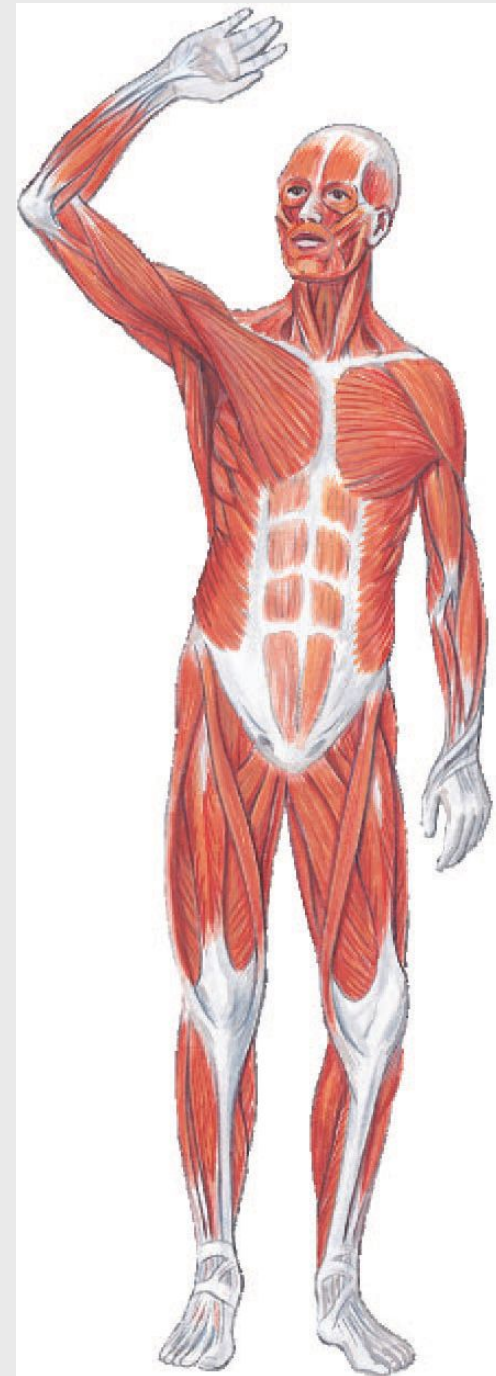


ГОУ ВПО ОрГМА Росздрава
кафедра нормальной
физиологии

Физиология мышц



Активное движение

- Одно из характерных свойств всех живых систем начиная от простейших и кончая самыми сложными

Биологическое движение

- Сокращение различных мышц,
- Движение листьев,
- Биение ресничек,
- Движение жгутиков,
- Деление клеток,
- Движение протоплазмы.

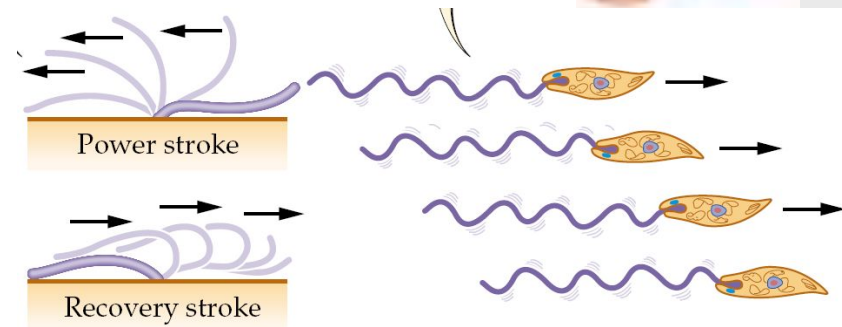
- Все разнообразные формы проявления двигательной активности имеют общую черту – превращение химической энергии в механическую.

Формы движения

- Амебoidalное



- Мерцательное



- Мышечное
(для тел большой
массы)

Мышечное движение наиболее эффективный способ перемещения

- **10,2 метра в секунду**
- **километры**

- **0,2 миллиметра в секунду**
- **сантиметры**



- Мышечными называют все типы клеток, функция которых состоит в сокращении.

- У млекопитающих имеются три главных типа клеток, специально приспособленных для сокращения: волокна скелетных мышц , клетки сердечной мышцы , гладкомышечные клетки.

Классификации мышц

Гистологическая

кая

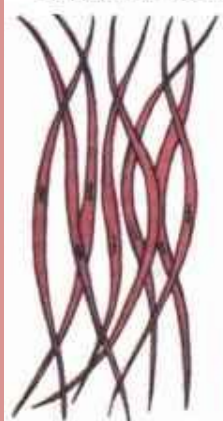


Поперечнополосатые



ые

Гладкие

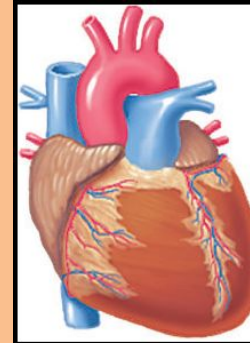


АНАТОМИЧЕСКАЯ

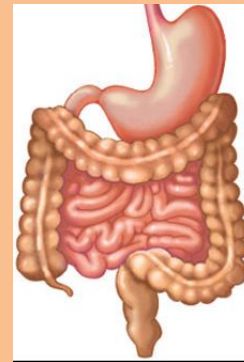
СКЕЛЕТНЫЕ



СЕРДЕЧНАЯ



ВИСЦЕРАЛЬНЫЕ



Функциональная

ая

произвольные



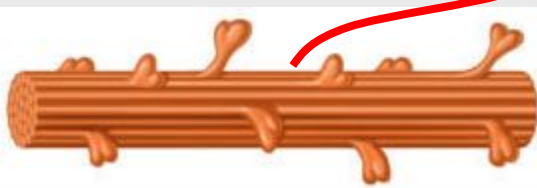
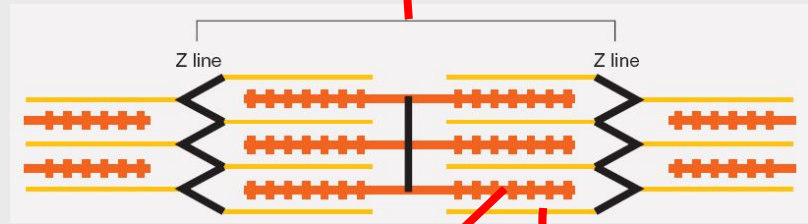
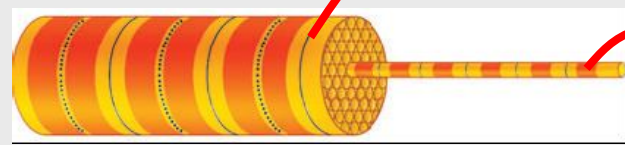
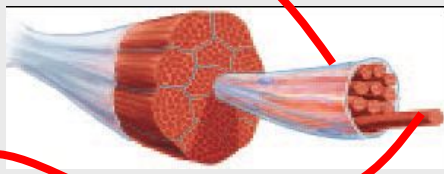
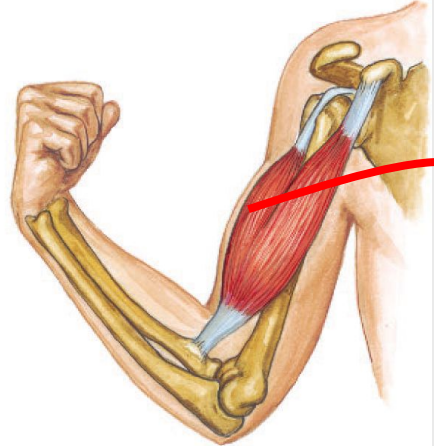
непроизвольные



Скелетная мышца



Уровни структурной организации скелетных мышц



Мышца

x1

Пучок мышечных волокон

x5

Мышечное волокно

X 500

Миофибрилла

X 10000

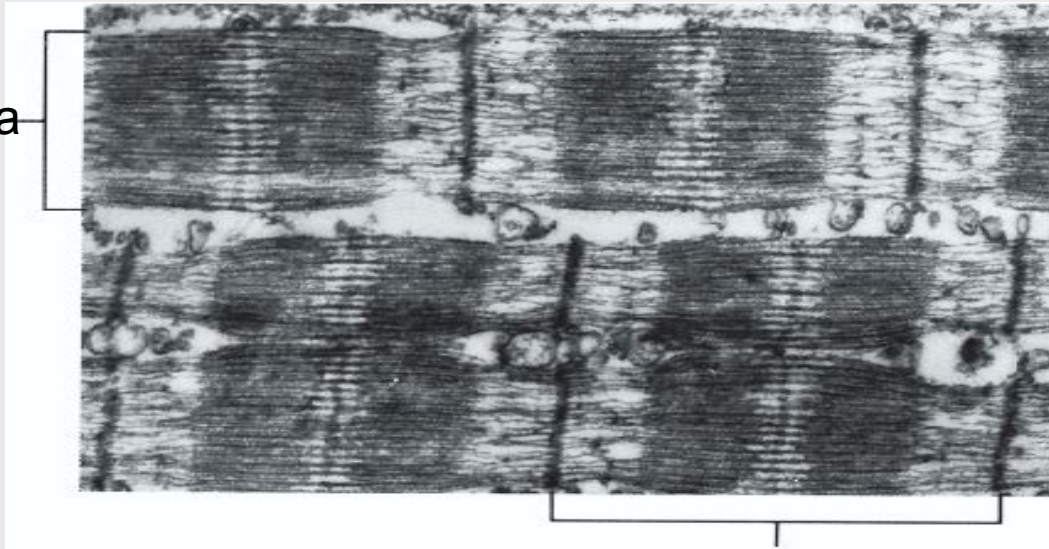
Саркомер

X 50000

Миофиламенты

X 1000000

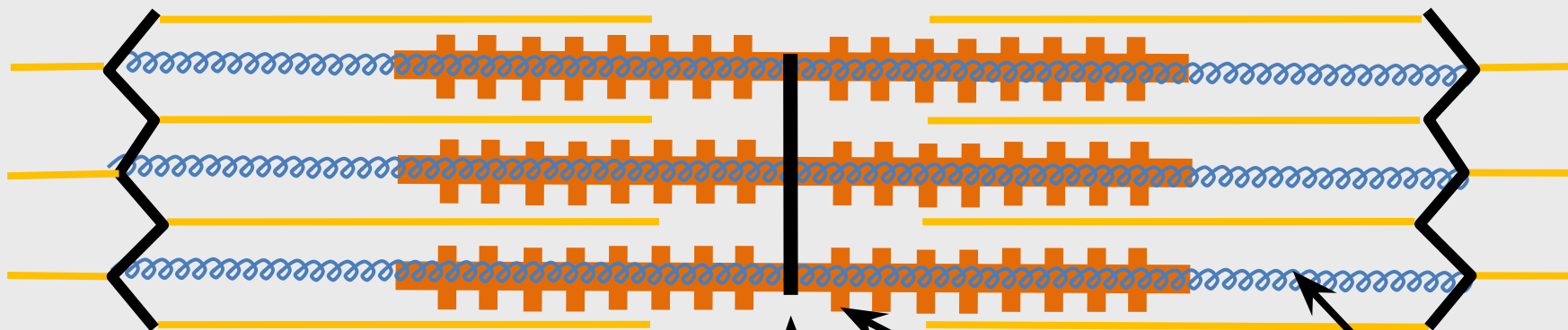
миофибрилла



саркомер

Z - линия

Z - линия

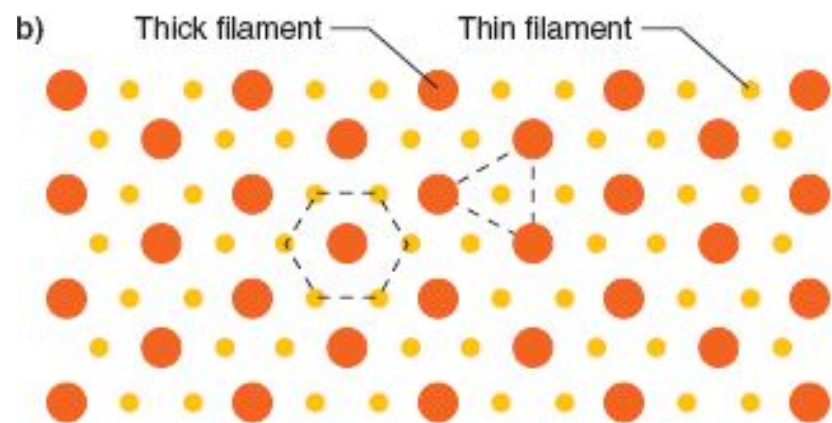
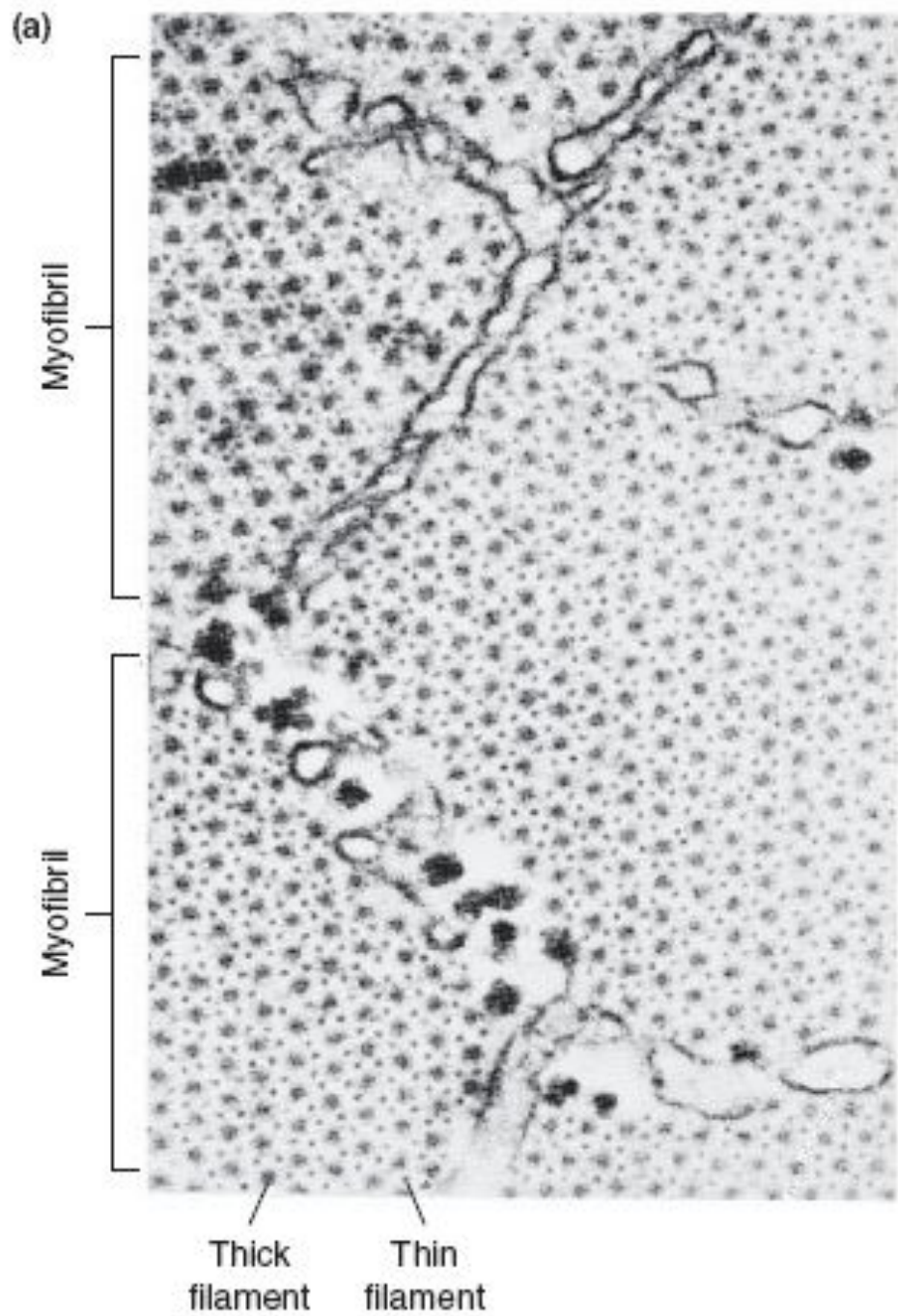


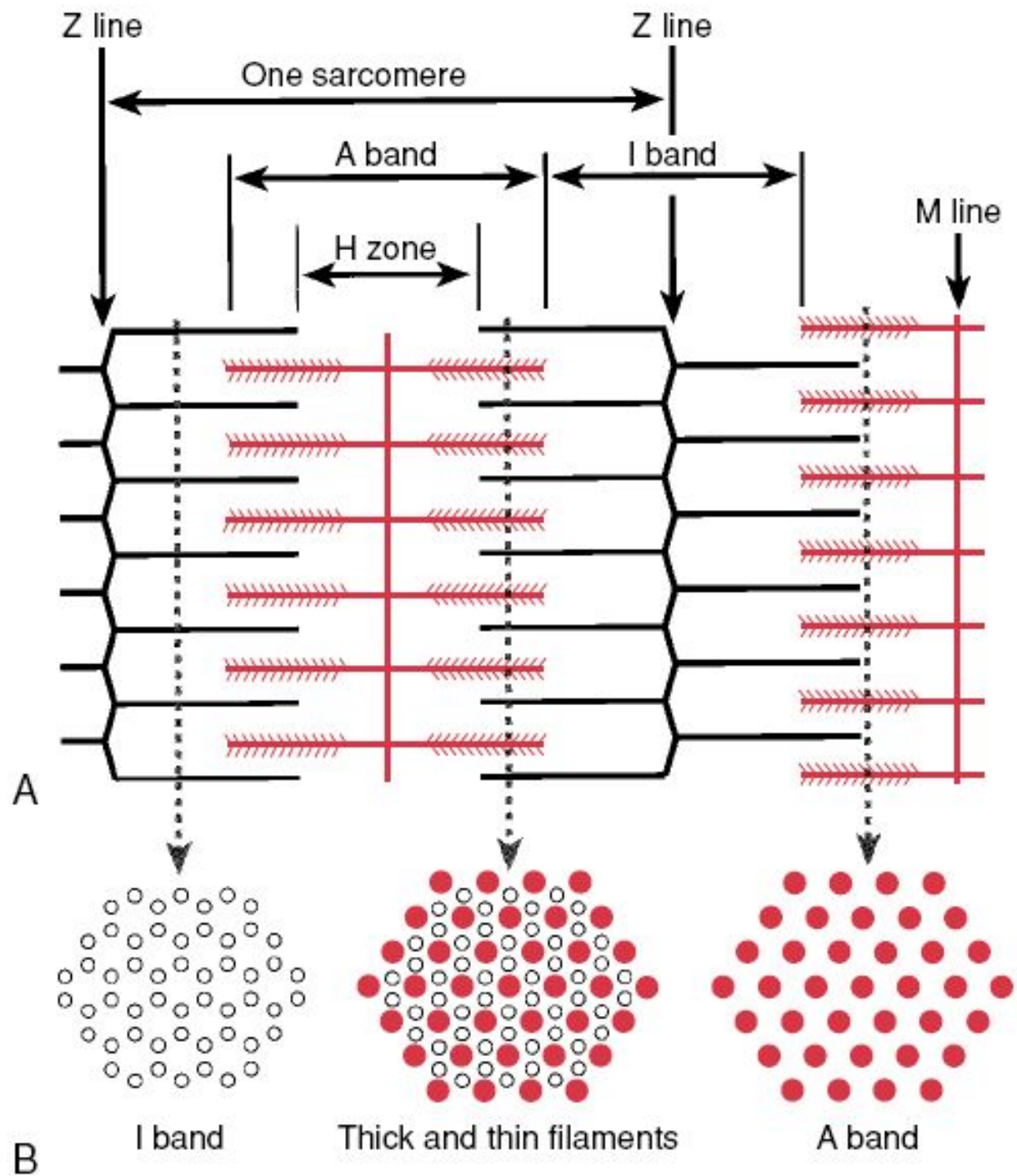
Тонкие
нити

M - линия

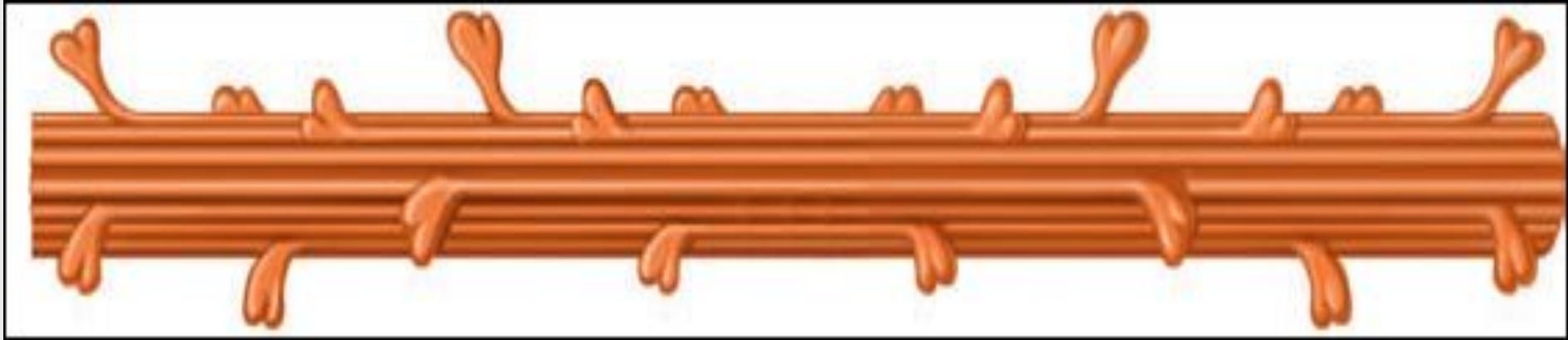
Толстые нити

Титиновые нити

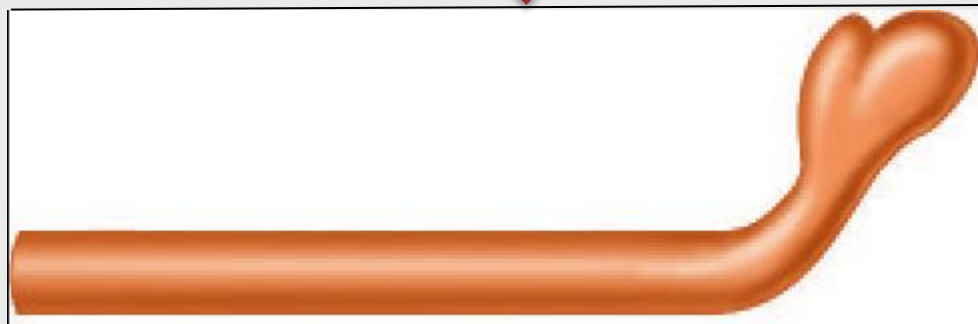




Миозиновые нити (толстые нити)

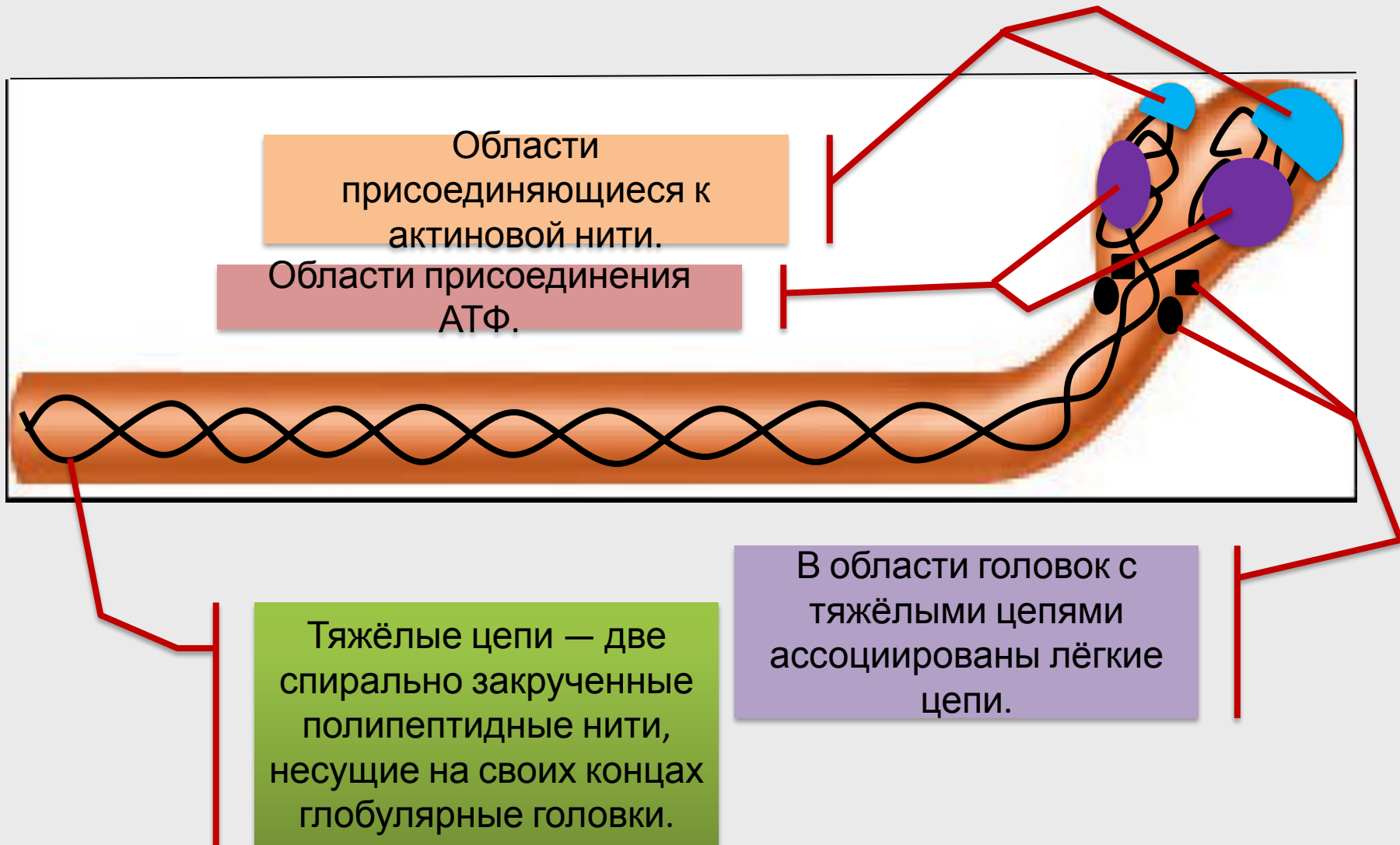


**Каждая миозиновая нить состоит из
300–400 молекул миозина.**

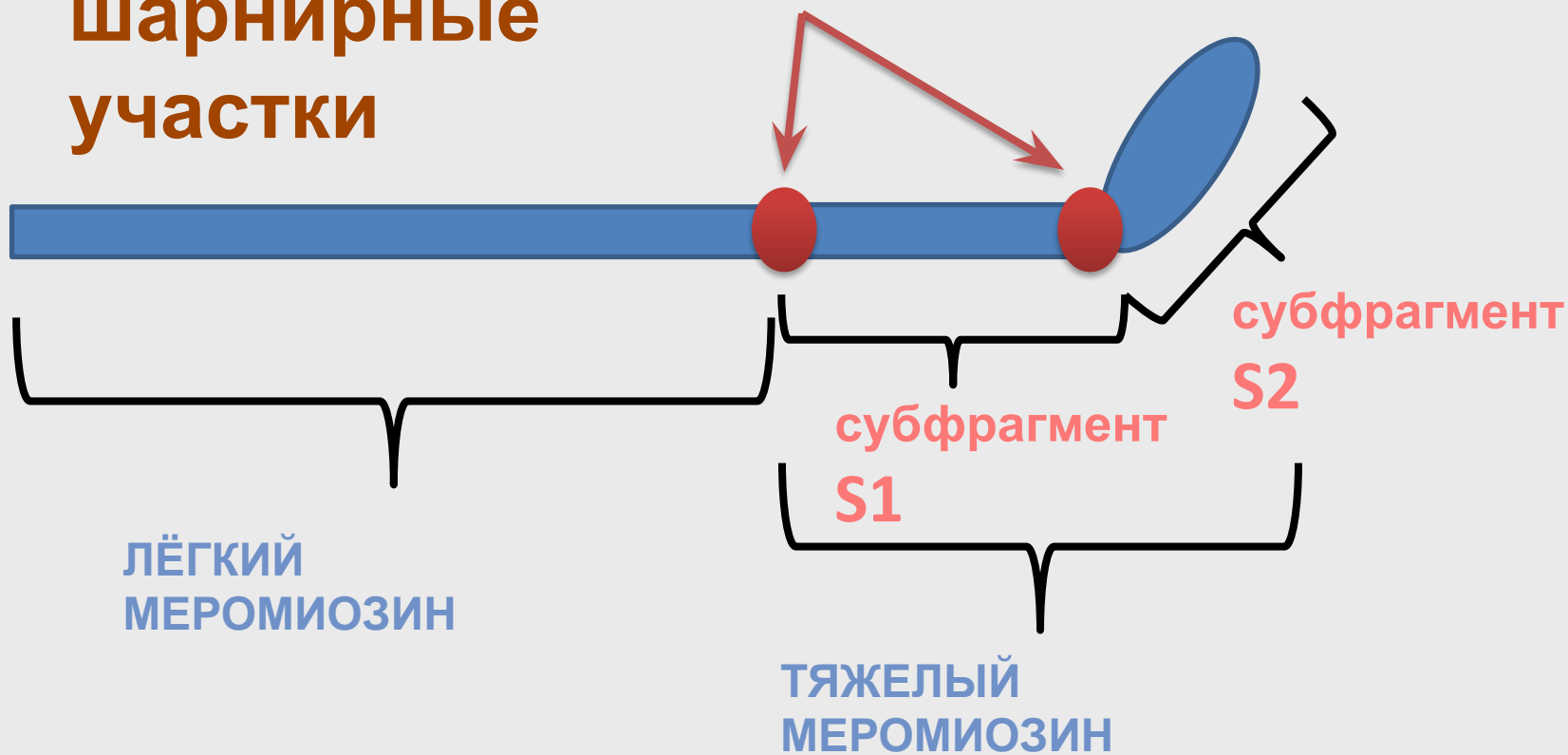


Строение молекулы миозина

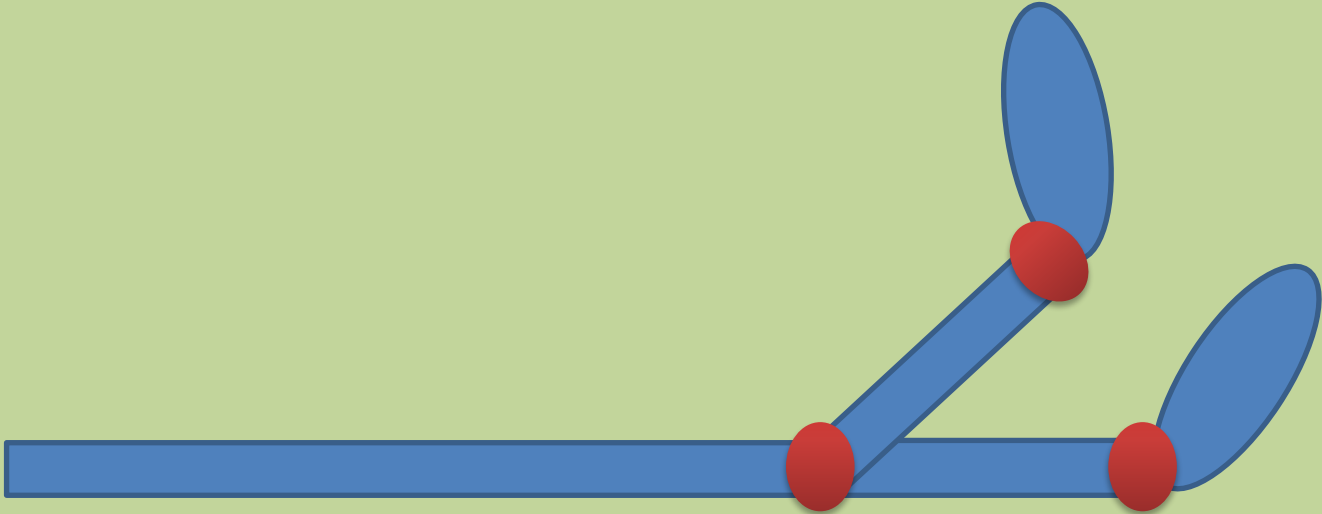
Миозин — гексамер (две тяжёлые и четыре лёгкие цепи).

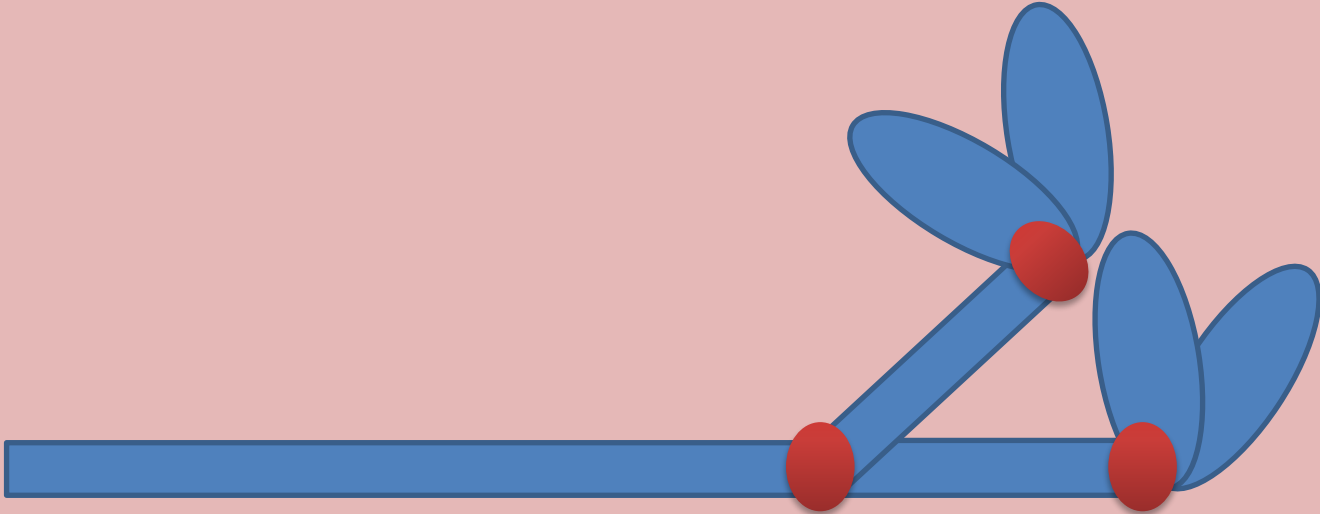


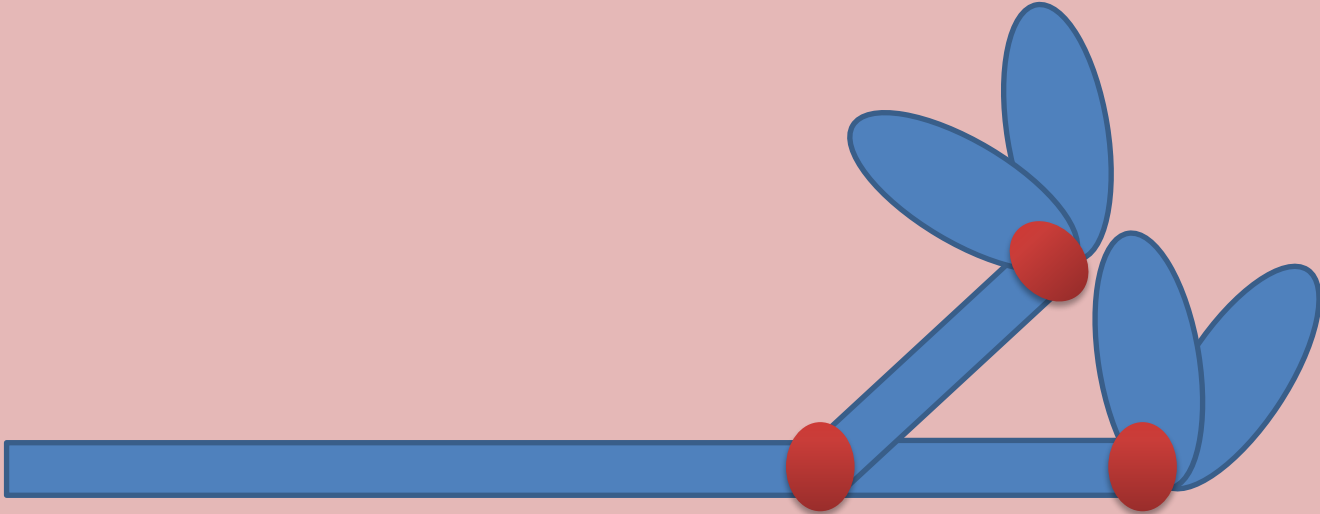
шарнирные
участки

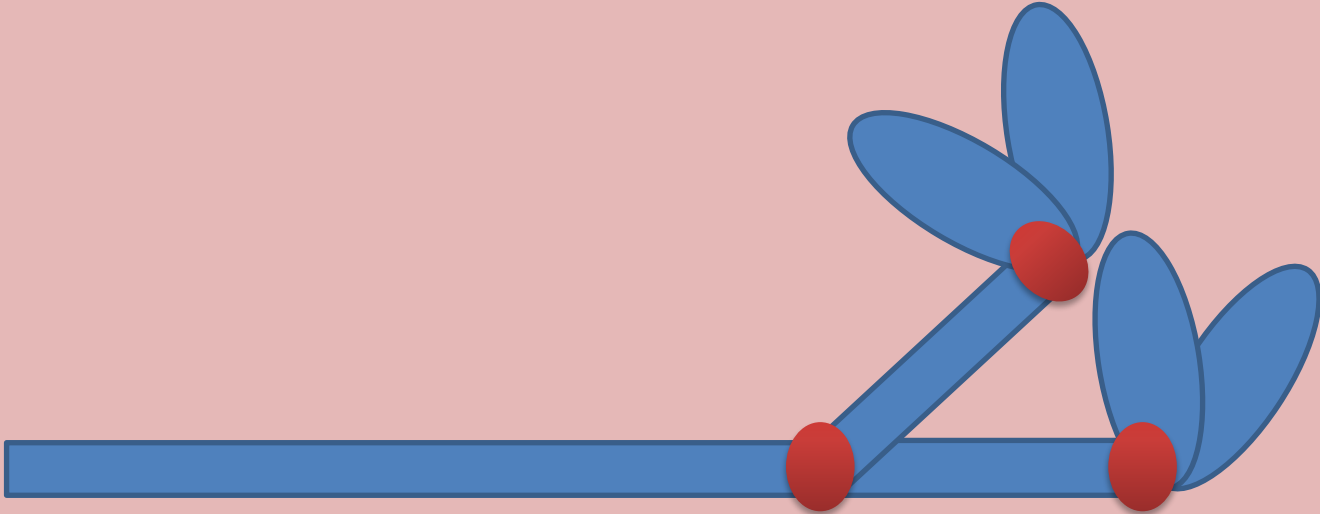


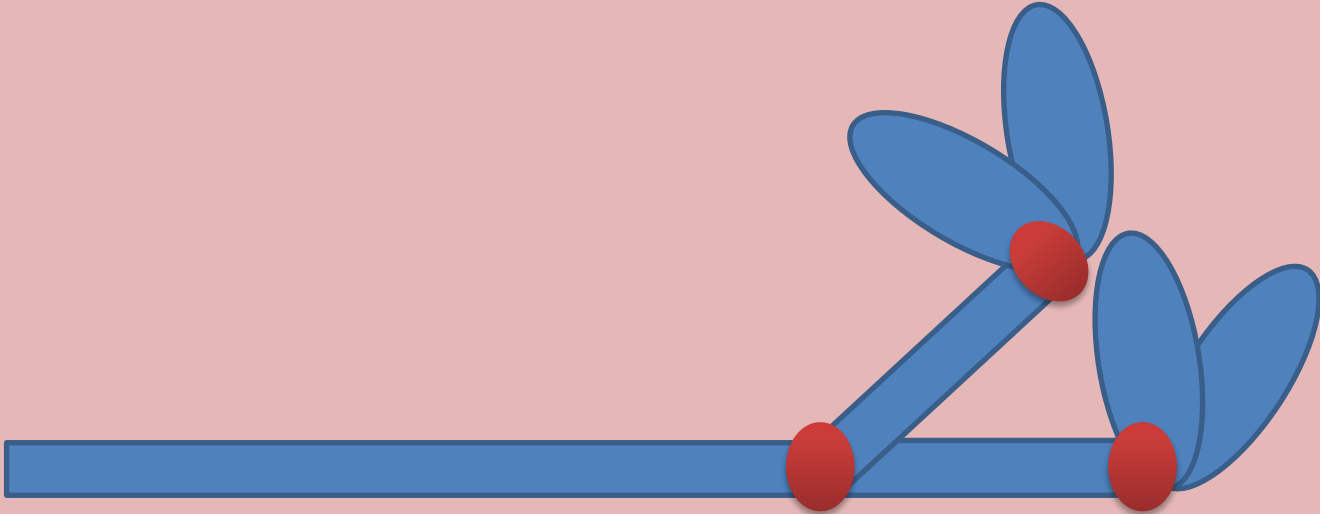




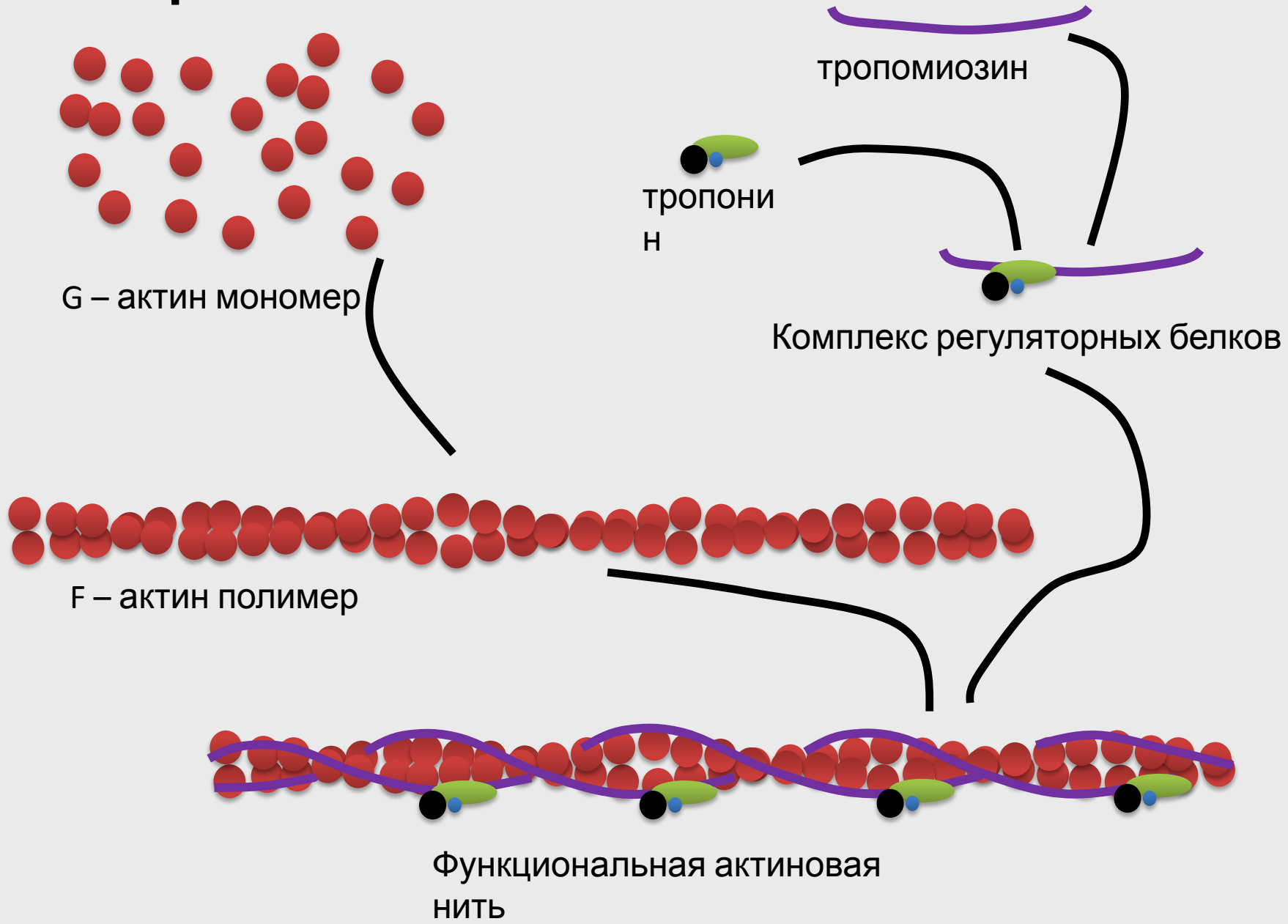








Строение актиновых нитей

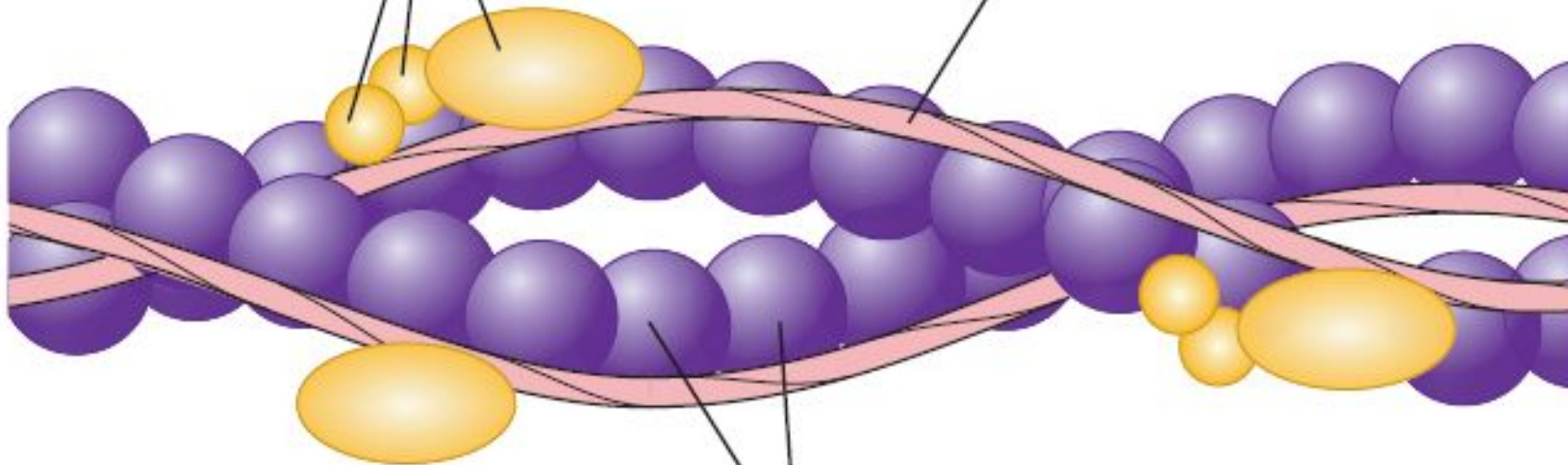


тропо́ни

Н

тропомиози

Н



G -

актин

Последовательность процессов при мышечном сокращении

Деполаризация постсинаптической мембраны и генерация ПД.

Распространение ПД по плазмолемме МВ .

Передача сигнала в триадах на саркоплазматический ретикулум.

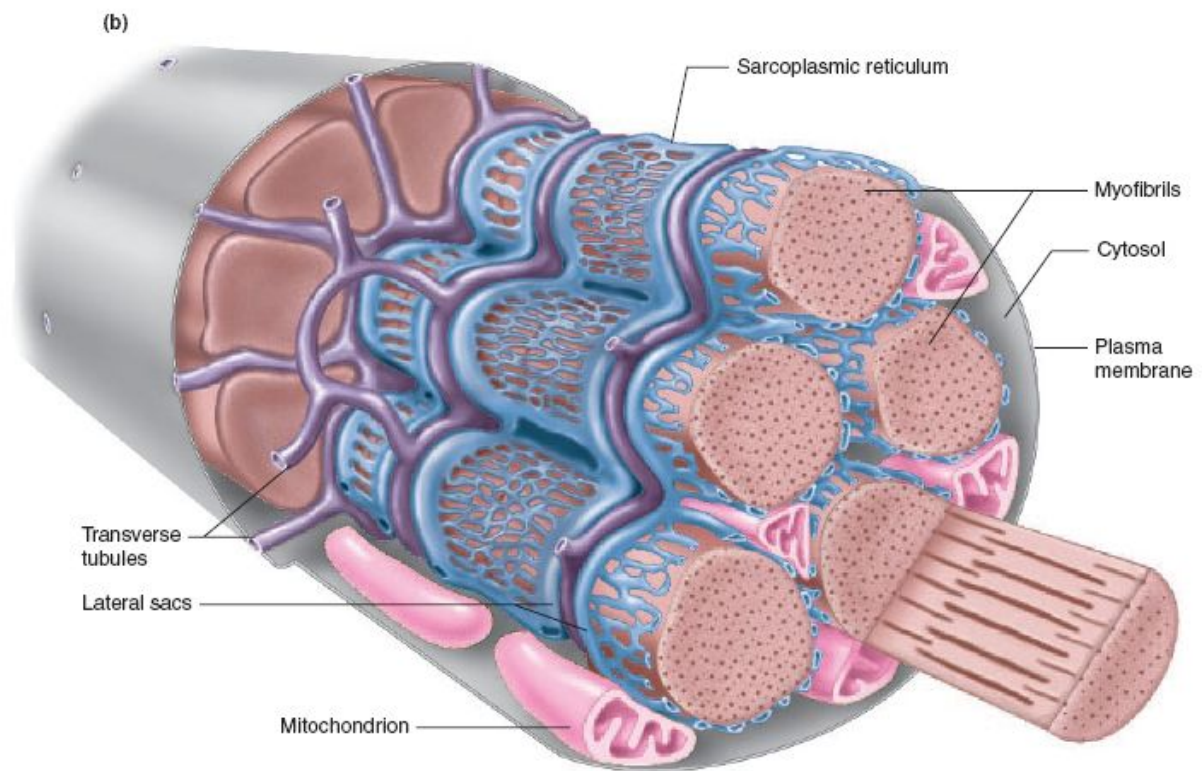
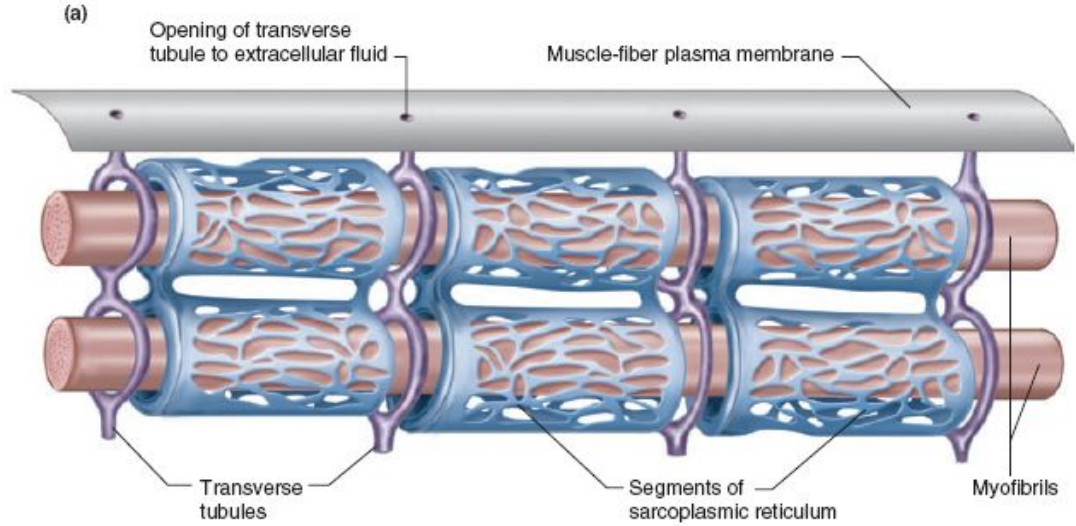
Выброс Ca^{2+} из саркоплазматического ретикулума.

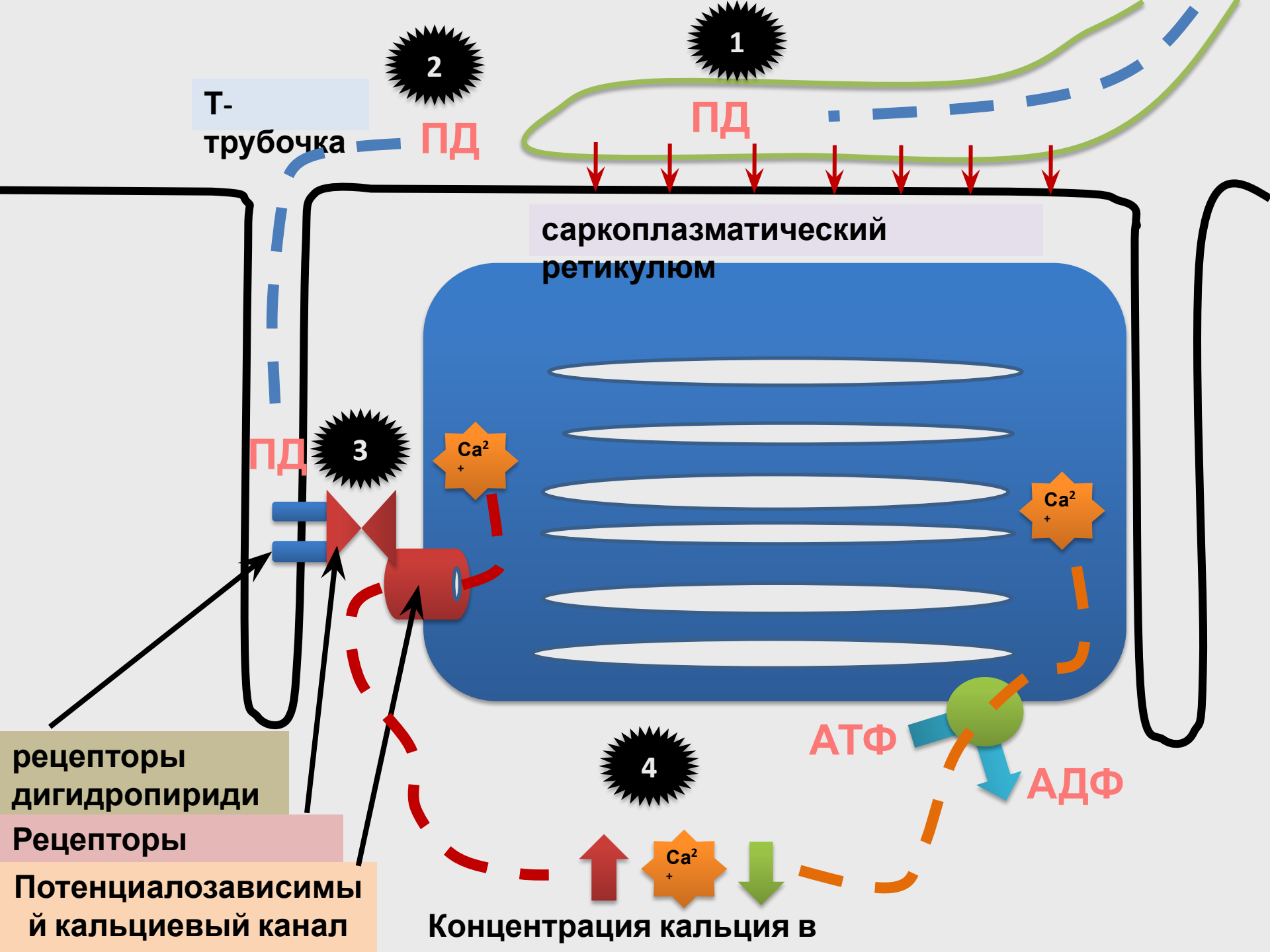
Связывание Ca^{2+} тропонином С
Взаимодействие тонких и толстых нитей (формирование мостиков),
появление тянущего усилия и скольжение нитей относительно

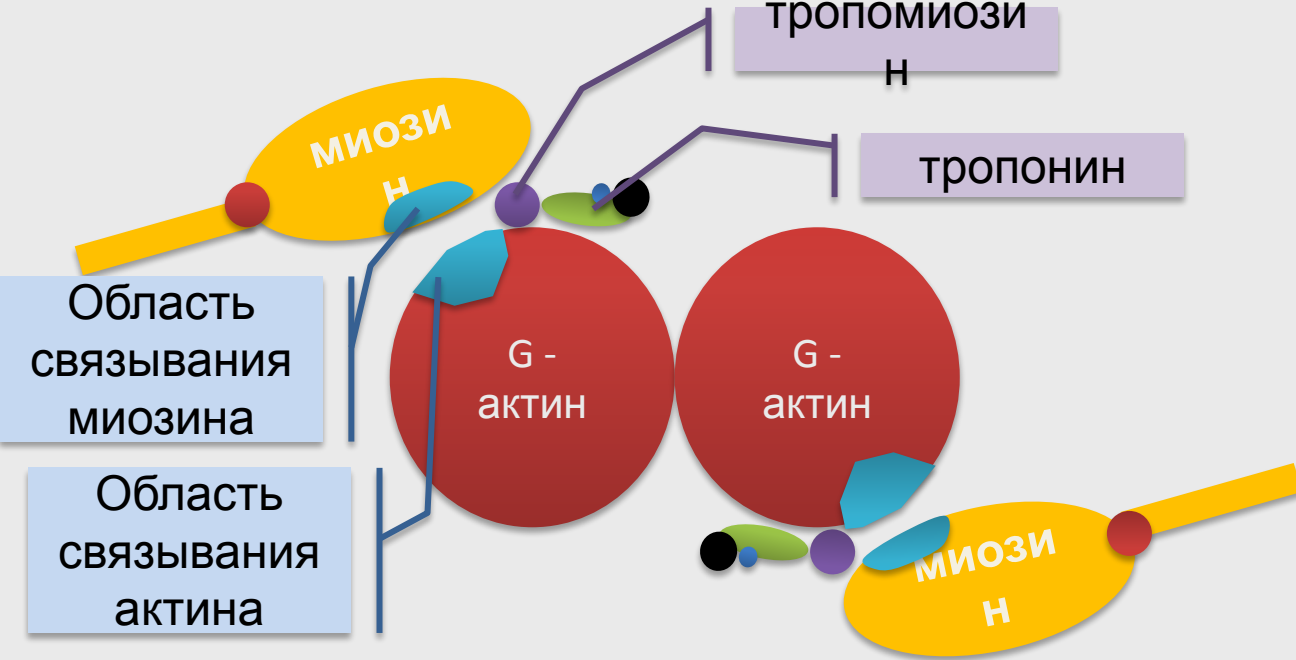
Цикл взаимодействия нитей.

Укорочение саркомеров и сокращение МВ.

Расслабление.







$Ca^{2+} < 10^{-9} M$

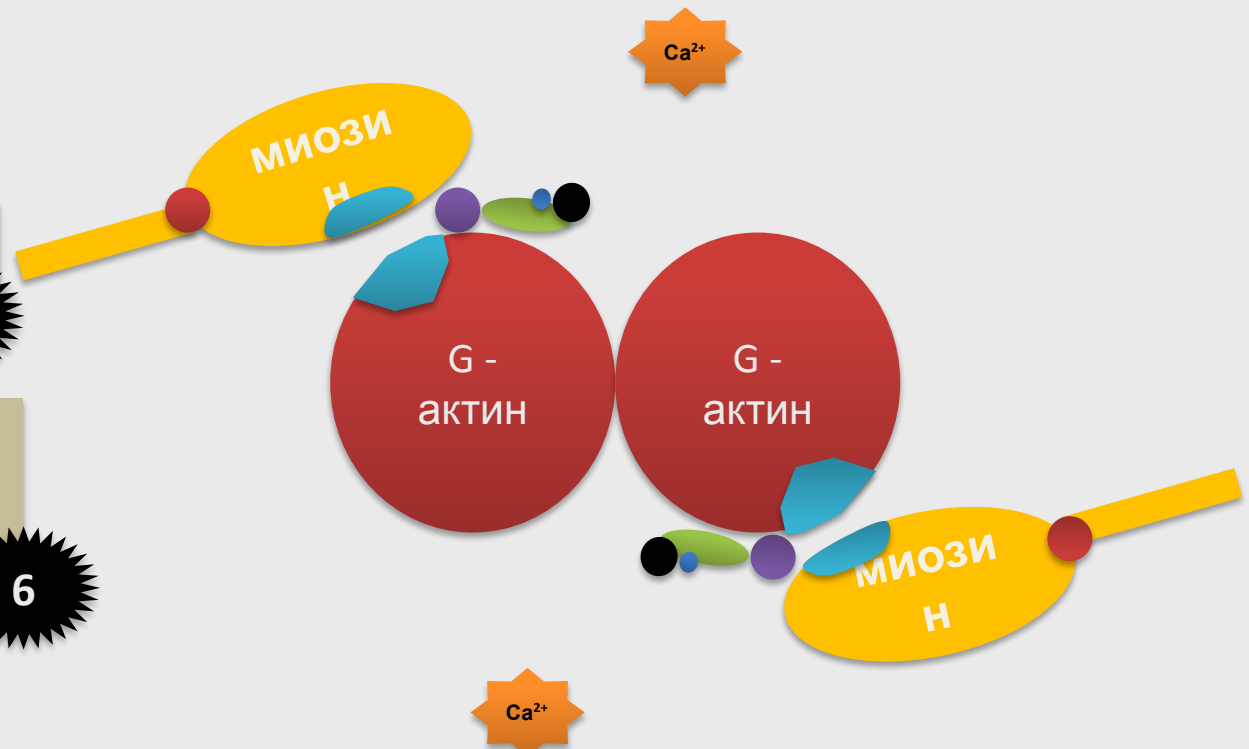
Ca^{2+} не связан с тропонином.

Взаимодействие актина с миозином заблокировано.

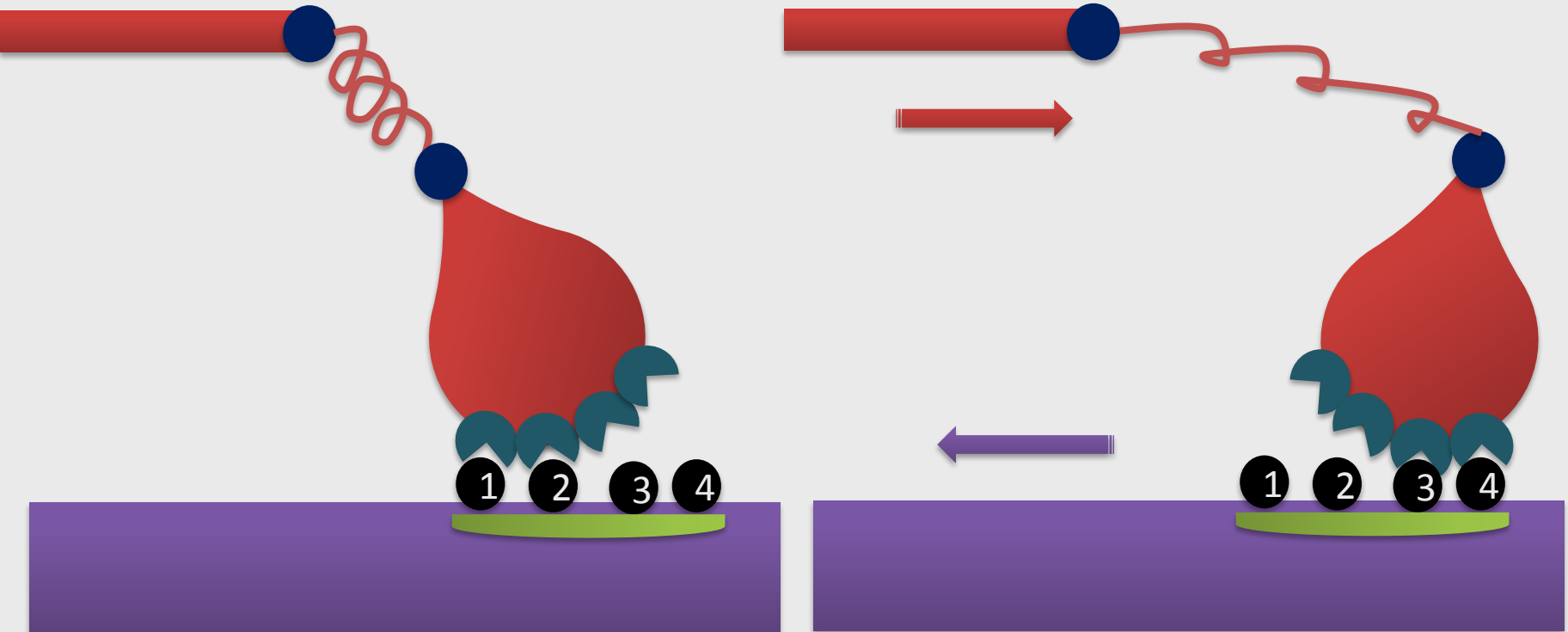
$Ca^{2+} < 10^{-5} M$

Ca^{2+} связан с тропонином. 5

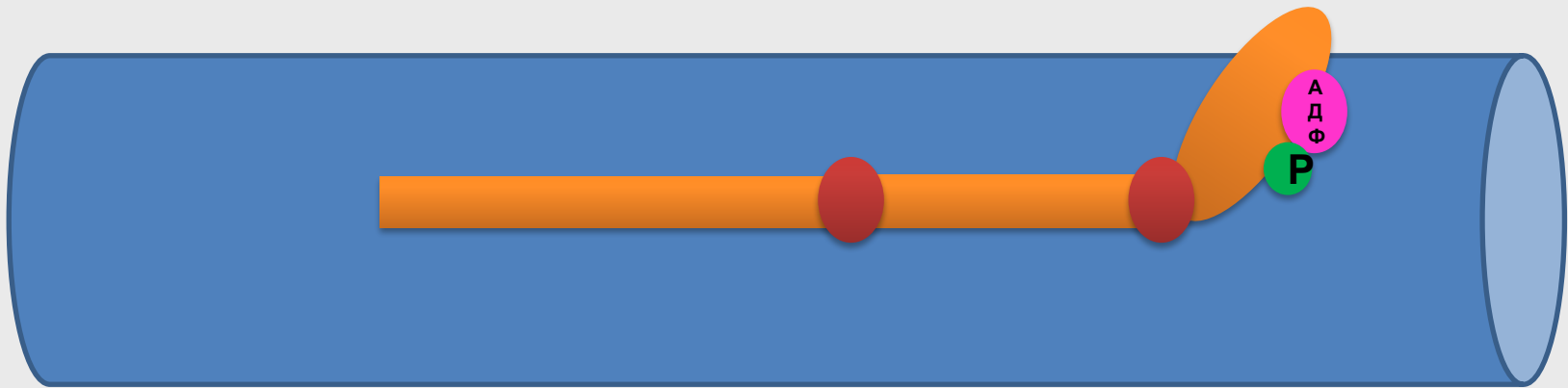
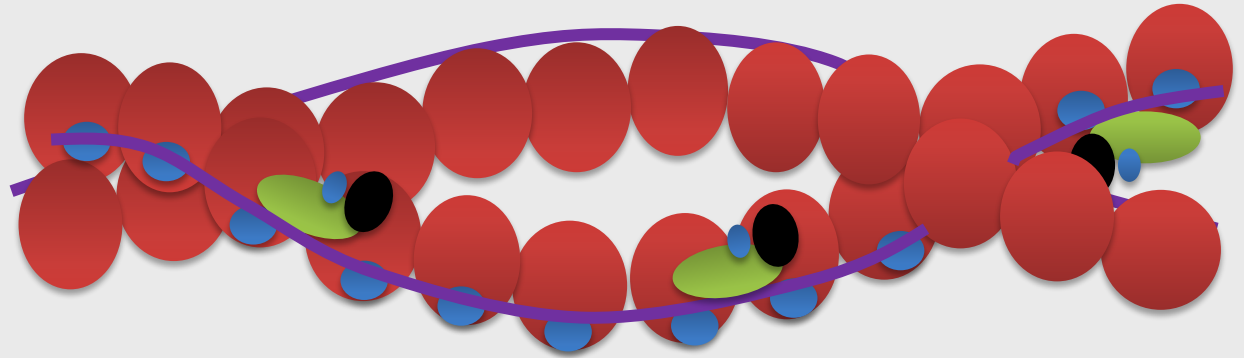
Взаимодействие актина с миозином разблокировано. 6



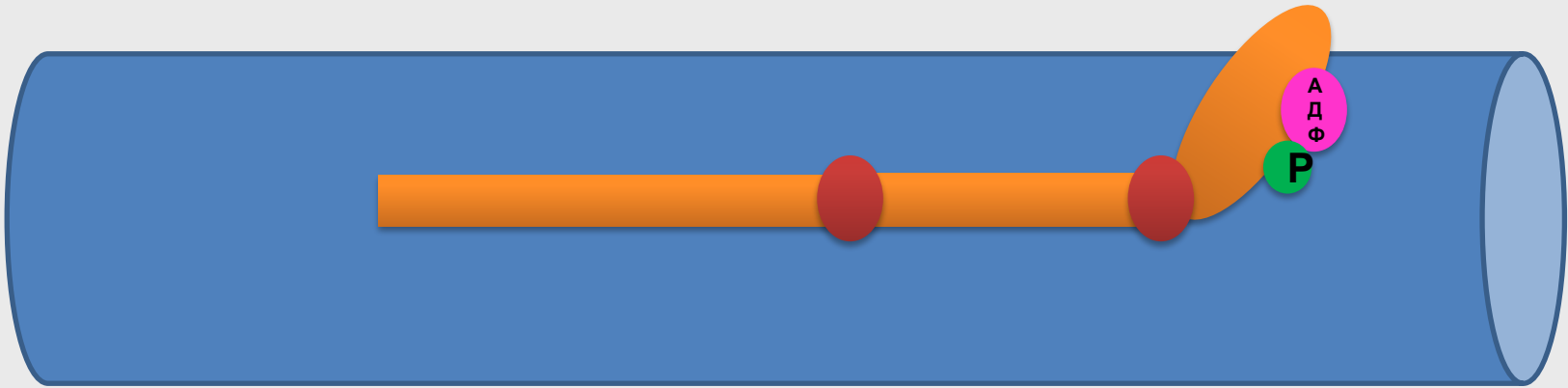
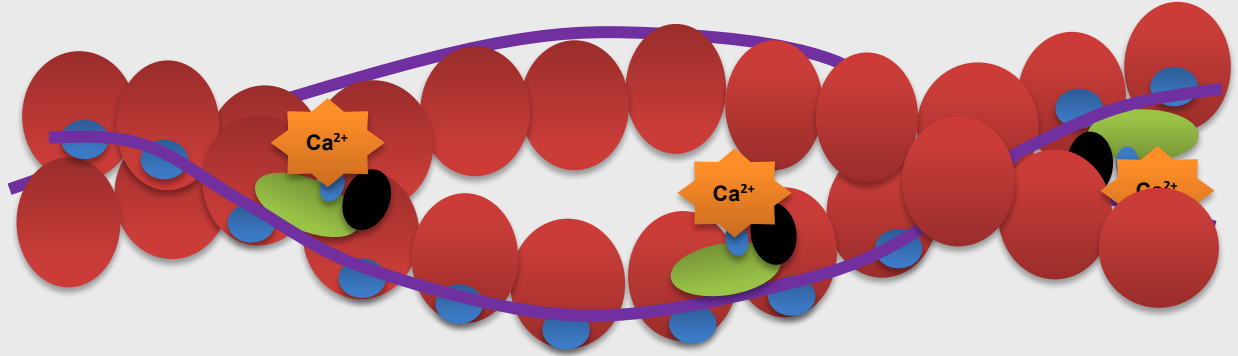
Модель мостика Хаксли-Симмонса



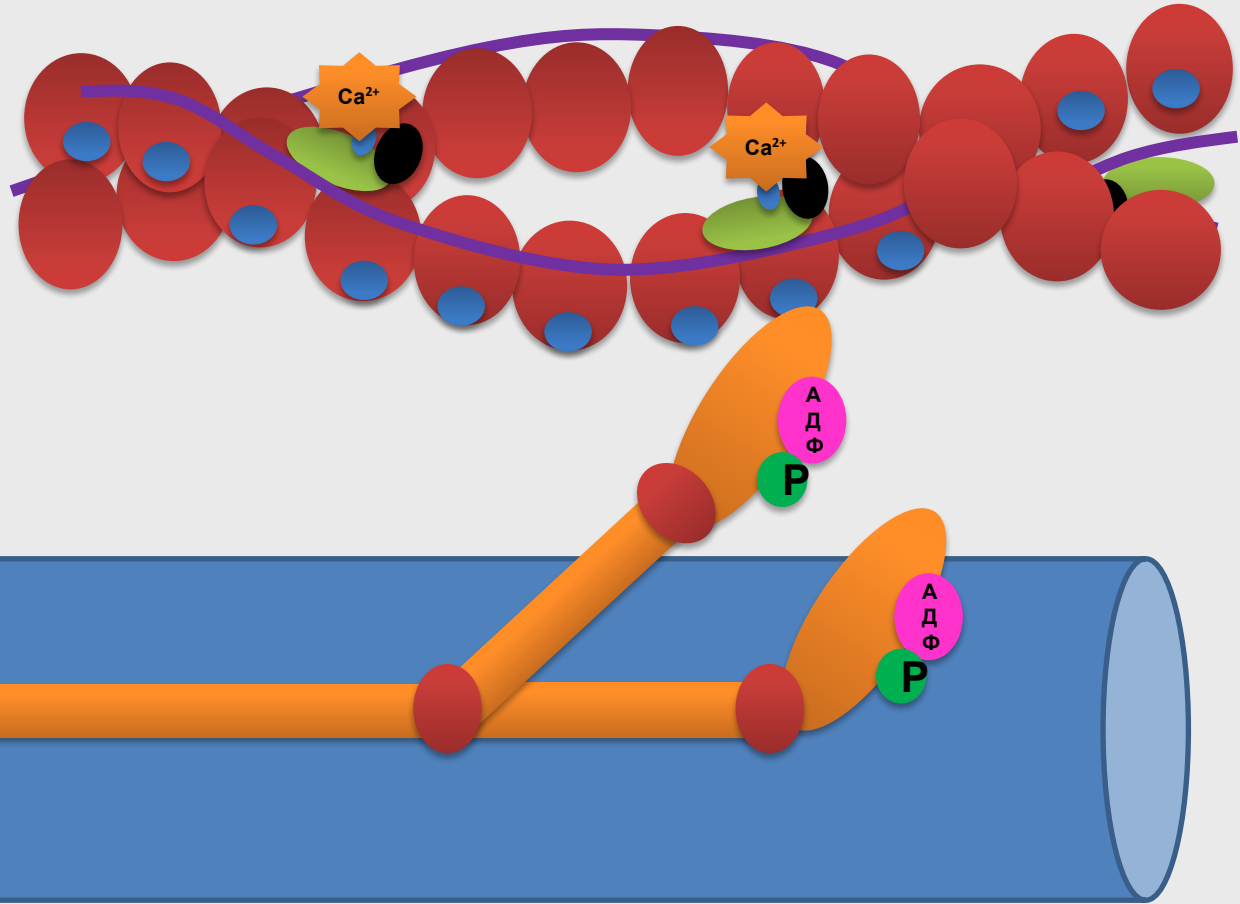
Цикл взаимодействия нитей



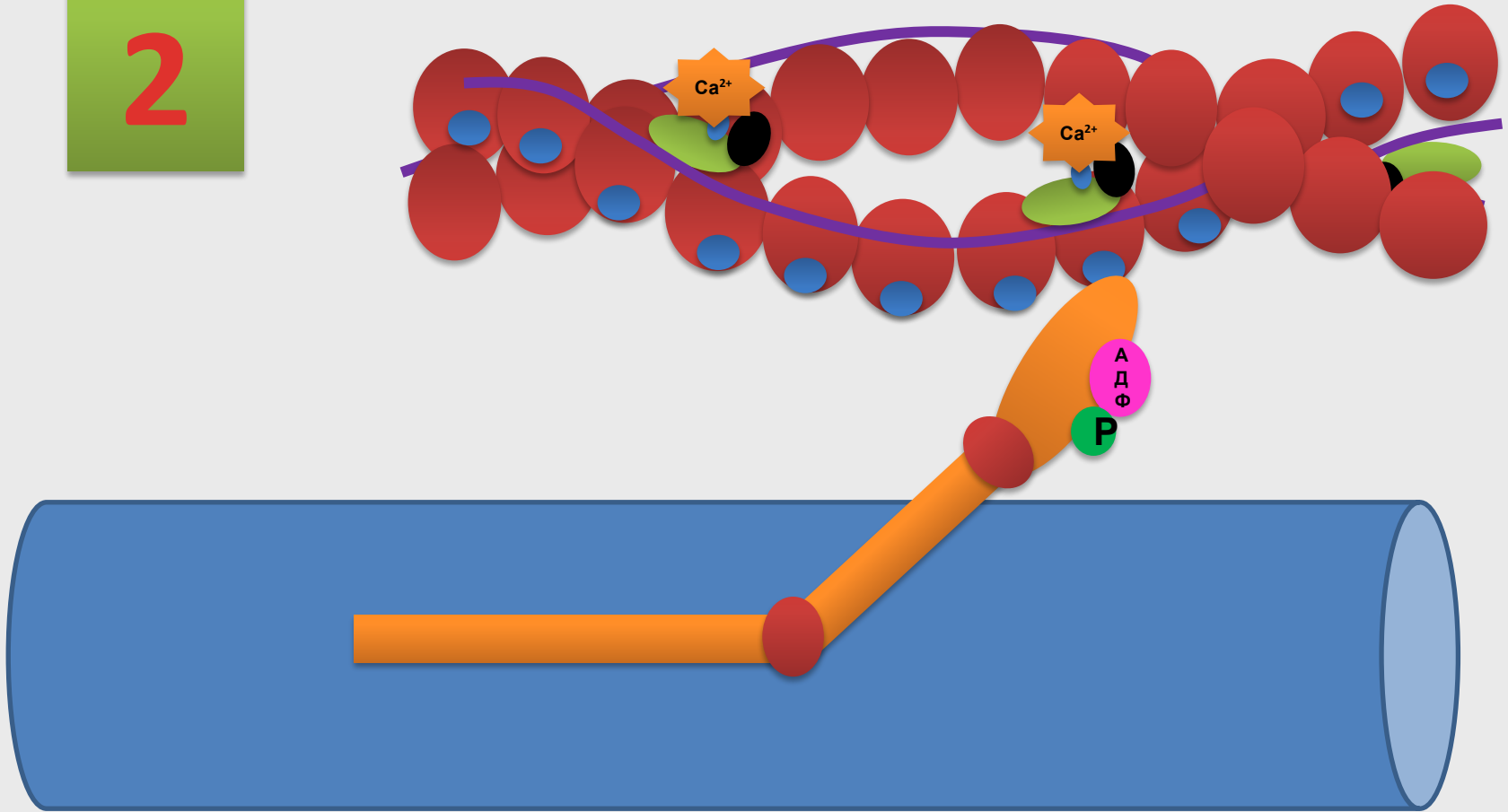
1

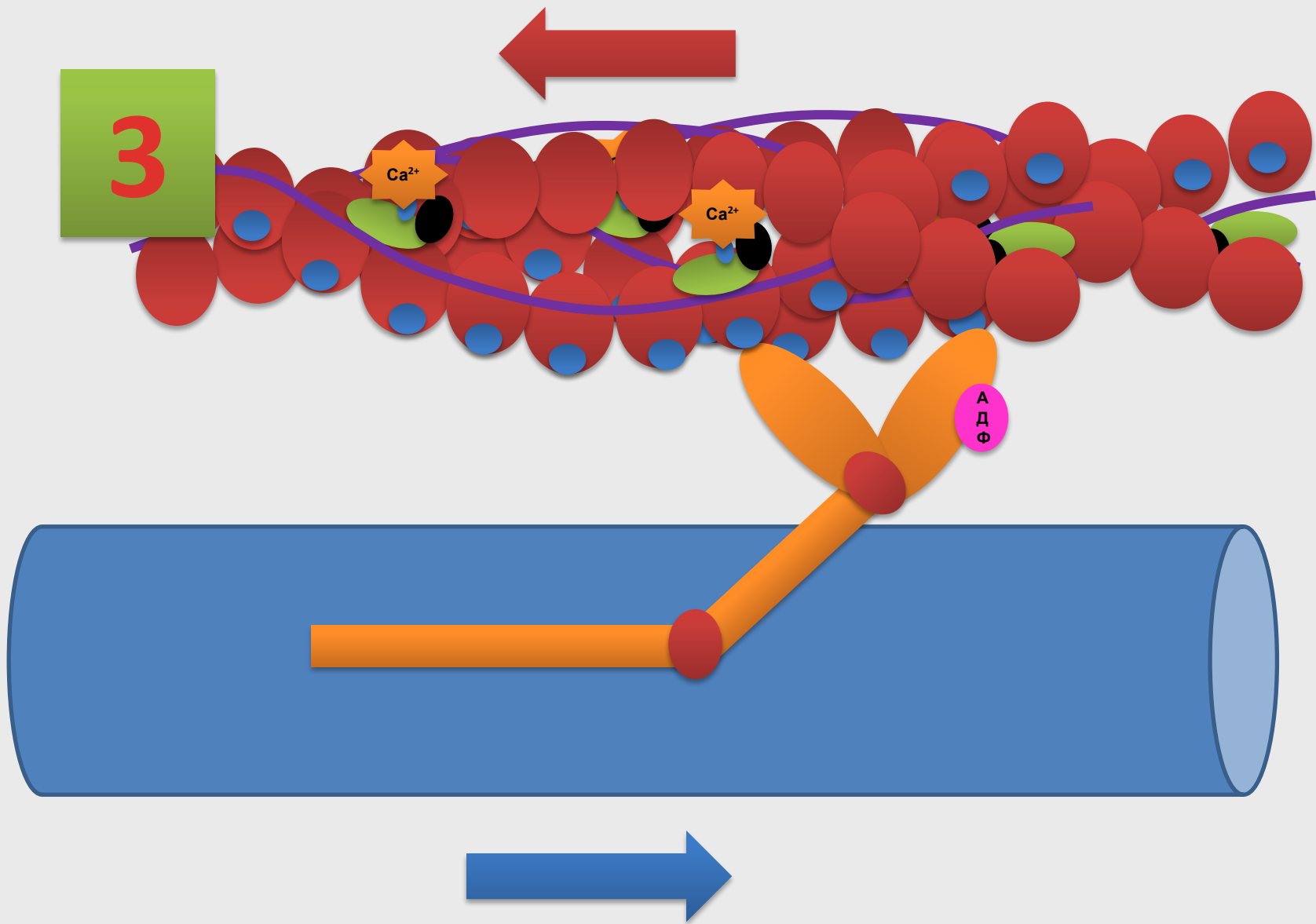


1

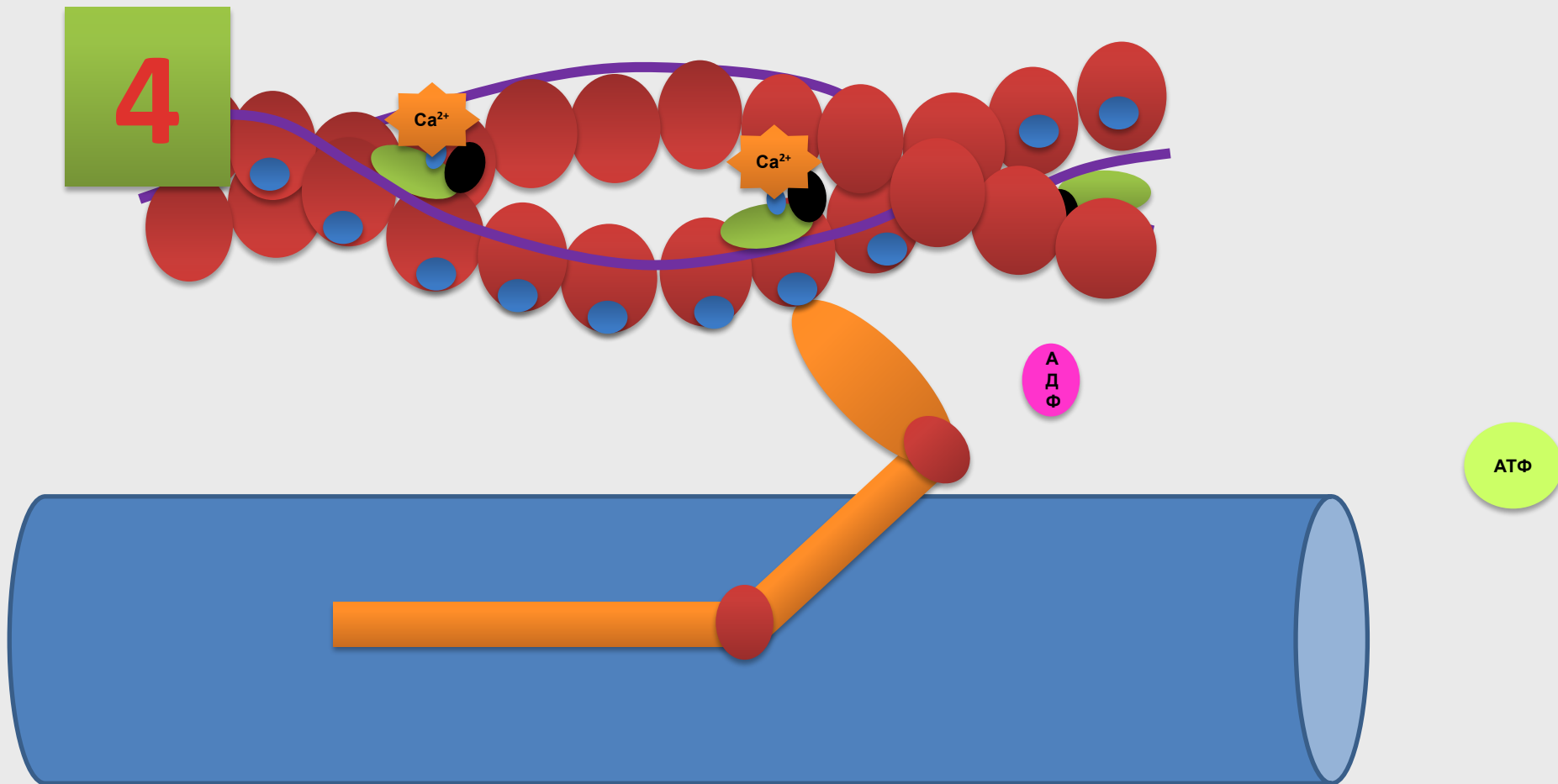


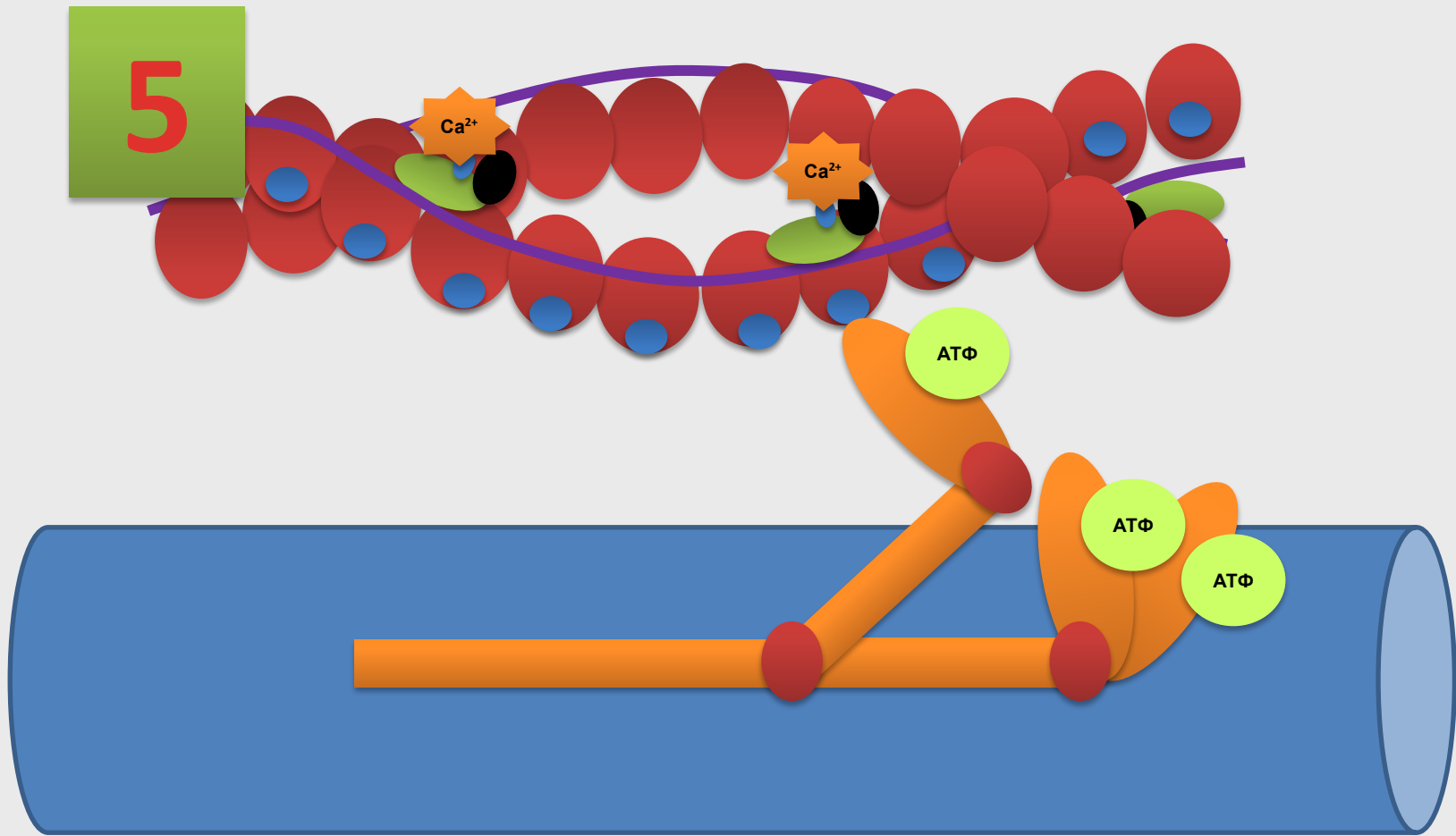
2



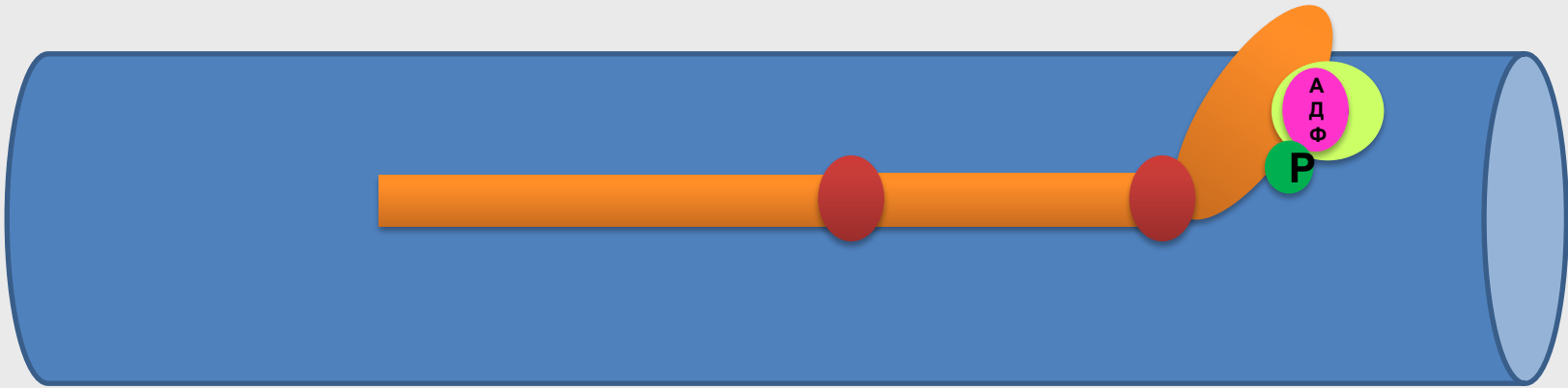
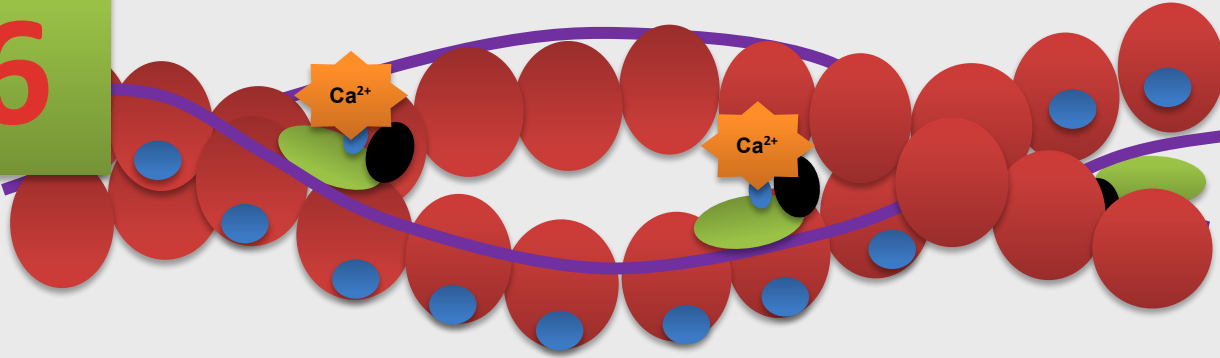


4

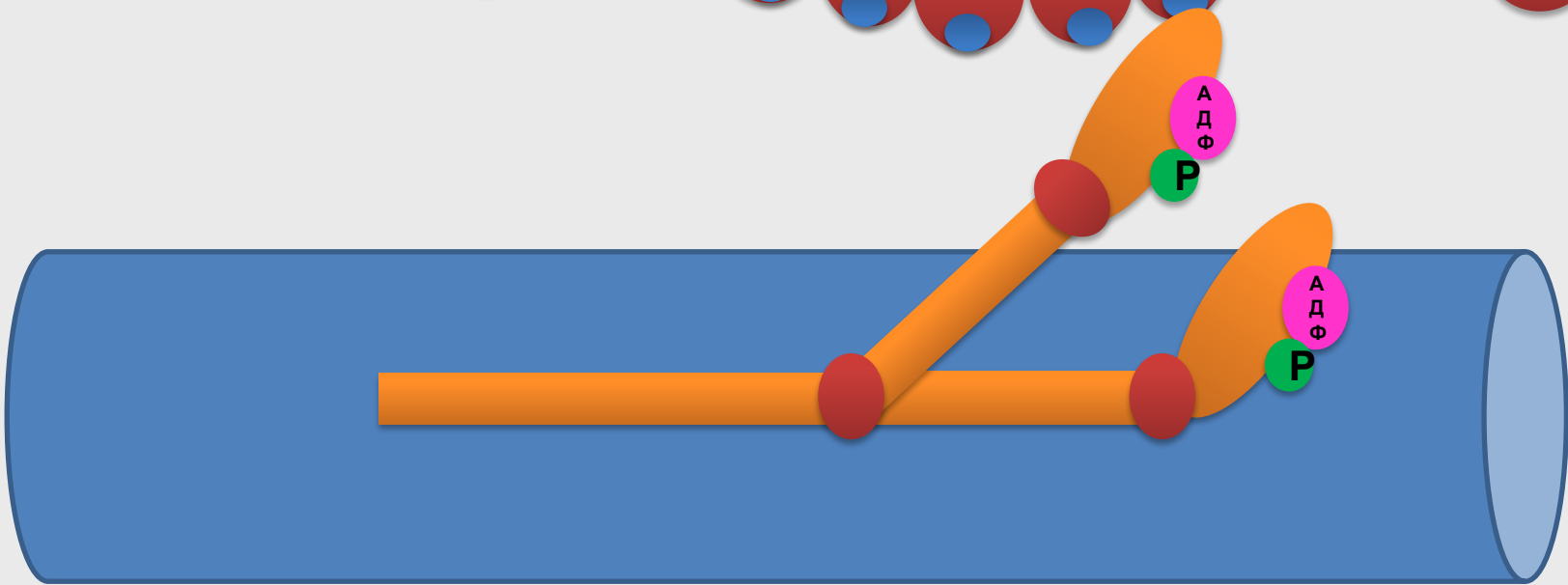
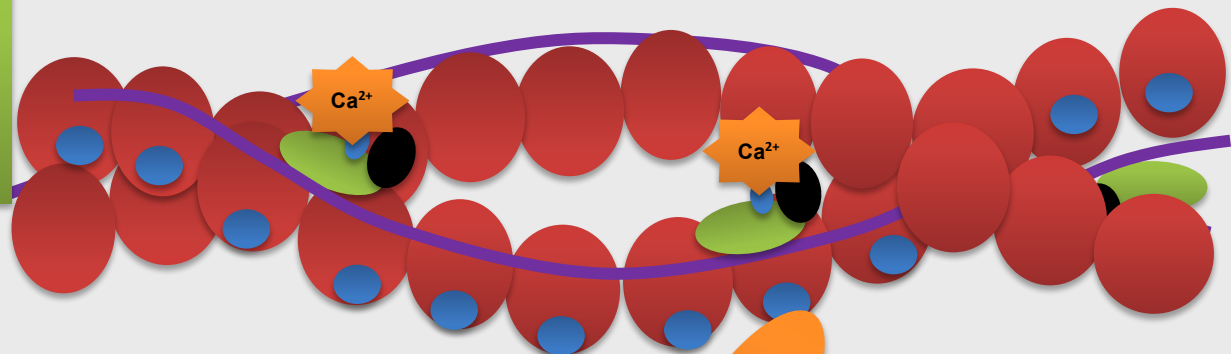




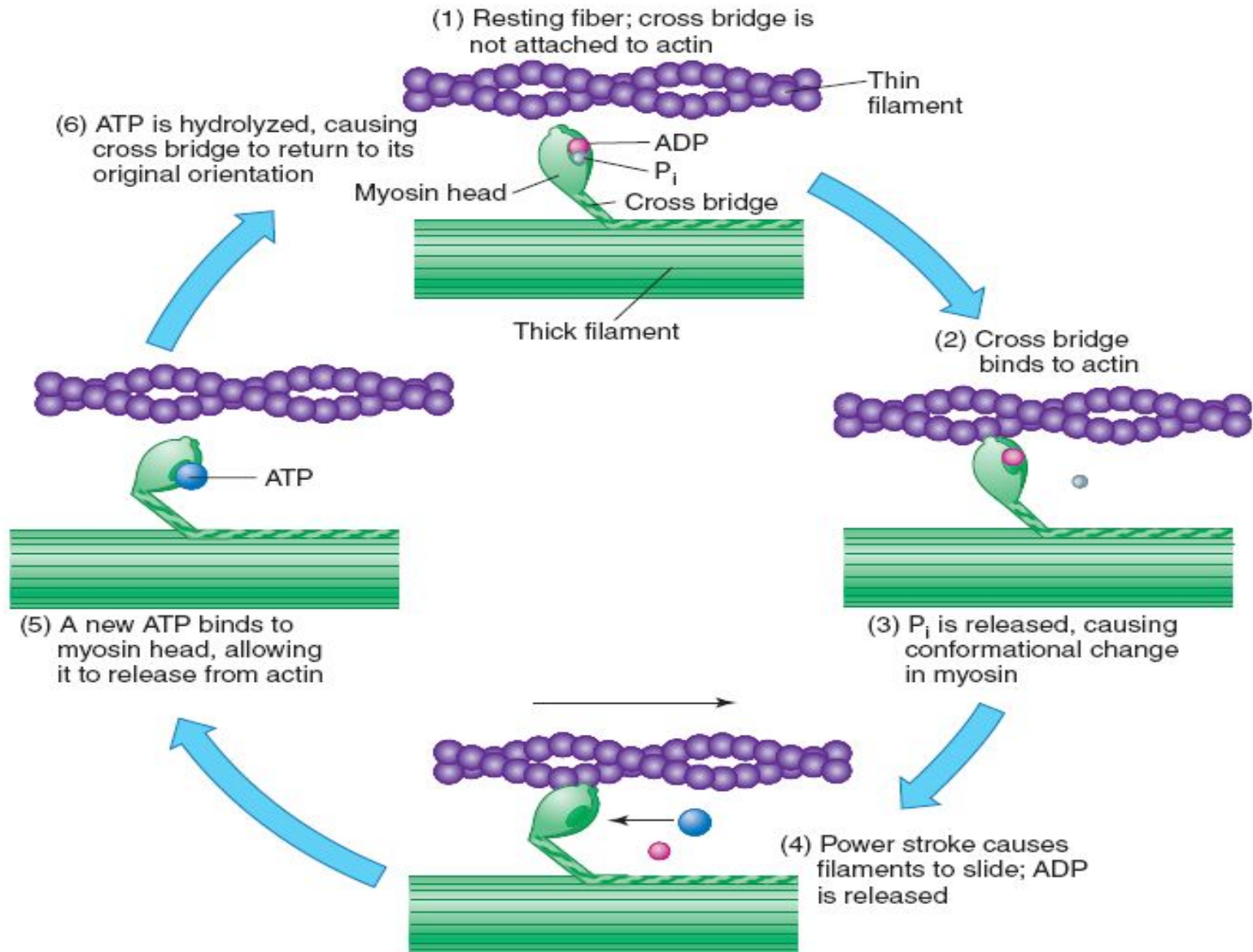
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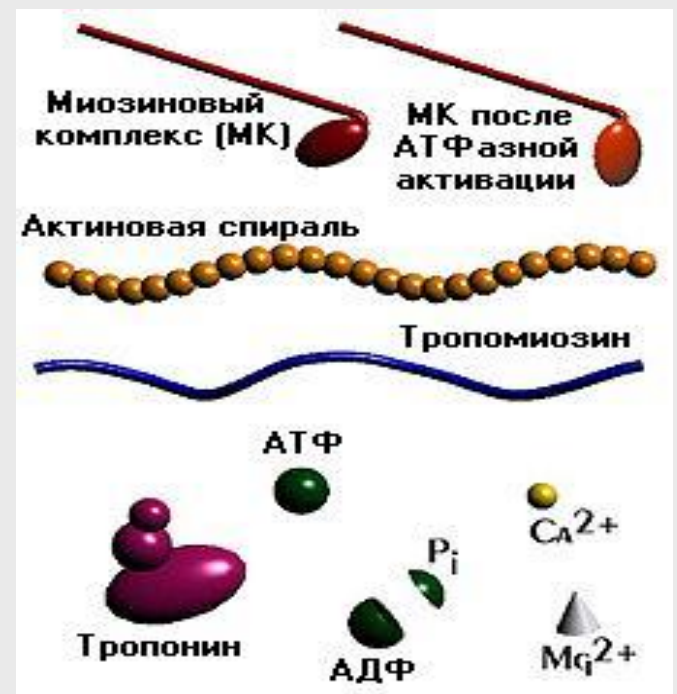
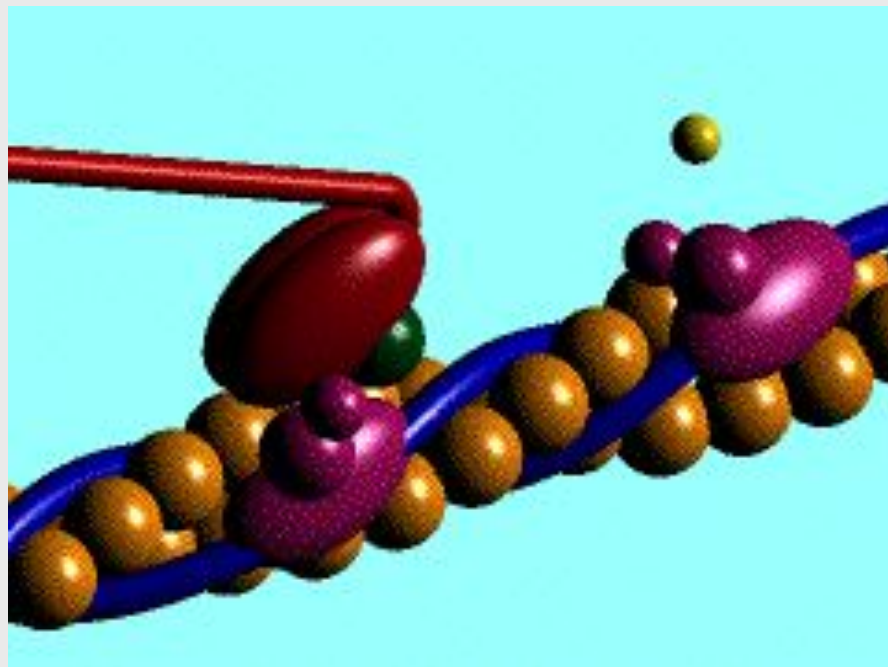


1 = 7



Цикл взаимодействия нитей





Укорочение саркомеров и сокращение

MP

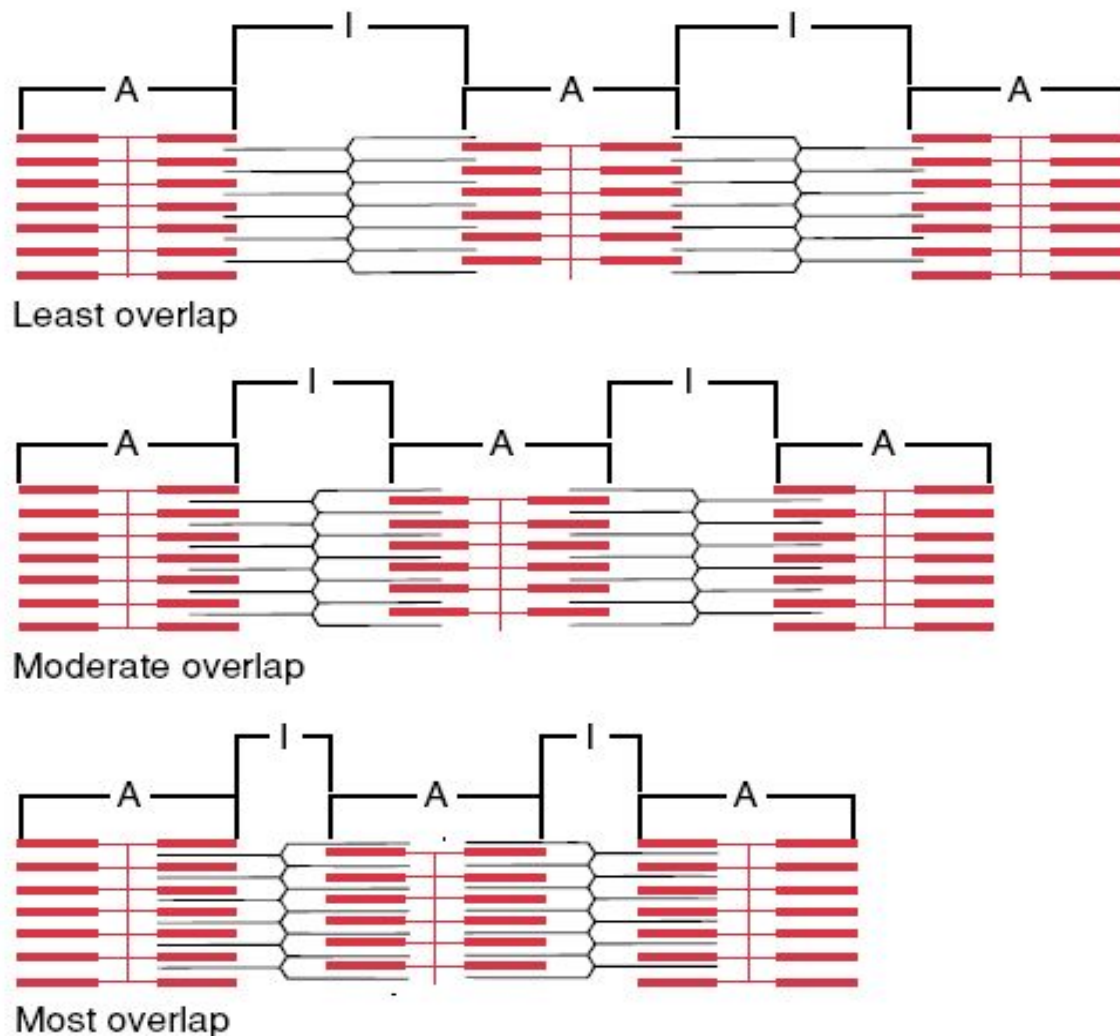


FIGURE 8.8

The multiplying effect of sarcomeres placed in series. The overall shortening is the sum of the shortening of the individual sarcomeres.

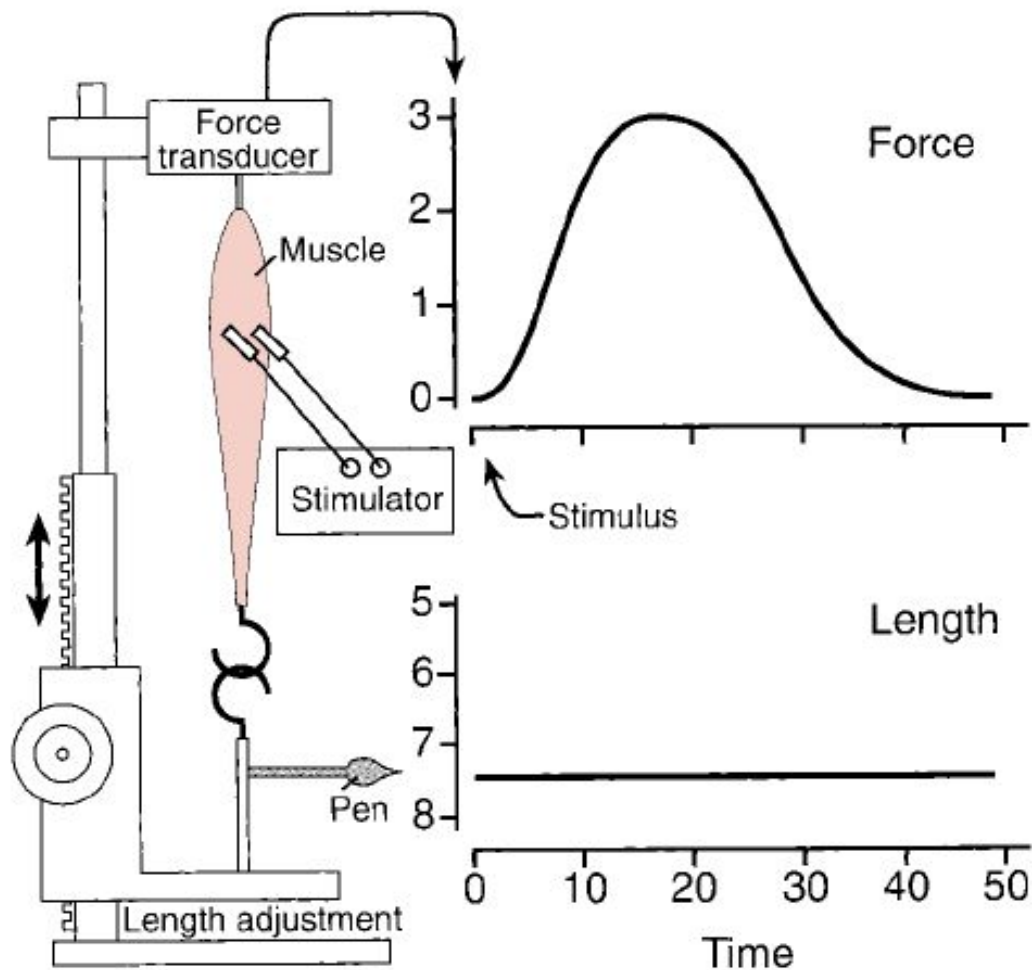


FIGURE 9.7 A simple apparatus for recording isometric contractions. The length of the muscle (marked on the graph by the pen attached near its lower end) is adjustable at rest but is held constant during contraction. The force transducer provides a record of the isometric force response to a single stimulus at a fixed length (isometric by definition). (Force, length, and time units are arbitrary.)

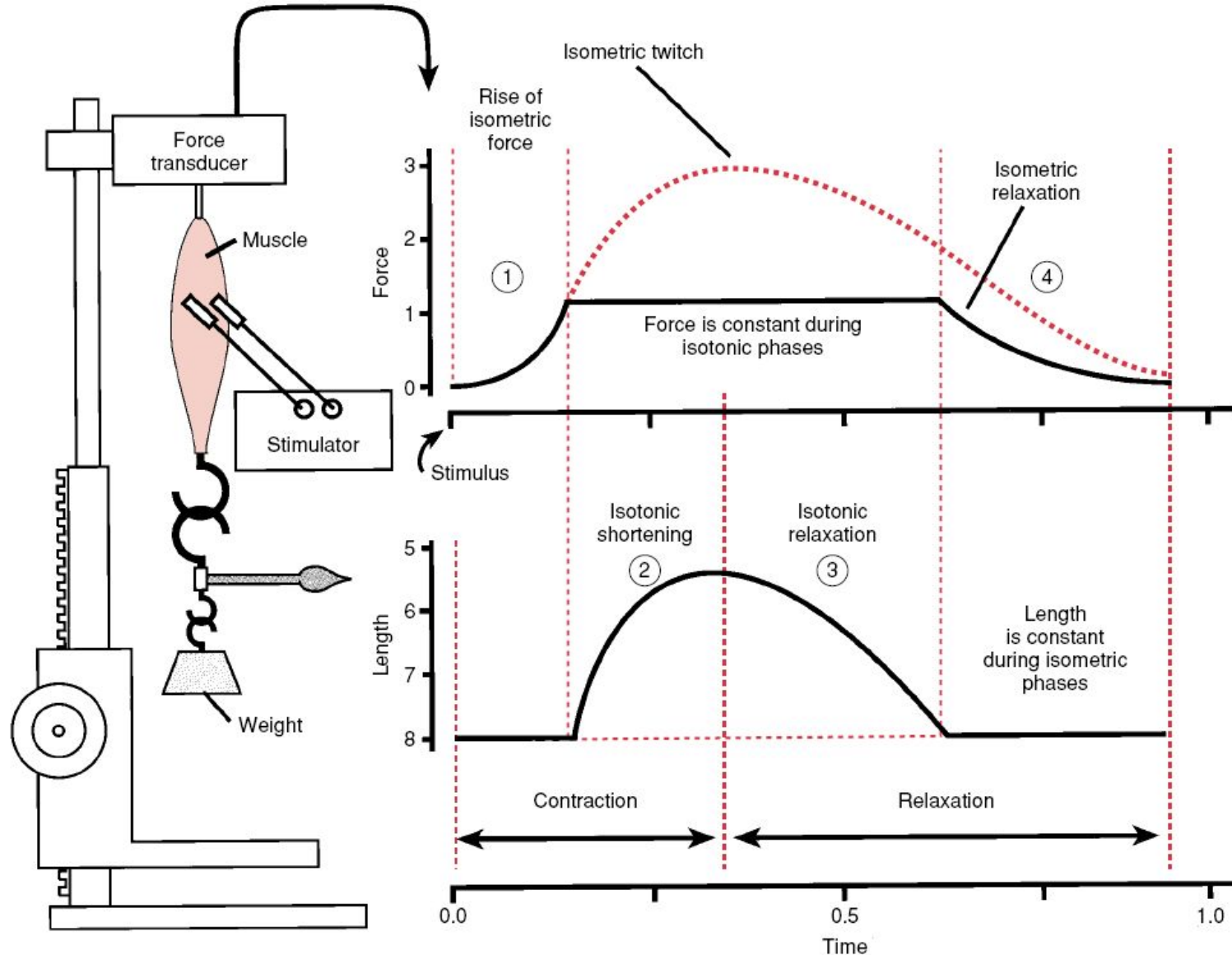


FIGURE 9.8 A modified apparatus showing the recording of a single isotonic switch. The pen at the lower end of the muscle marks its length, and the weight attached to the muscle provides the afterload, while the platform beneath the weight prevents the muscle from being overstretched at rest. The first part of the contraction, until sufficient force has developed to lift the weight, is isometric. During shortening and

isotonic relaxation the force is constant (isotonic conditions), and during the final relaxation, conditions are again isometric because the muscle no longer lifts the weight. The dotted lines in the force and length traces show the isometric twitch that would have resulted if the force had been too large (greater than 3 units) for the muscle to lift. (Force, length, and time units are arbitrary.) (See text for details.)

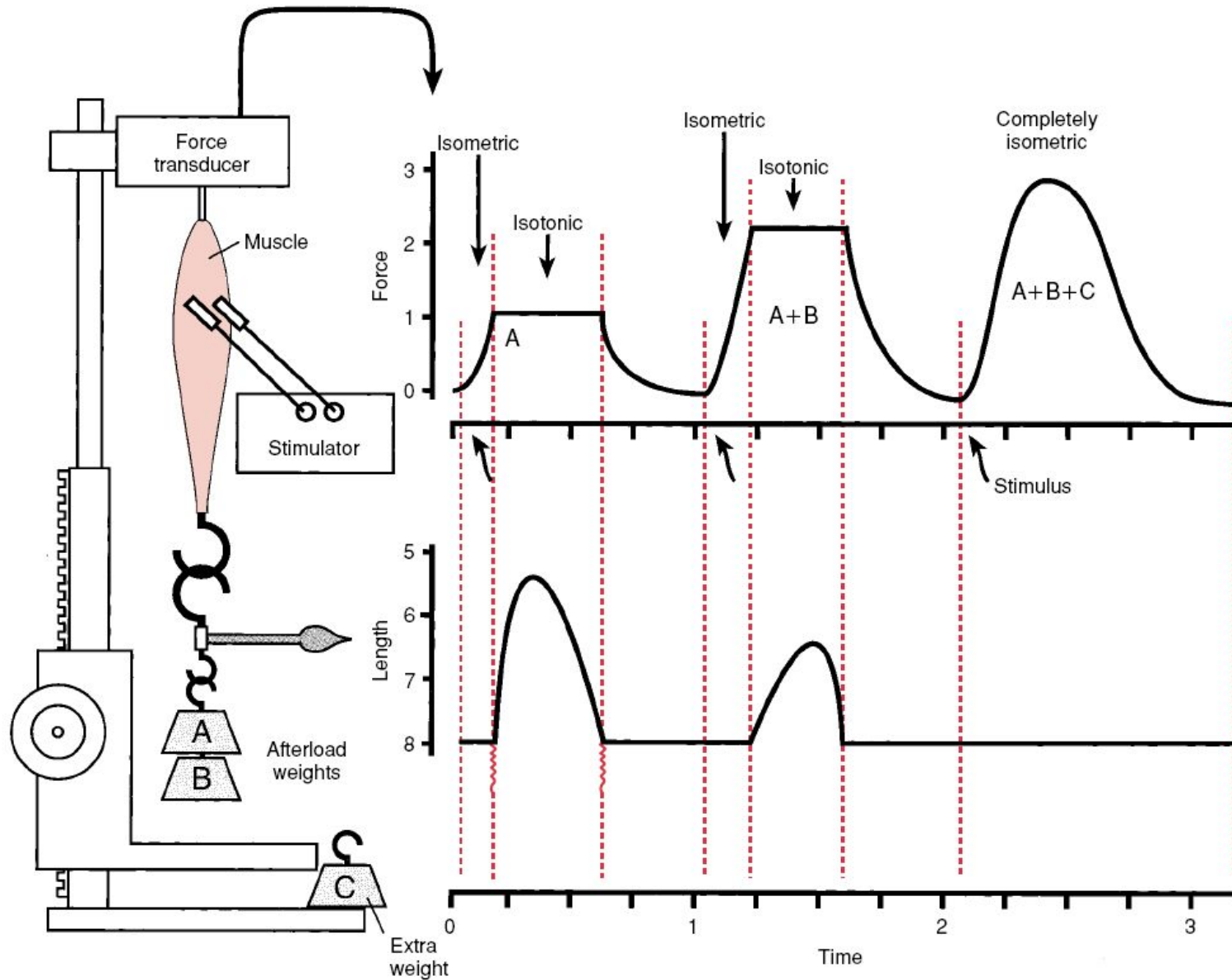
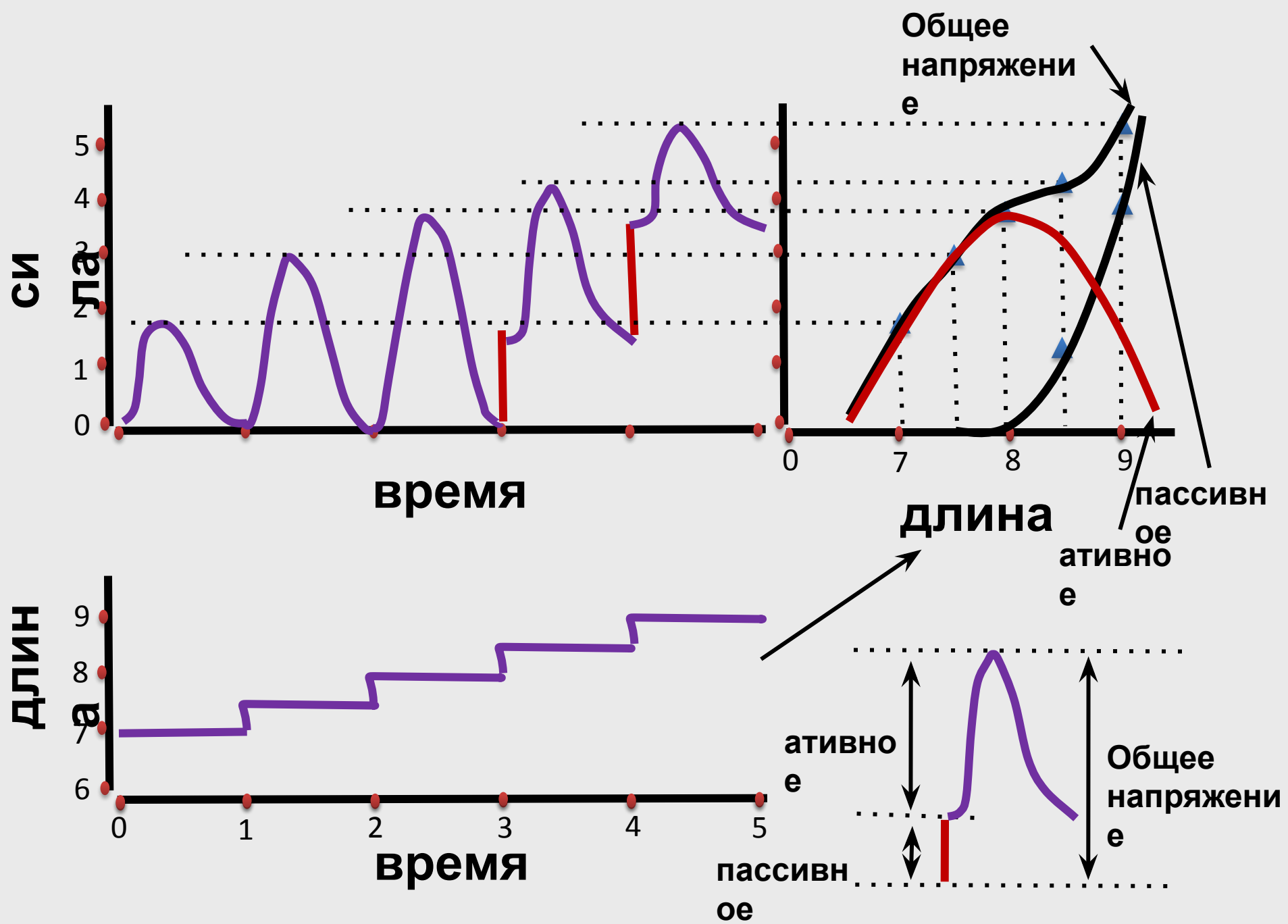
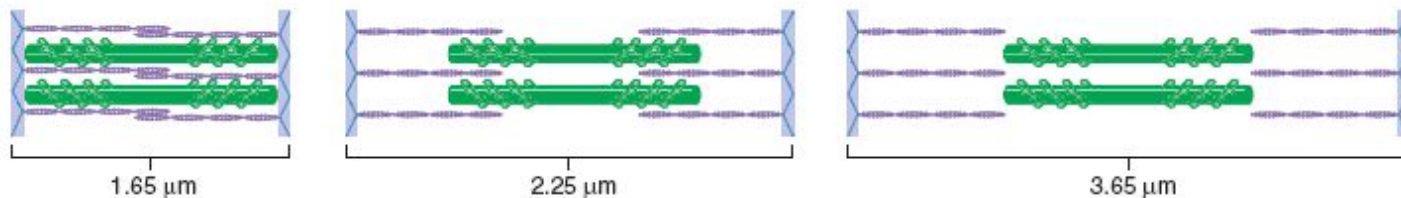
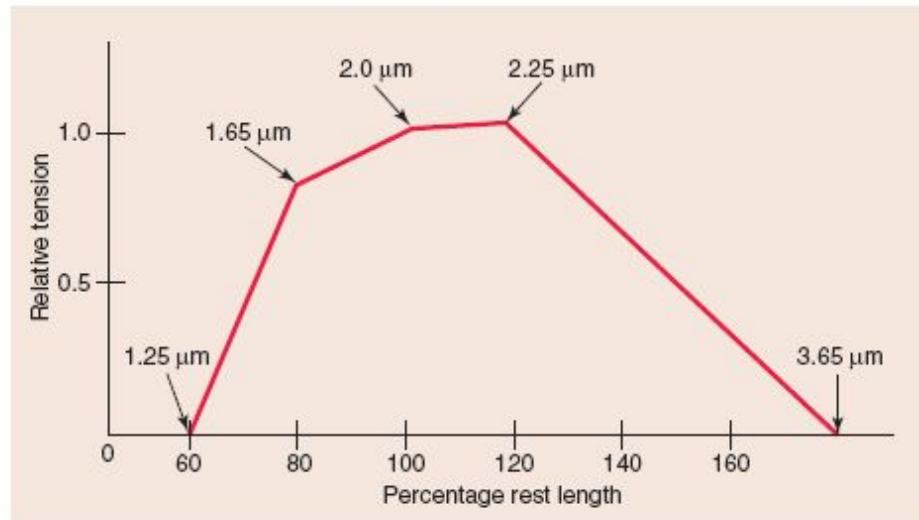


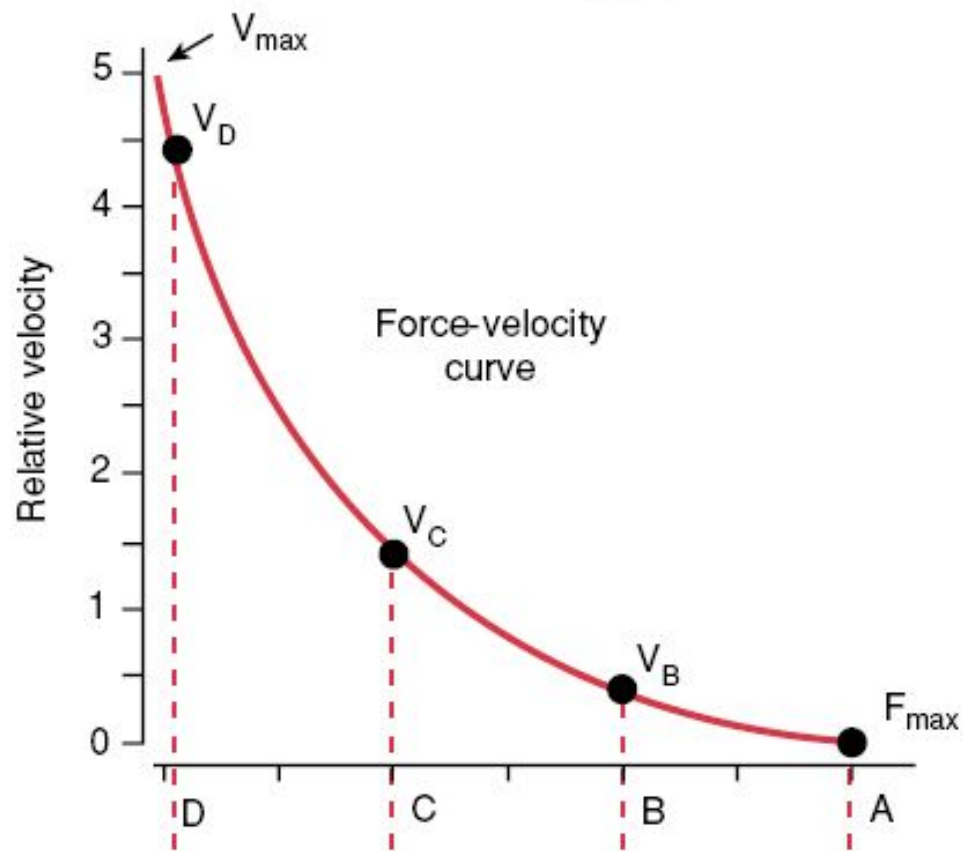
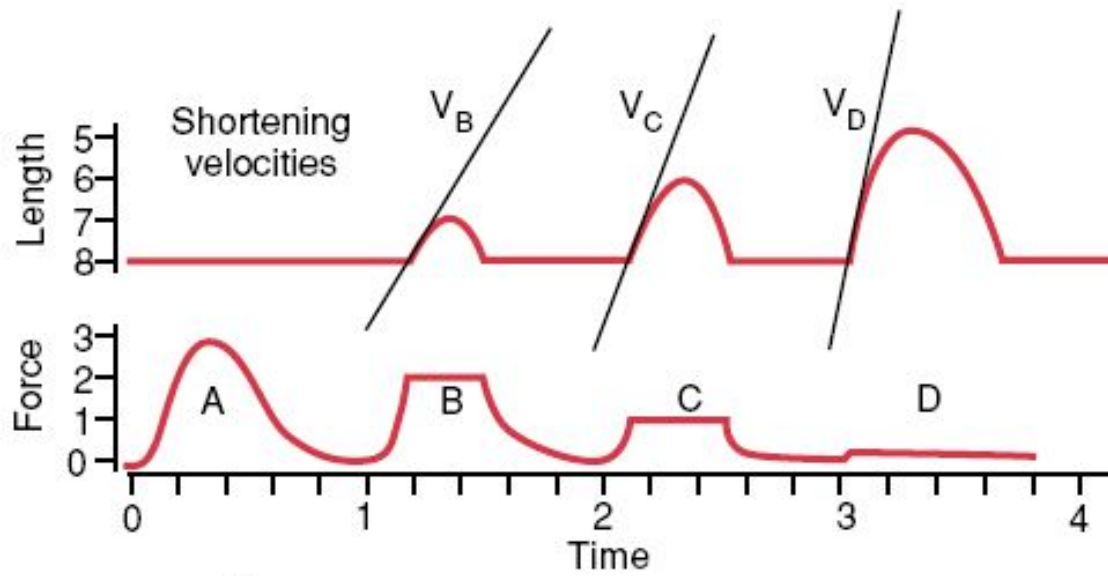
FIGURE 9.9 A series of afterloaded isotonic contractions. The curves labeled A and A + B correspond to the force and shortening records during the lifting of those weights. In each case, the adjustable platform prevents the muscle from being stretched by the attached weight, and all con-

tractions start from the same muscle length. Note the lower force and greater shortening with the lower weight (A). If weight C (total weight = A + B + C) is added to the afterload, the muscle cannot lift it, and the entire contraction remains isometric. (Force, length, and time units are arbitrary.)

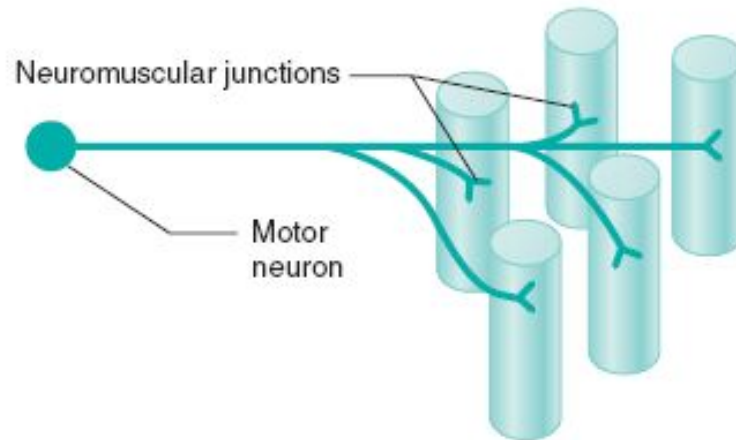




■ **Figure 12.20** The length-tension relationship in skeletal muscles. Maximum relative tension (1.0 on the y axis) is achieved when the muscle is 100% to 120% of its resting length (sarcomere lengths from 2.0 to 2.25 μm). Increases or decreases in muscle (and sarcomere) lengths result in rapid decreases in tension.



(a) Single motor unit



(b) Two motor units

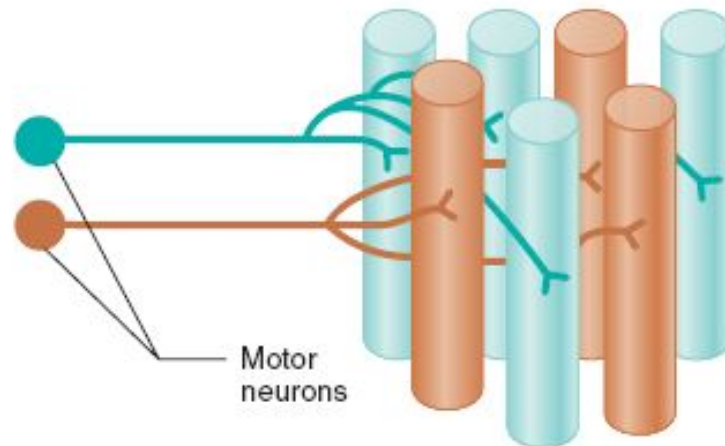


FIGURE 9-17

(a) Single motor unit consisting of one motor neuron and the muscle fibers it innervates. (b) Two motor units and their intermingled fibers in a muscle.

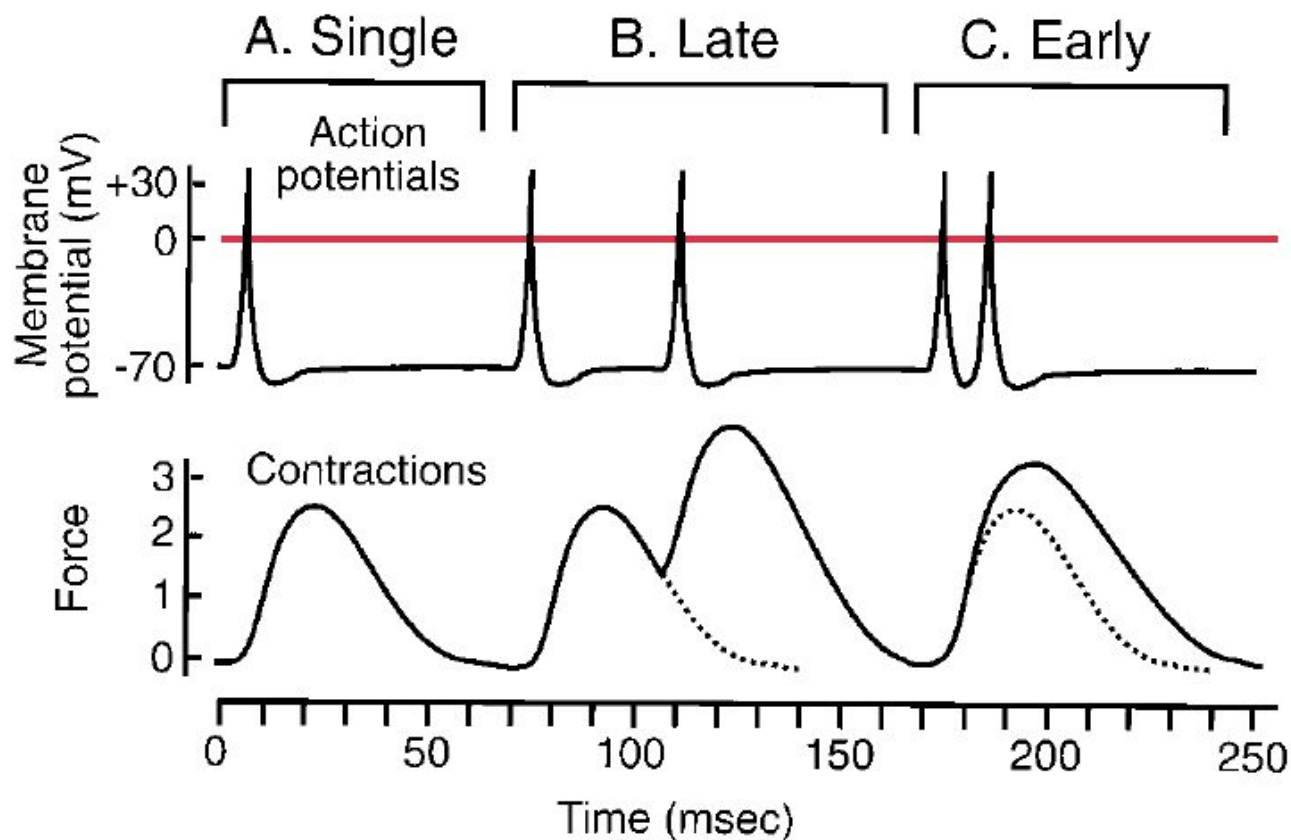


FIGURE 9.4

Temporal summation of muscle twitches. A, The first contraction is in response to a single action potential. B, The next contraction shows the summed response to a second stimulus given during relaxation; the two individual responses are evident. C, The last contraction is the result of two stimuli in quick succession. Though measured force was still rising when the second stimulus was given, the fact that there could be an added response shows that internal activation had begun to decline. In all cases, the solid line in the lower graph represents the actual summed tension.

Motor nerve action potentials

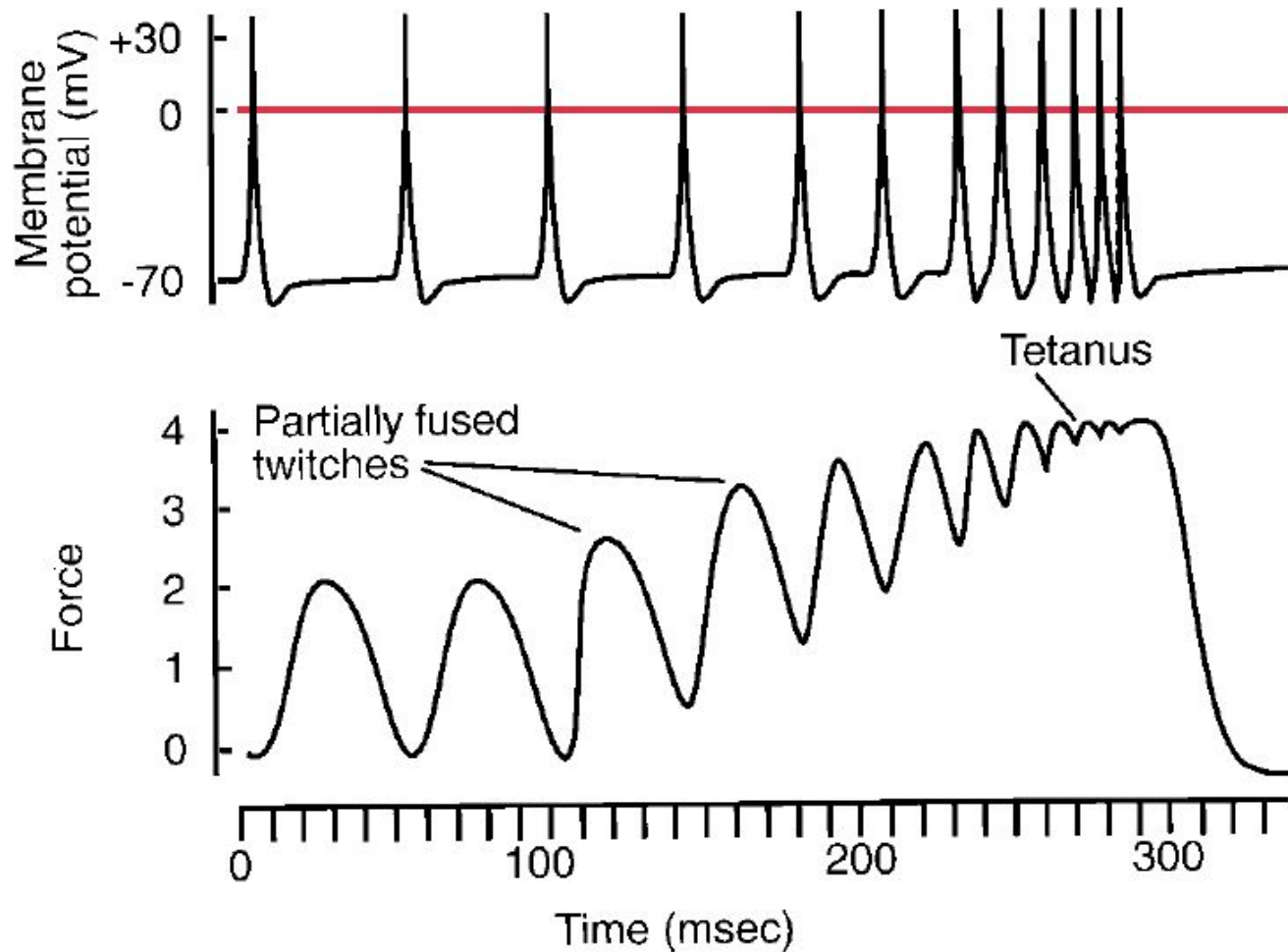


FIGURE 9.5

Fusion of twitches into a smooth tetanus.

The interval between successive stimuli steadily decreases until no relaxation occurs between stimuli.

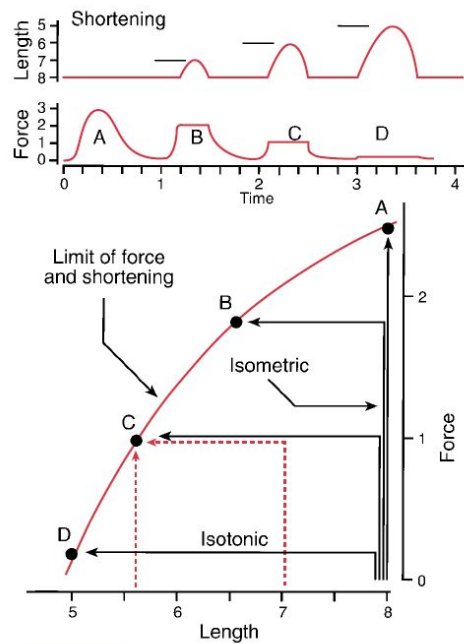


FIGURE 9.12 The relationship between isotonic and isometric contractions. The top graphs show the contractions from Figure 9.11, with different amounts of shortening. The bottom graph shows, for contractions B, C, and D, the initial portion is isometric (the line moves upward at constant length) until the afterload force is reached. The muscle then shortens at the afterload force (the line moves to the left) until its length reaches a limit determined (at least approximately) by the isometric length-tension curve. The dotted lines show that the same final force/length point can be reached by several different approaches. Relaxation data, not shown on the graph, would trace out the same pathways in reverse. (Force, length, and time units are arbitrary.)

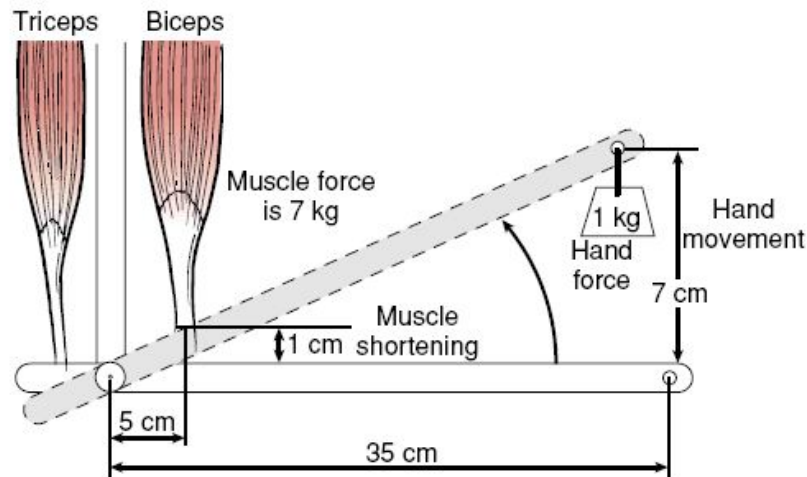


FIGURE 9.13 Antagonistic pairs and the lever system of skeletal muscle. Contraction of the biceps muscle lifts the lower arm (flexion) and elongates the triceps, while contraction of the triceps lowers the arm and hand (extension) and elongates the biceps. The bones of the lower arm are pivoted at the elbow joint (the fulcrum of the lever); the force of the biceps is applied through its tendon close to the fulcrum; the hand is 7 times as far away from the elbow joint. Thus, the hand will move 7 times as far (and fast) as the biceps shortens (lever ratio, 7:1), but the biceps will have to exert 7 times as much force as the hand is supporting.

TABLE 9.1 Classification of Skeletal Muscle Fiber Types

Metabolic Type	Fast Twitch		Slow Twitch
	Fast Glycolytic (White)	Fast Oxidative-Glycolytic (Red)	Slow Oxidative (Red)
Metabolic properties			
ATPase activity	High	High	Low
ATP source(s)	Anaerobic glycolysis	Anaerobic glycolysis/ Oxidative phosphorylation	Oxidative phosphorylation
Glycolytic enzyme content	High	Moderate	Low
Number of mitochondria	Low	High	High
Myoglobin content	Low	High	High
Glycogen content	High	Moderate	Low
Fatigue resistance	Low	Moderate	High
Mechanical properties			
Contraction speed	Fast	Fast	Slow
Force capability	High	Medium	Low
SR Ca ²⁺ -ATPase activity	High	High	Moderate
Motor axon velocity	100 m/sec	100 m/sec	85 m/sec
Structural properties			
Fiber diameter	Large	Moderate	Small
Number of capillaries	Few	Many	Many
Functional role in body	Rapid and powerful movements	Medium endurance	Postural/endurance
Typical example	Latissimus dorsi	Mixed-fiber muscle, such as vastus lateralis	Soleus

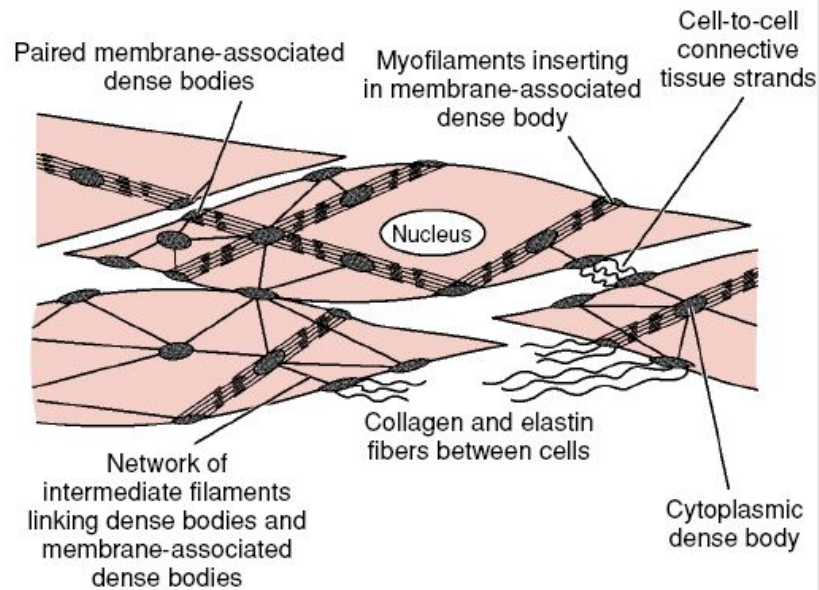


FIGURE 9.15 The contractile system and cell-to-cell connections in smooth muscle. Note regions of association between thick and thin filaments that are anchored by the cytoplasmic and membrane-associated dense bodies. A network of intermediate filaments provides some spatial organization (see, especially, the left side). Several types of cell-to-cell mechanical connections are shown, including direct connections and connections to the extracellular connective tissue matrix. Structures are not necessarily drawn to scale. (See text for details.)

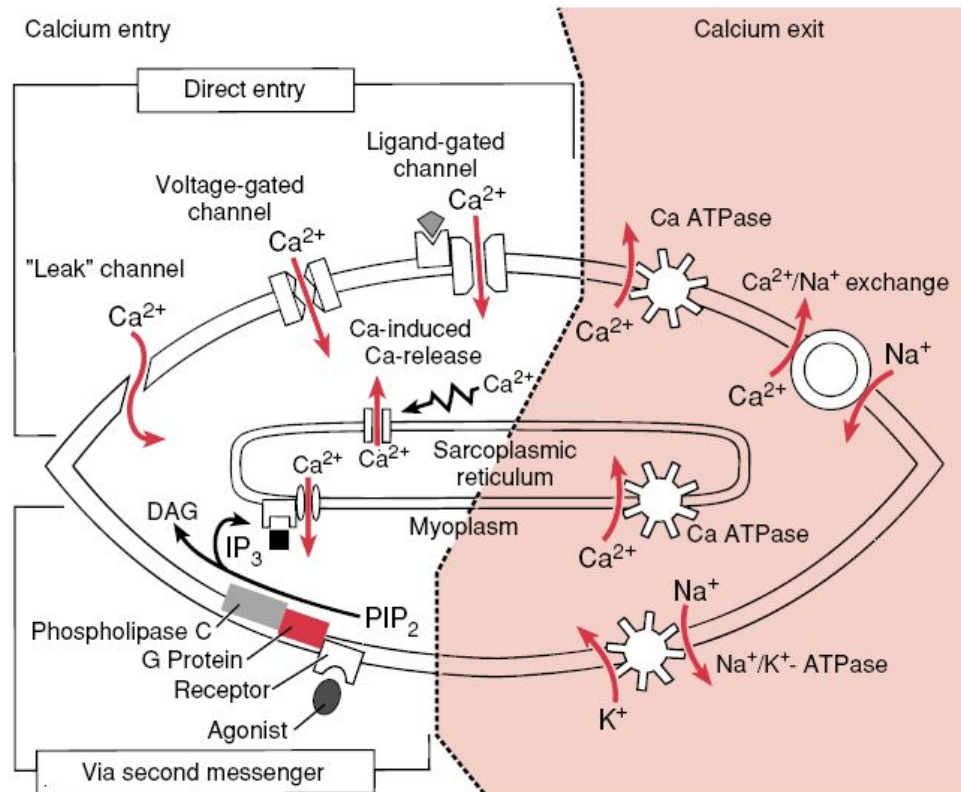
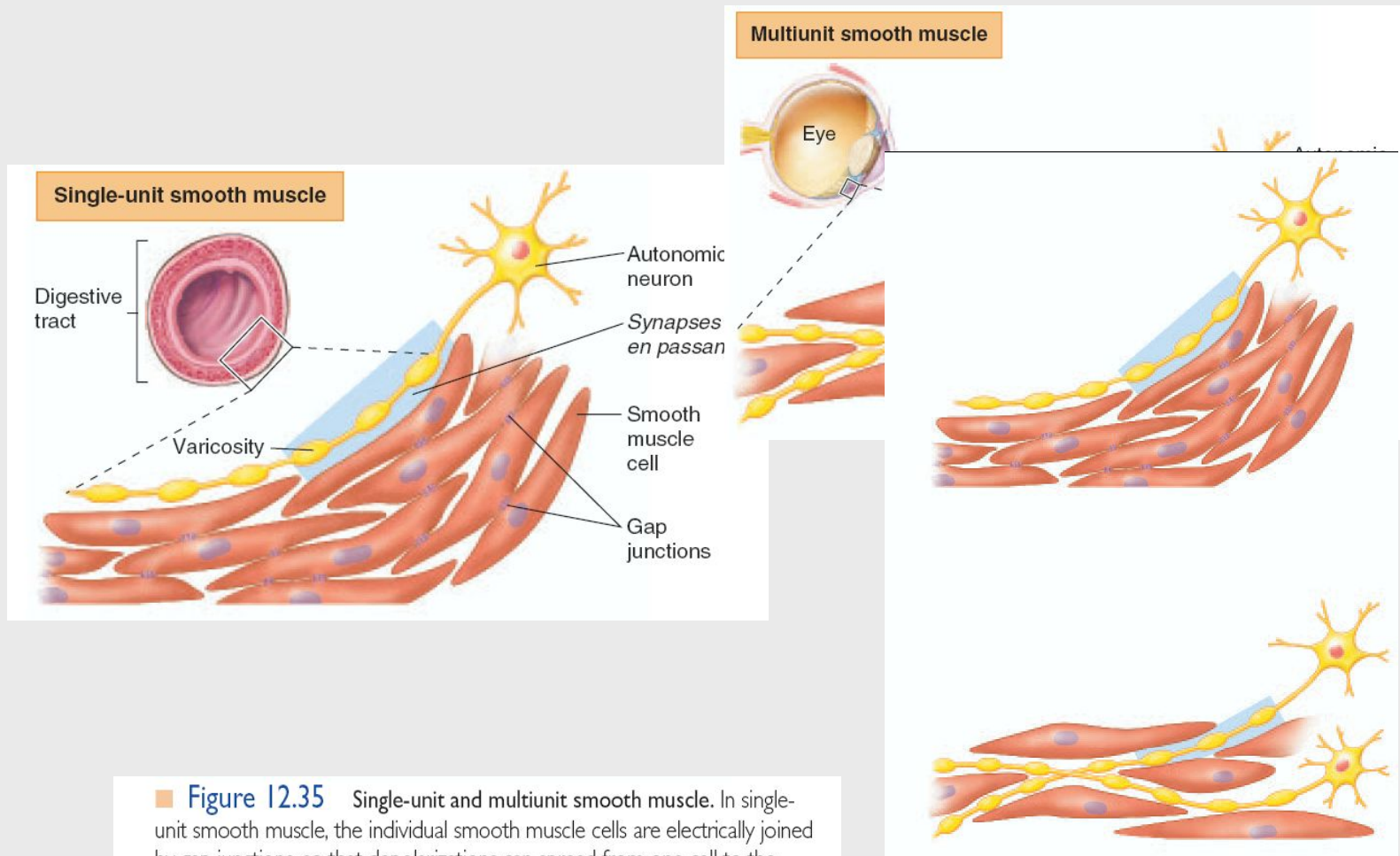


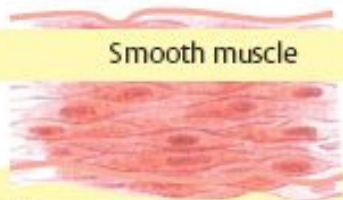
FIGURE 9.16 Major routes of calcium entry and exit from the cytoplasm of smooth muscle. The ATPase reactions are energy-consuming ion pumps. The processes on the left side increase cytoplasmic calcium and promote contraction; those on the right decrease internal calcium and cause relaxation. PIP_2 , phosphatidylinositol 4,5-bisphosphate; IP_3 , inositol 1,4,5-trisphosphate; DAG, diacylglycerol.



■ **Figure 12.35** Single-unit and multiunit smooth muscle. In single-unit smooth muscle, the individual smooth muscle cells are electrically joined by gap junctions, so that depolarizations can spread from one cell to the next. In multiunit smooth muscle, each smooth muscle cell must be stimulated by an axon. The axons of autonomic neurons have varicosities, which release neurotransmitters, and which form *synapses en passant* with the smooth muscle cells.

Structure and function

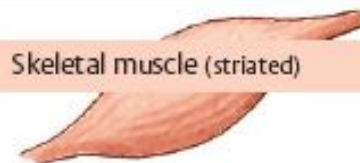
Smooth muscle



Cardiac muscle (striated)



Skeletal muscle (striated)



Motor end-plates

None

None

Yes

Fibers

Fusiform, short (≤ 0.2 mm)

Branched

Cylindrical, long (≤ 15 cm)

Mitochondria

Few

Many

Few (depending on muscle type)

Nucleus per fiber

1

1

Multiple

Sarcomeres

None

Yes, length ≤ 2.6 μ m

Yes, length ≤ 3.65 μ m

Electr. coupling

Some (single-unit type)

Yes (functional syncytium)

No

Sarcoplasmic reticulum

Little developed

Moderately developed

Highly developed

Ca²⁺ "switch"

Calmodulin/caldesmon

Troponin

Troponin

Pacemaker

Some spontaneous rhythmic activity ($1s^{-1}$ – $1h^{-1}$)

Yes (sinus nodes ca. $1s^{-1}$)

No (requires nerve stimulus)

Response to stimulus

Change in tone or rhythm frequency

All or none

Graded

Tetanic

Yes

No

Yes

Work range

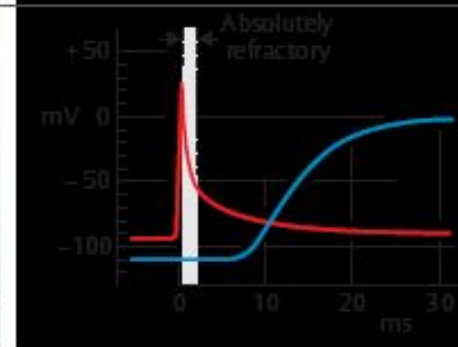
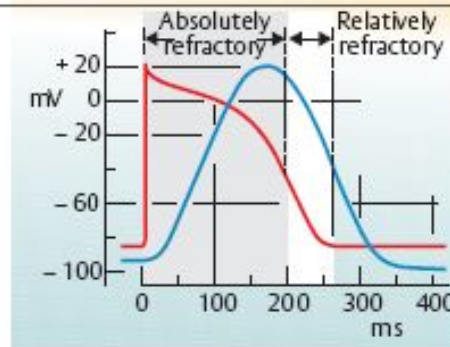
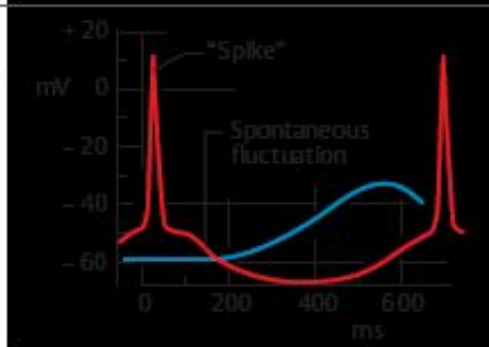
Length-force curve is variable

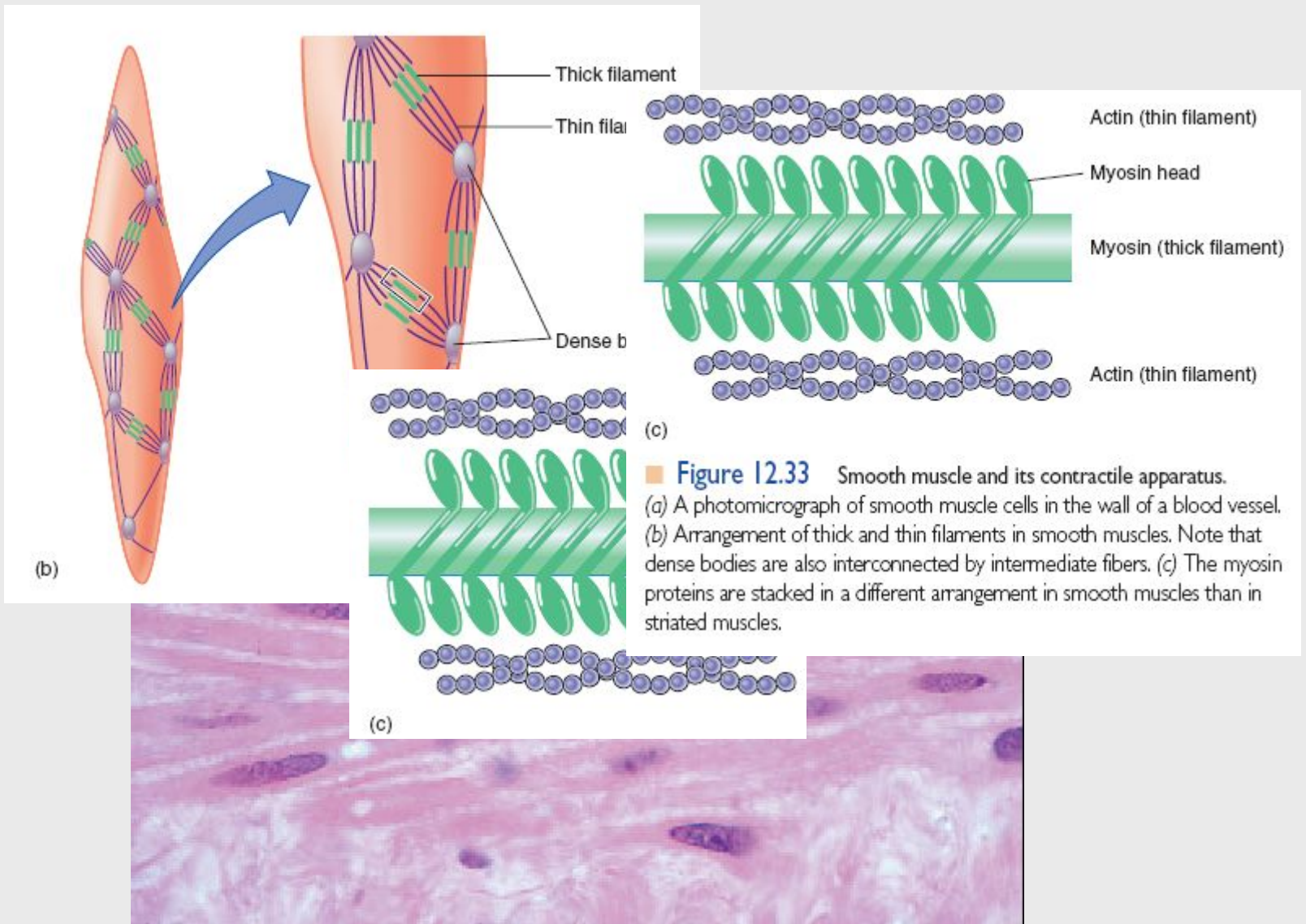
In rising length-force curve (see 2.15E)

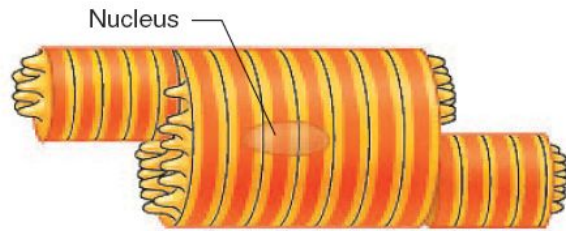
At peak of length-force curve (see 2.15E)

Response to stimulus

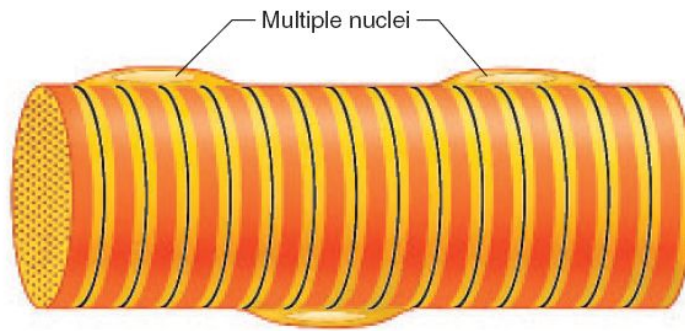
Potential —
Muscle tension —



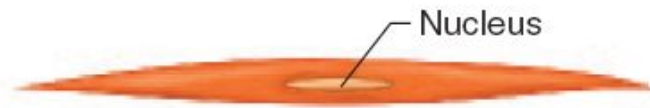




Cardiac muscle cell



Skeletal muscle fiber



Smooth muscle cell