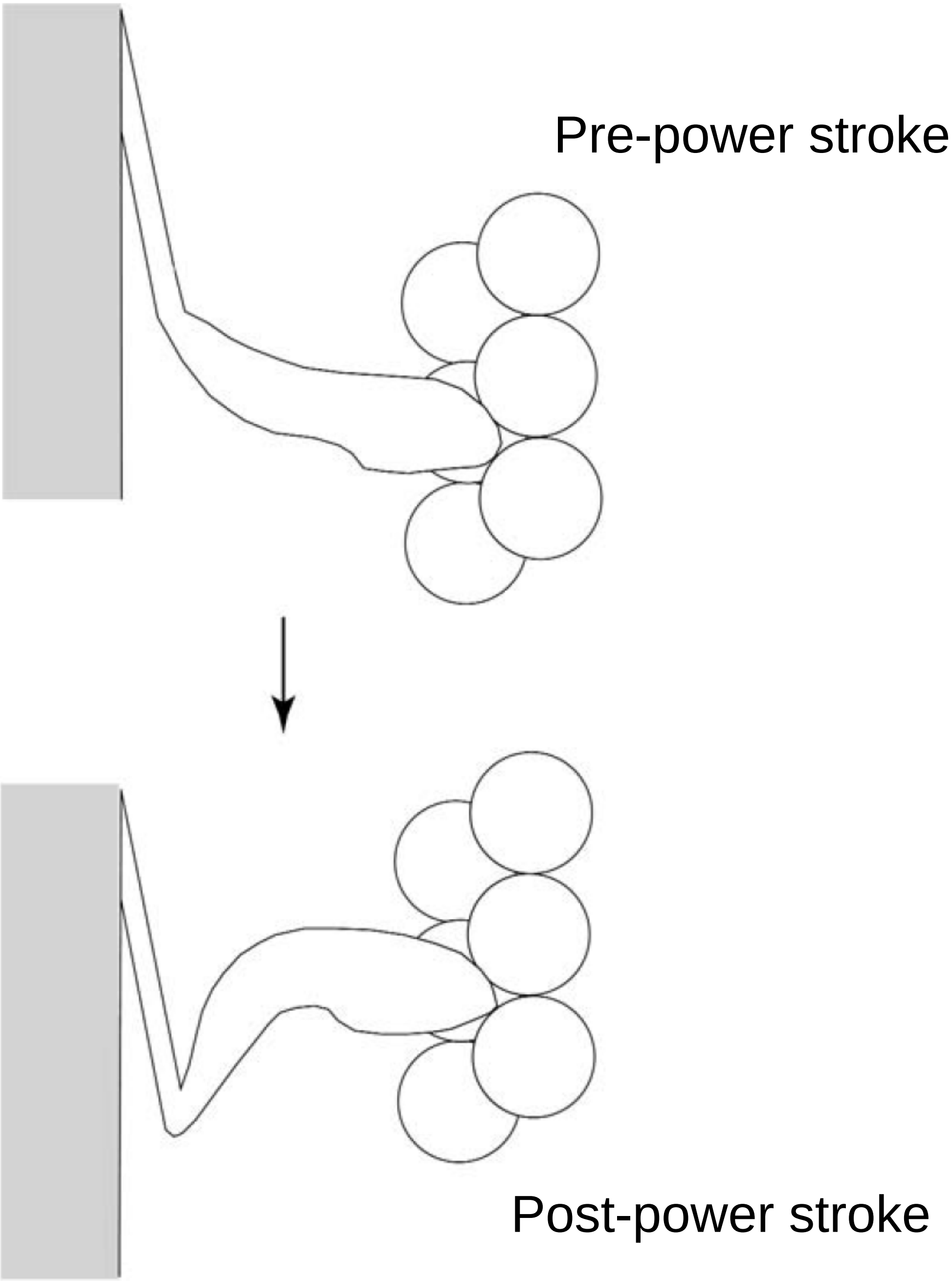


Myosin molecules form the thick filament

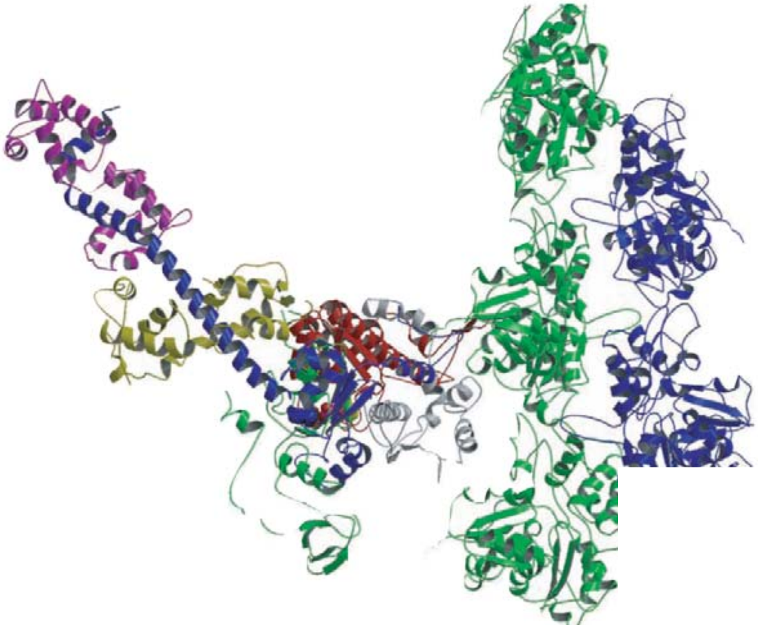


The actomyosin complex, a molecular motor (1993, Rayment et al.)



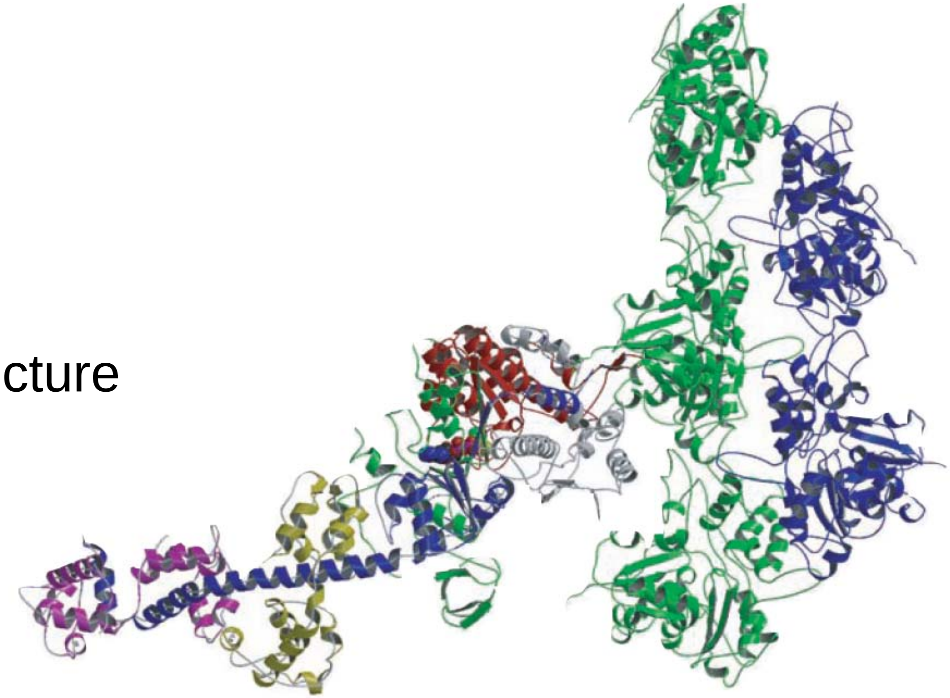


Interaction thin and thick filaments

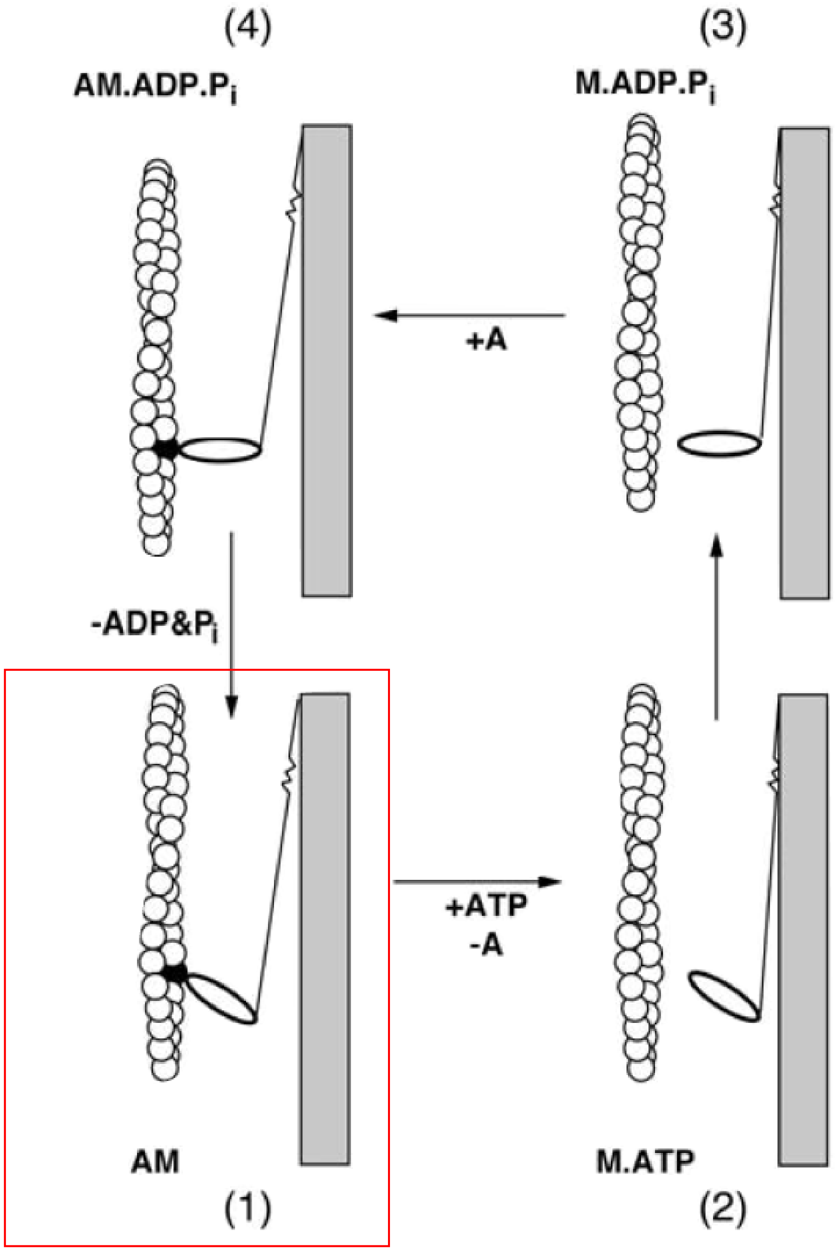


Pre-power stroke structure

Post-power stroke structure

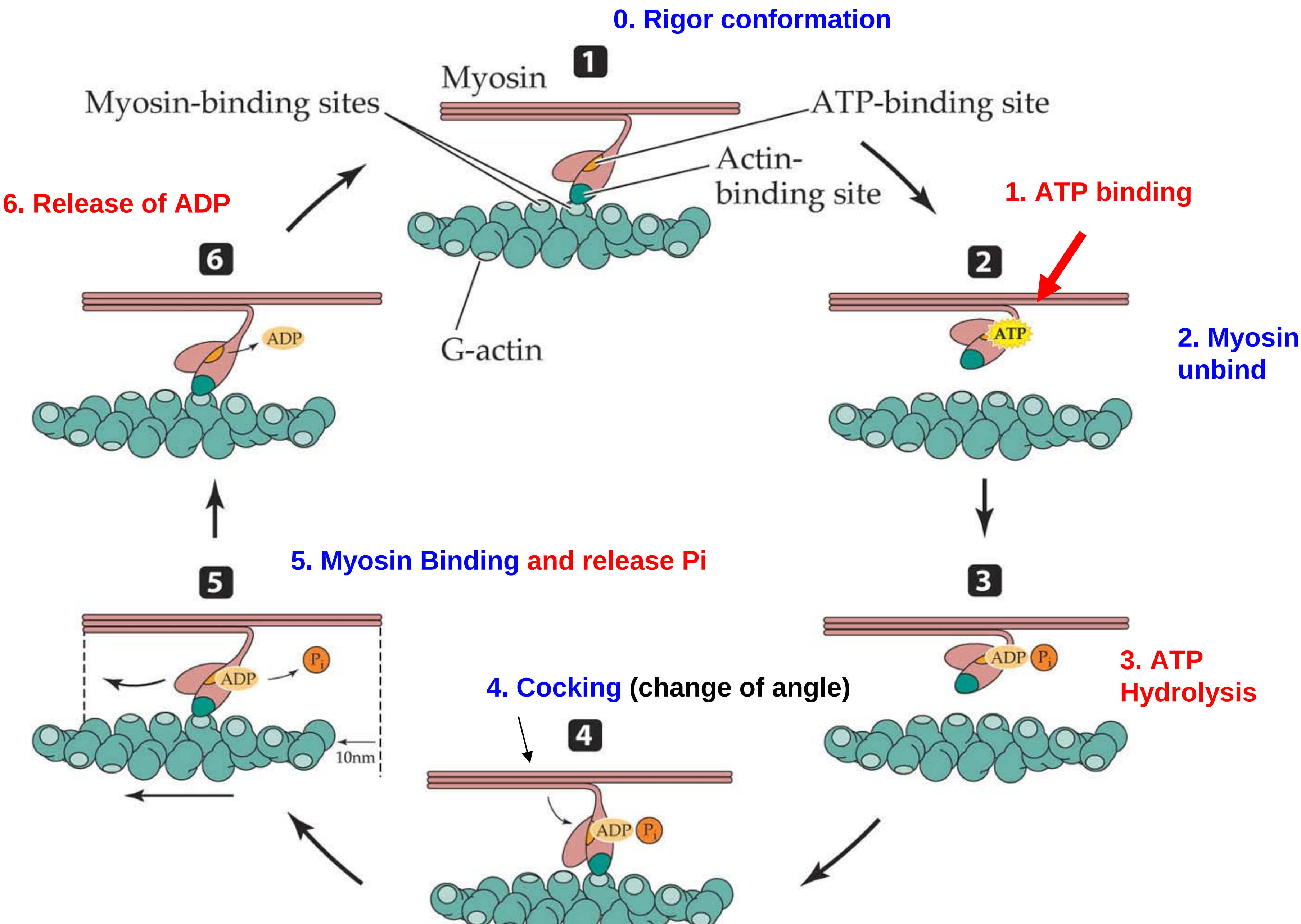


Molecular interactions that underlie muscle contraction

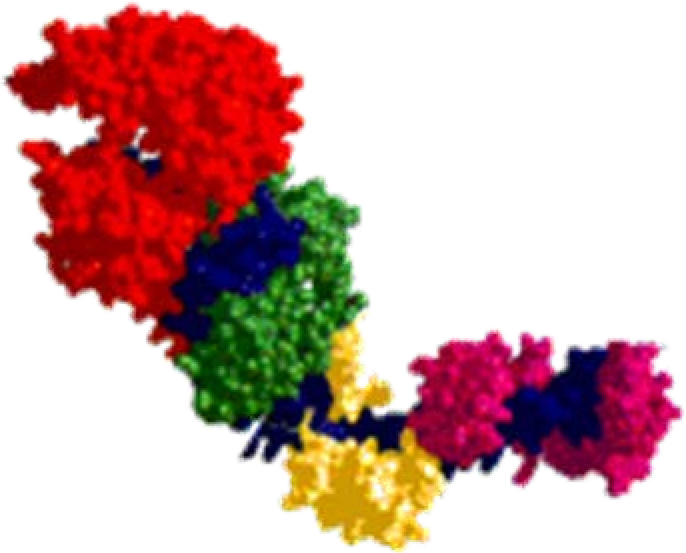


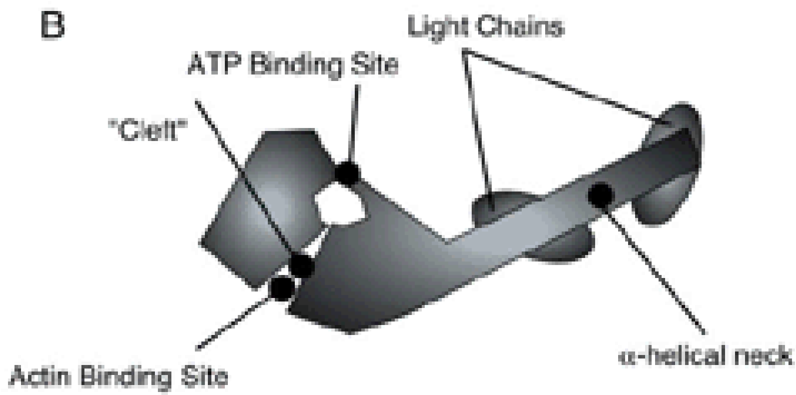
Rigor state

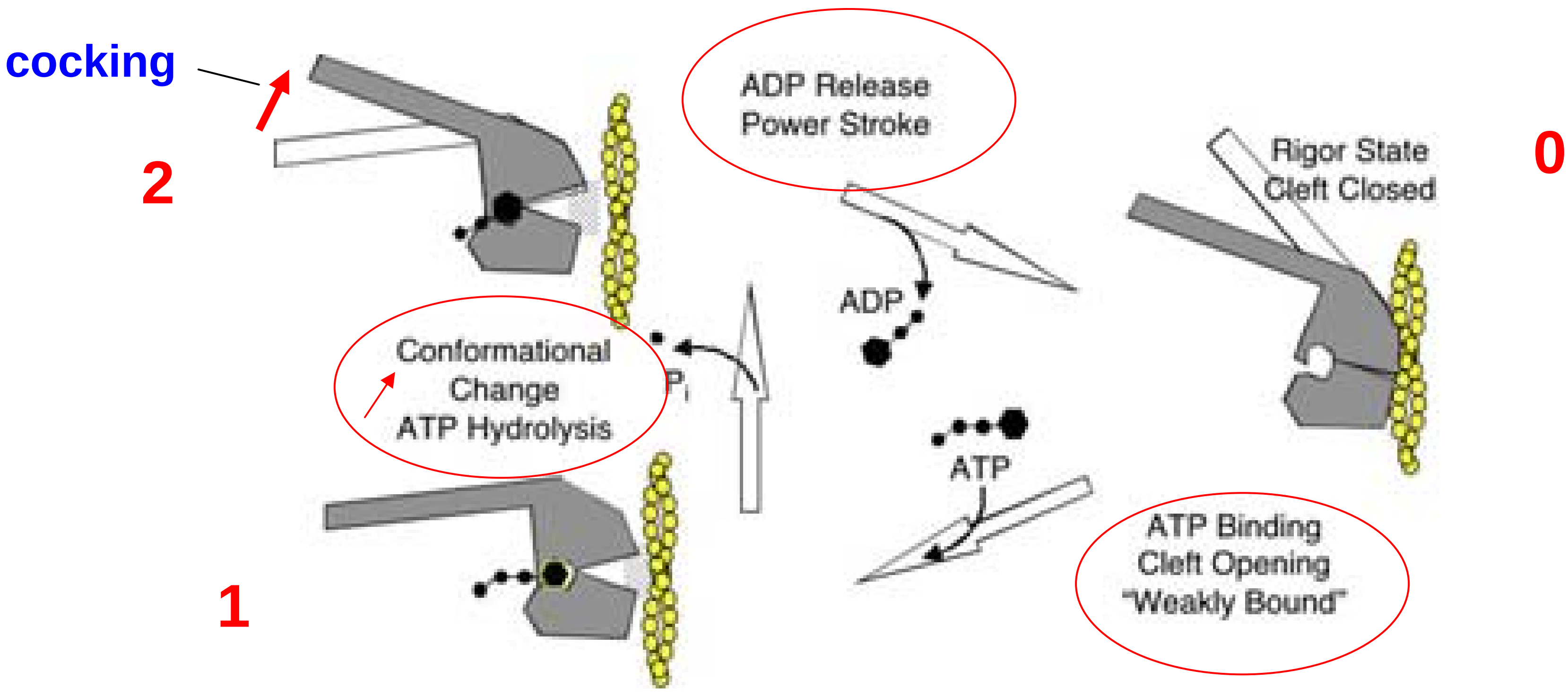
Molecular interactions that underlie muscle contraction



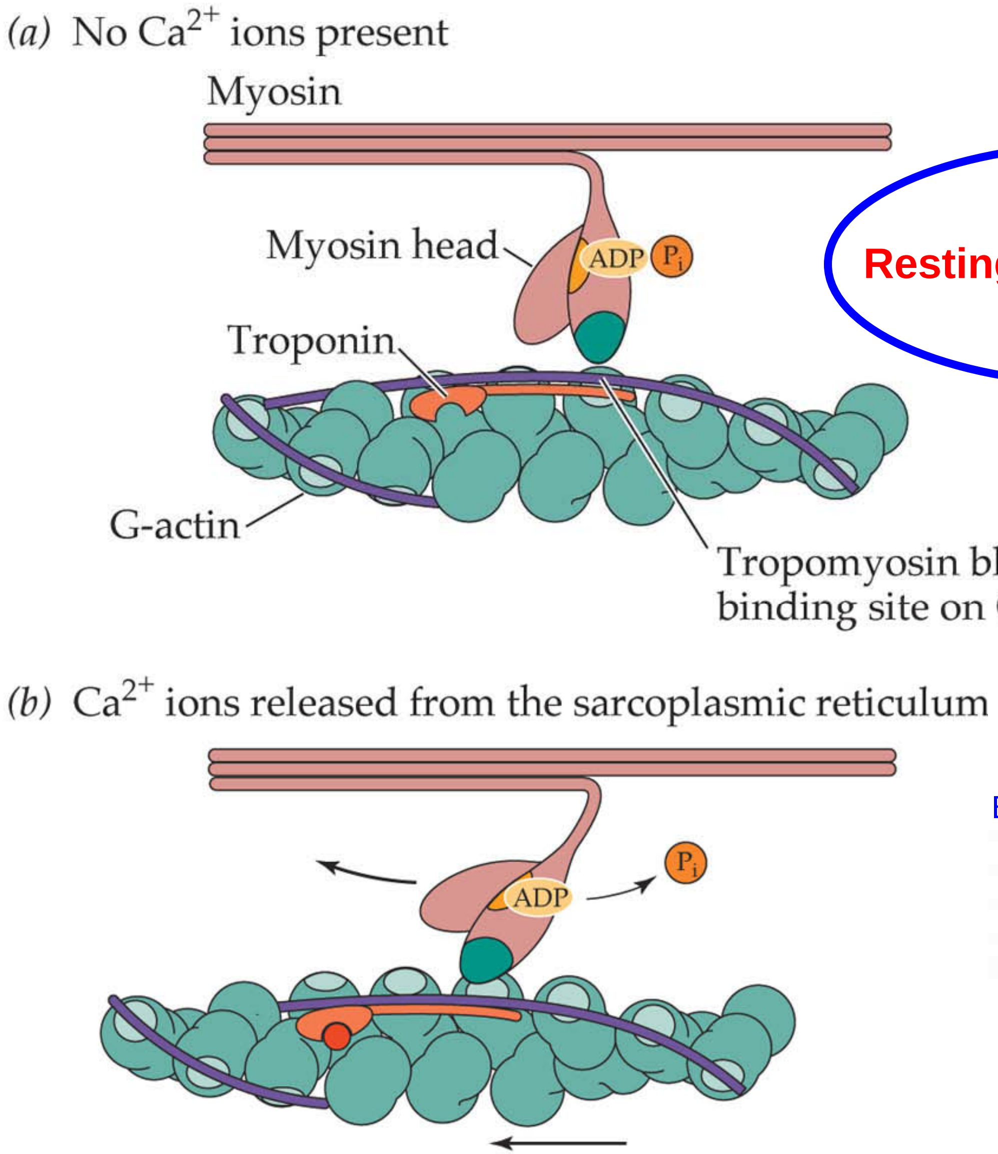
Molecular interactions that underlie muscle contraction



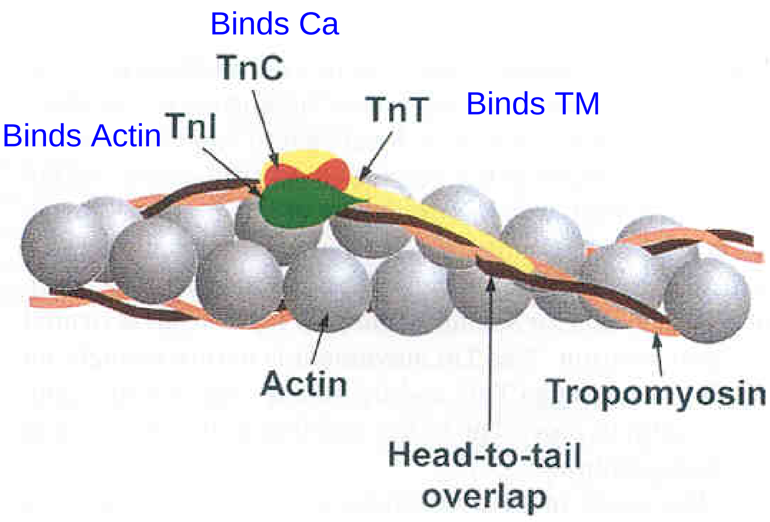




Regulation of contraction by Ca^{2+} and regulatory proteins



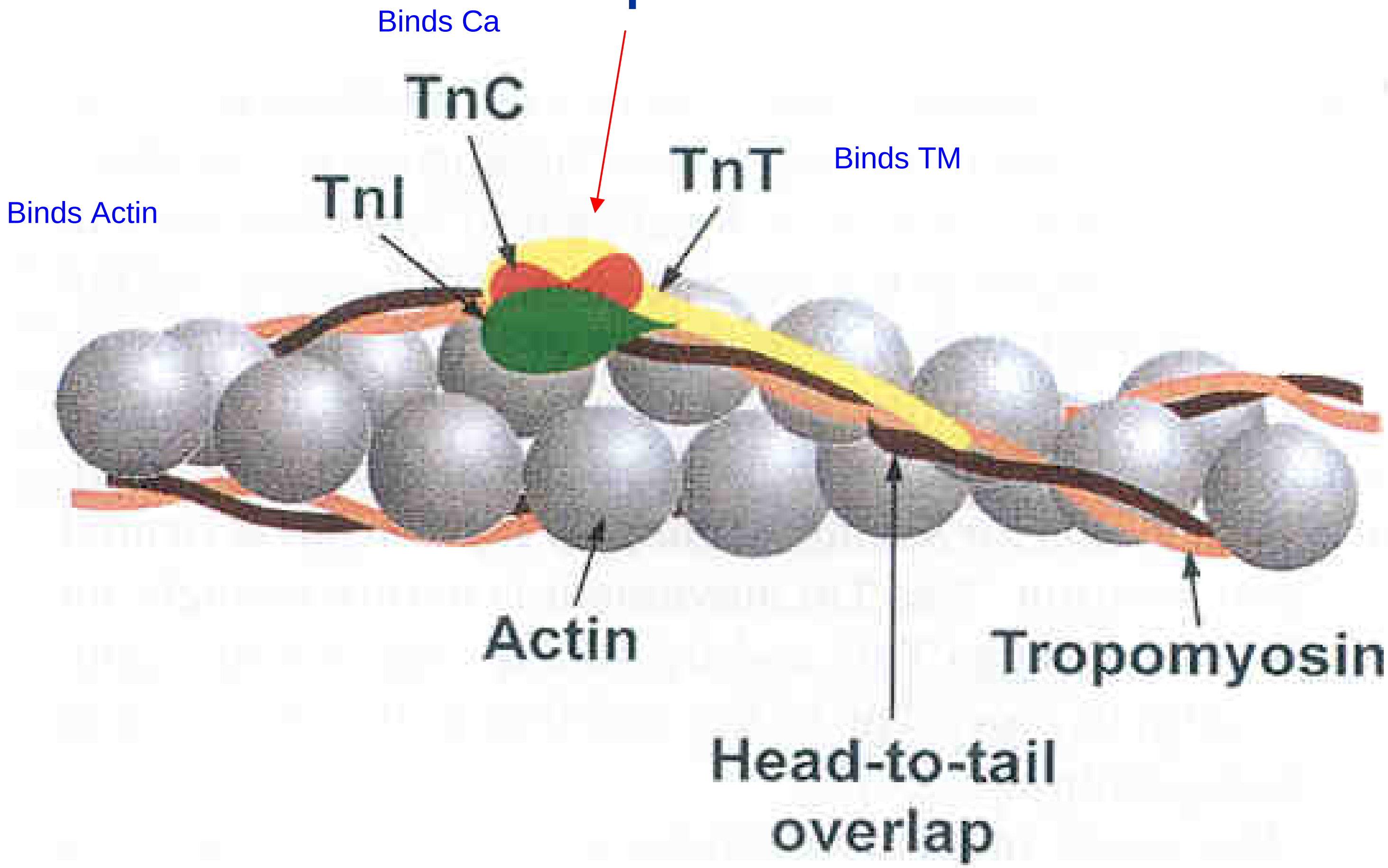
Resting muscle (primed)



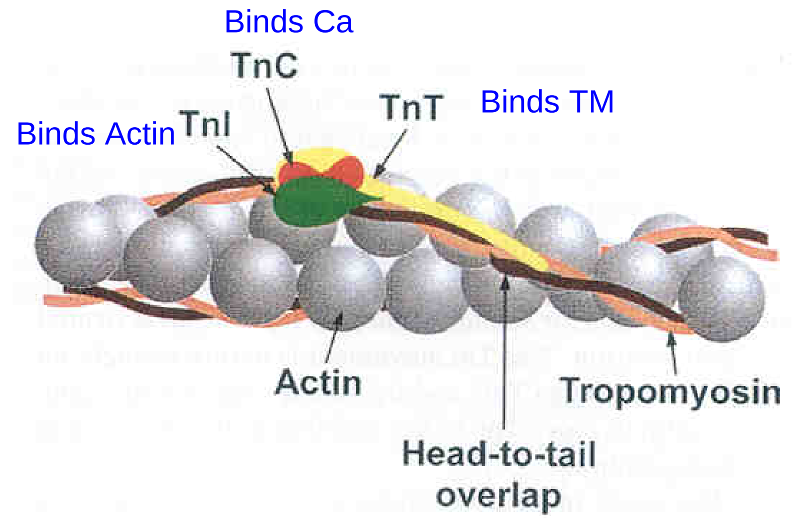
Muscle contracts only when Ca^{2+} is available

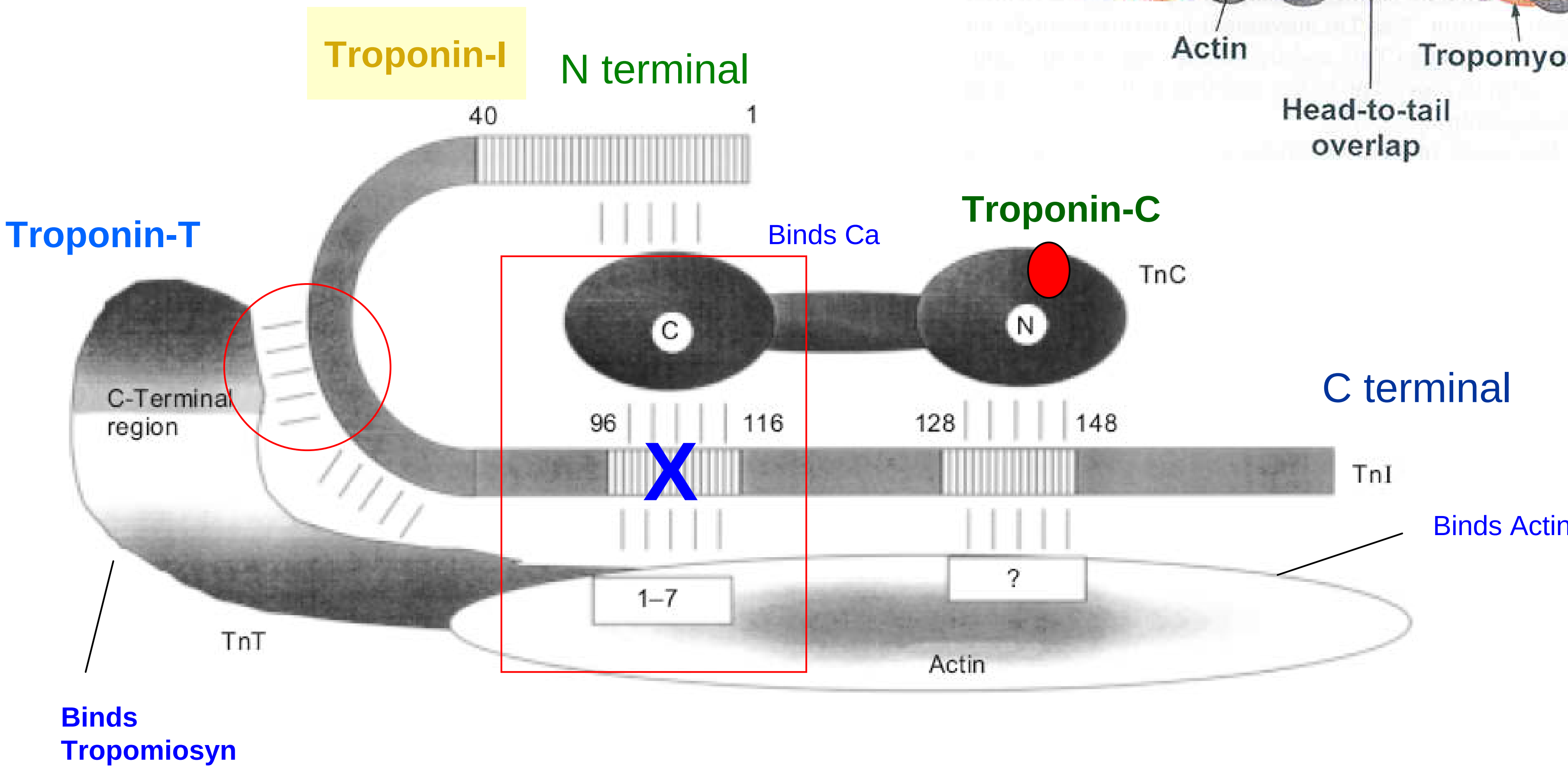
Regulation of contraction by Ca^{2+} and regulatory proteins

Troponin has 3 subunits

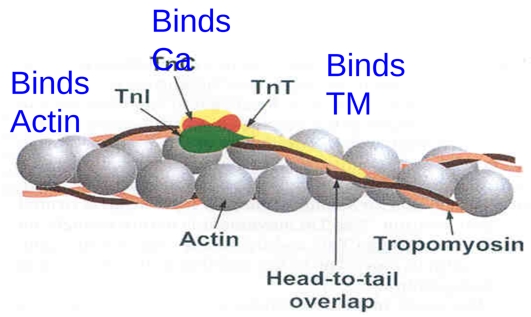


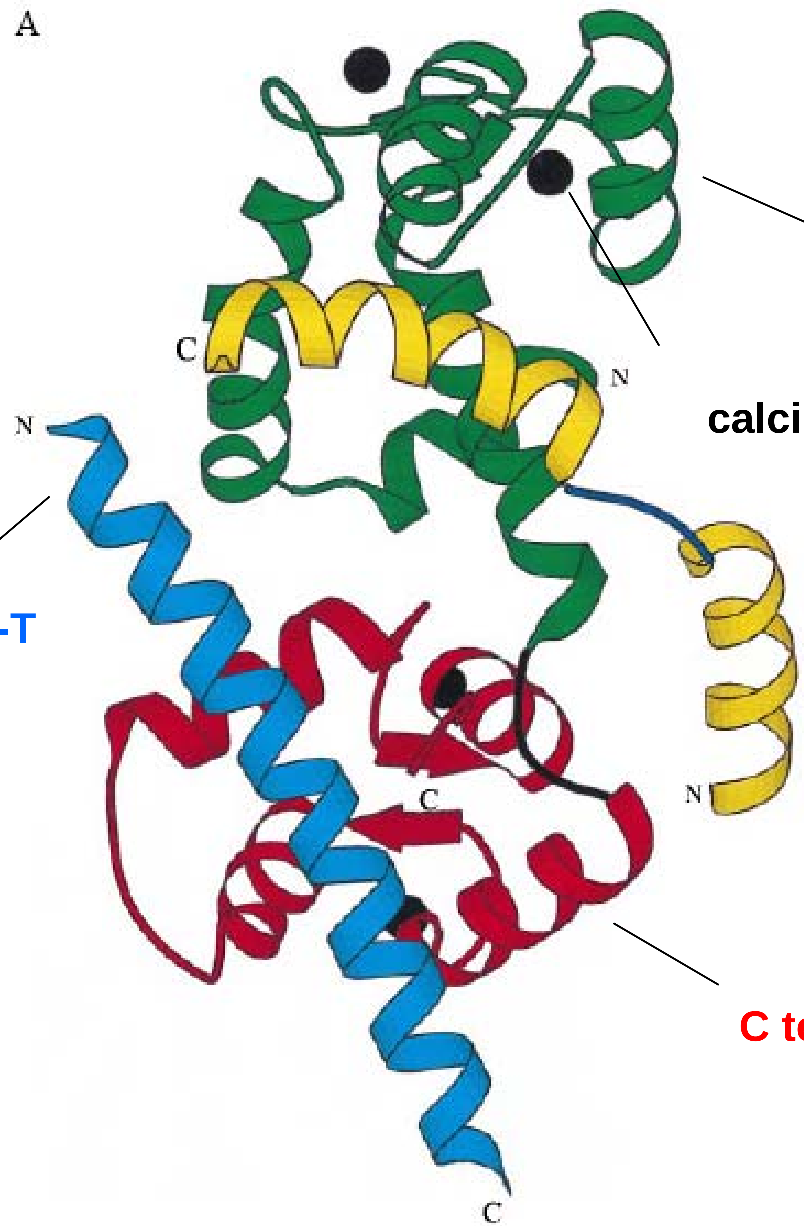
Regulation of contraction by Ca^{2+} and regulatory proteins





Structure Troponin





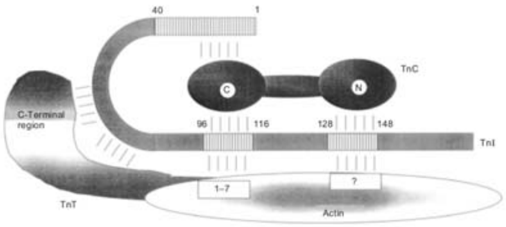
N terminal Troponin-C

calcium

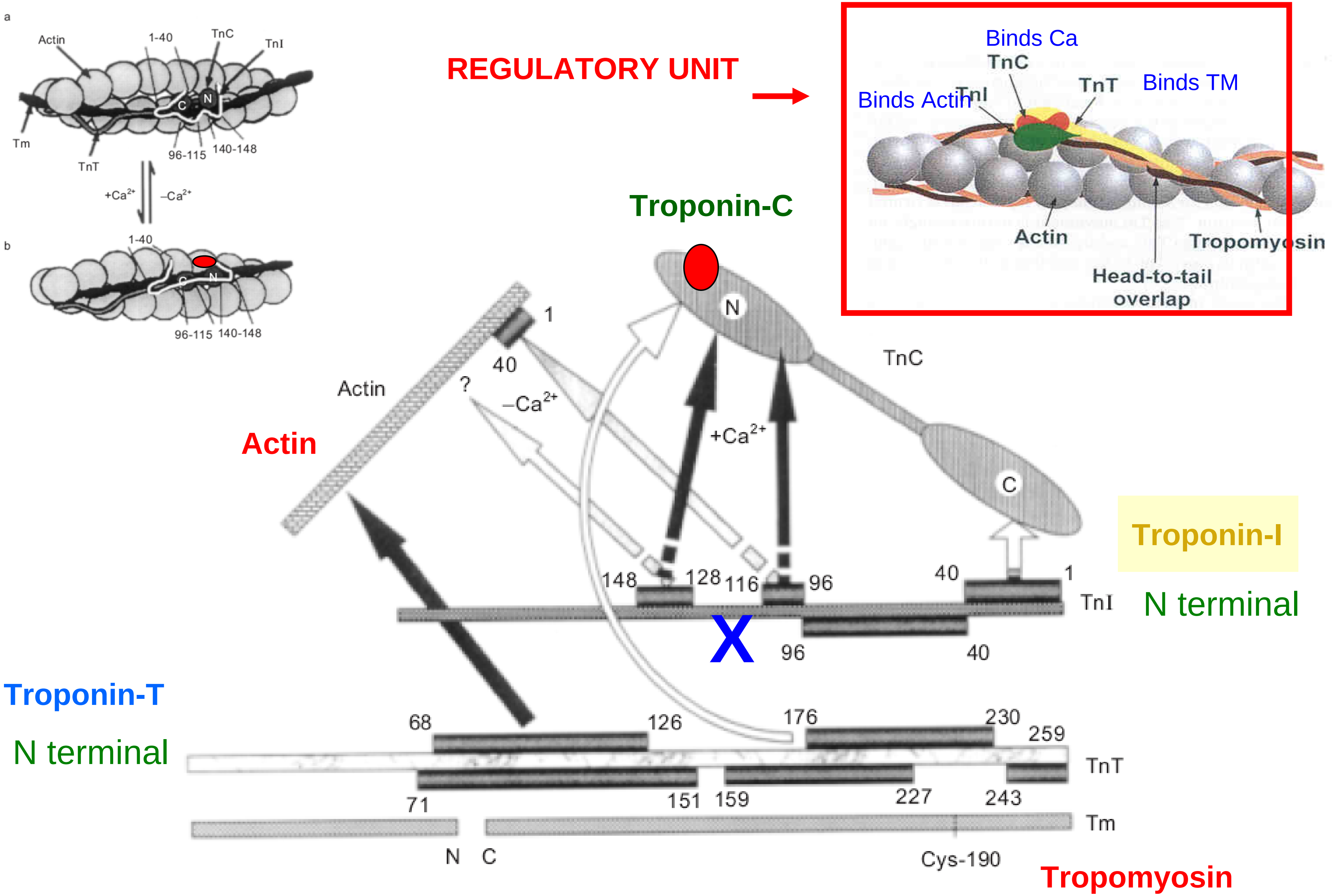
Troponin-T

Troponin-I

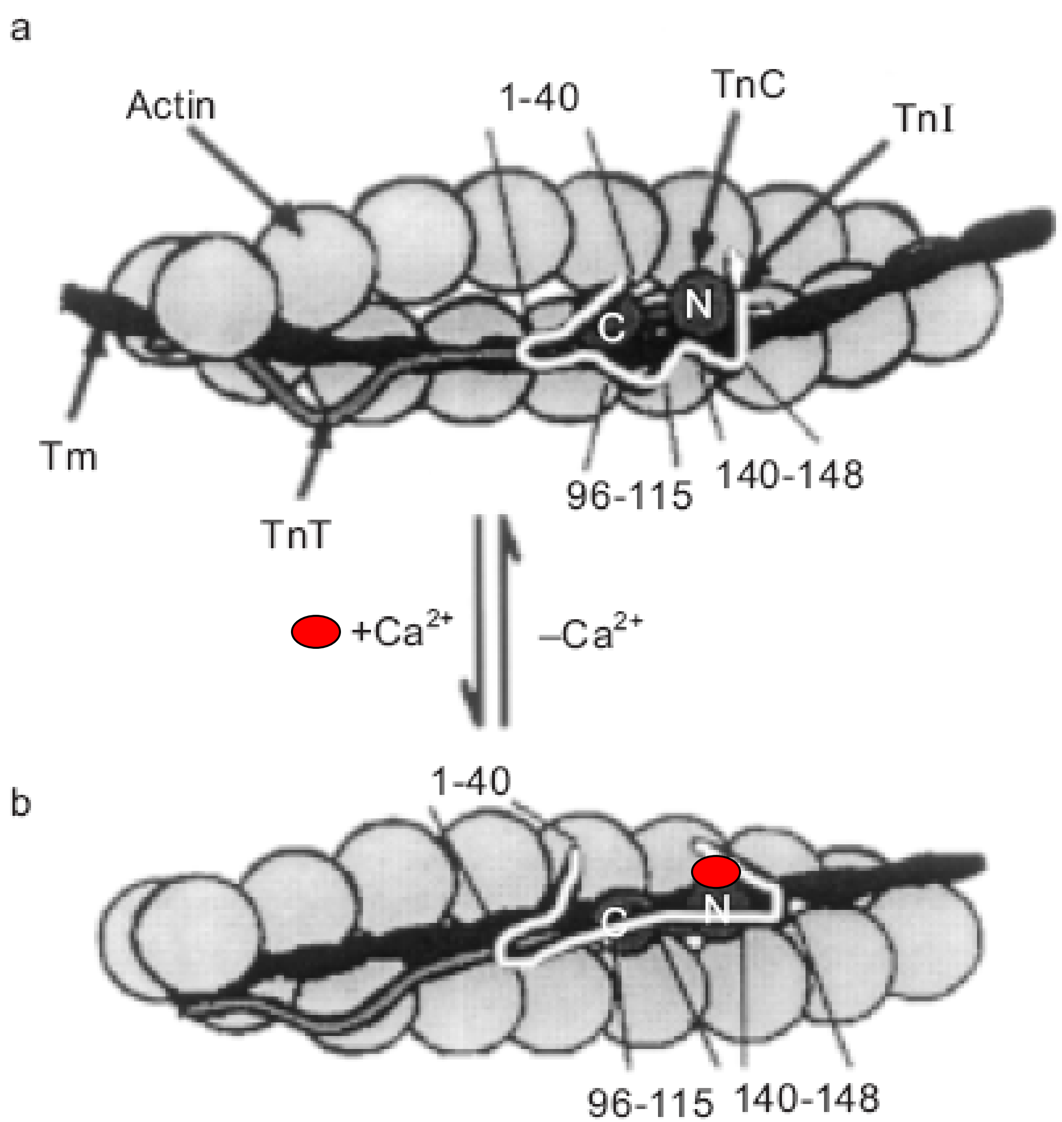
C terminal Troponin-C



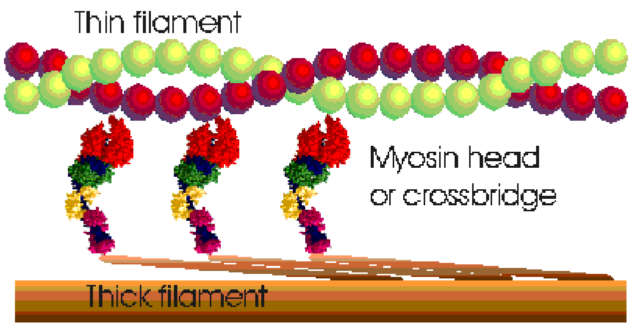
Regulation of contraction by Ca^{2+} and regulatory proteins

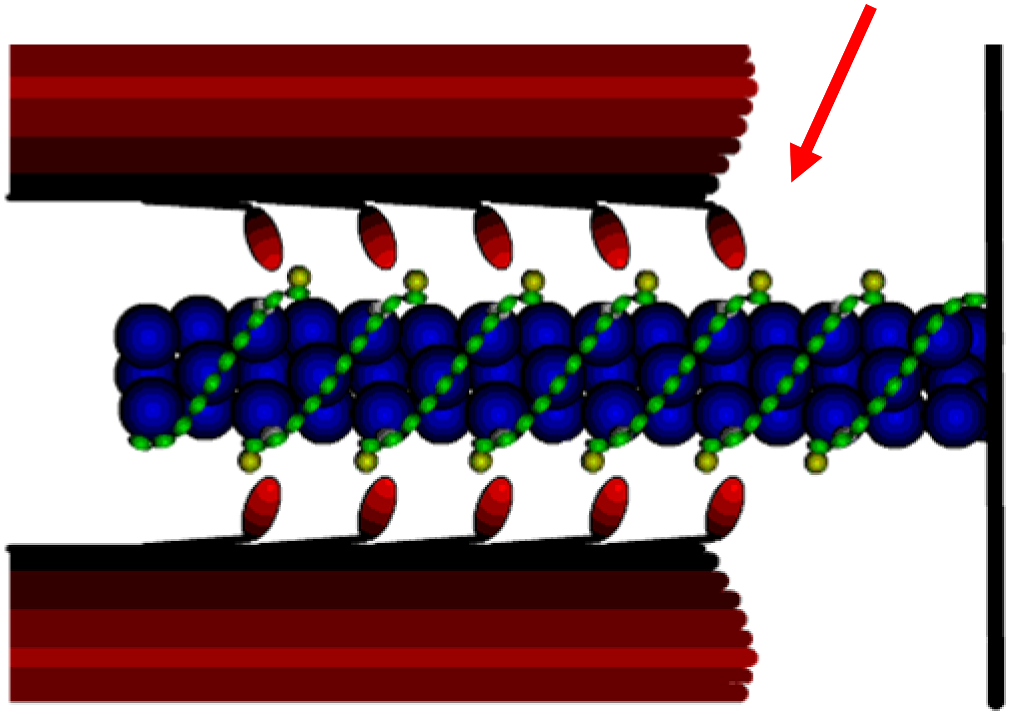


Regulation of contraction by Ca^{2+} and regulatory proteins

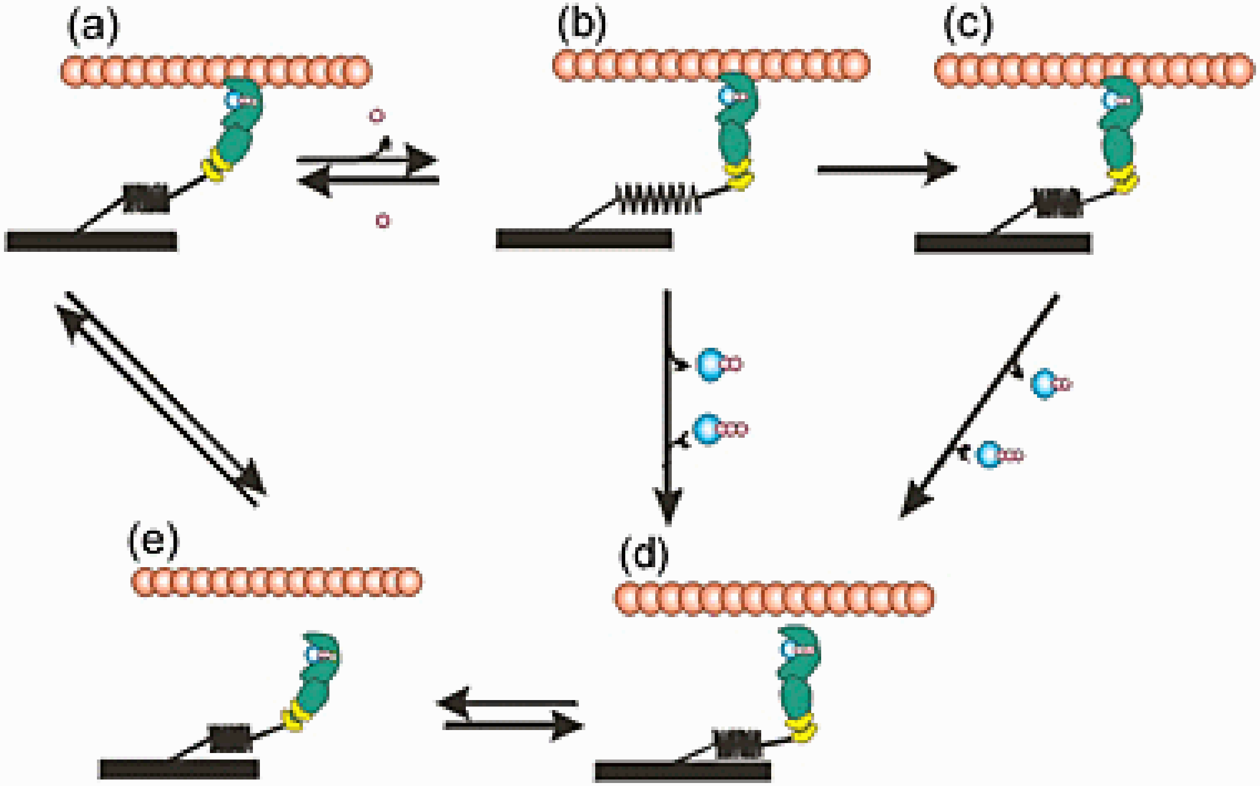


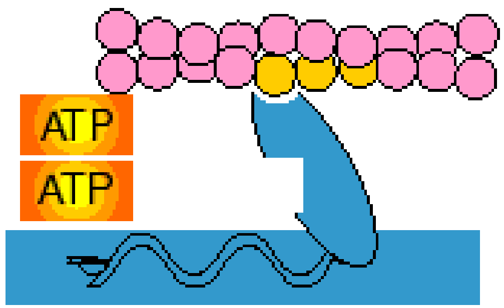
Regulation of contraction by Ca^{2+} and regulatory proteins

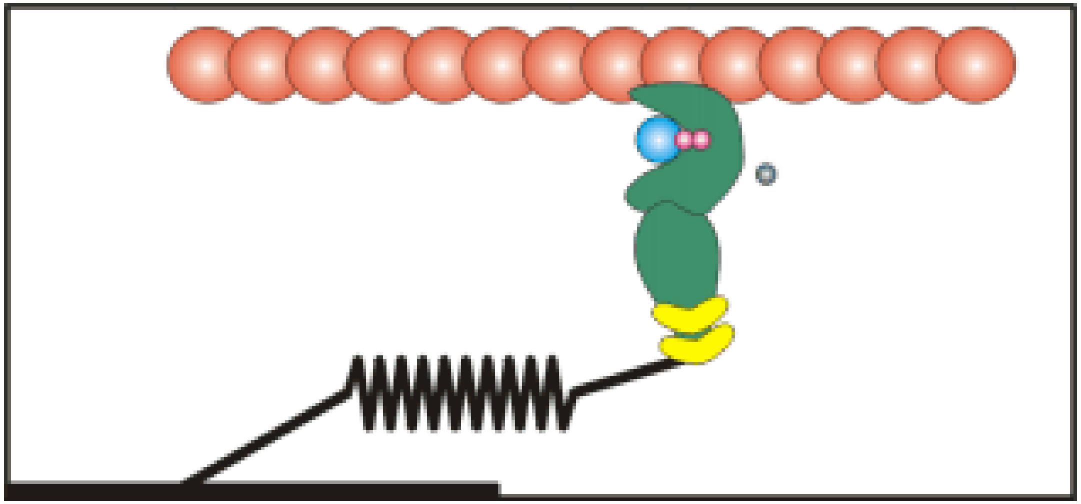




The action potential inhibits the calcium pumps, and calcium escapes from the **sarcoplasmic reticulum.**

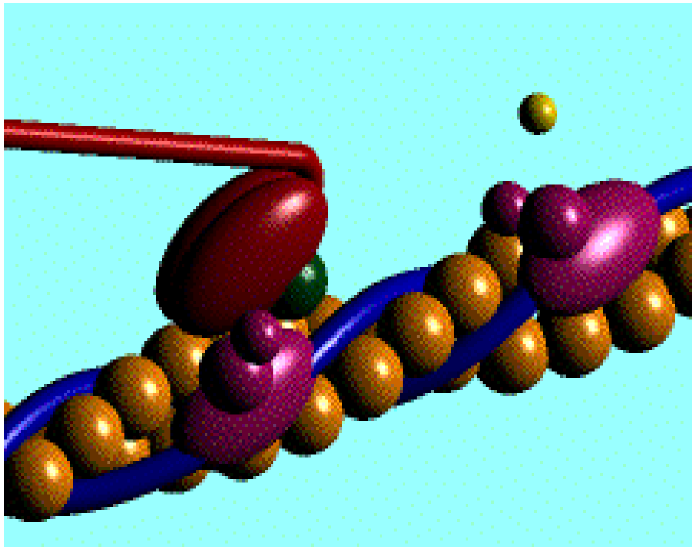

(a)
(b)
(c)
(d)
(e)

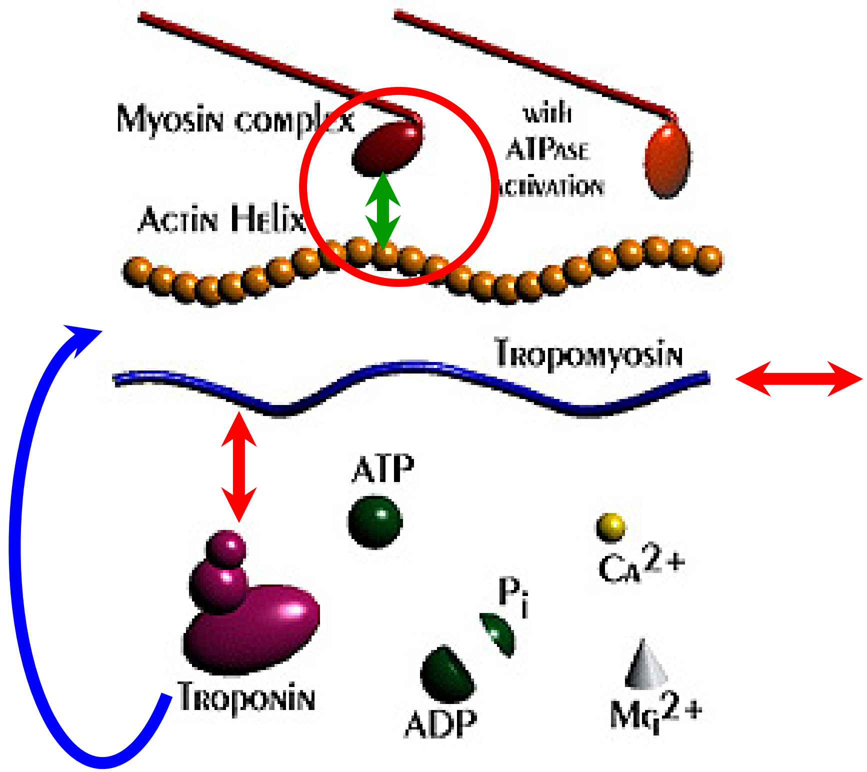

ATP
ATP

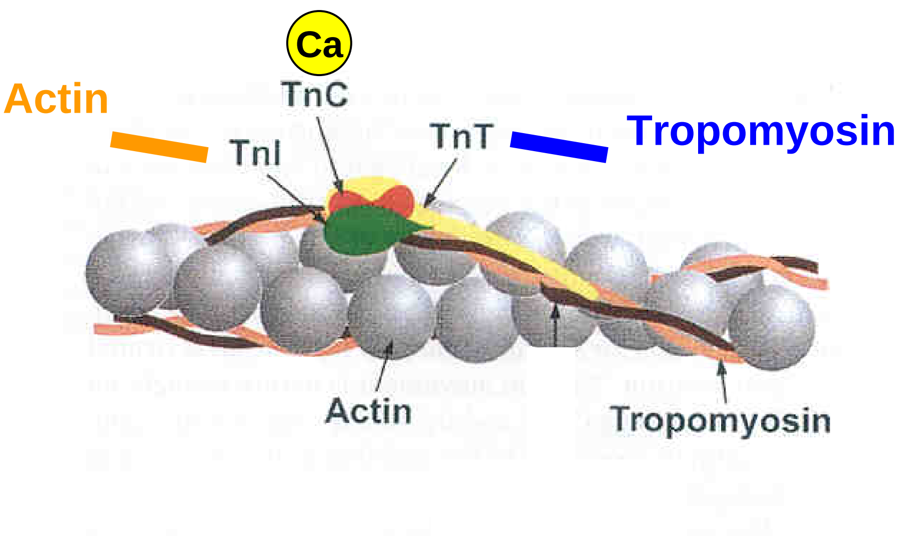


Regulation of contraction by Ca^{2+} and regulatory proteins

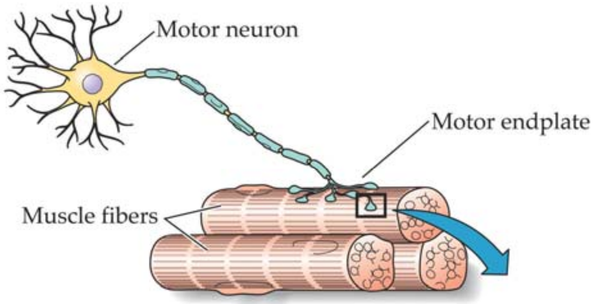
Contraction = the right interaction of myosin and actin





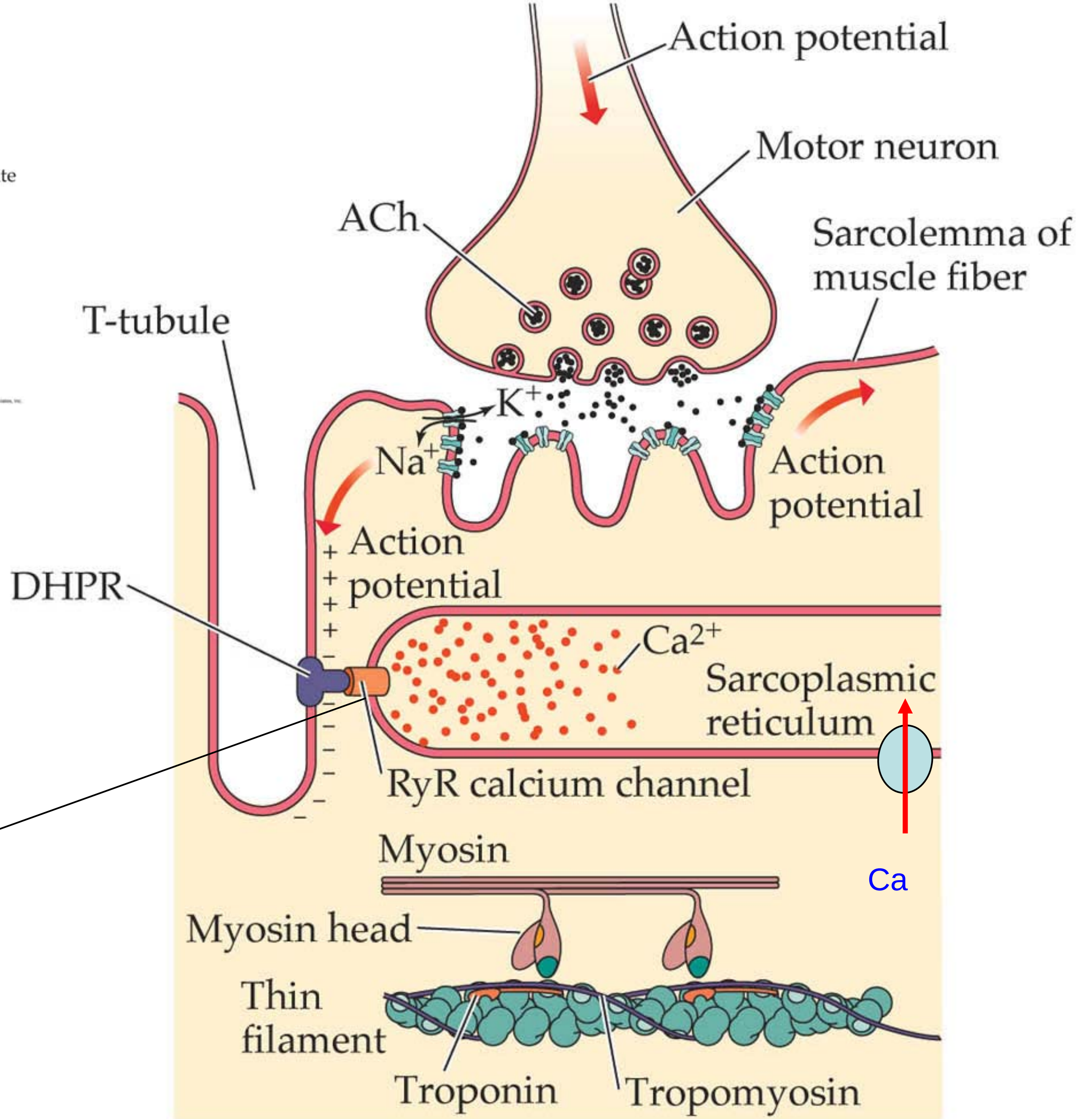


Excitation–contraction coupling



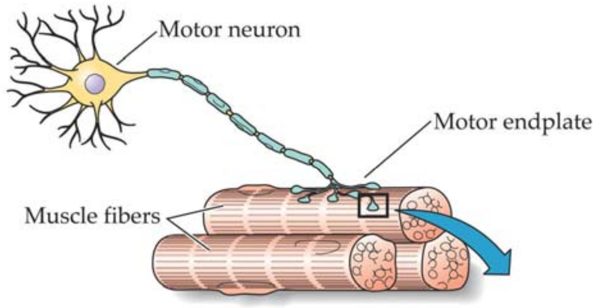
Dihydropyridine receptor

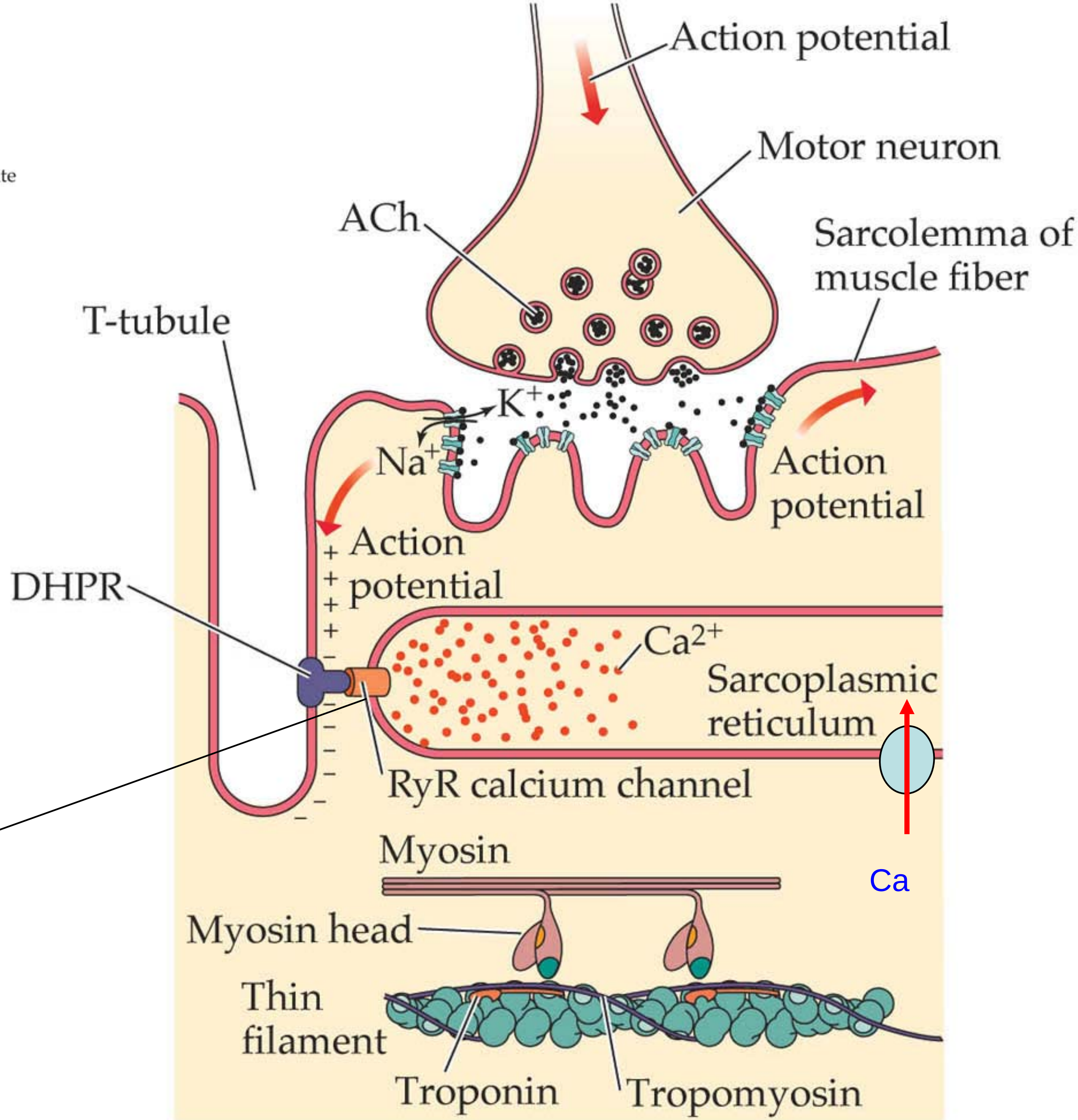
Ryanodine receptor



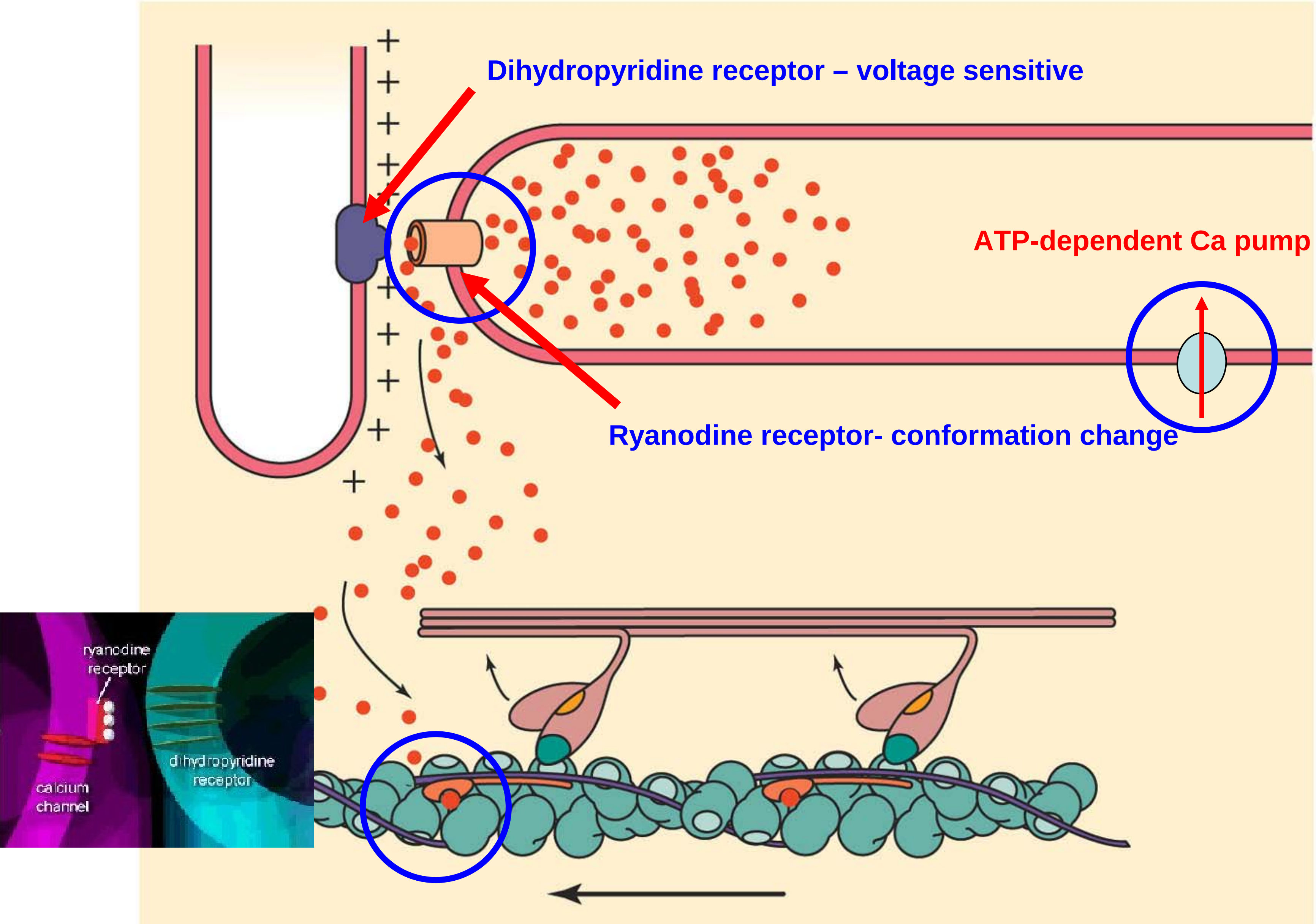
T tubules and Sarcoplasmic reticulum

Excitation-contraction coupling





Excitation-contraction coupling



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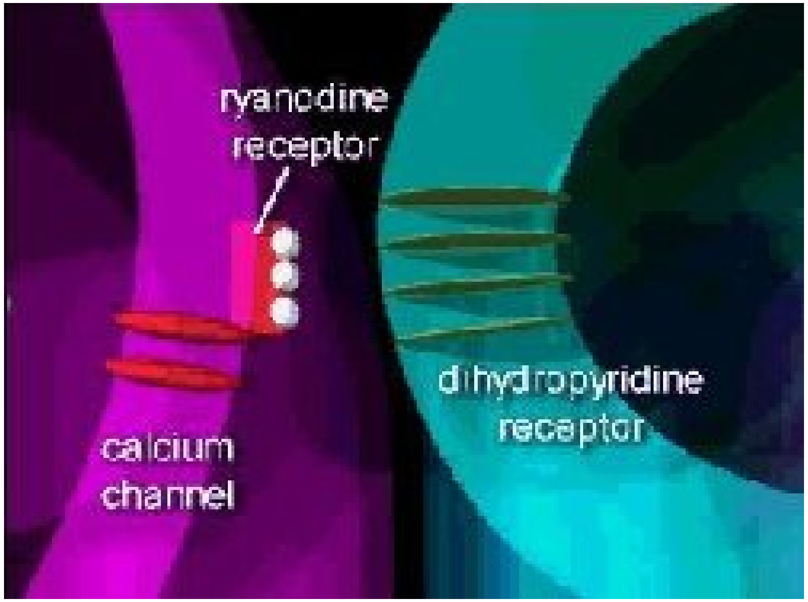
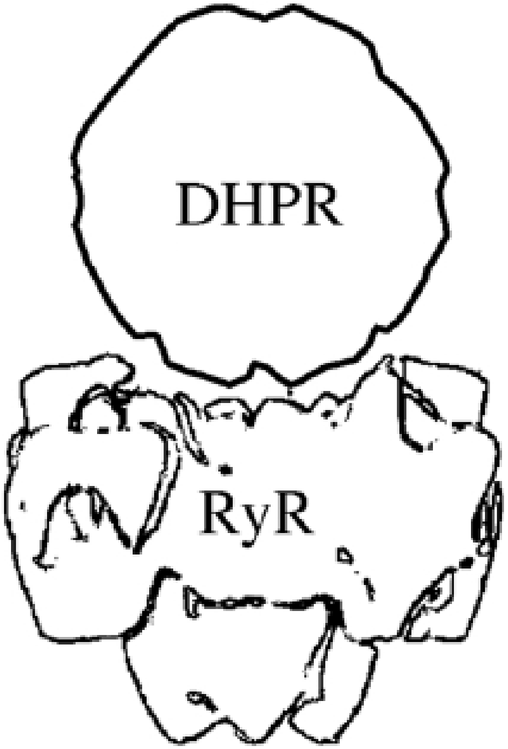
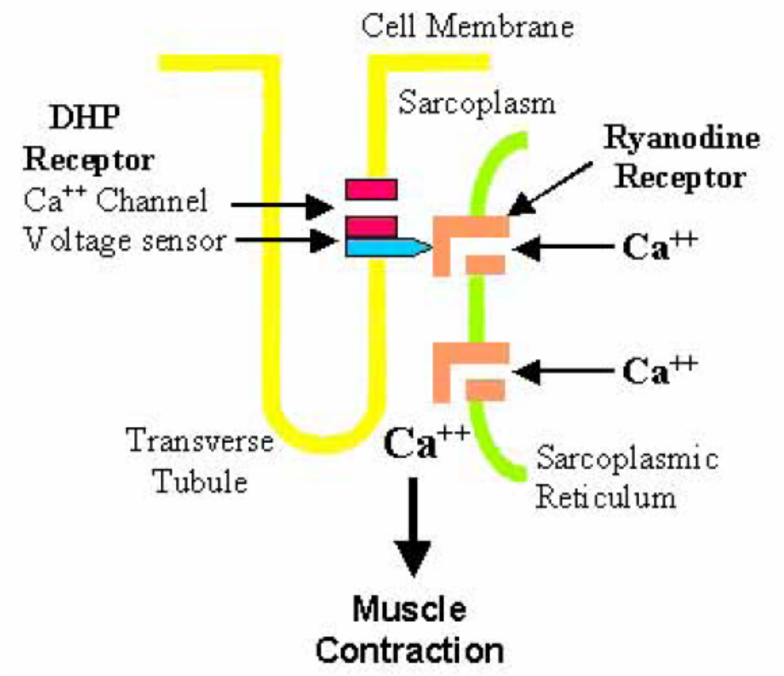
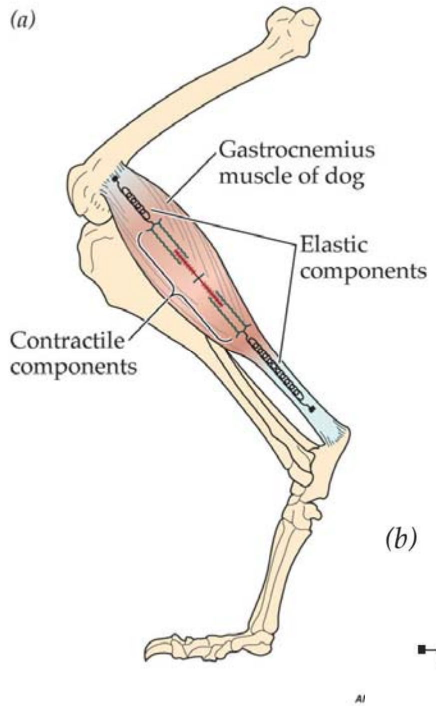
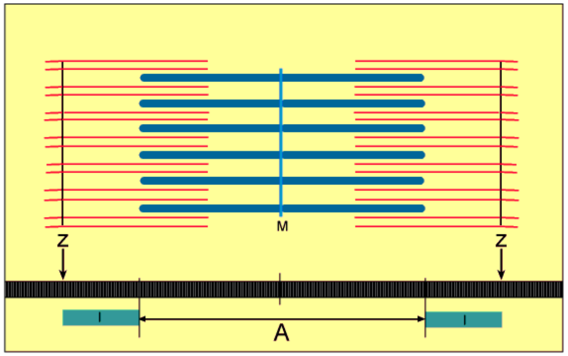


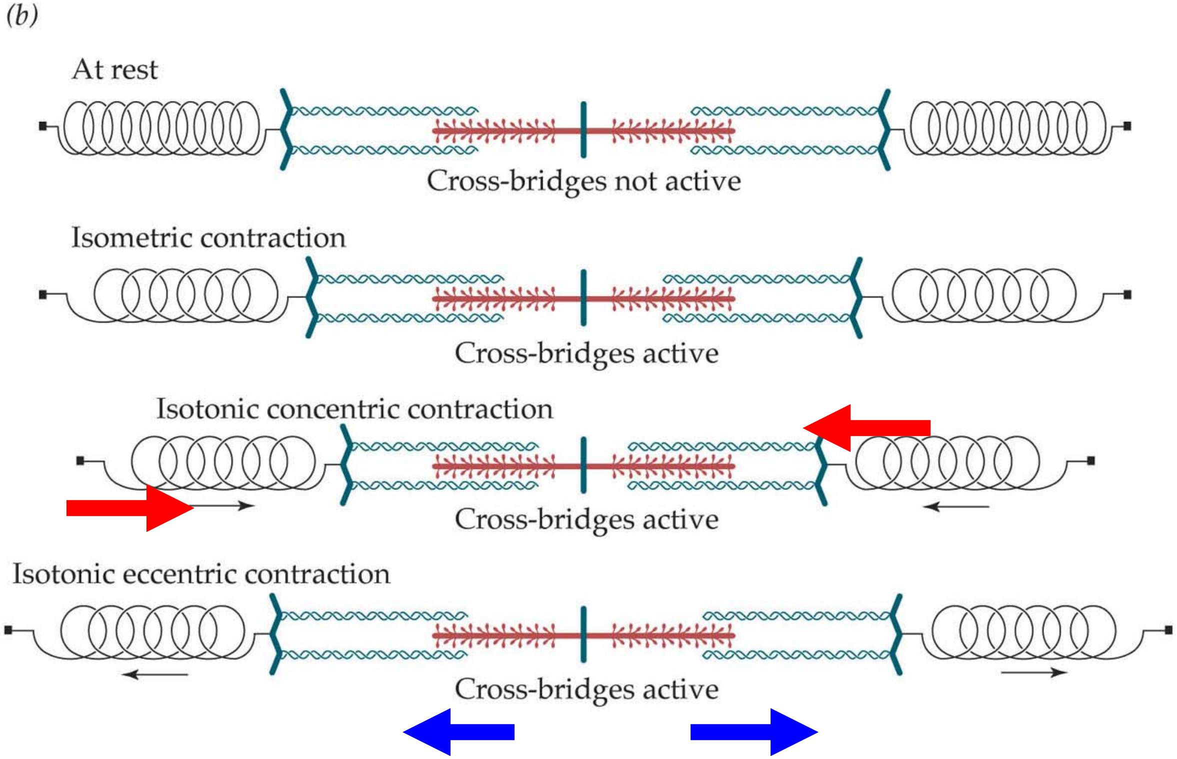




Interaction between contractile and elastic components







Same length

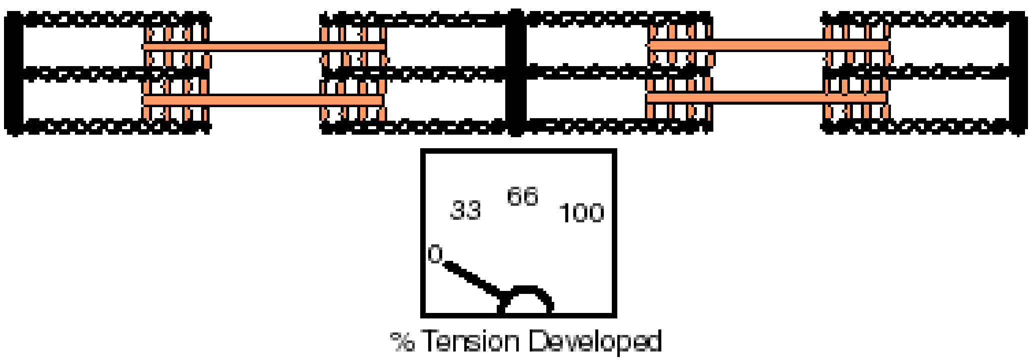
Change of length

Concentric and eccentric contractions are isotonic contractions

Whole Skeletal Muscles: Isometric and isotonic contractions

Twitch: force developed by a muscle fiber in response to a unique electrical or nervous stimulation.

The force exerted by a muscle on a load is called **muscle tension**

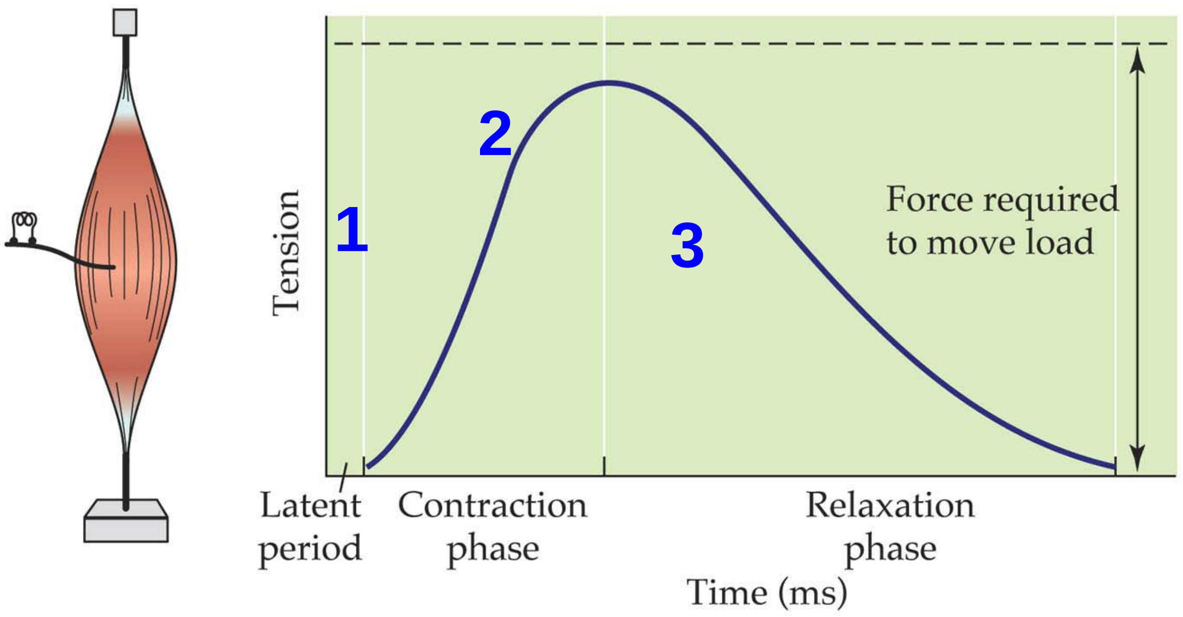


The tension is proportional to the number of attached cross-bridges

Whole Skeletal Muscles: Isometric and isotonic contractions

ISOMETRIC: same length

(a) Isometric recording



The force exerted by a muscle on a load is called **muscle tension**

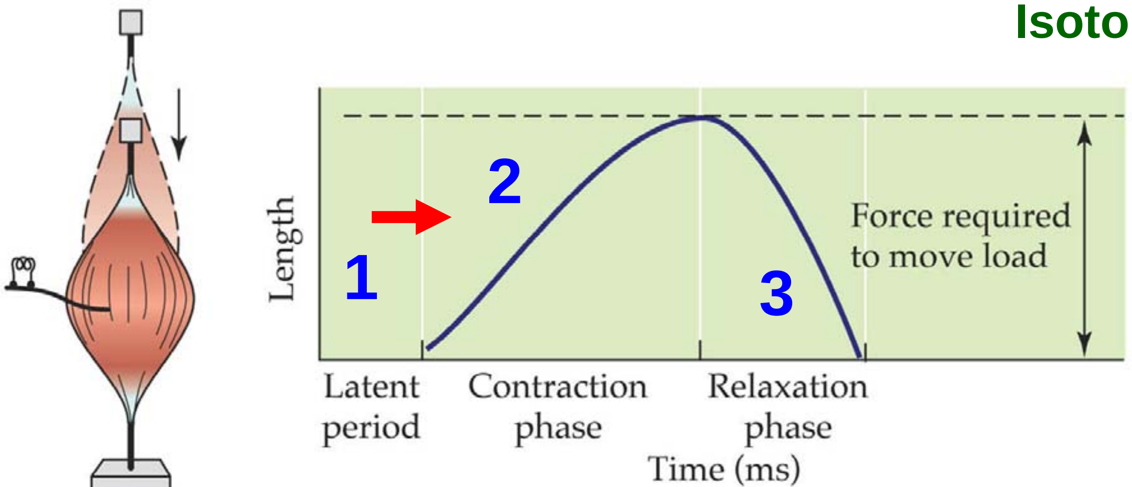
The muscle contracts and do not move the load

Whole Skeletal Muscles: Isometric and isotonic contractions

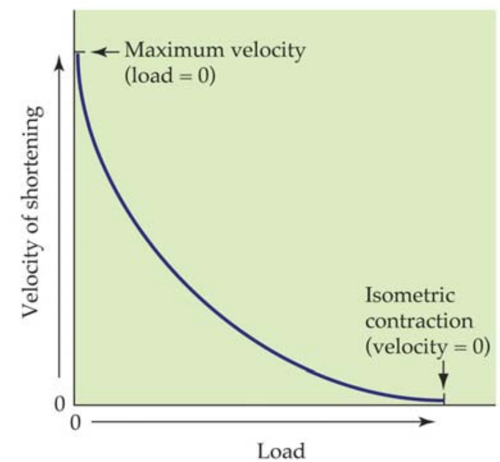
ISOTONIC: same tension

If the tension is > force of the load
The muscle changes length
Isotonic contraction

(b) Isotonic recording

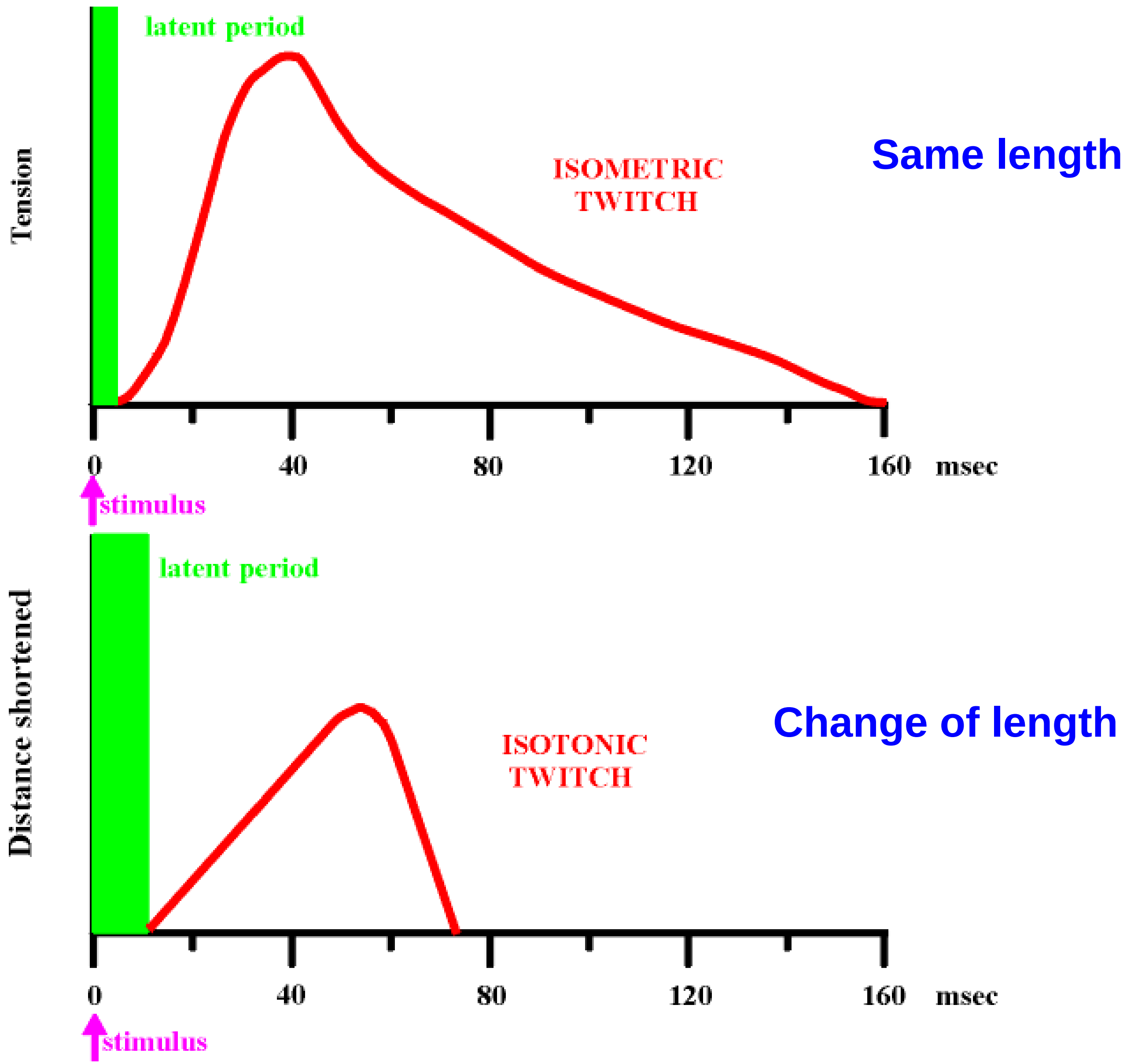


The muscle <u>shortens</u> and move **the load**

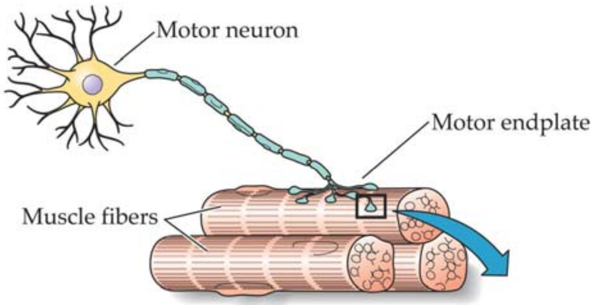


Velocity of shortening decreases as the load increases

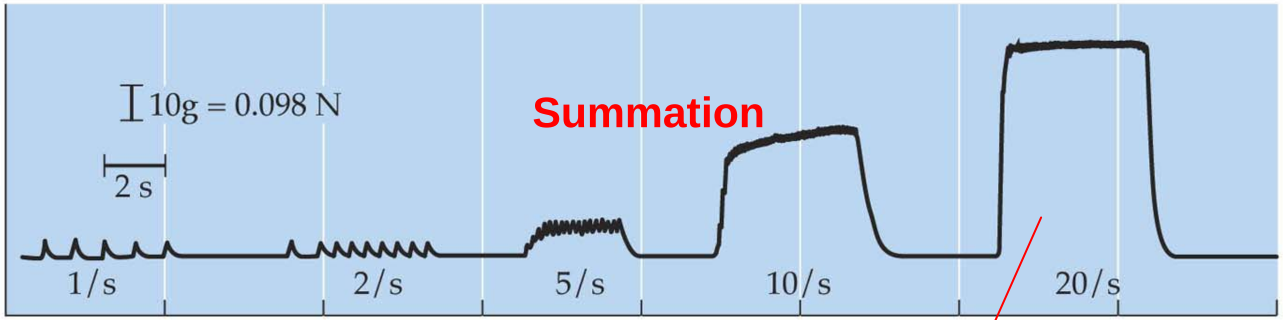
Whole Skeletal Muscles: Isometric and isotonic contractions



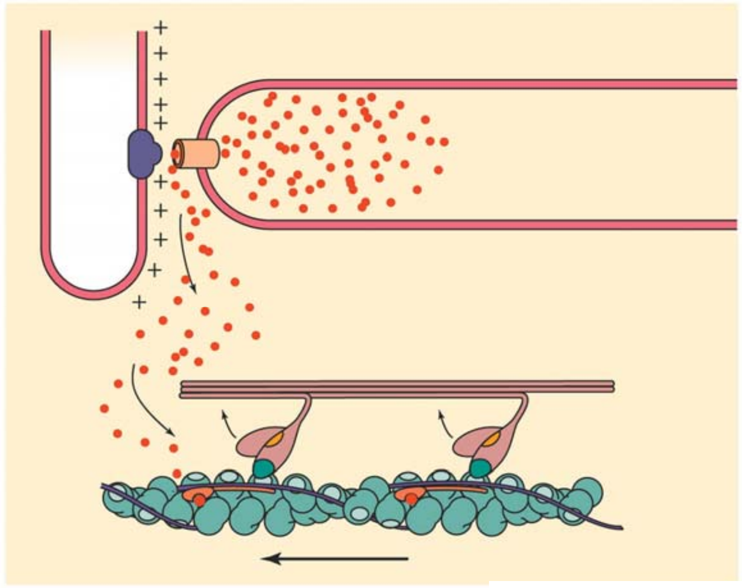
Summation and tetanus



The frequency of action potentials determines the tension developed by a muscle



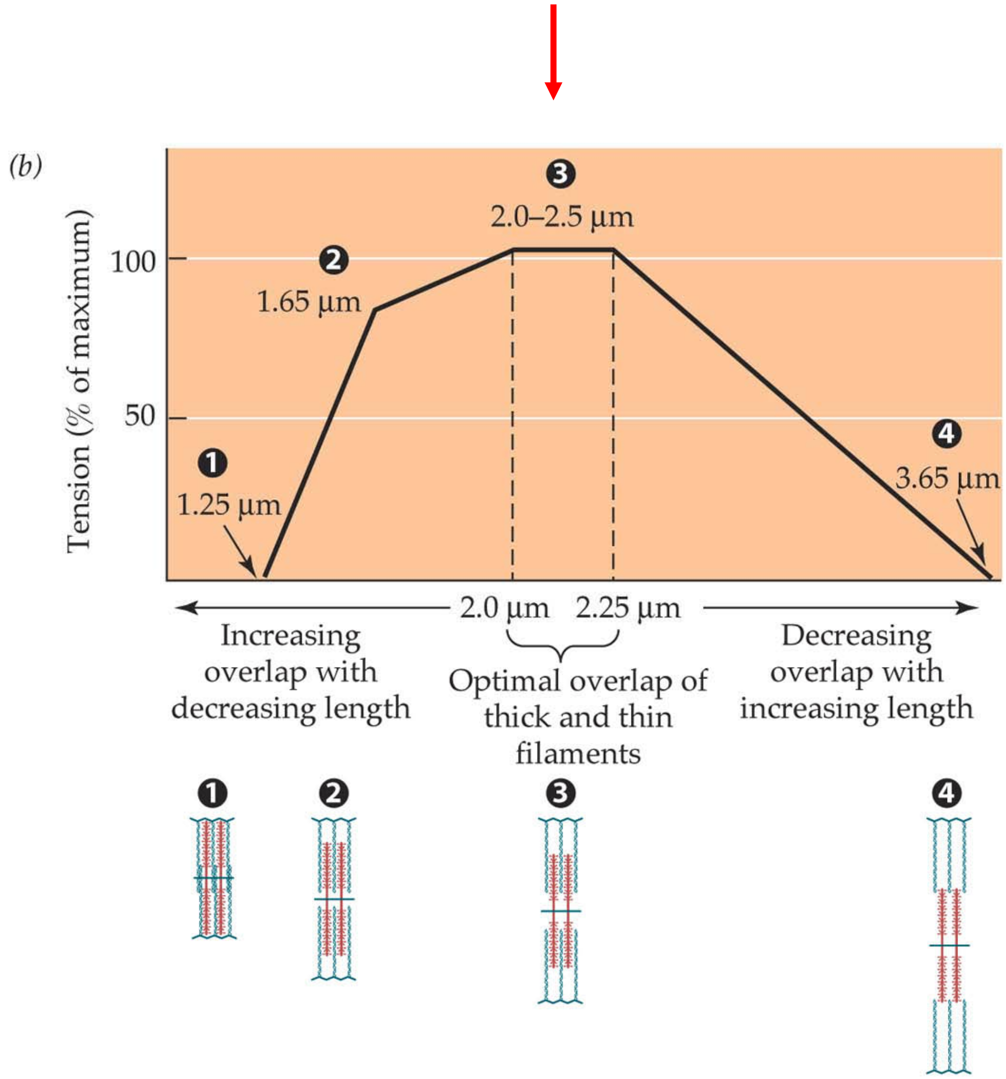
Tetanus : smoothly fused contraction



Sustained calcium in the cytoplasm permits summation and tetanus

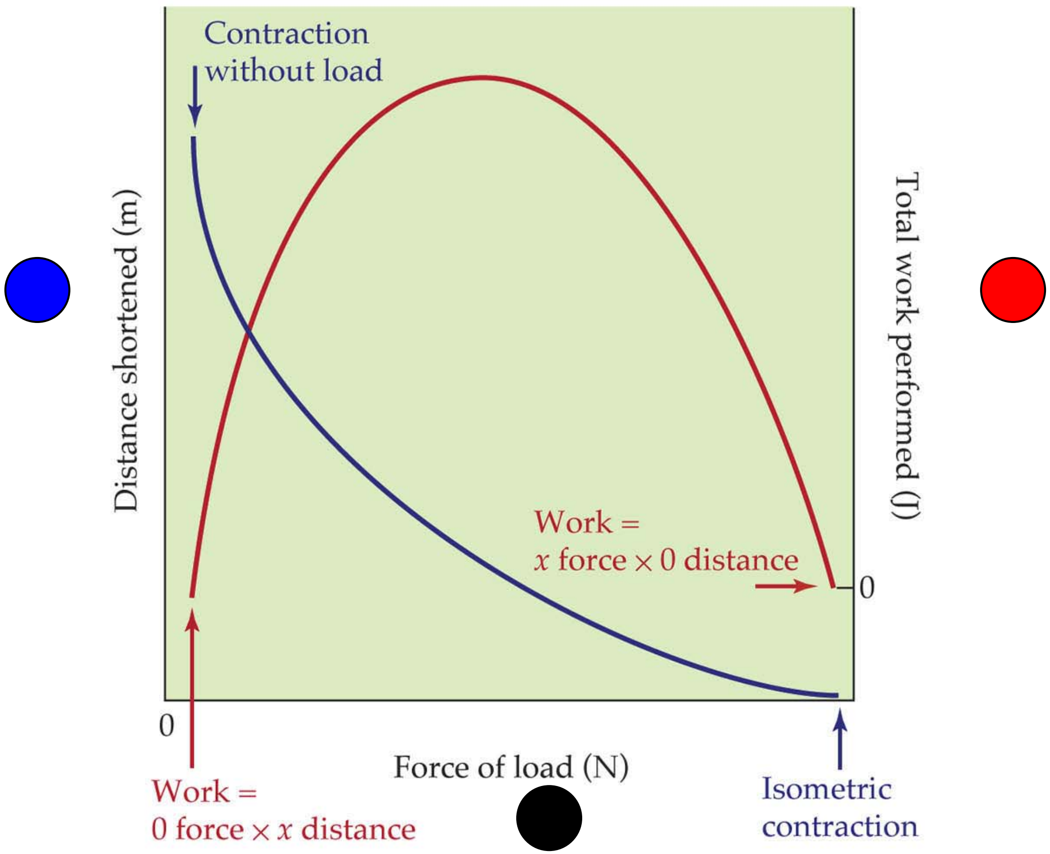
The relationship between length and tension produced by skeletal muscle

Muscles develop the most tension if they start contracting at an ideal length.



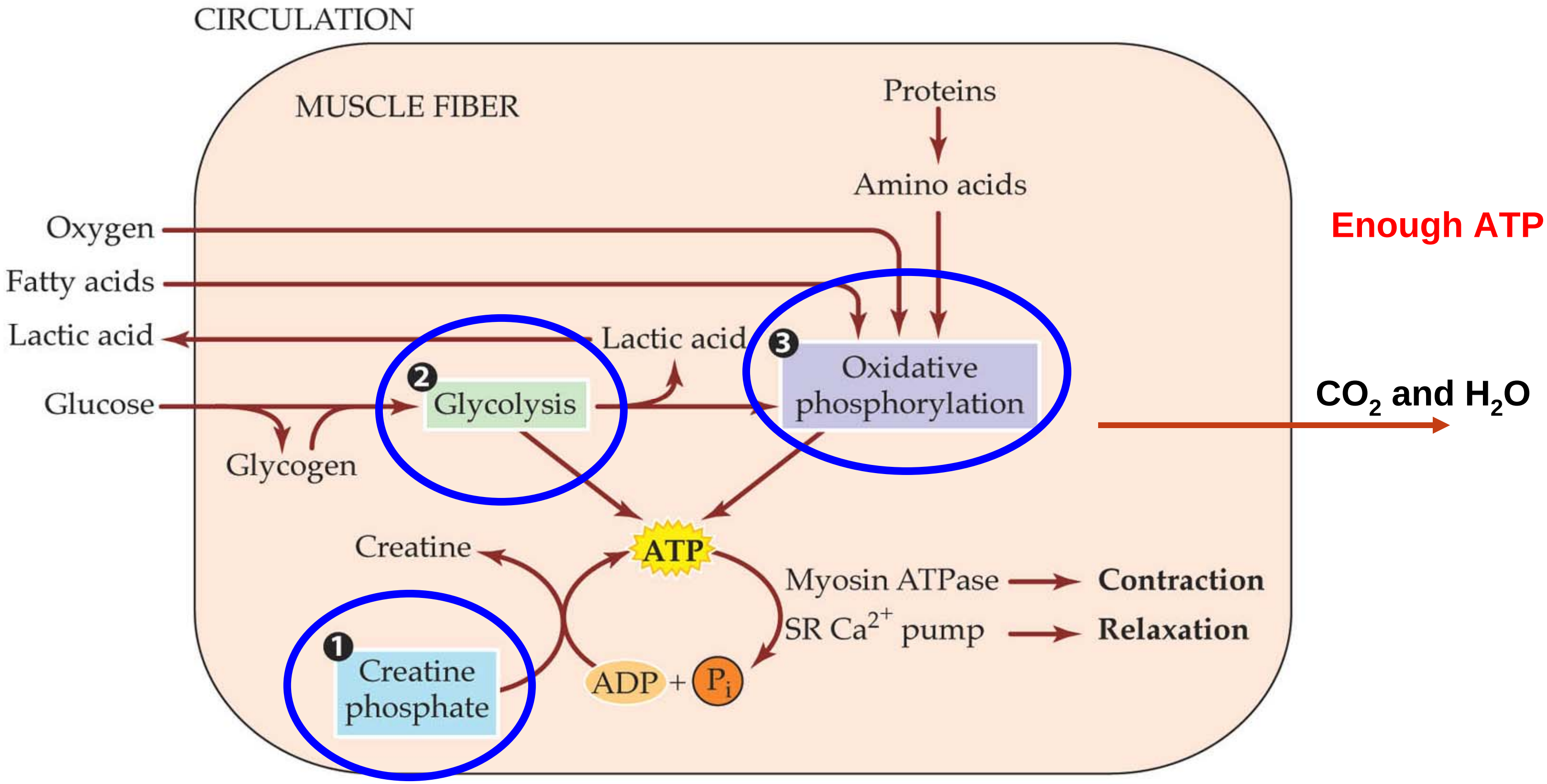
Work done by a muscle during contraction

Work: force x distance



The force exerted by a muscle is proportional to its volume

MUSCLE ENERGETICS: The production and use of ATP



Enough ATP for seconds!

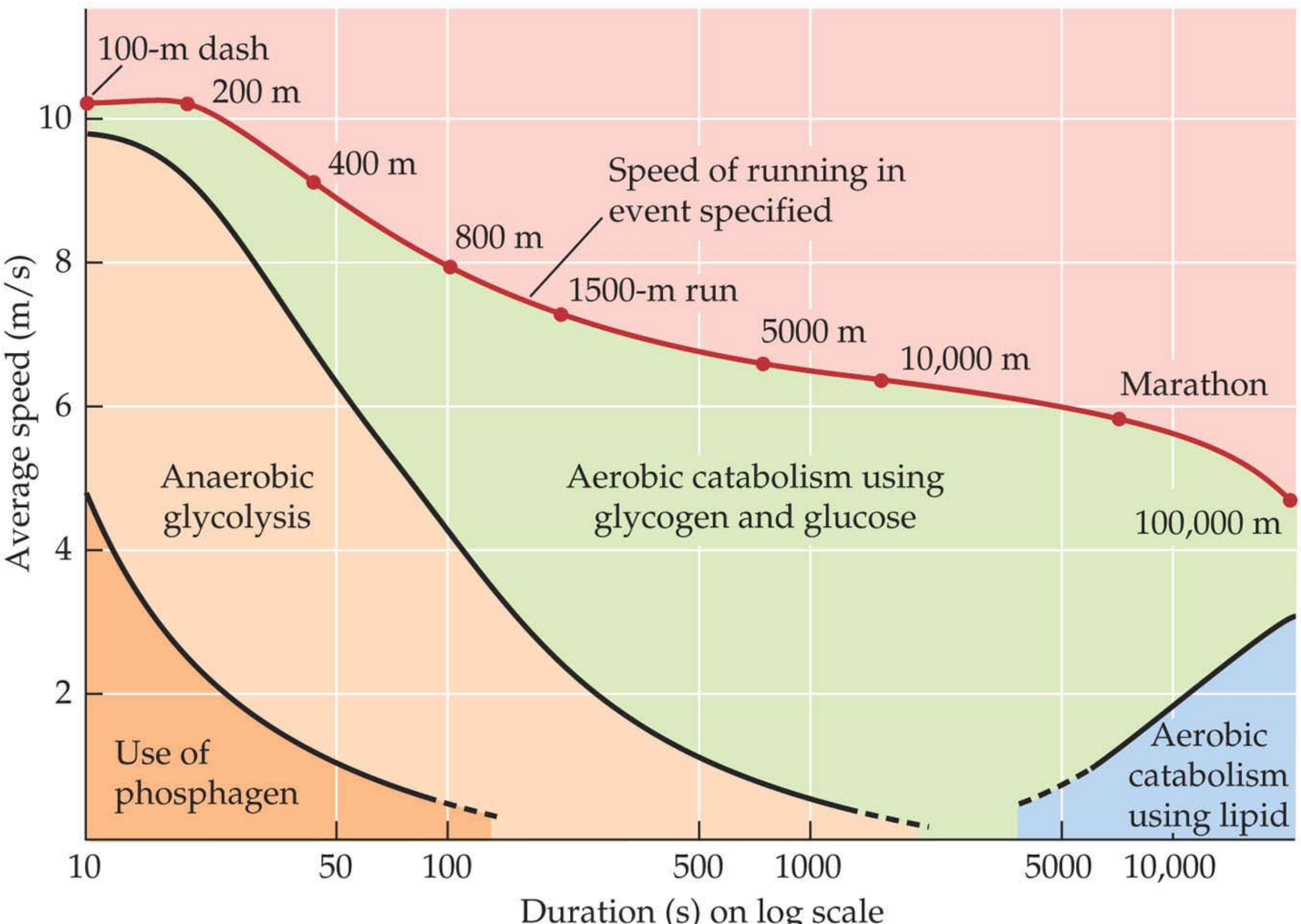
How fast?
How much?
How quickly can accelerate?

Characteristics of the three principal mechanisms of ATP production in vertebrate muscle

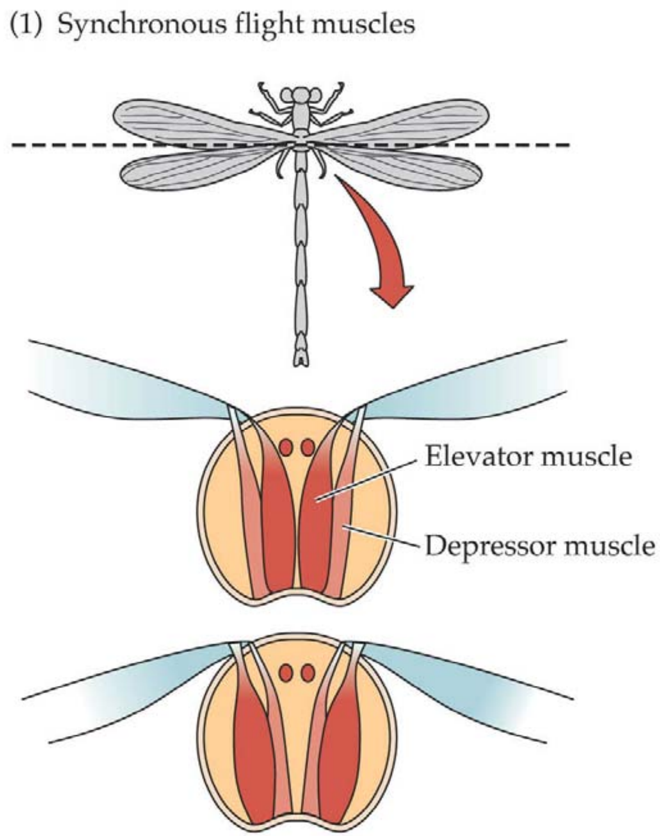
	Aerobic catabolism	Anaerobic glycolysis	Use of phosphagen
Peak rate of ATP synthesis	Low	High	Very high
Maximum yield of ATP in one episode of use	Very high (indefinite)	Low	Very low
Rate of acceleration	Low	High	High

Note

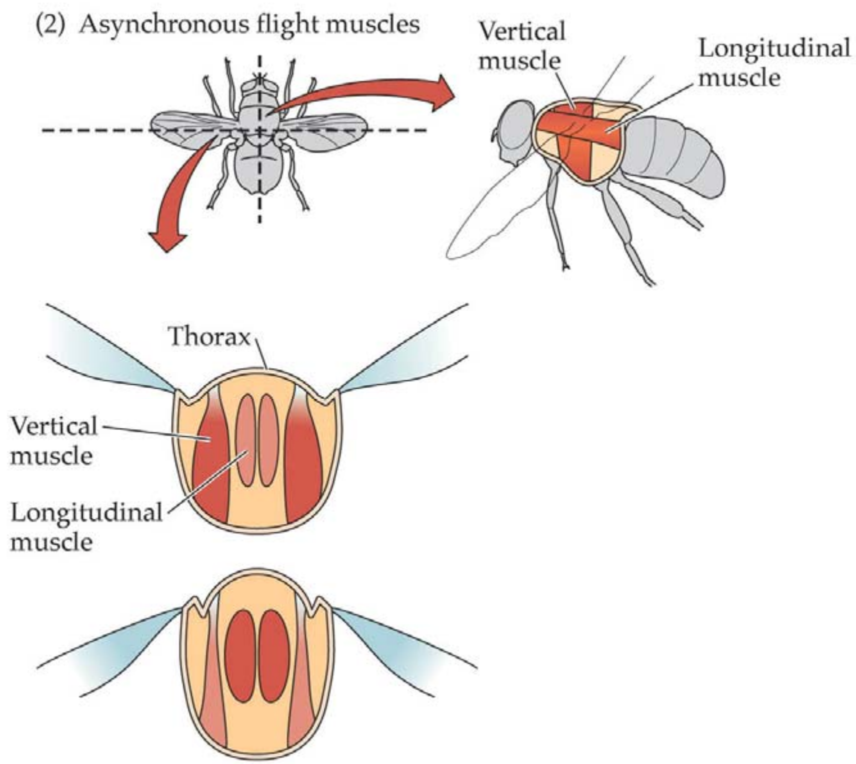
The mechanisms of meeting the ATP costs of world-class competitive running



Insects exhibit two types of flight muscles: synchronous and asynchronous

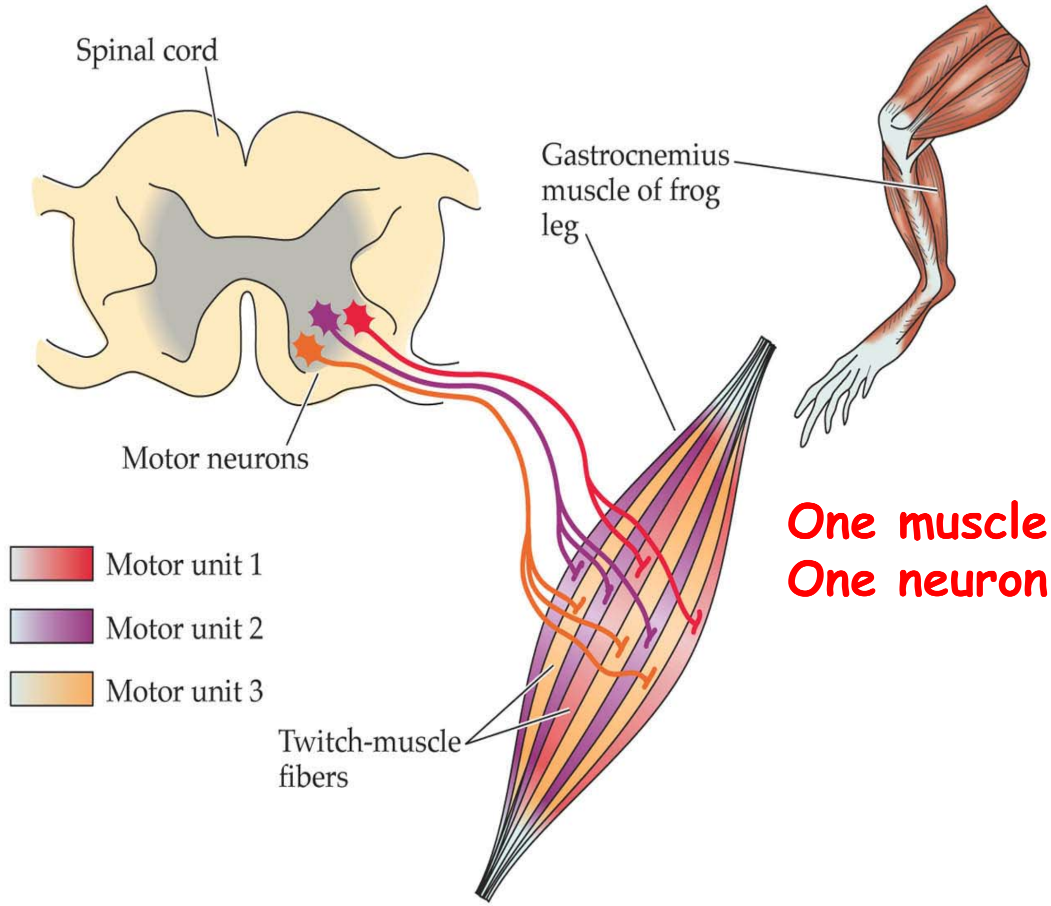


Resonant mechanical properties of thorax and wings



Neural control of skeletal muscle

Vertebrate skeletal muscles consist of many different, independent motor units



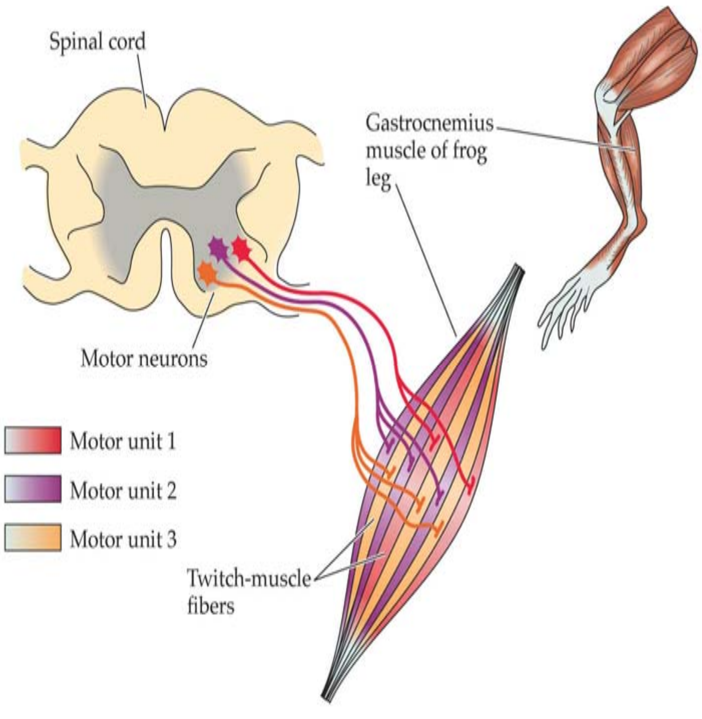
One muscle ---many neurons
One neuron---many fibers (one motor unit)

Variation in the frequency of AP regulates tension in <u>one motor unit</u>

Recruitment of motor units regulates tension <u>in the muscle</u>

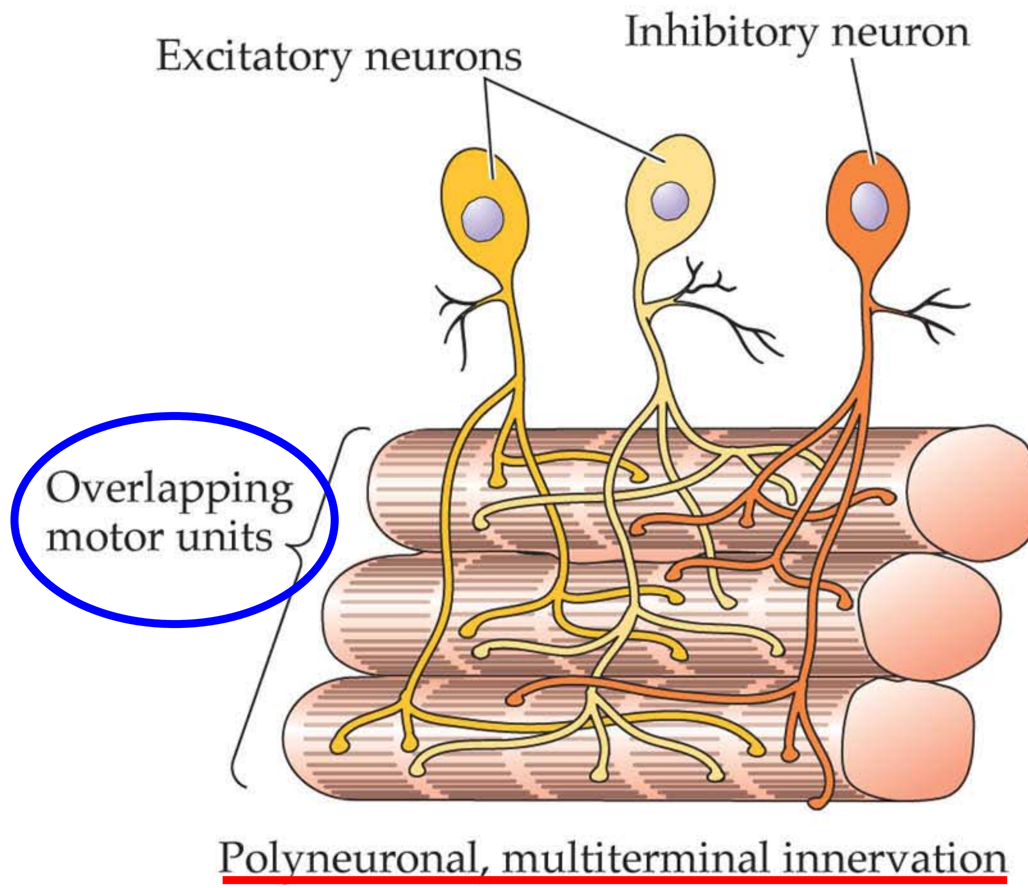
Innervations patterns of vertebrate muscle fibers and arthropod muscle fibers

Vertebrate



Muscles organized in motor units

(*b*) Arthropod muscle fibers



Degree of depolarization (IPSPs and EPSPs balance) regulates tension