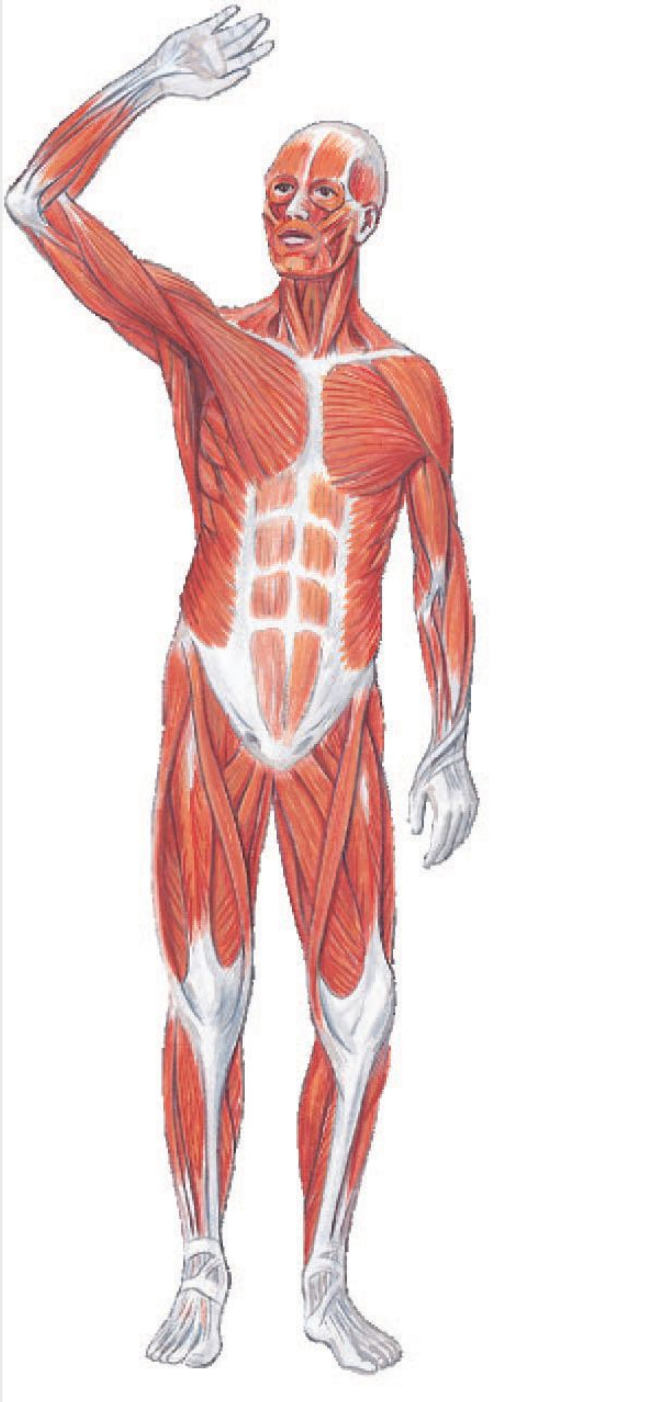
ГОУ ВПО ОрГМА Росздрава
кафедра нормальной физиологии

# Физиология мышц



# Активное движение

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

# Биологическое движение

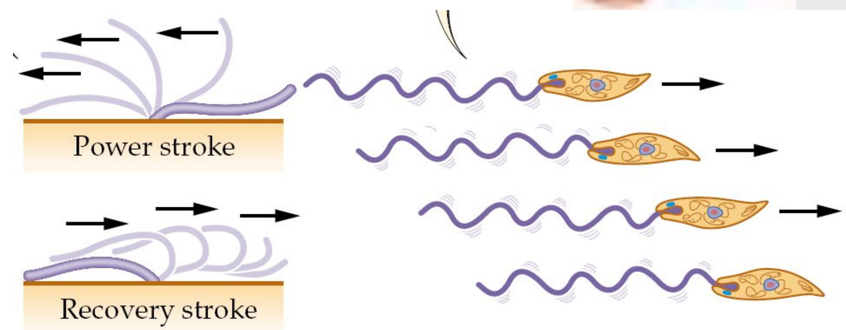
- Сокращение различных мышц,
- Движение листьев,
- Биение ресничек,
- Движение жгутиков,
- Деление клеток,
- Движение протоплазмы.

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

# Формы движения

- *Амебойдно*

- ***Мерцательное***




- ***Мышечное***

***(для тел большой массы)***

# Мышечное движение наиболее эффективный способ перемещения

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

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

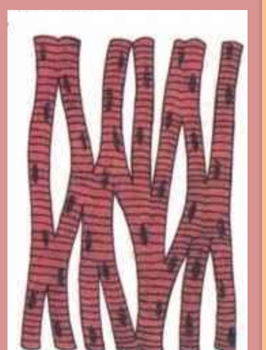
- Мышечными называют все типы клеток, функция которых состоит в сокращении.

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

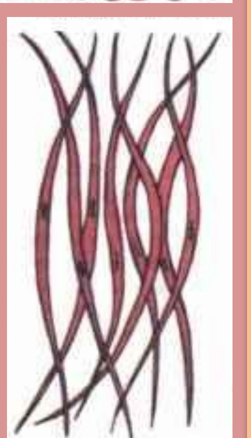
# Классификации мышц

## Гистологическая

Поперечнополосатые



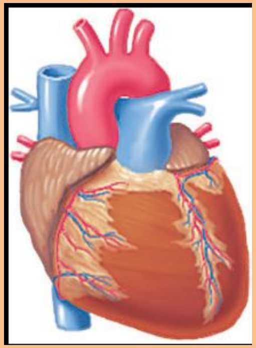
Гладкие



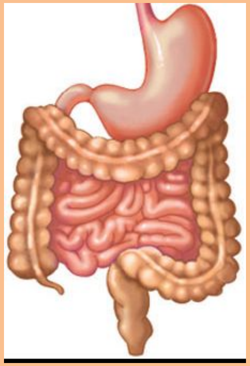
## АНАТОМИЧЕСКАЯ

СКЕЛЕТНЫЕ

СЕРДЕЧНАЯ



ВИСЦЕРАЛЬНЫЕ



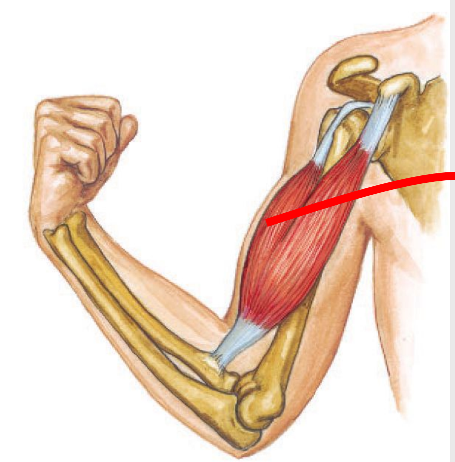
## Функциональная

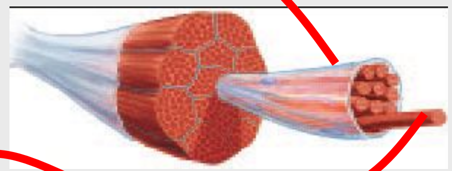
произвольные

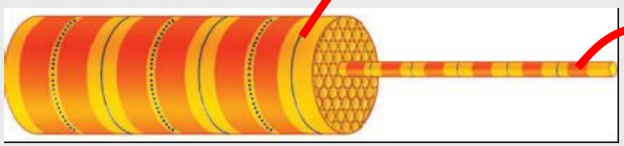
непроизвольные

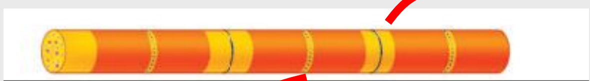
# Скелетная мышца

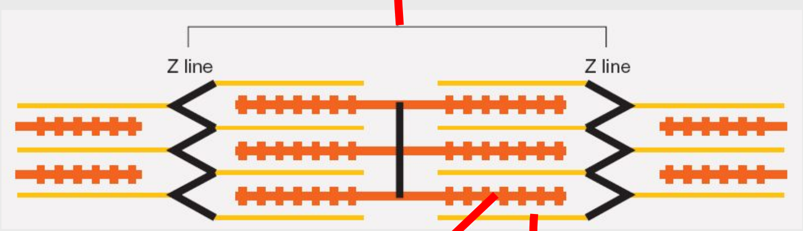
# Уровни структурной организации скелетных мышц

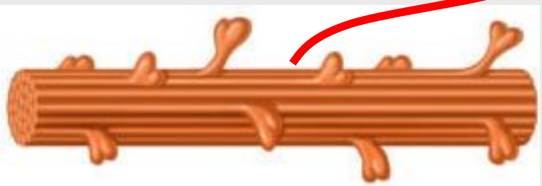










**Мышца**
**x1**

↓

**Пучок мышечных волокон**
**x5**

↓

**Мышечное волокно**
**X 500**

↓

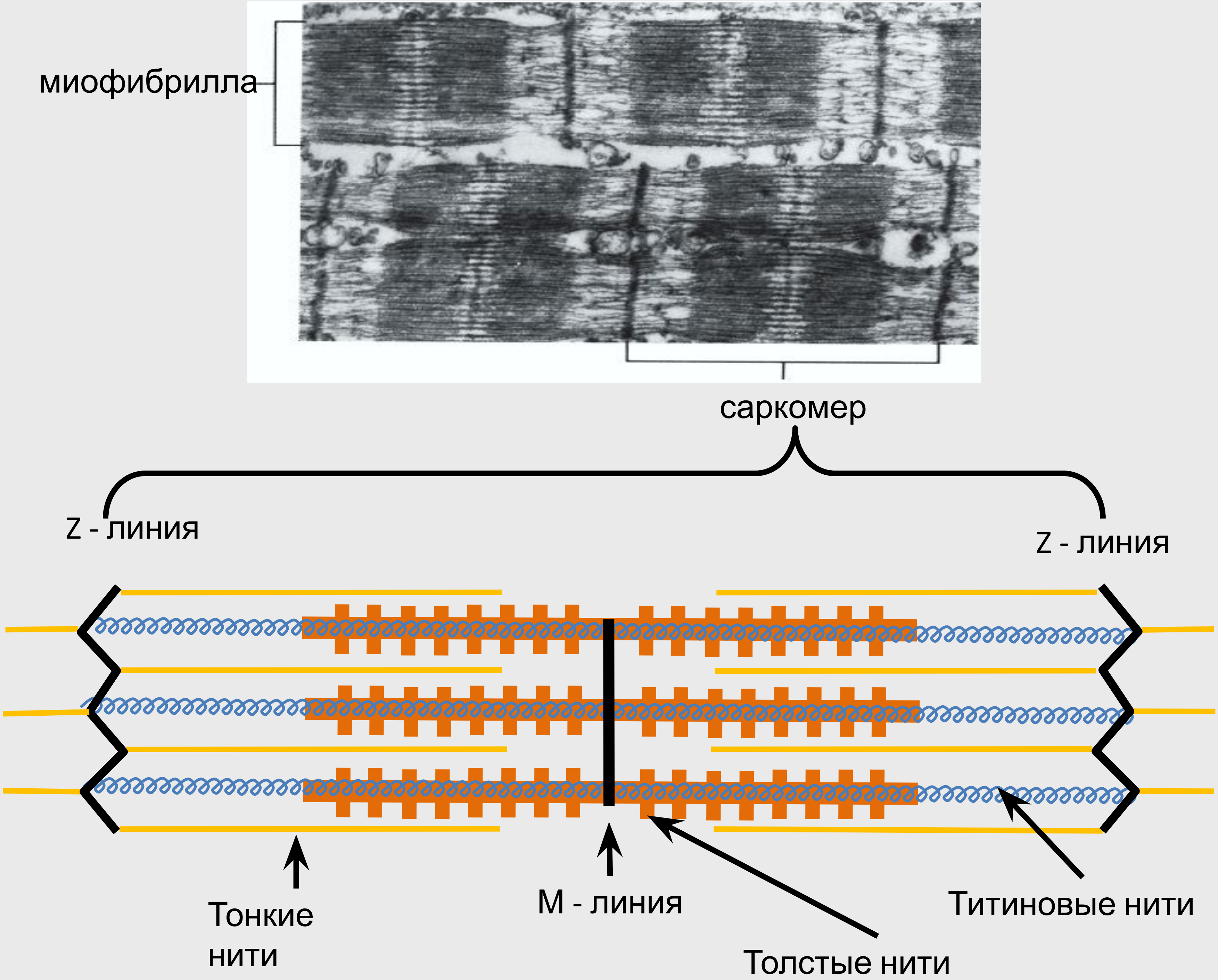
**Миофибрилла**
**X 10000**

↓

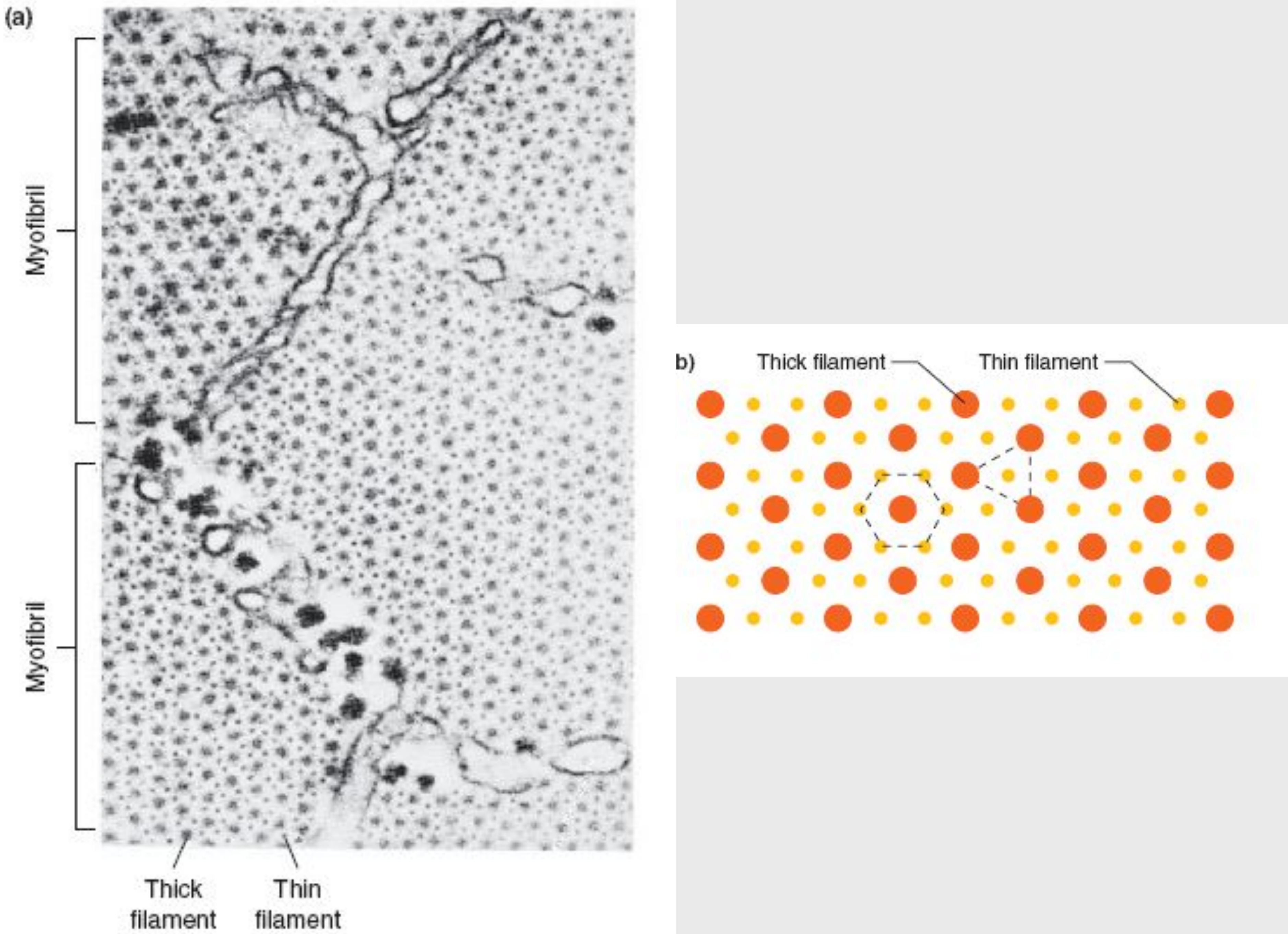
**Саркомер**
**X 50000**

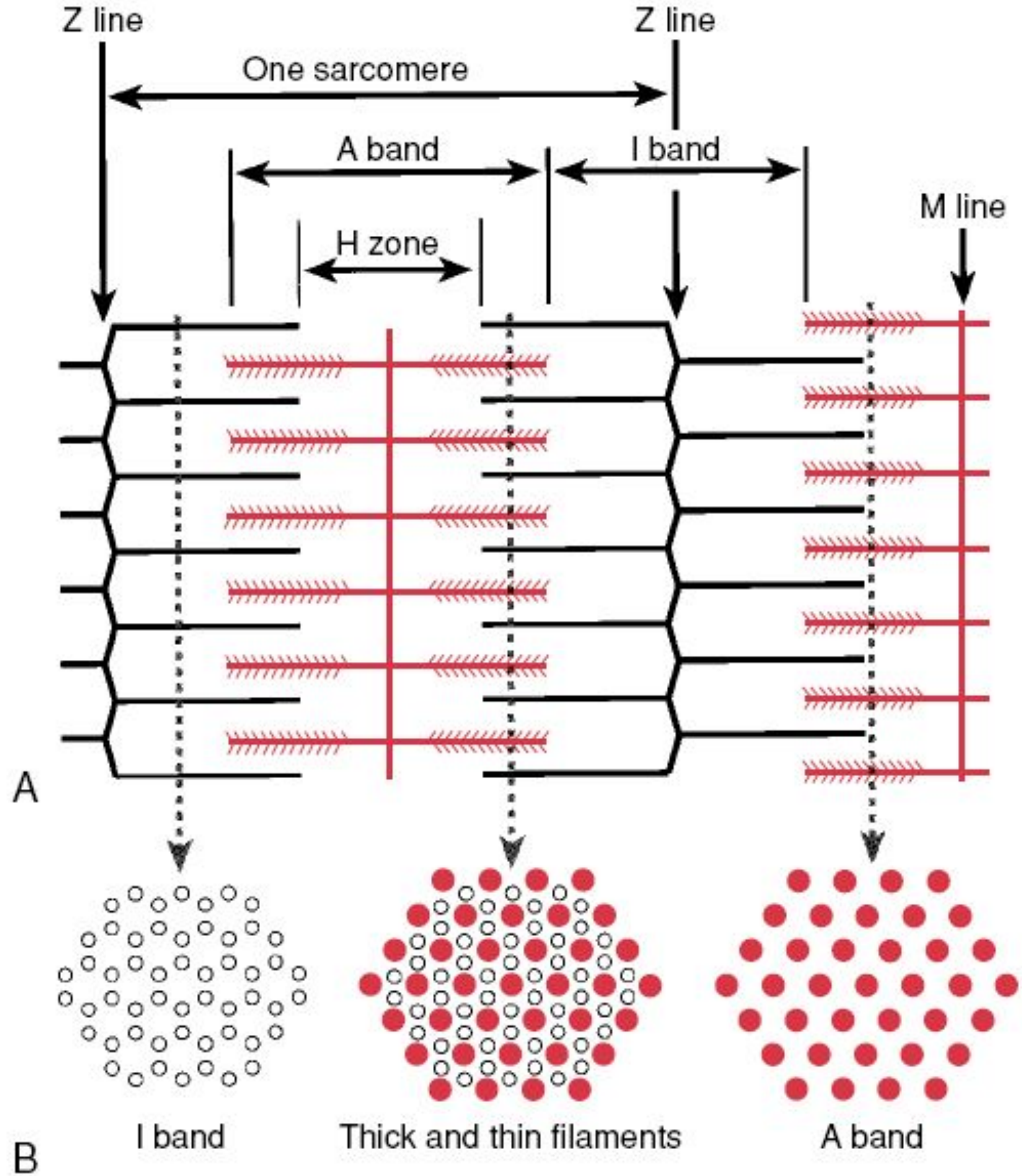
↓

**Миофиламенты**
**X 1000000**



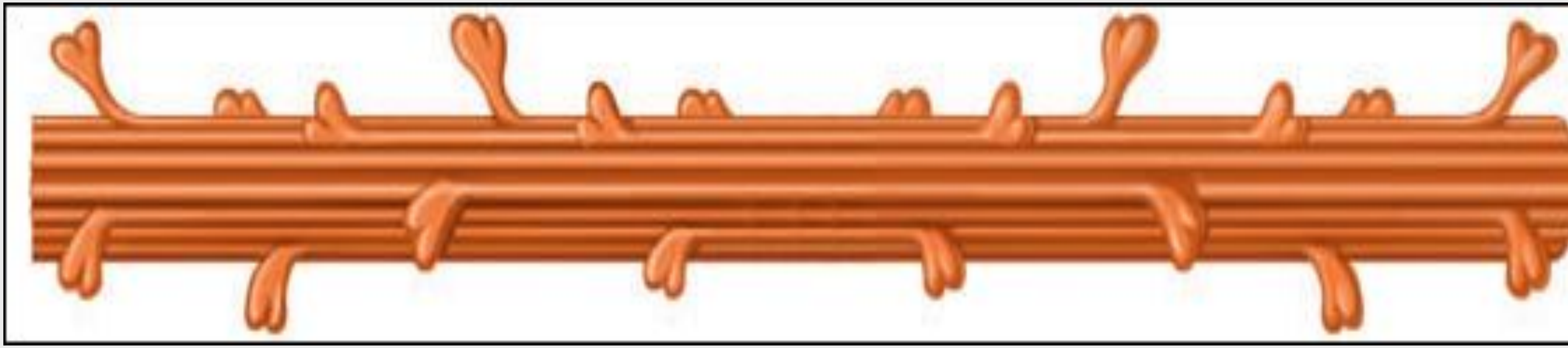
миофибрилла
саркомер
Z - линия
Z - линия
Тонкие нити
М - линия
Толстые нити
Титиновые нити


(a)
Myofibril
Myofibril
Thick filament
Thin filament
b)
Thick filament
Thin filament

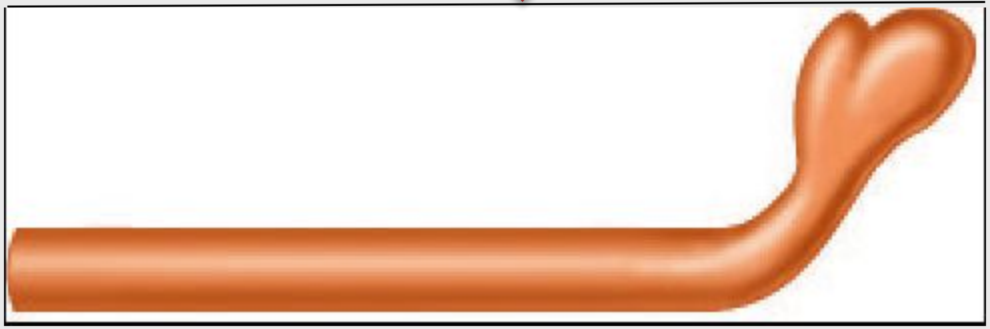


Z line
Z line
One sarcomere
A band
I band
H zone
M line
A
B
I band
Thick and thin filaments
A band

# Миозиновые нити (толстые нити)



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

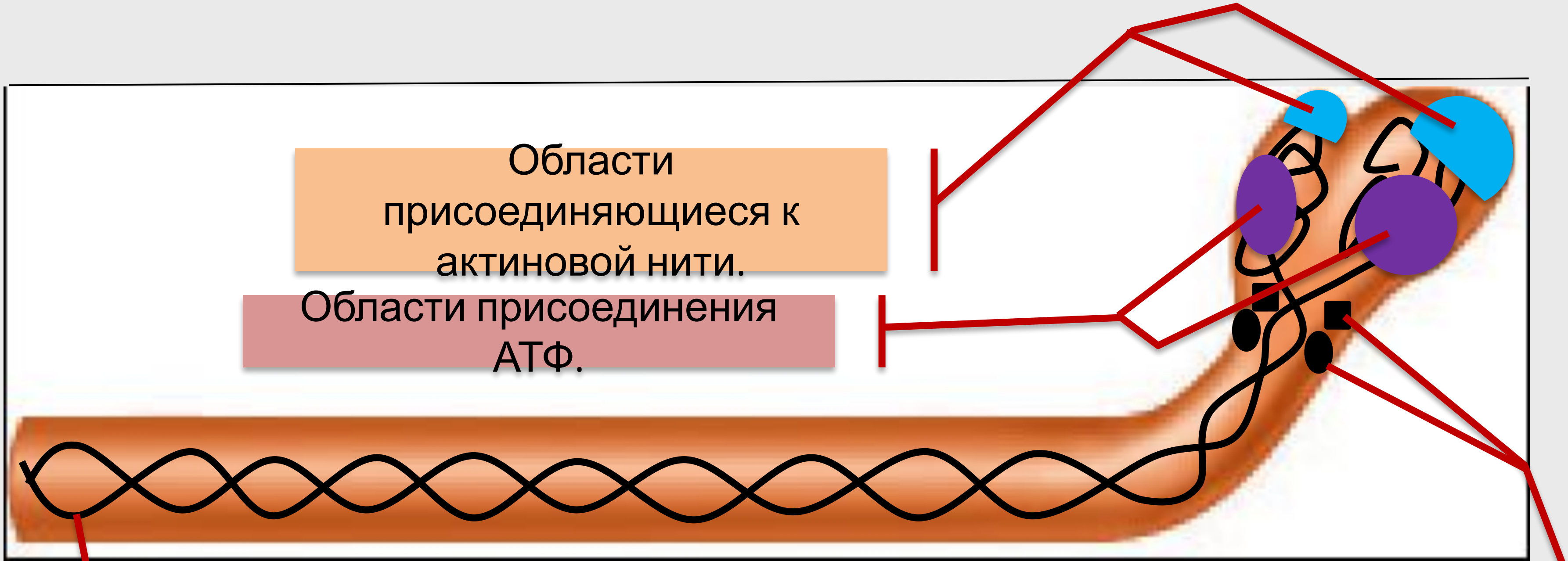


# Строение молекулы миозина

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

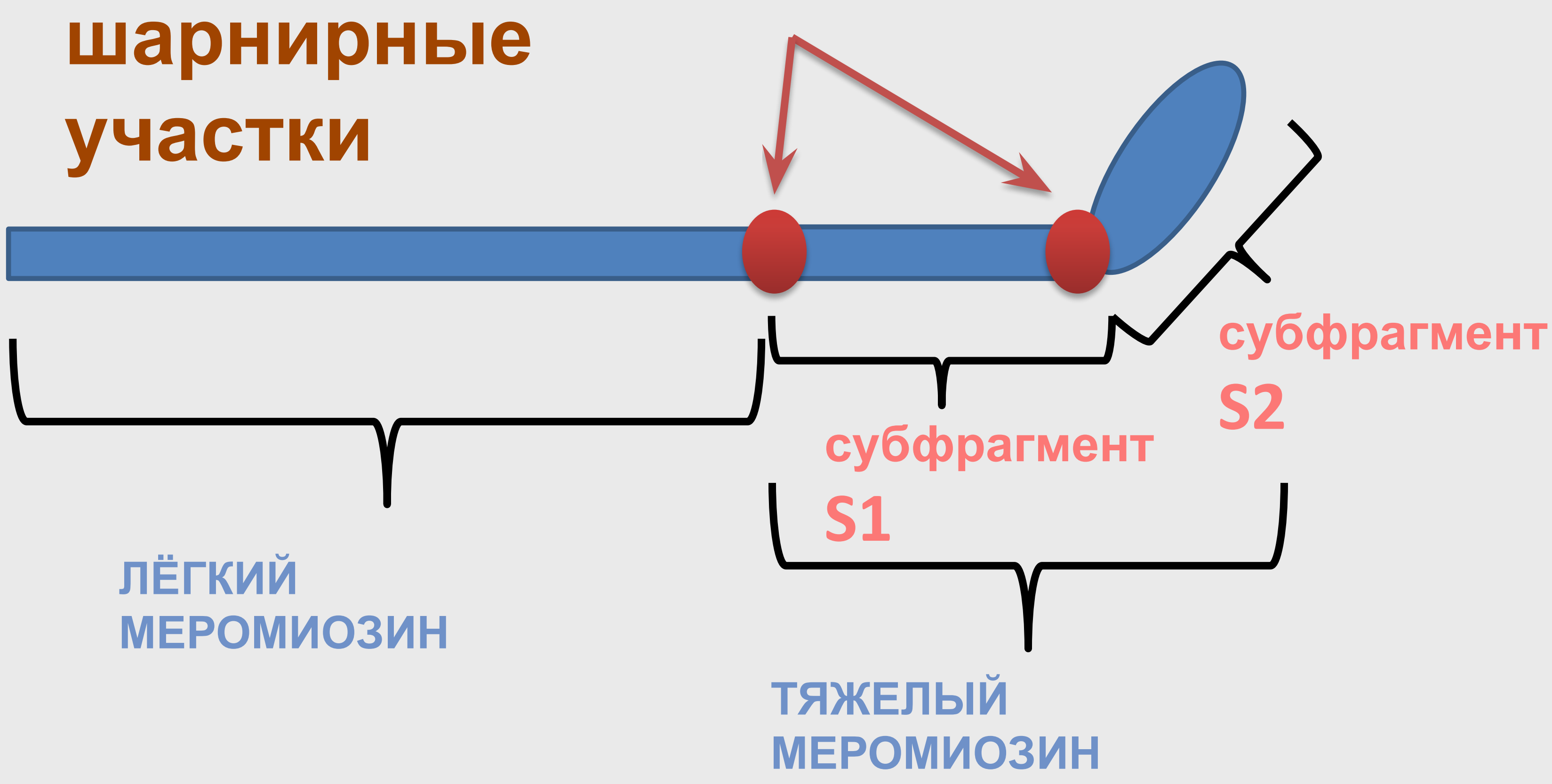
Области присоединяющиеся к актиновой нити.

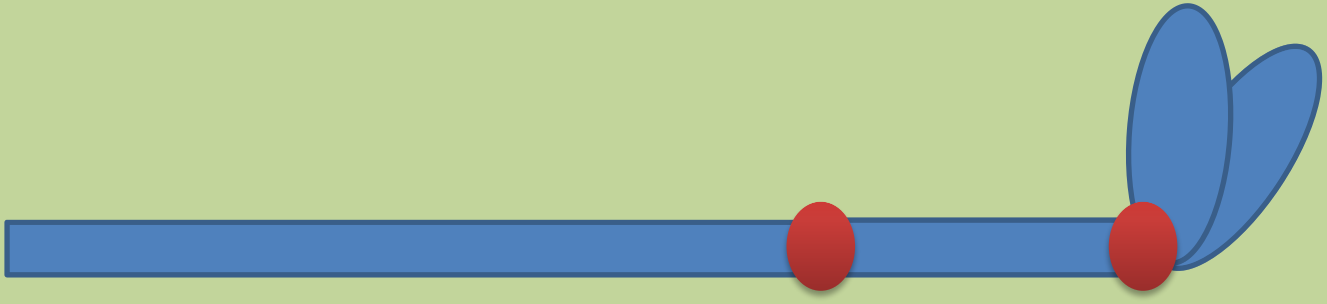
Области присоединения АТФ.

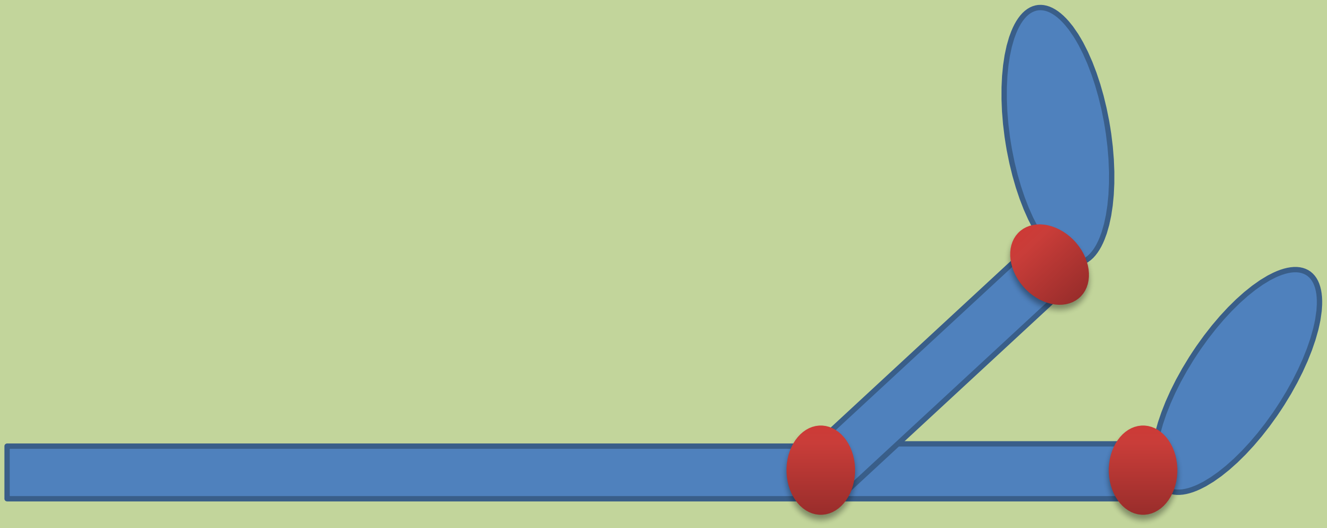


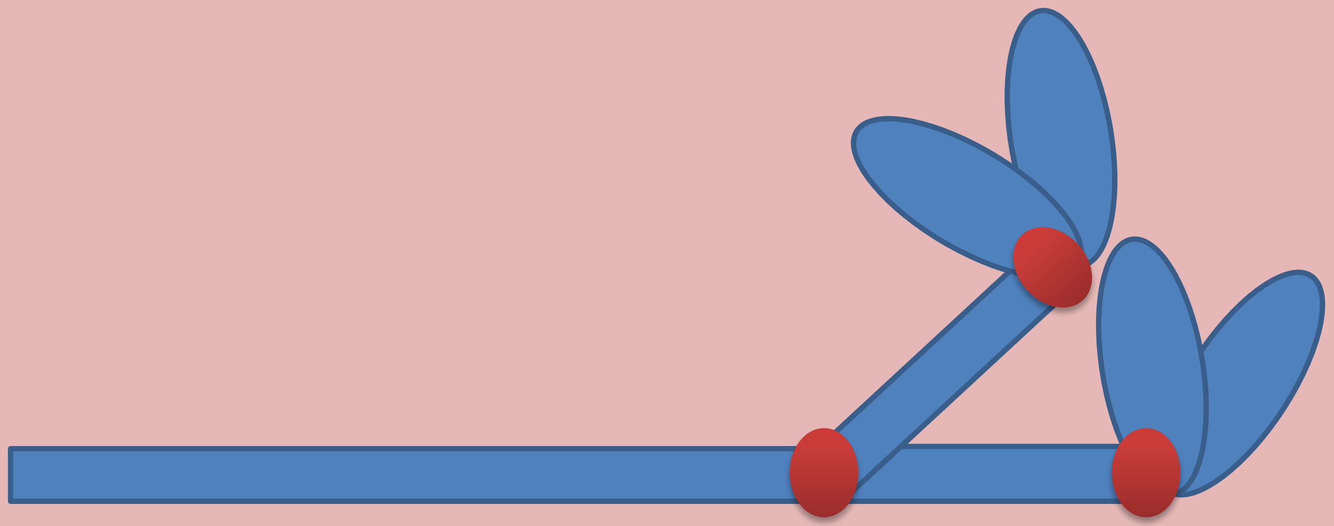
Тяжёлые цепи — две спирально закрученные полипептидные нити, несущие на своих концах глобулярные головки.

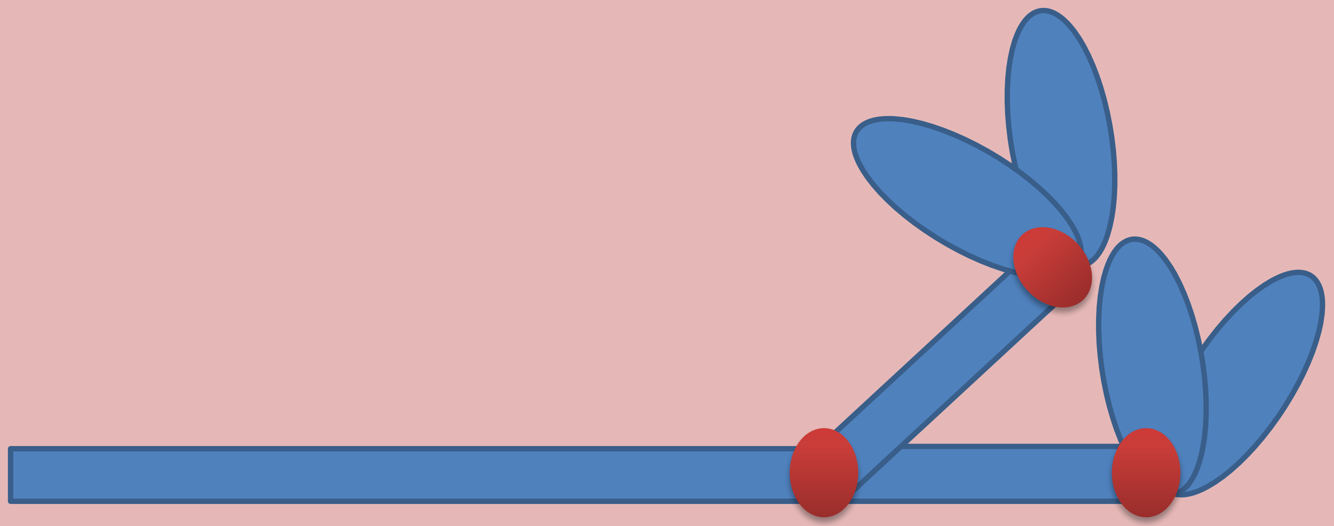
В области головок с тяжёлыми цепями ассоциированы лёгкие цепи.

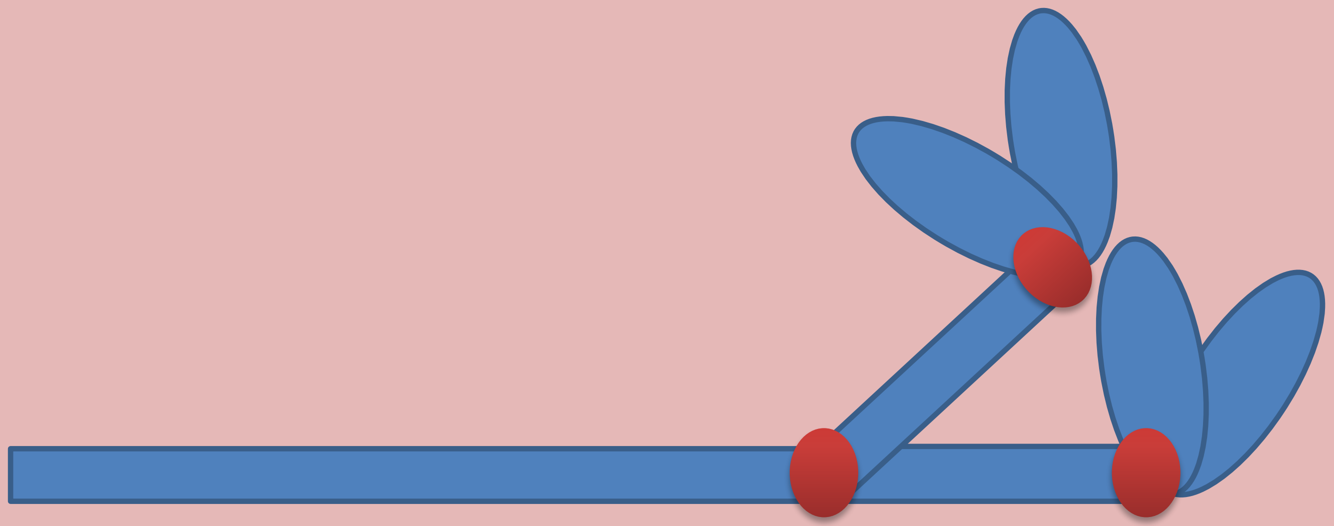

шарнирные
участки
субфрагмент
S2
субфрагмент
S1
ЛЁГКИЙ
МЕРОМИОЗИН
ТЯЖЕЛЫЙ
МЕРОМИОЗИН

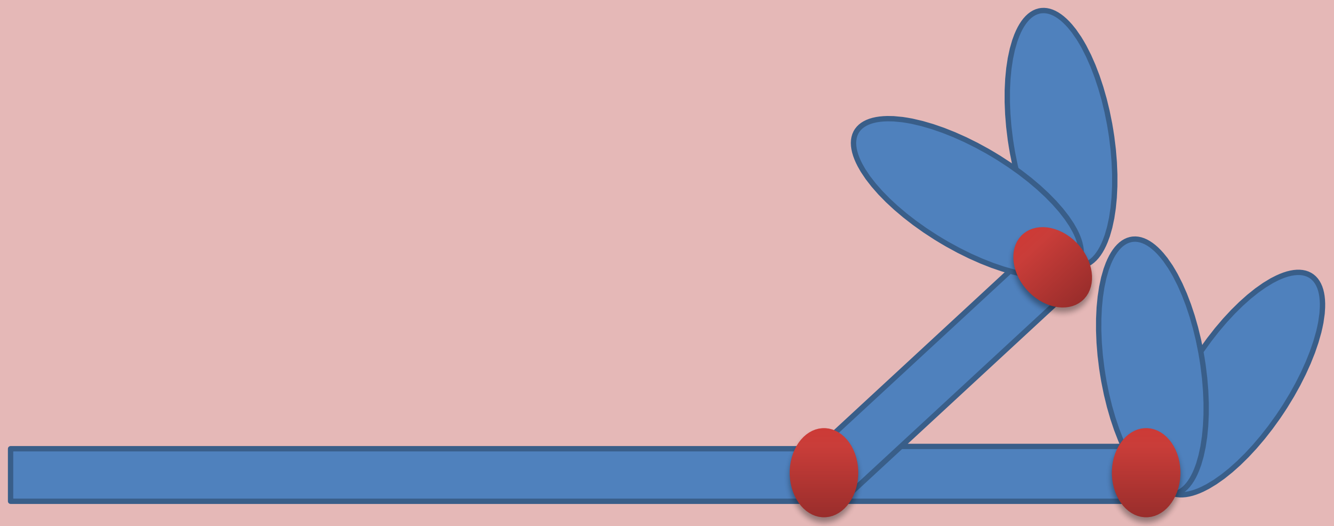




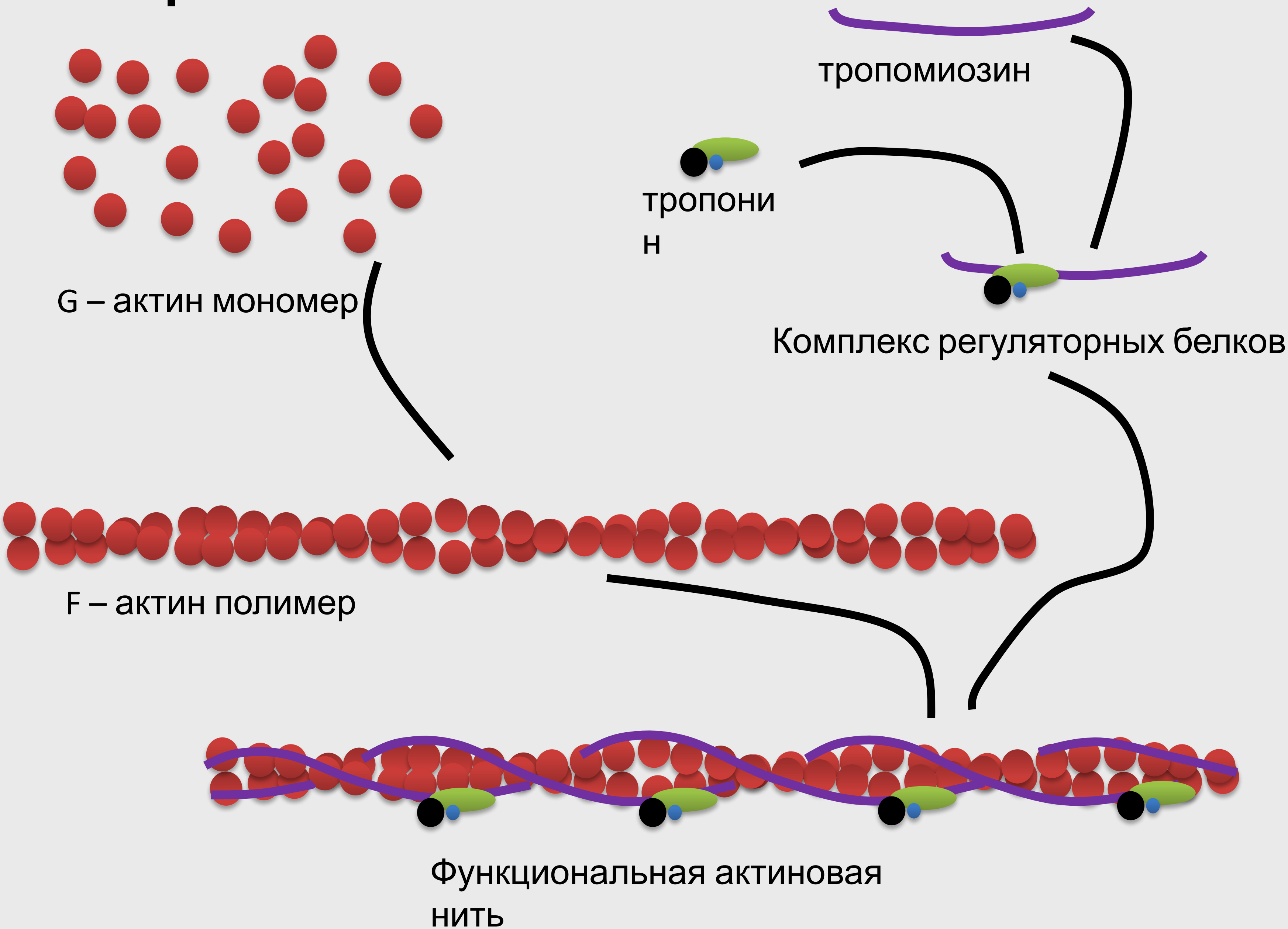


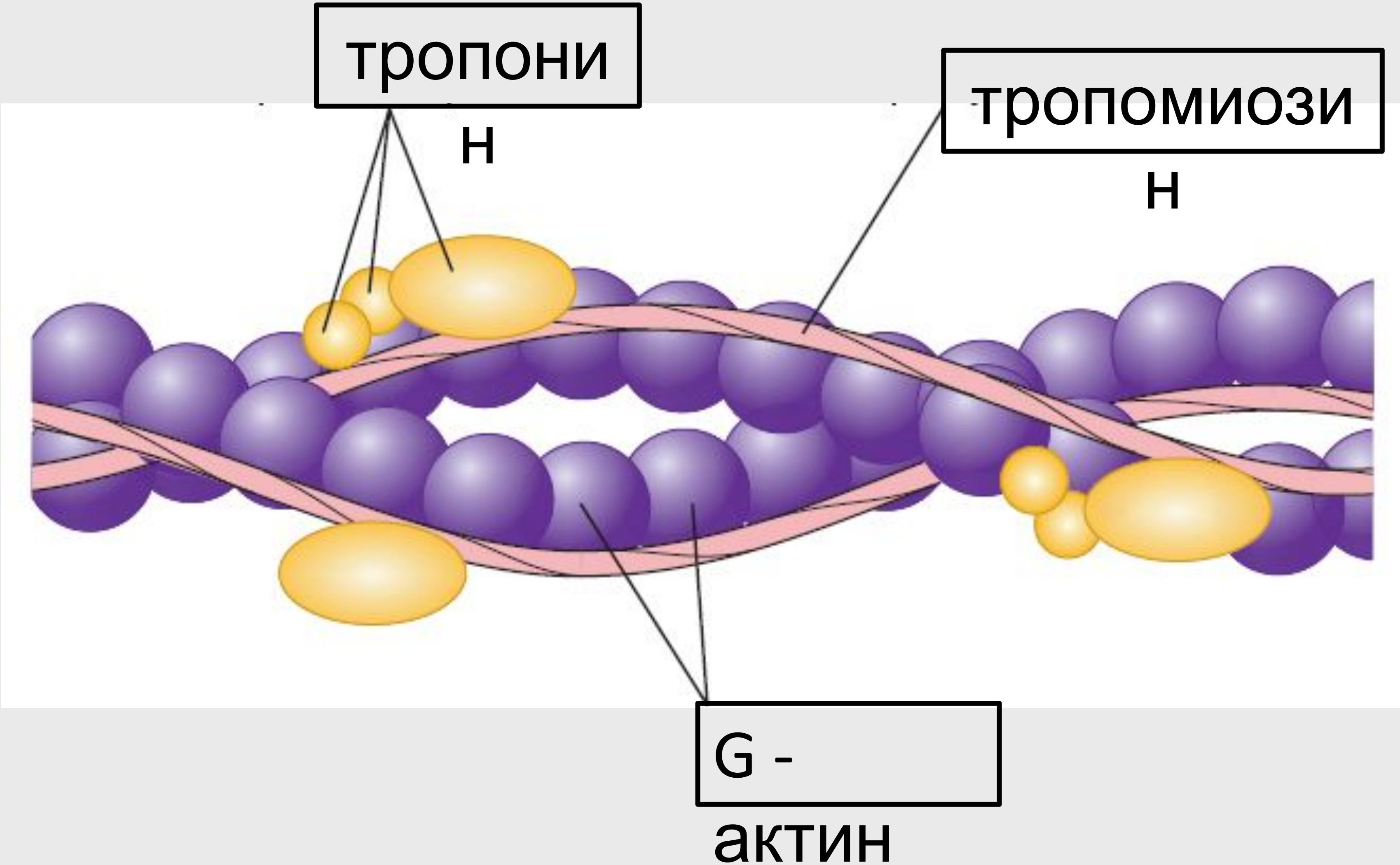






# Строение актиновых нитей

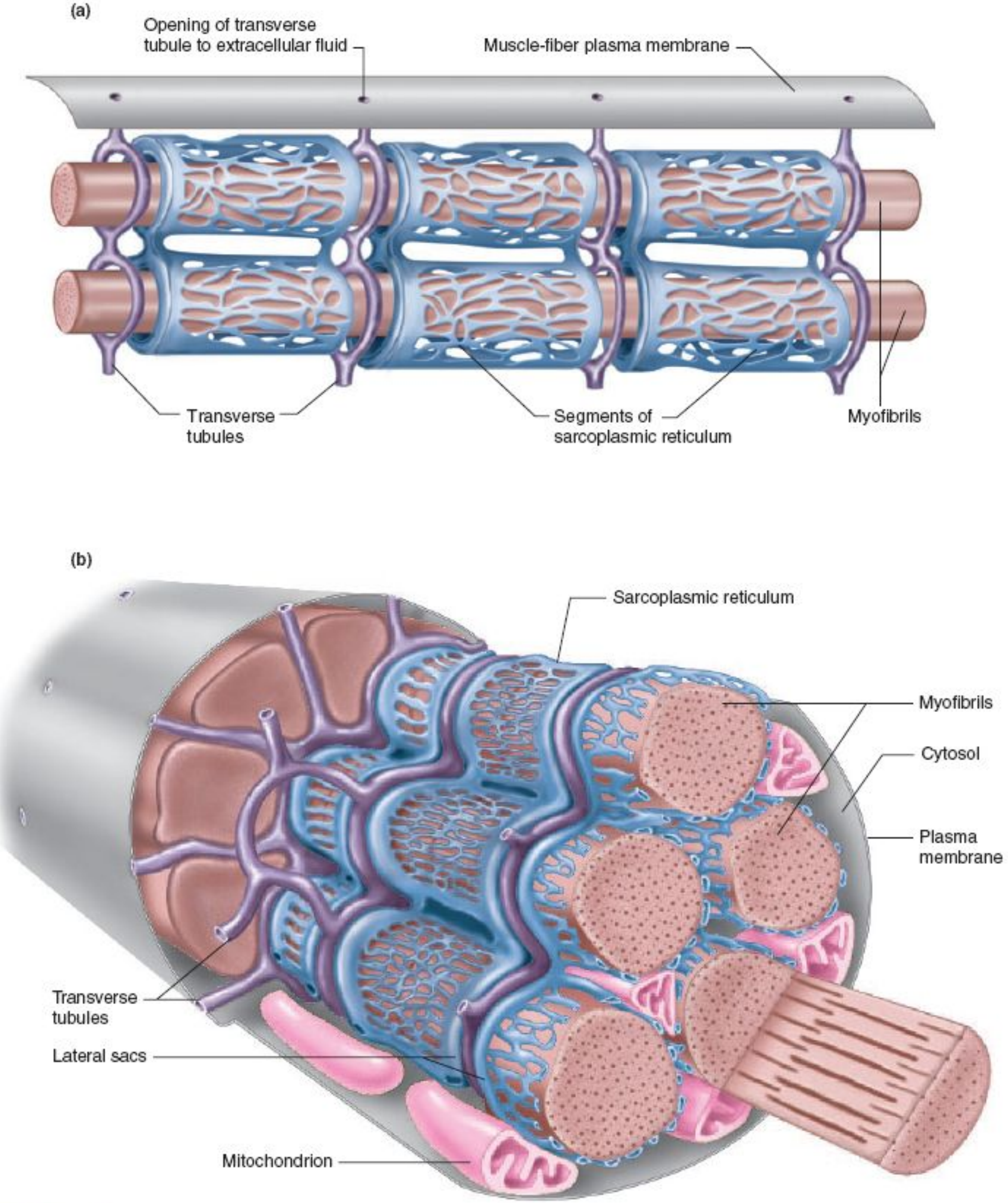




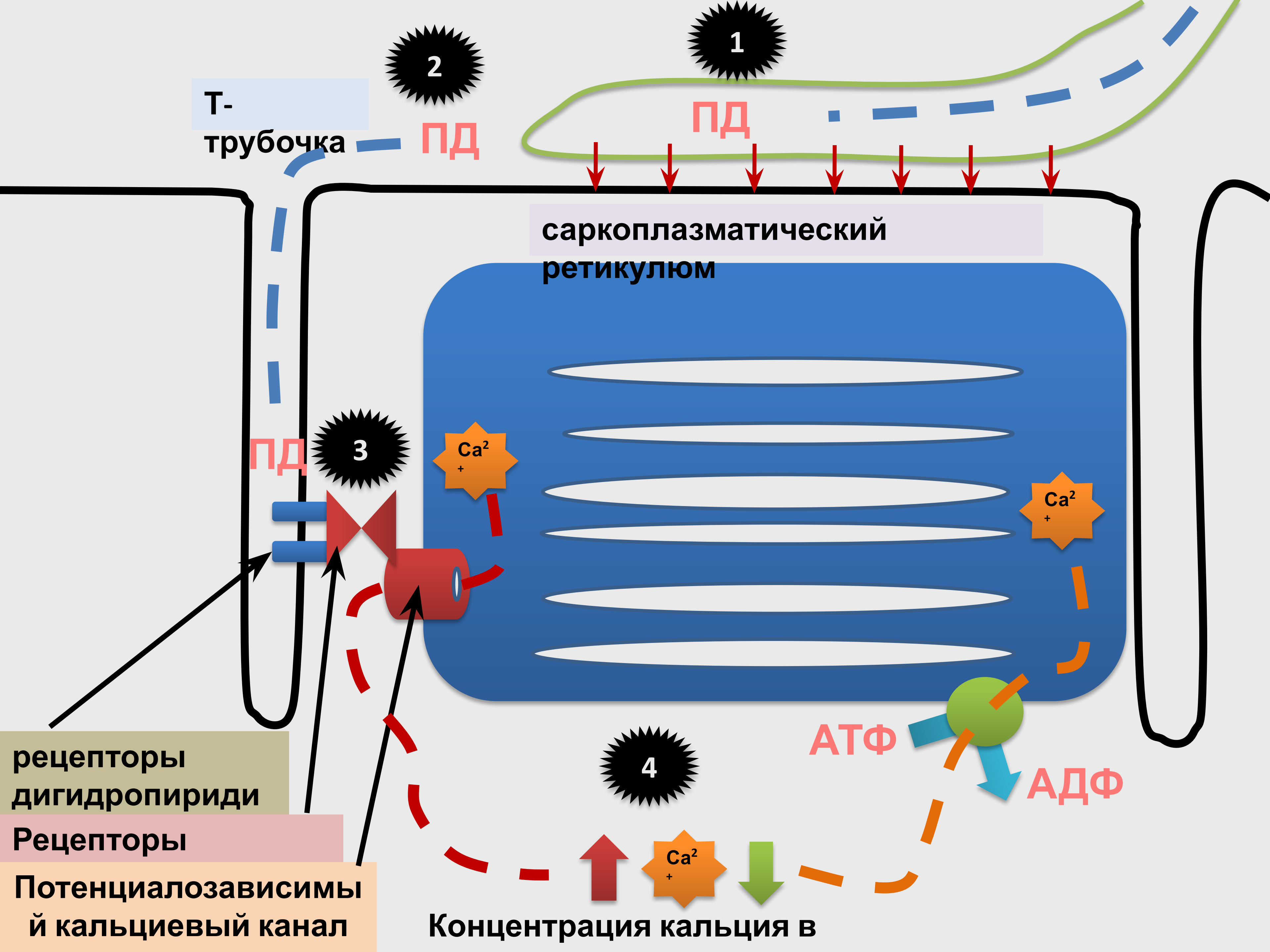
тропони
н
тропомиози
н
G -
актин

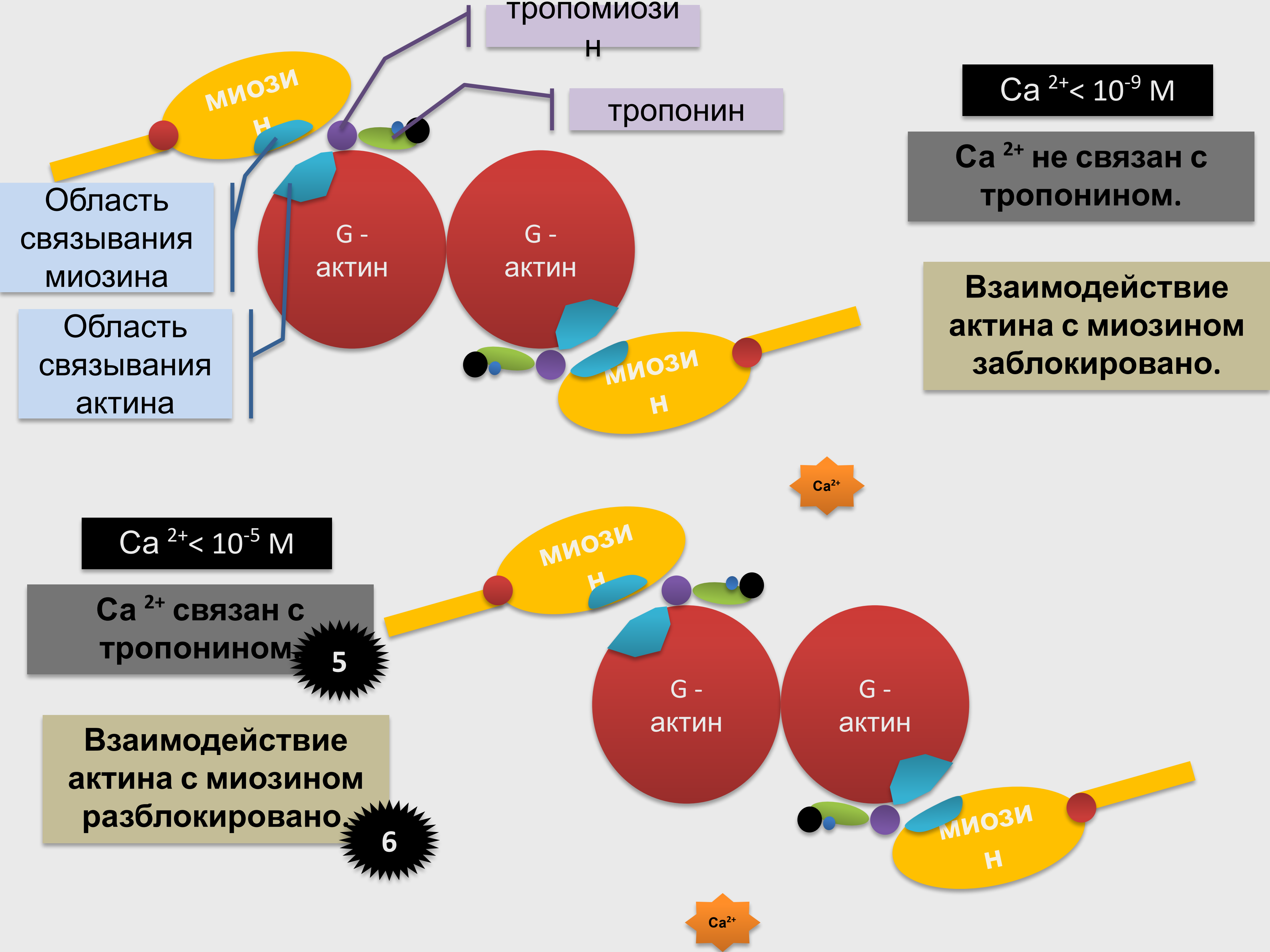
# Последовательность процессов при мышечном сокращении

- Деполяризация постсинаптической мембраны и генерация ПД.
- Распространение ПД по плазмолемме МВ .
- Передача сигнала в триадах на саркоплазматический ретикулум.
- Выброс Ca2+ из саркоплазматического ретикулума.
- Связывание Ca2+ тропонином С тонких нитей.
- Взаимодействие тонких и толстых нитей (формирование мостиков), появление тянущего усилия и скольжение нитей относительно
- Цикл взаимодействия нитей.
- Укорочение саркомеров и сокращение МВ.
- Расслабление.



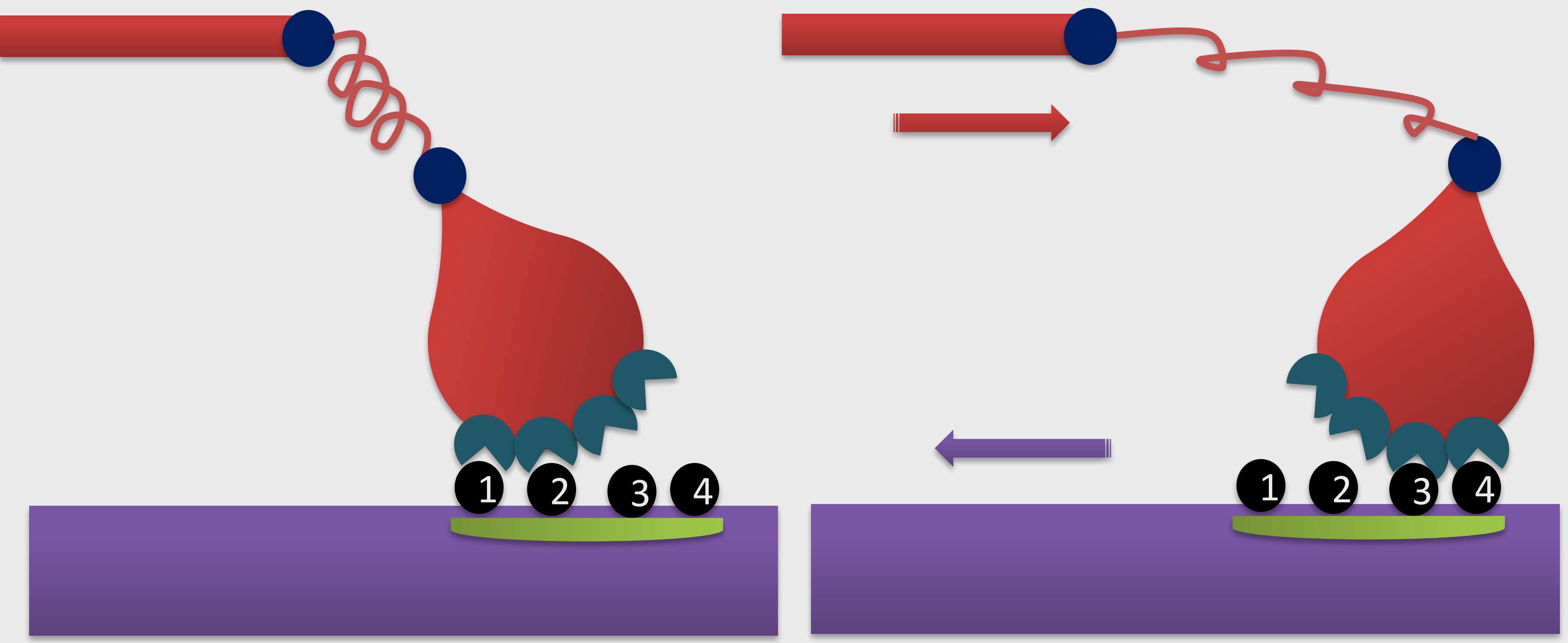
(a)
Opening of transverse tubule to extracellular fluid
Muscle-fiber plasma membrane
Transverse tubules
Segments of sarcoplasmic reticulum
Myofibrils
(b)
Sarcoplasmic reticulum
Myofibrils
Cytosol
Plasma membrane
Transverse tubules
Lateral sacs
Mitochondrion


1
2
Т-
трубочка
ПД
ПД
саркоплазматический
ретикулюм
3
ПД
Ca2
+
Ca2
+
АТФ
АДФ
4
Ca2
+
рецепторы
дигидропириди
Рецепторы
Потенциалозависимы
й кальциевый канал
Концентрация кальция в

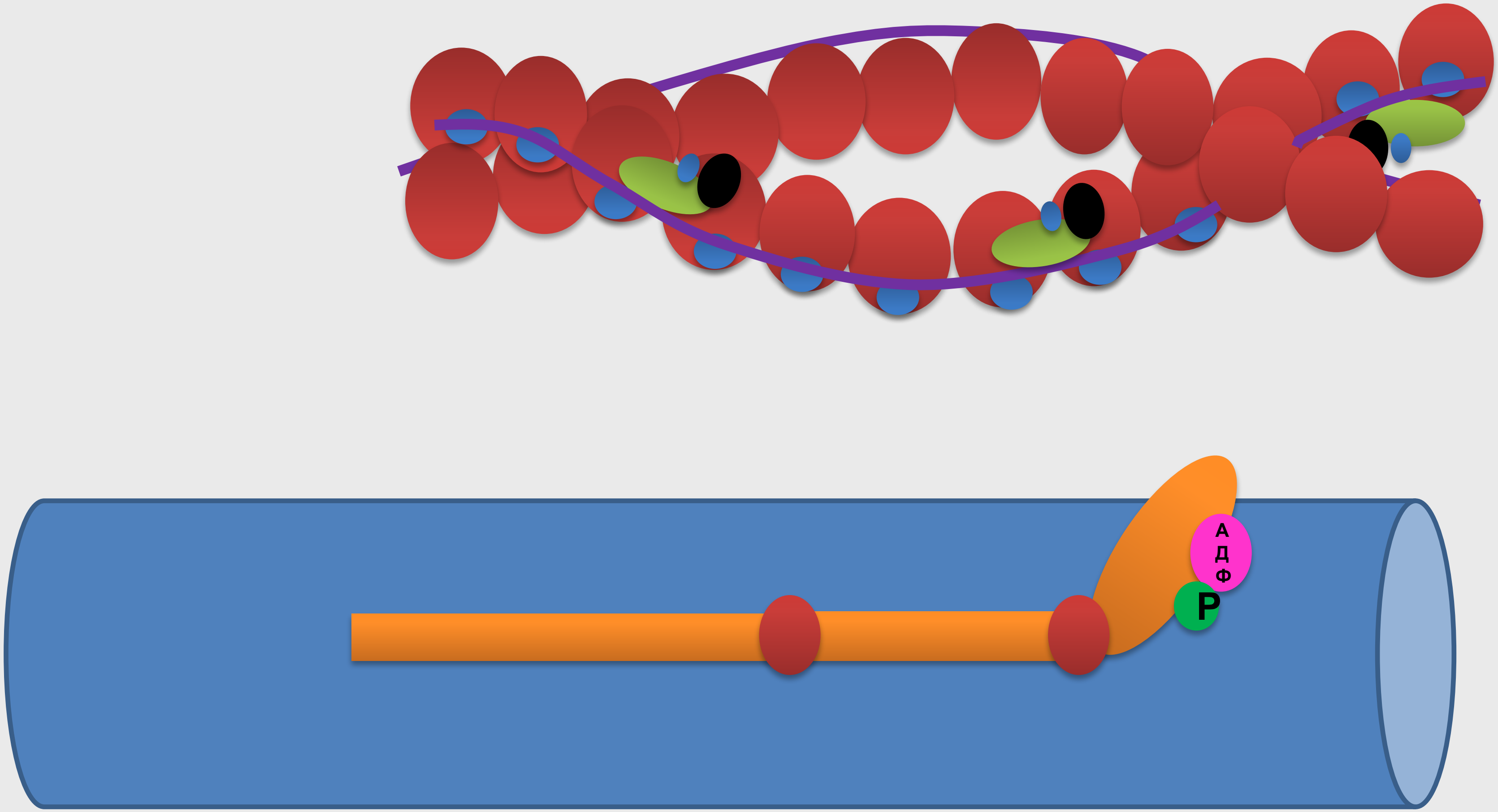


тропомиози
н
тропонин
миози
н
Область связывания миозина
Область связывания актина
G - актин
G - актин
миози
н
Ca 2+< 10-9 M
Ca 2+ не связан с тропонином.
Взаимодействие актина с миозином заблокировано.
Ca2+
Ca 2+< 10-5 M
Ca 2+ связан с тропонином.
5
Взаимодействие актина с миозином разблокировано.
6
миози
н
G - актин
G - актин
миози
н
Ca2+

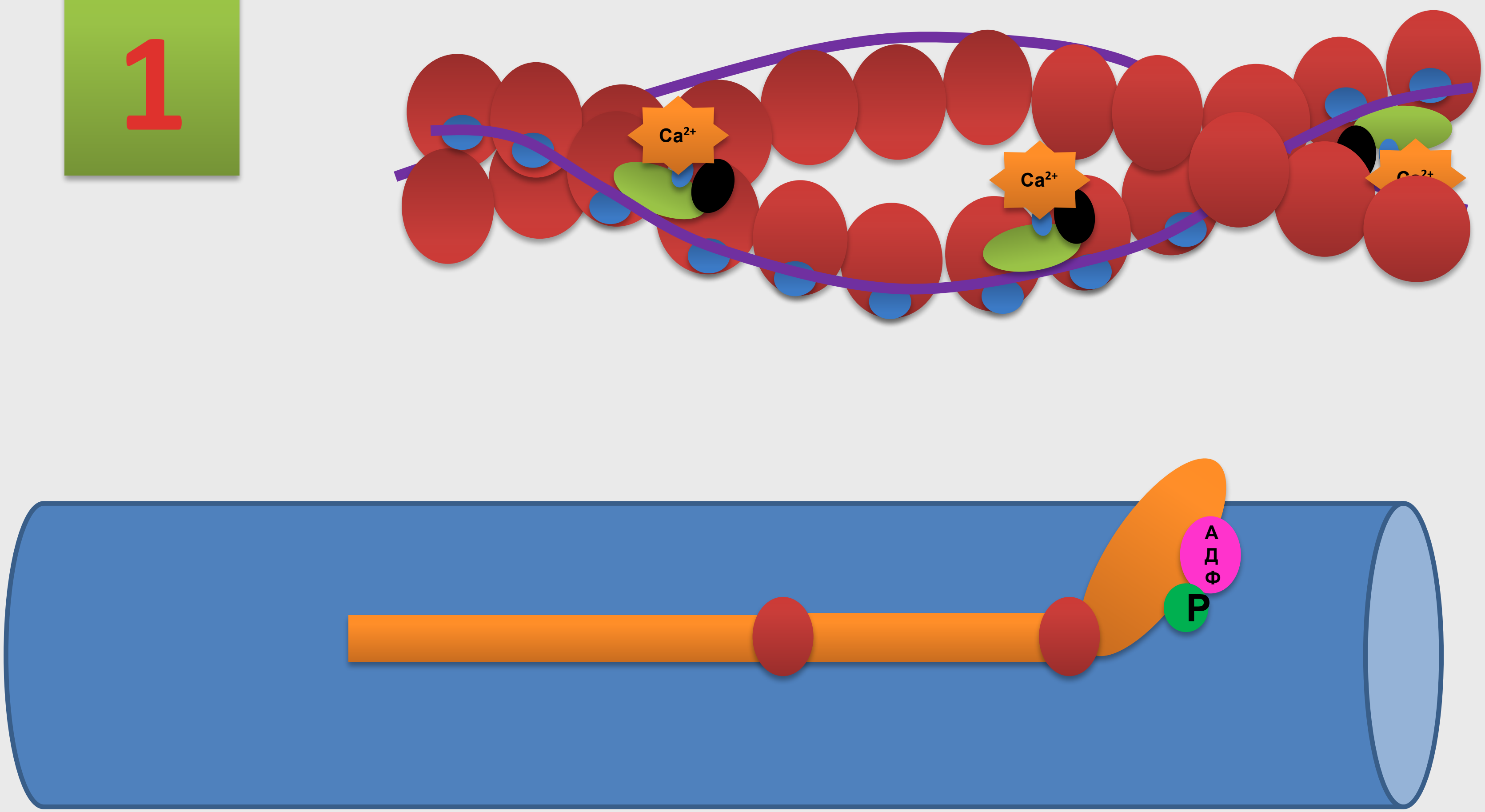
# Модель мостика Хаксли-Симмонса



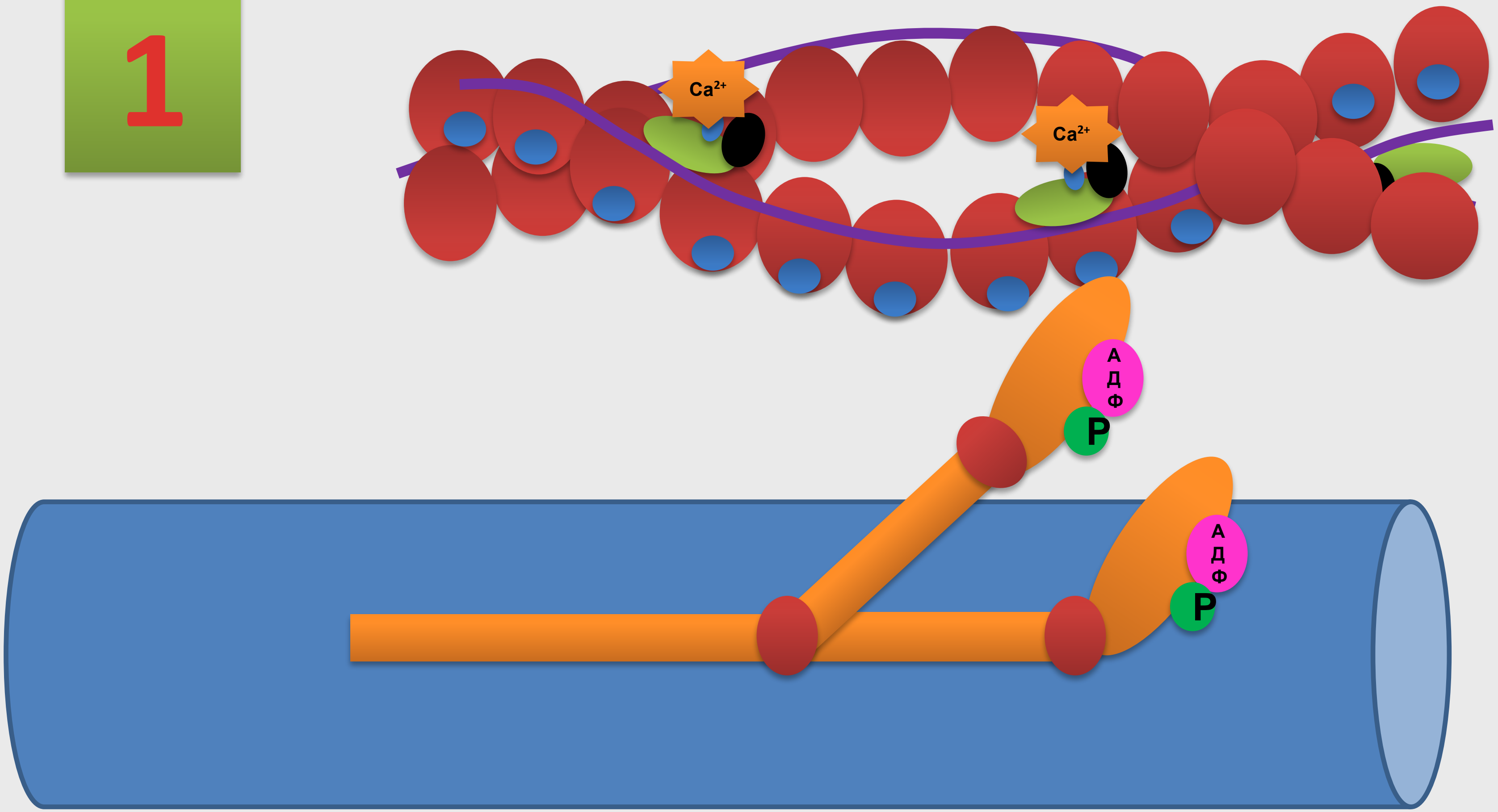
# Цикл взаимодействия нитей


АДФ
P

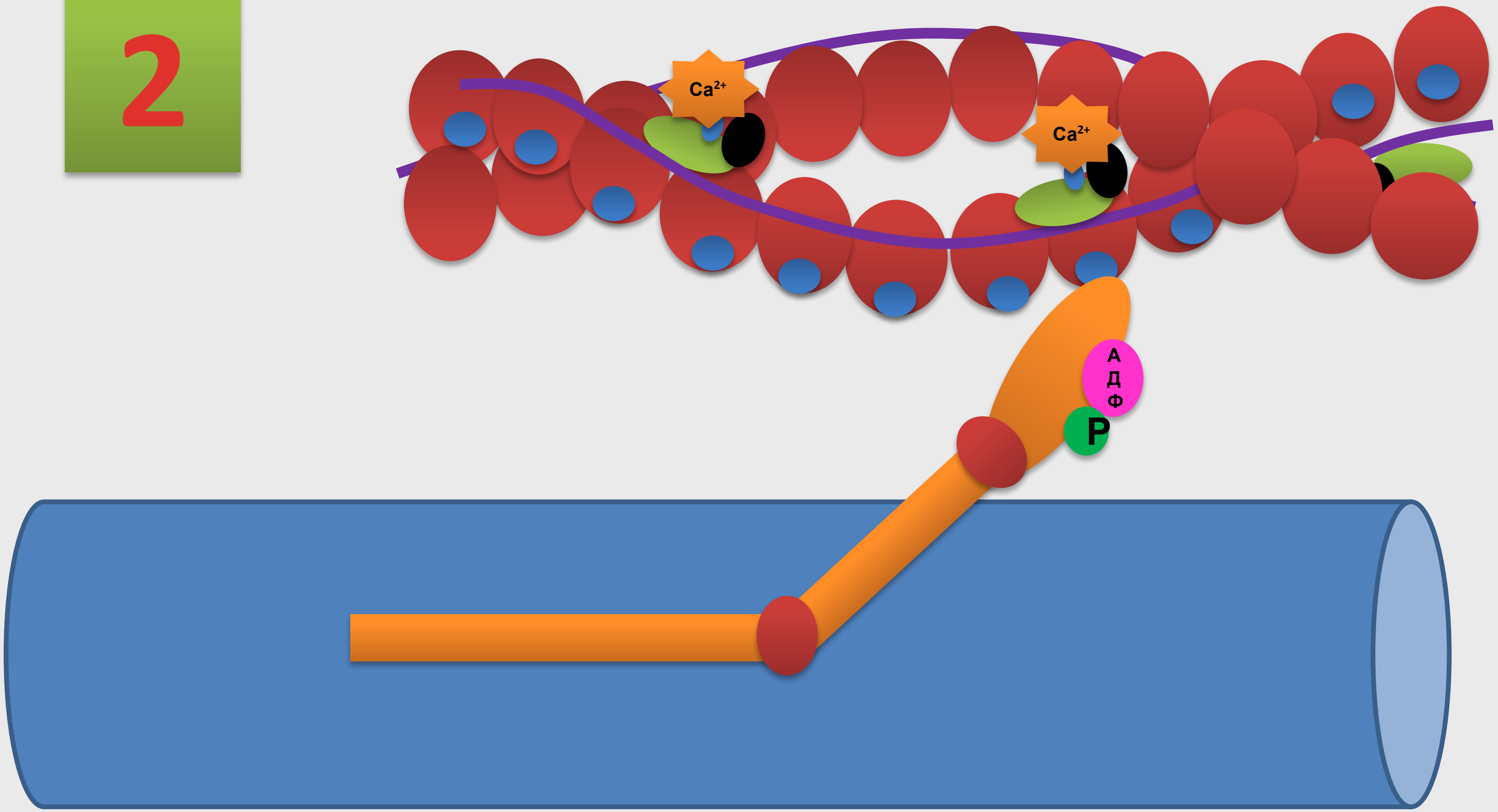
1

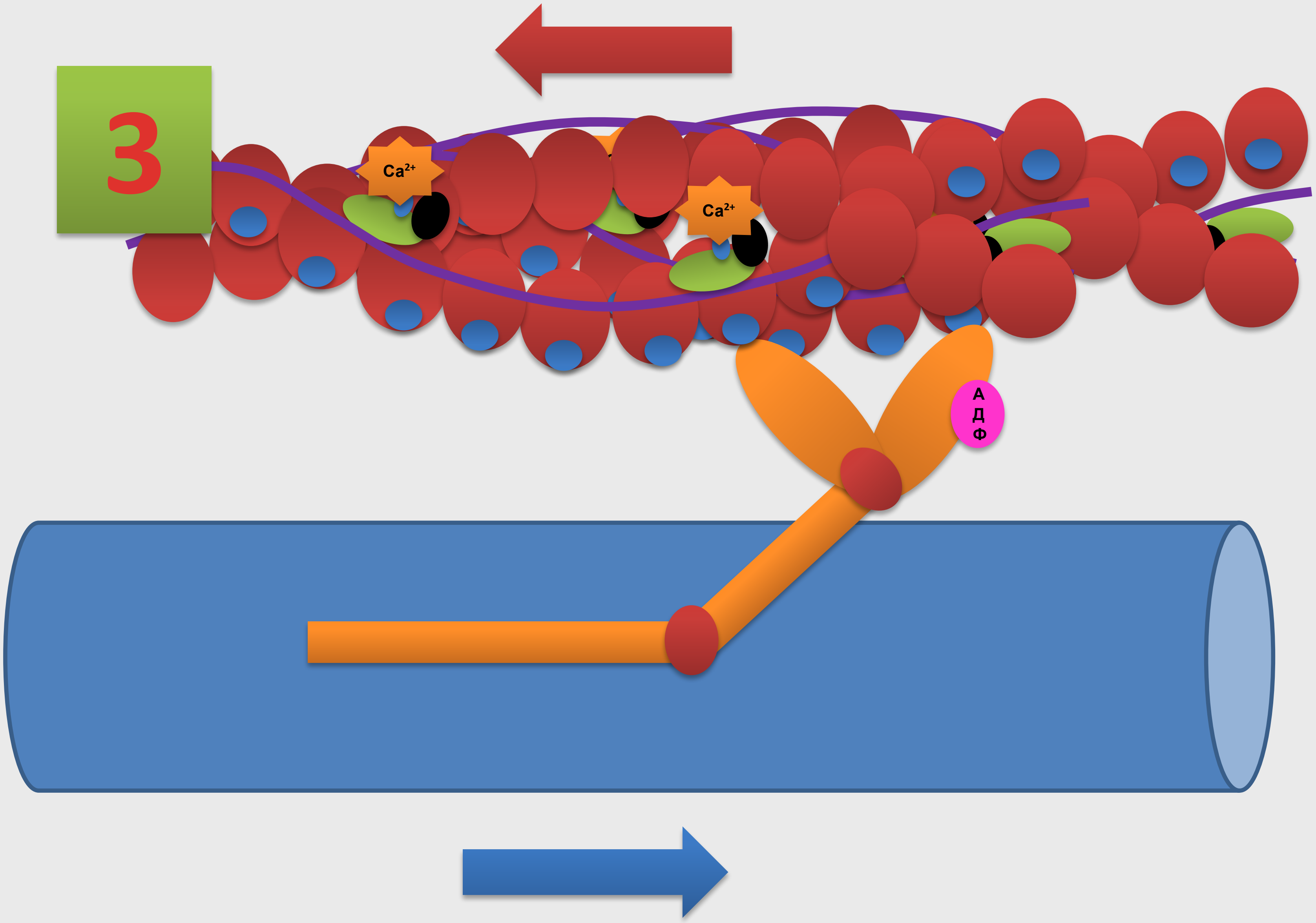


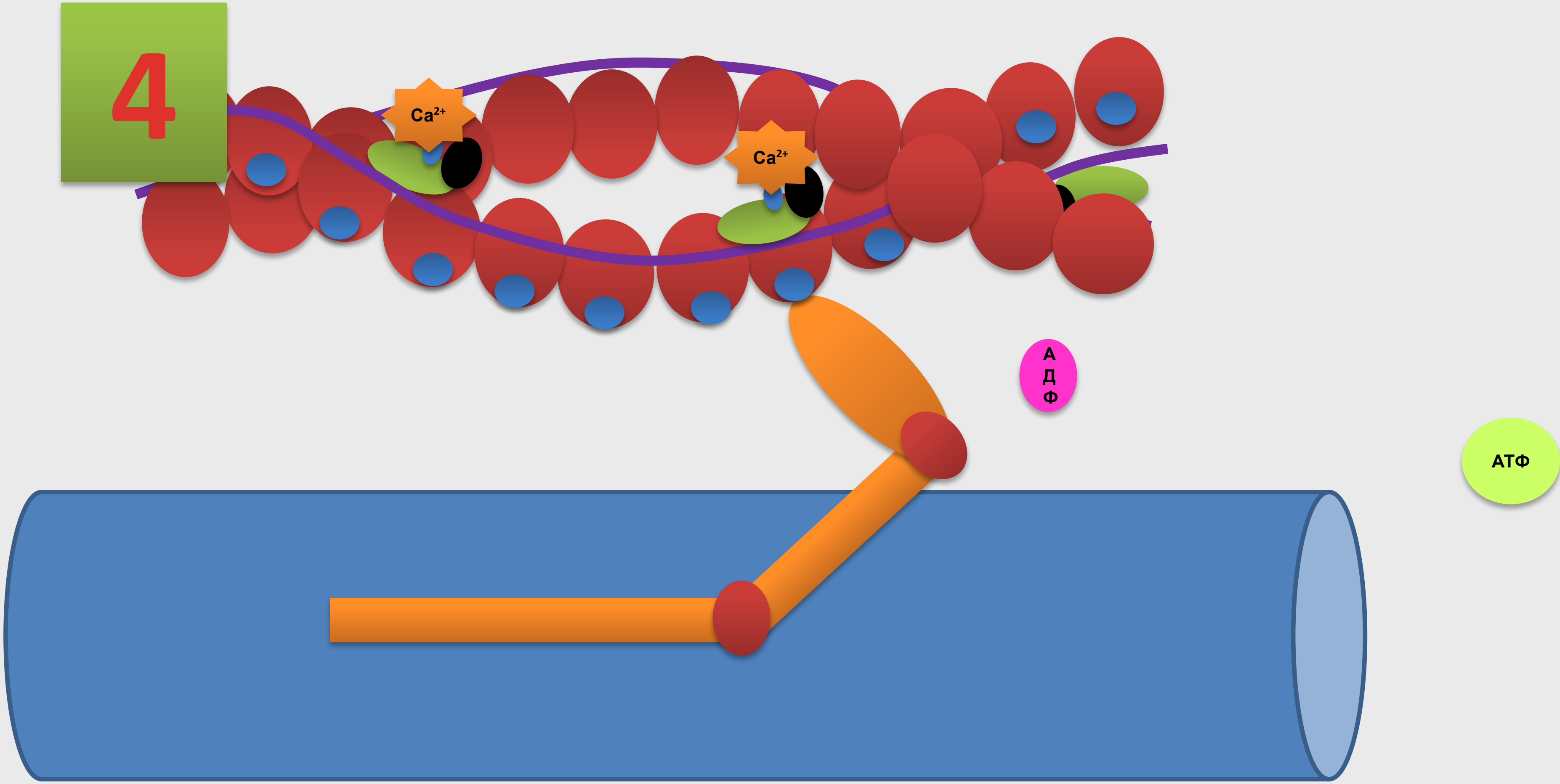
# 1

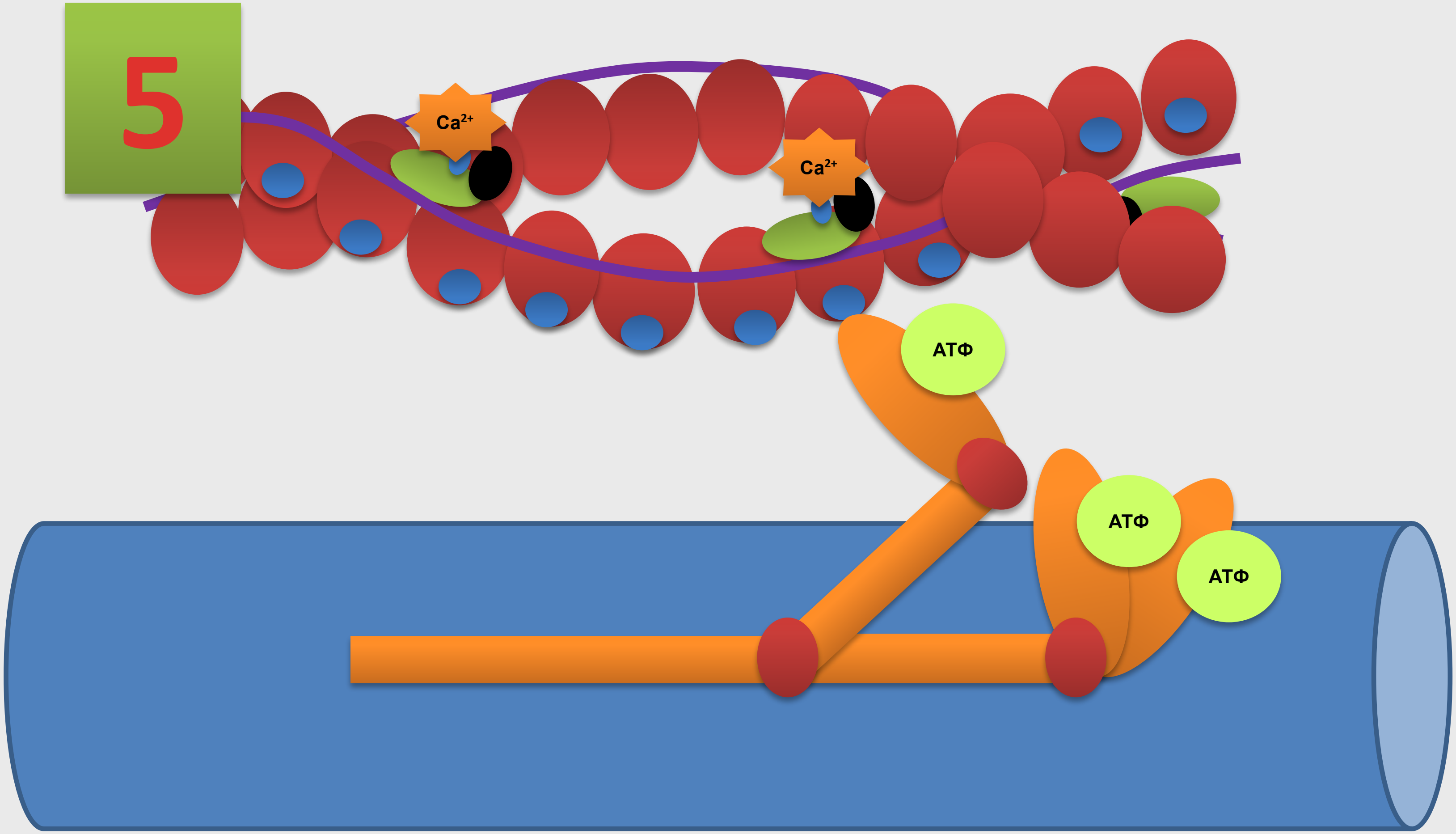


2

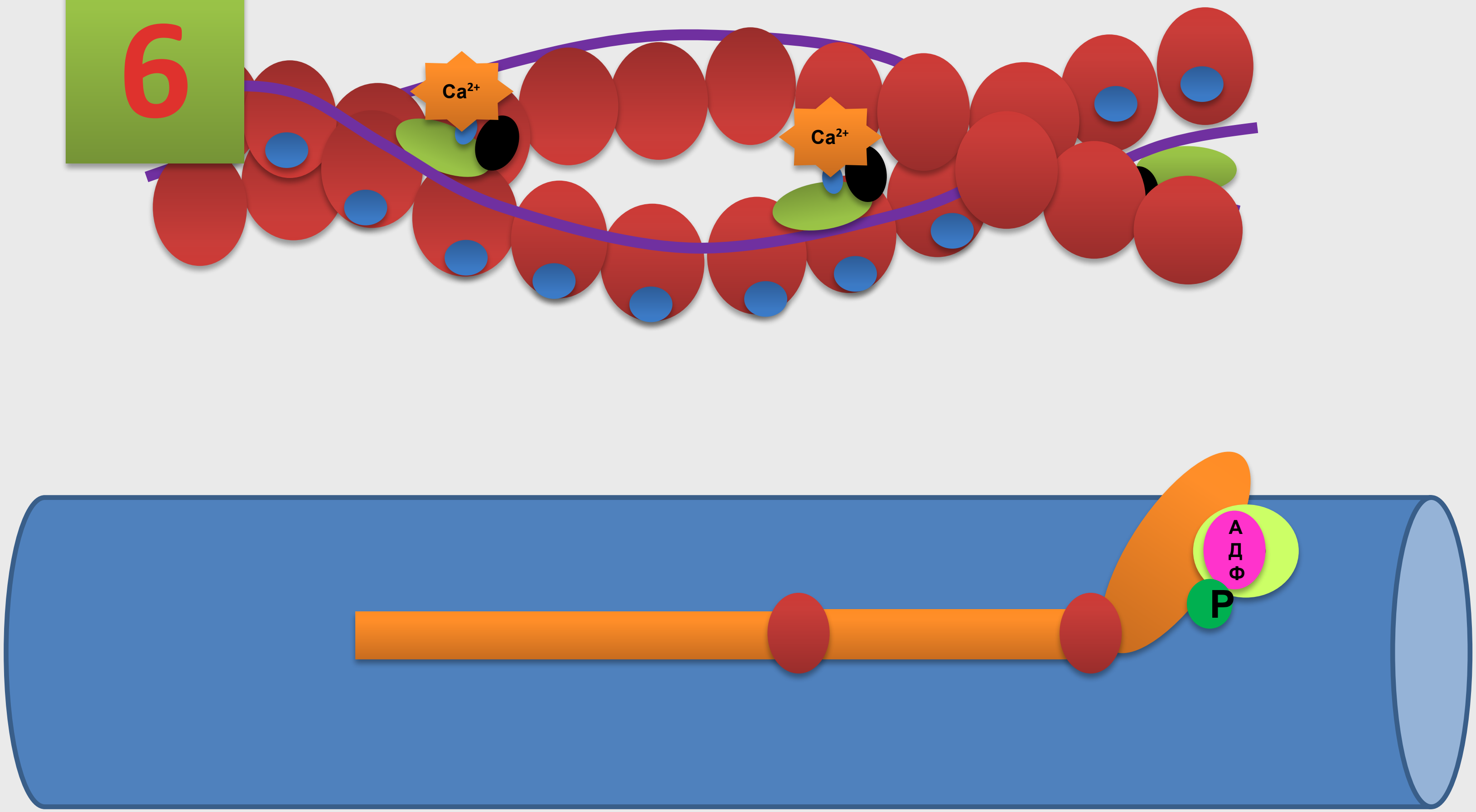



3
Ca2+
Ca2+
А
Д
Ф

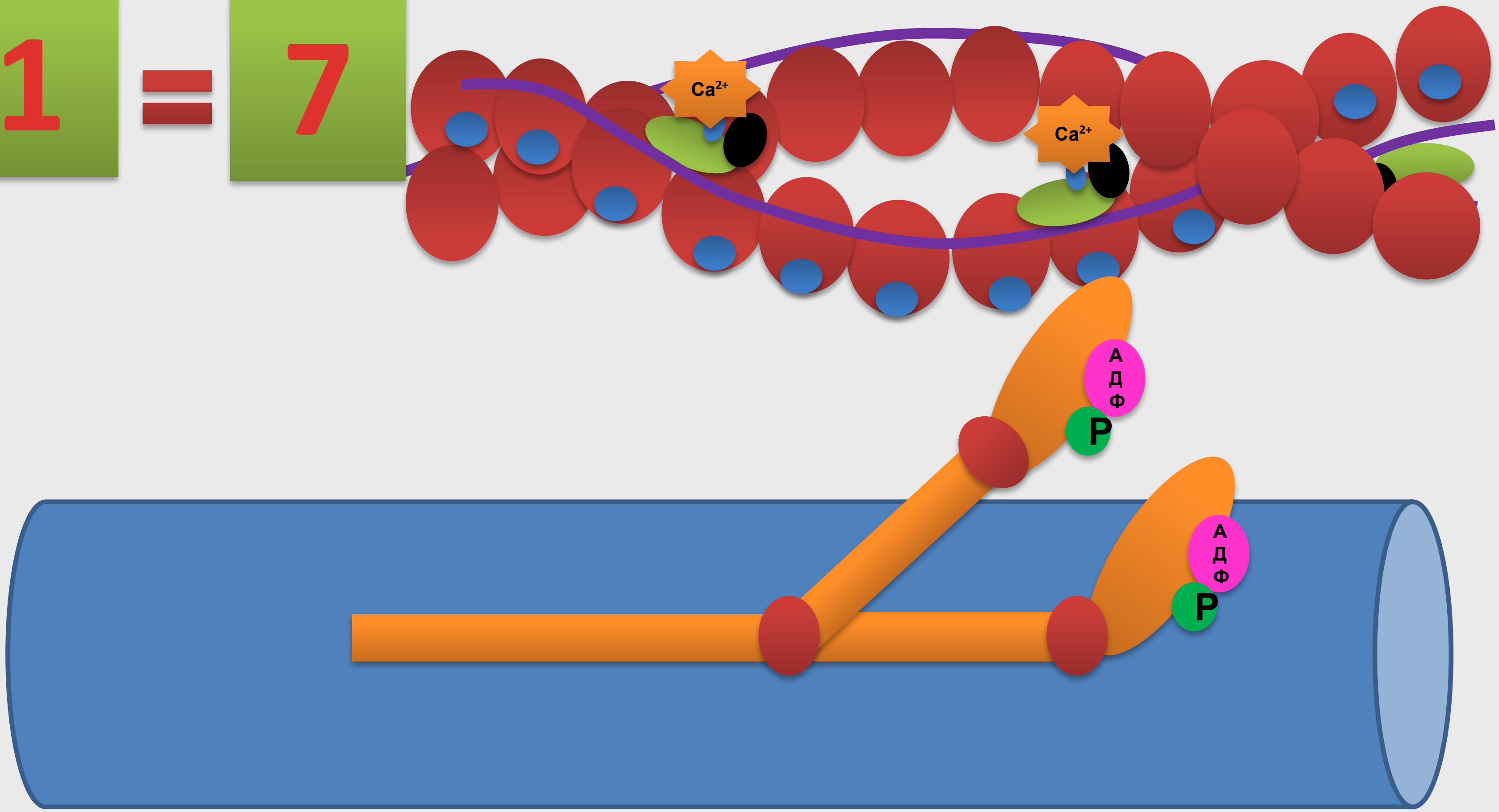

4
Ca2+
Ca2+
А
Д
Ф
АТФ


5
Ca2+
Ca2+
АТФ
АТФ
АТФ

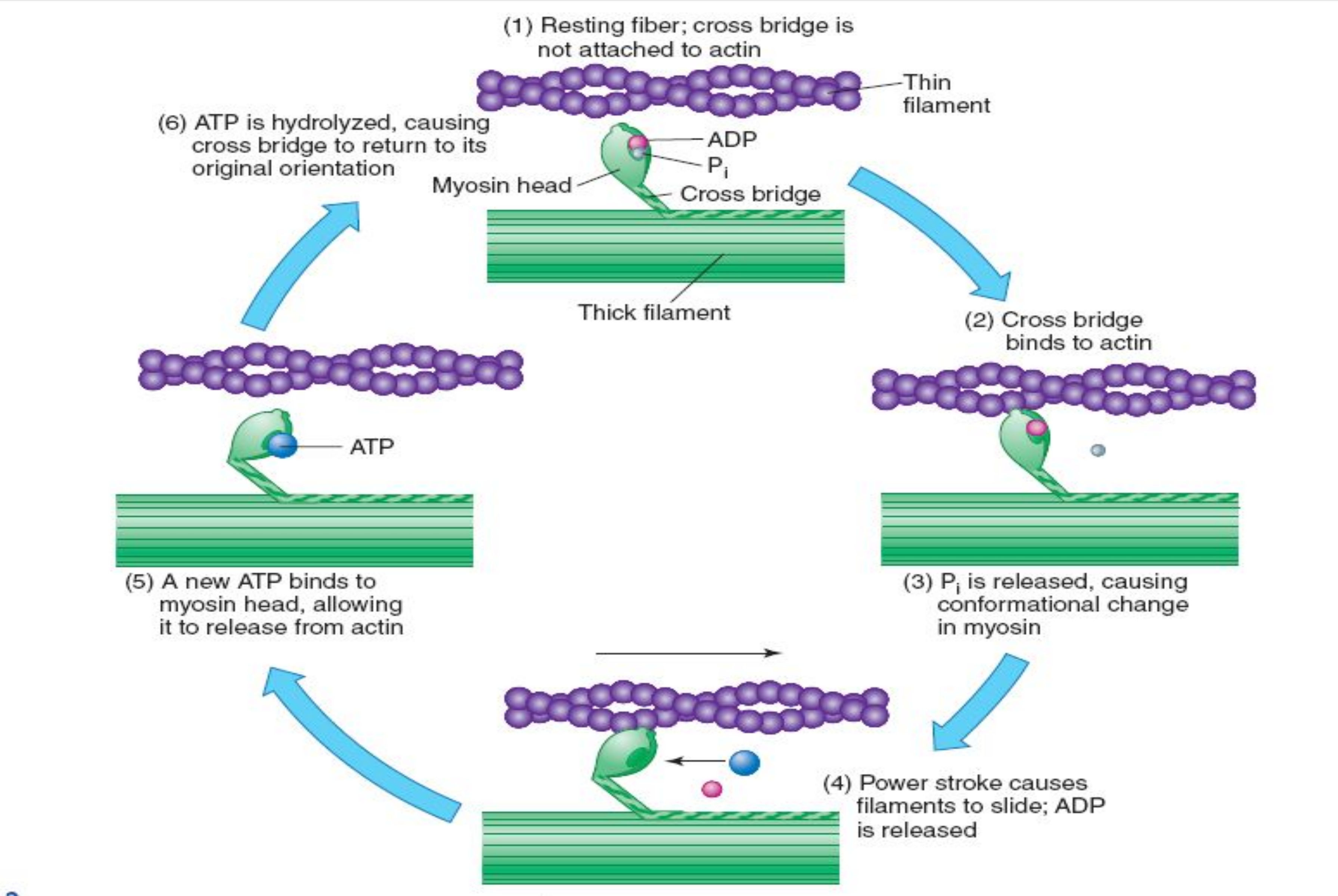
6

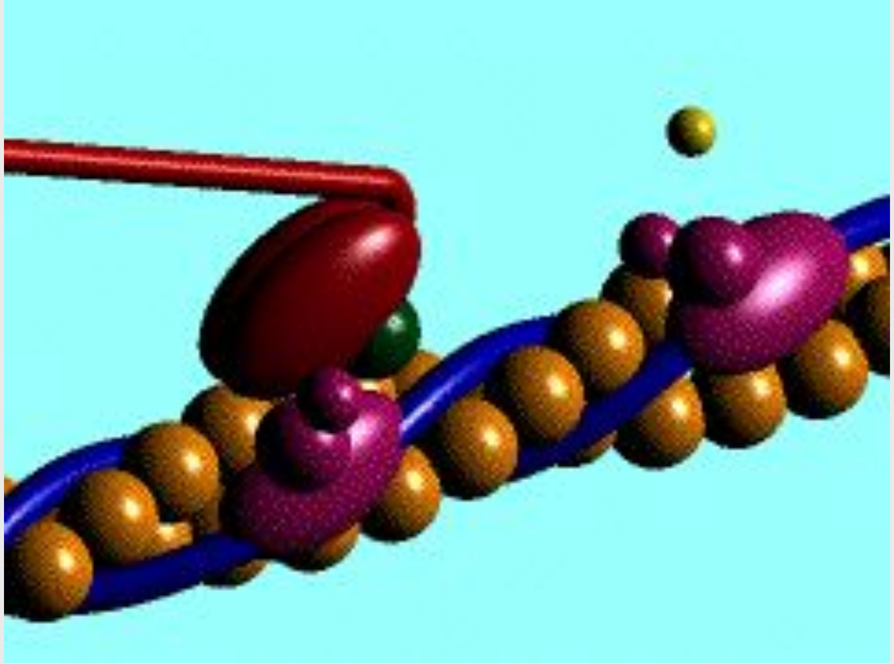


1 = 7



# Цикл взаимодействия нитей





Миозиновый комплекс (МК)
МК после АТФазной активации
Актиновая спираль
Тропомиозин
АТФ
$Ca^{2+}$
Тропонин
$P_i$
АДФ
$Mg^{2+}$

# Укорочение саркомеров и сокращение МВ

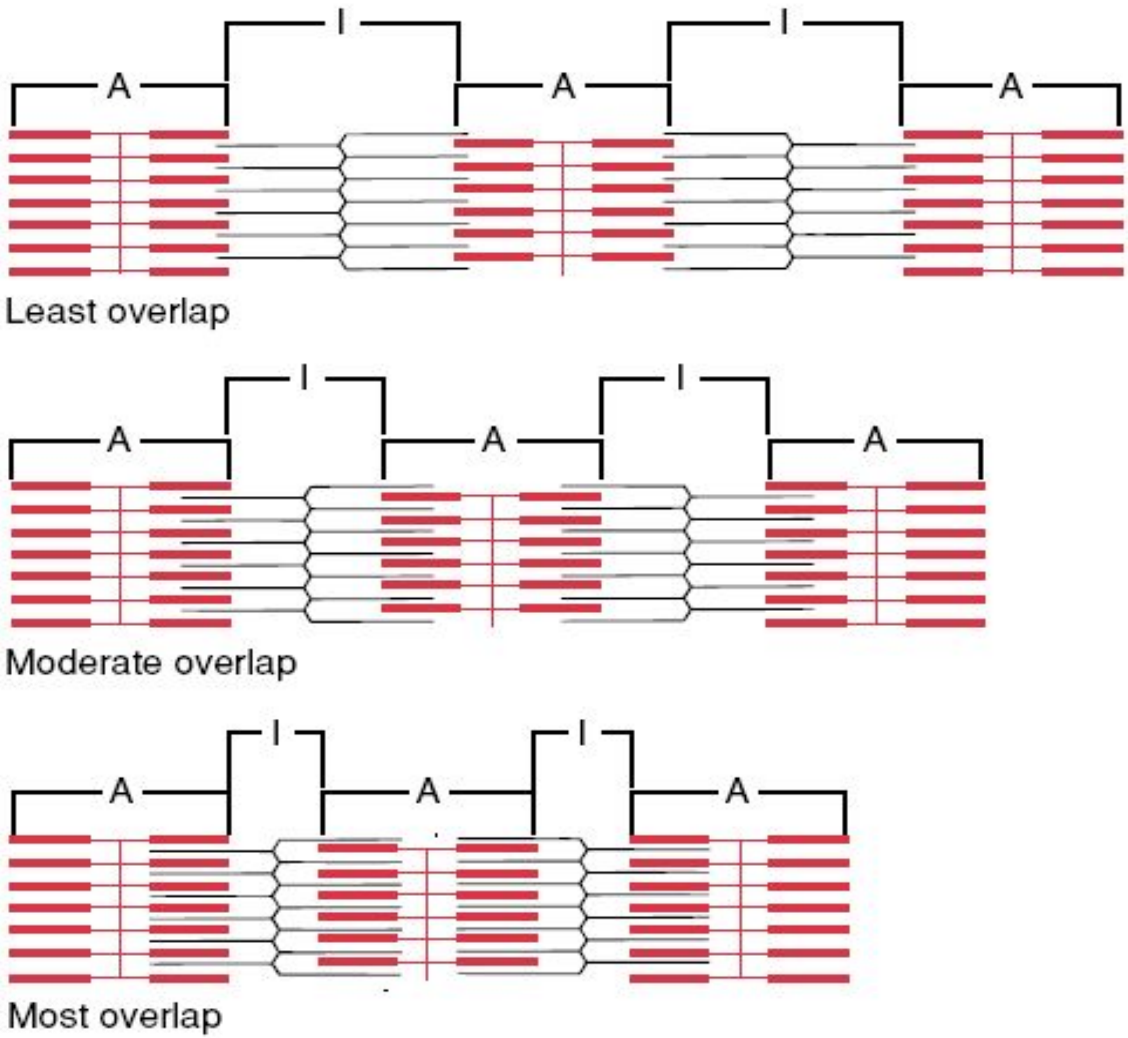



**FIGURE 8.8** **The multiplying effect of sarcomeres placed in series.** The overall shortening is the sum of the shortening of the individual sarcomeres.

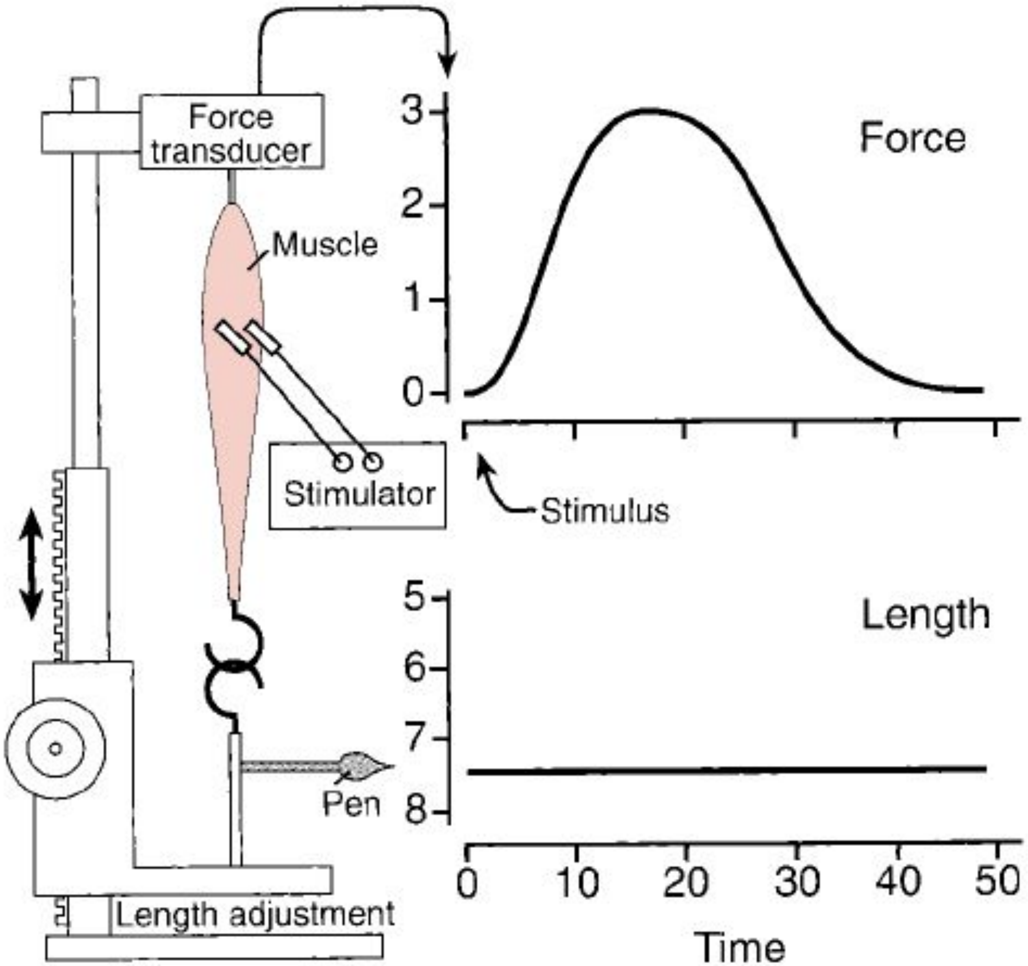



**FIGURE 9.7** **A simple apparatus for recording isometric contractions.** The length of the muscle (marked on the graph by the pen attached near its lower end) is adjustable at rest but is held constant during contraction. The force transducer provides a record of the isometric force response to a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

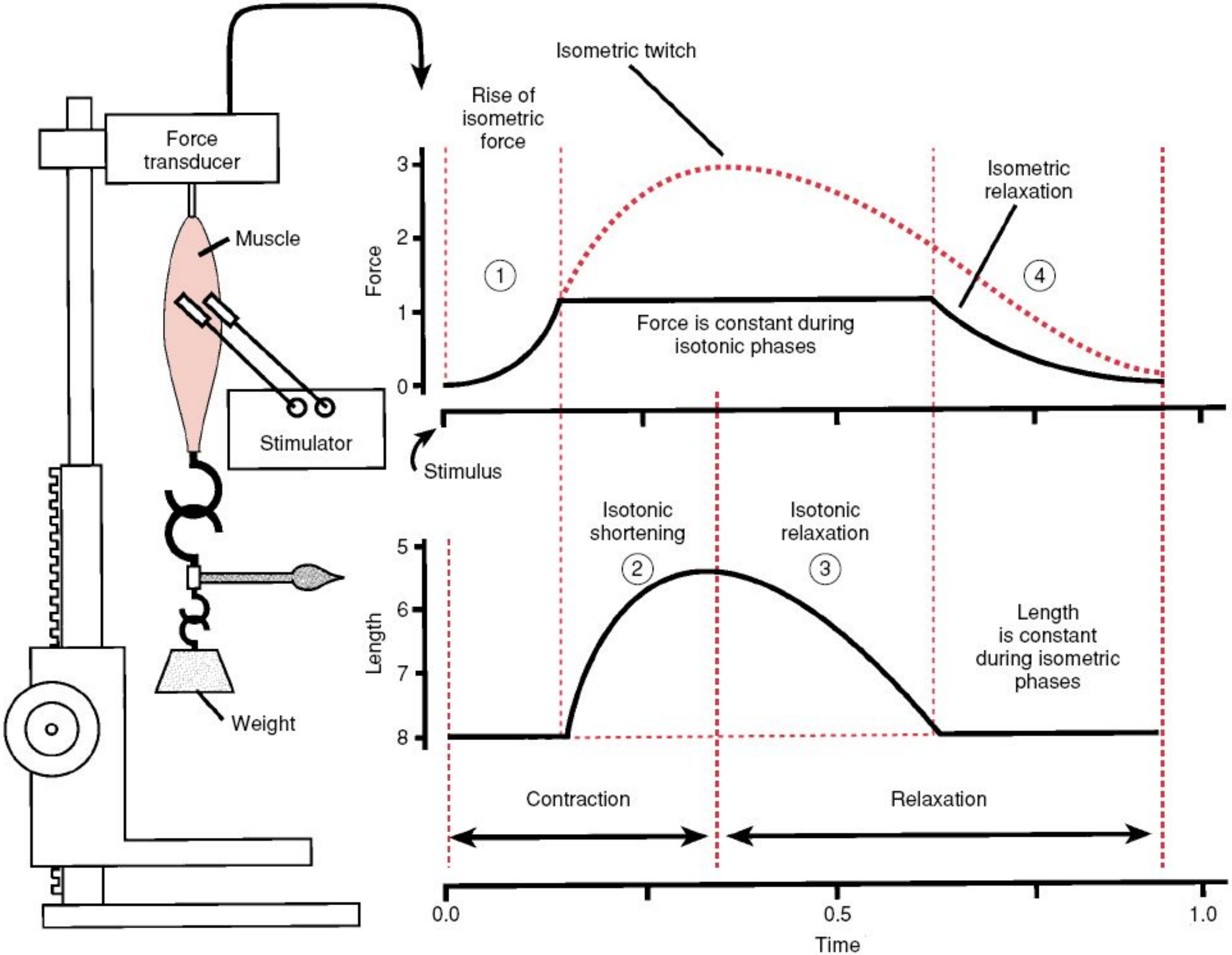



**FIGURE 9.8** **A modified apparatus showing the recording of a single isotonic switch.** The pen at the lower end of the muscle marks its length, and the weight attached to the muscle provides the afterload, while the platform beneath the weight prevents the muscle from being overstretched at rest. 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.)

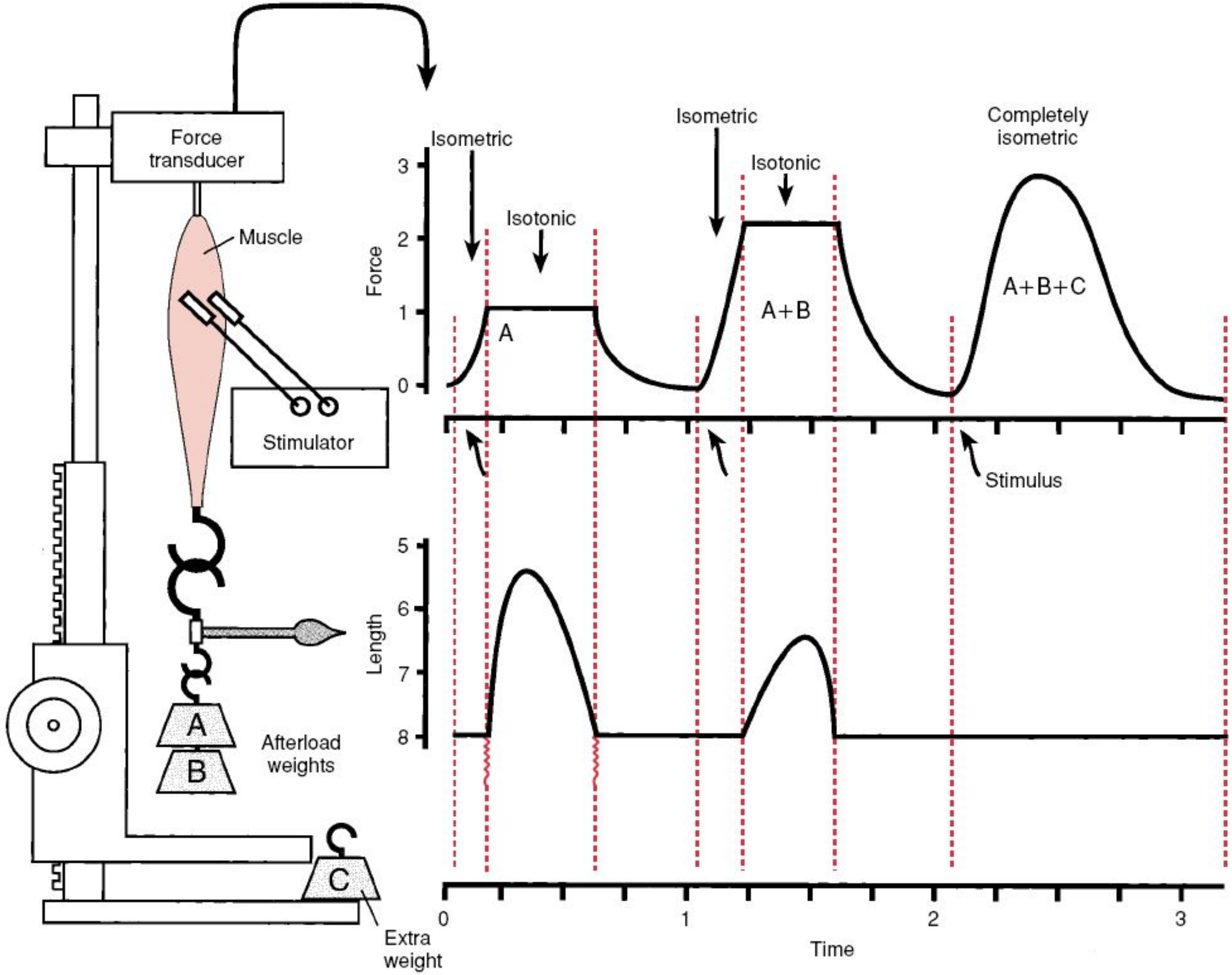
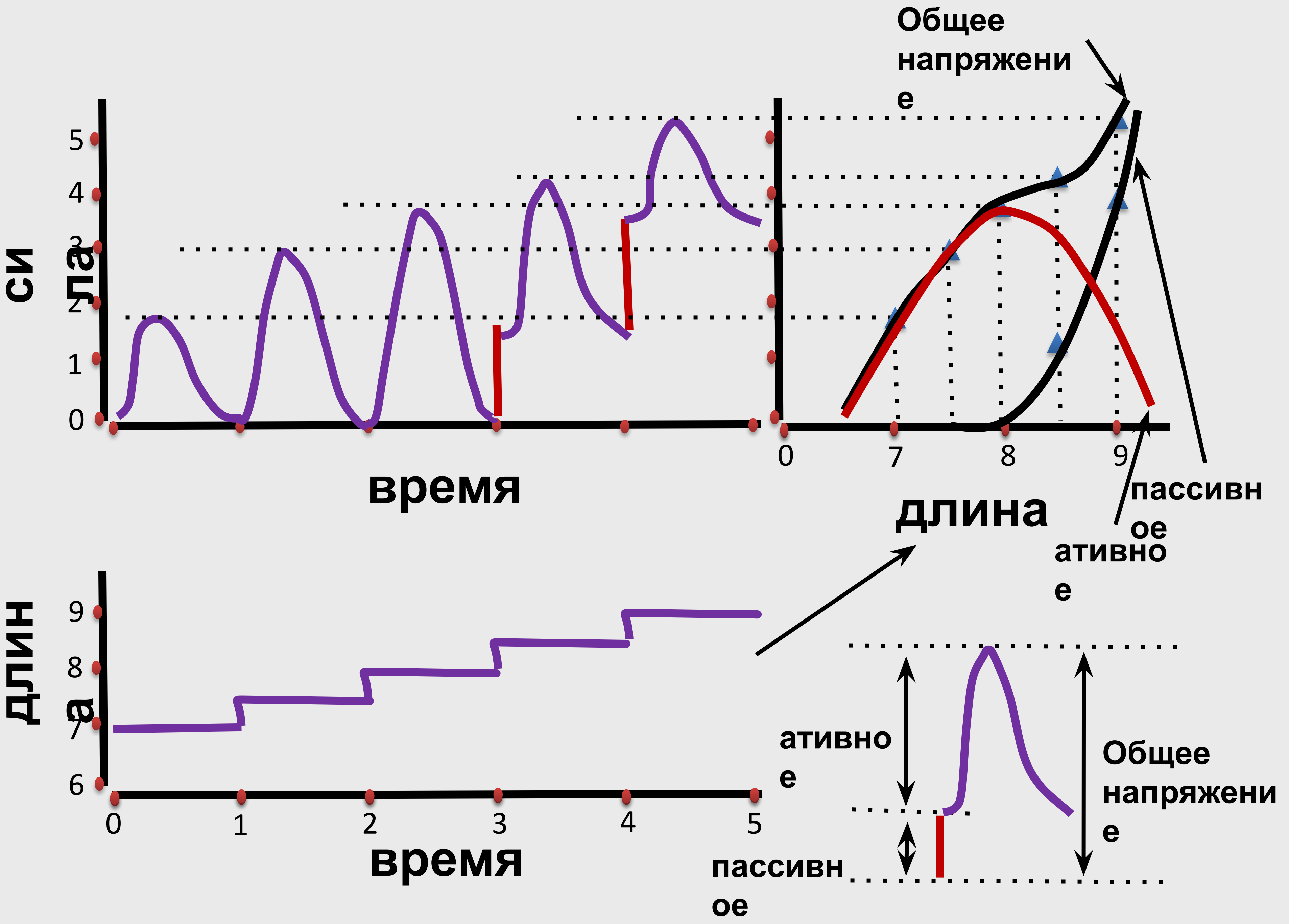



**FIGURE 9.9** **A series of afterloaded isotonic contractions.** The curves labeled A and A + B correspond to the force and shortening records during the lifting of those weights. In each case, the adjustable platform prevents the muscle from being stretched by the attached weight, and all contractions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



Общее напряжени е
си ла
5
4
3
2
1
0
время
0
7
8
9
длина
пассивн ое
ативно е
длин а
9
8
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6
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время
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Общее напряжени е
пассивн ое

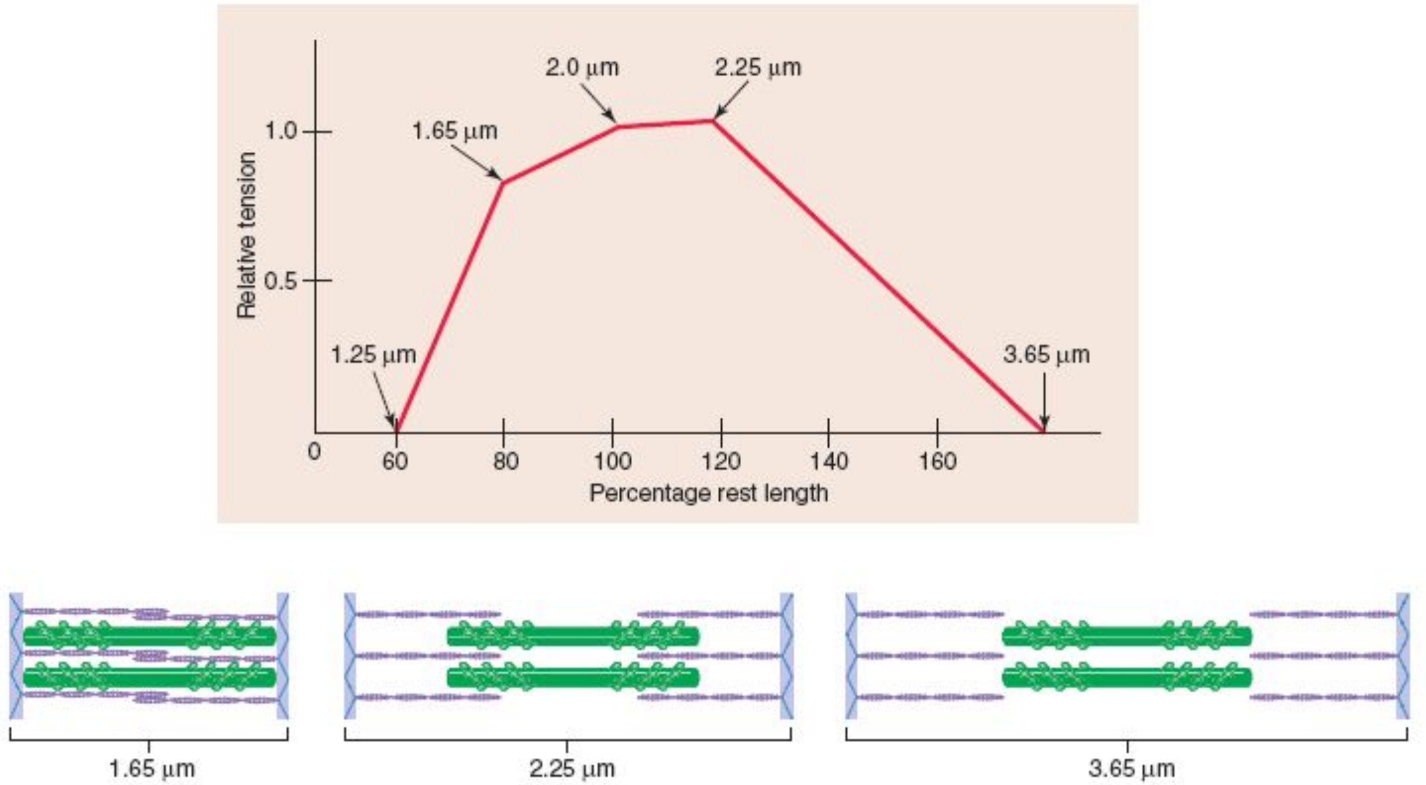
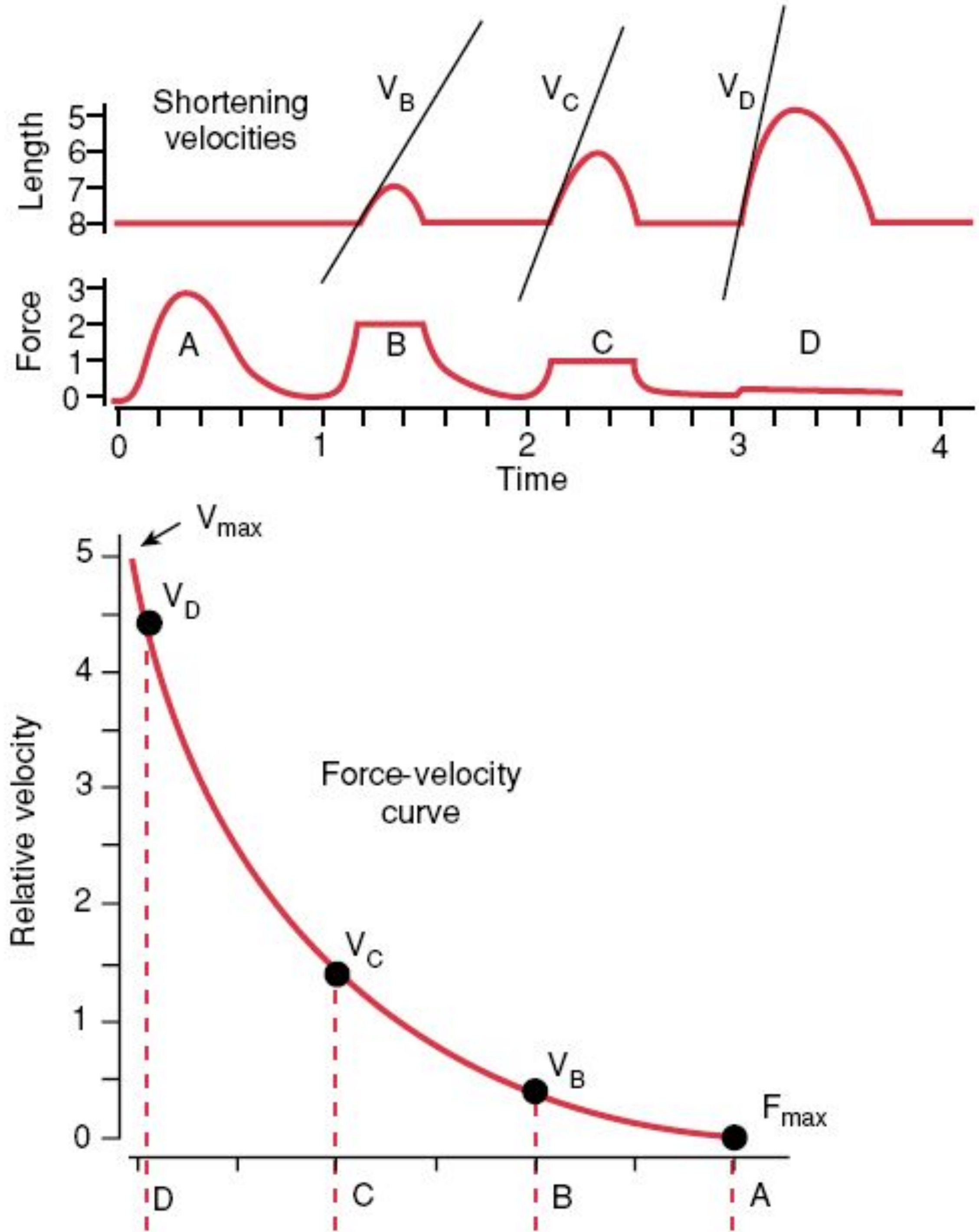



**Figure 12.20** **The length-tension relationship in skeletal muscles.** Maximum relative tension (1.0 on the *y* axis) is achieved when the muscle is 100% to 120% of its resting length (sarcomere lengths from 2.0 to 2.25 µm). Increases or decreases in muscle (and sarcomere) lengths result in rapid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



Shortening velocities
Length
5
6
7
8
V_B
V_C
V_D
Force
3
2
1
0
A
B
C
D
0
1
2
3
4
Time
V_max
Relative velocity
5
4
3
2
1
0
V_D
V_C
V_B
F_max
Force-velocity curve
D
C
B
A

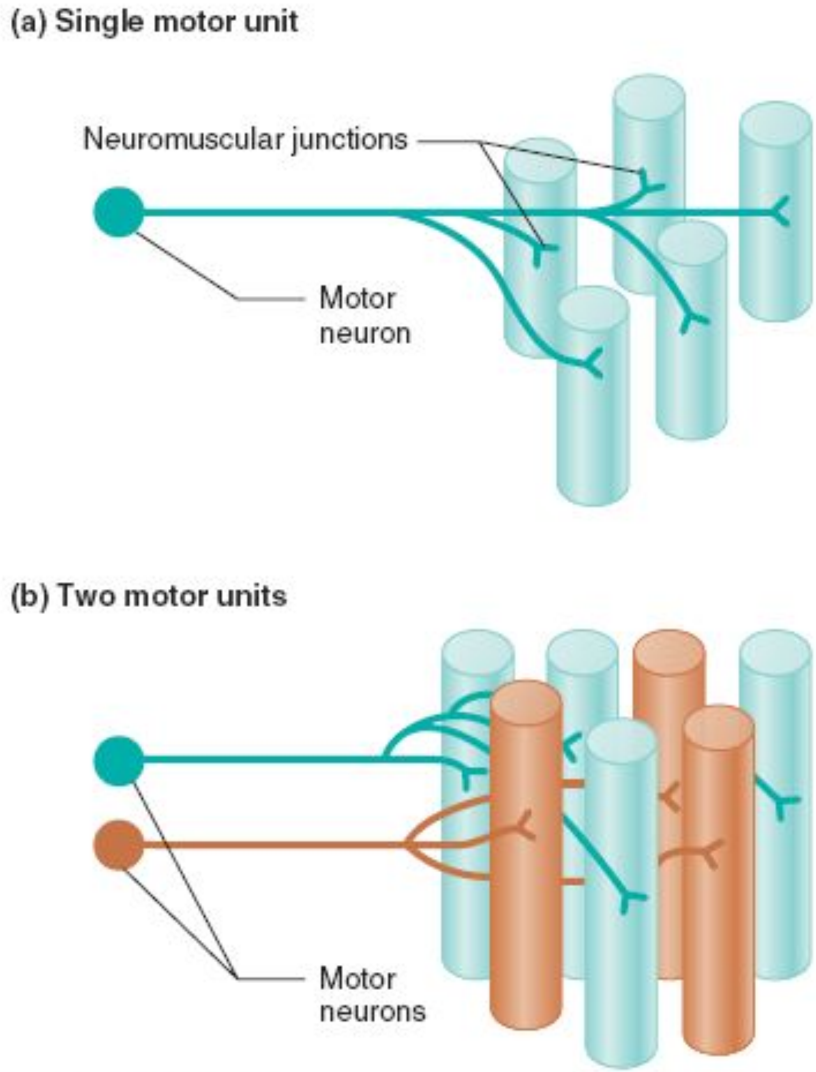



**FIGURE 9–17**

(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.

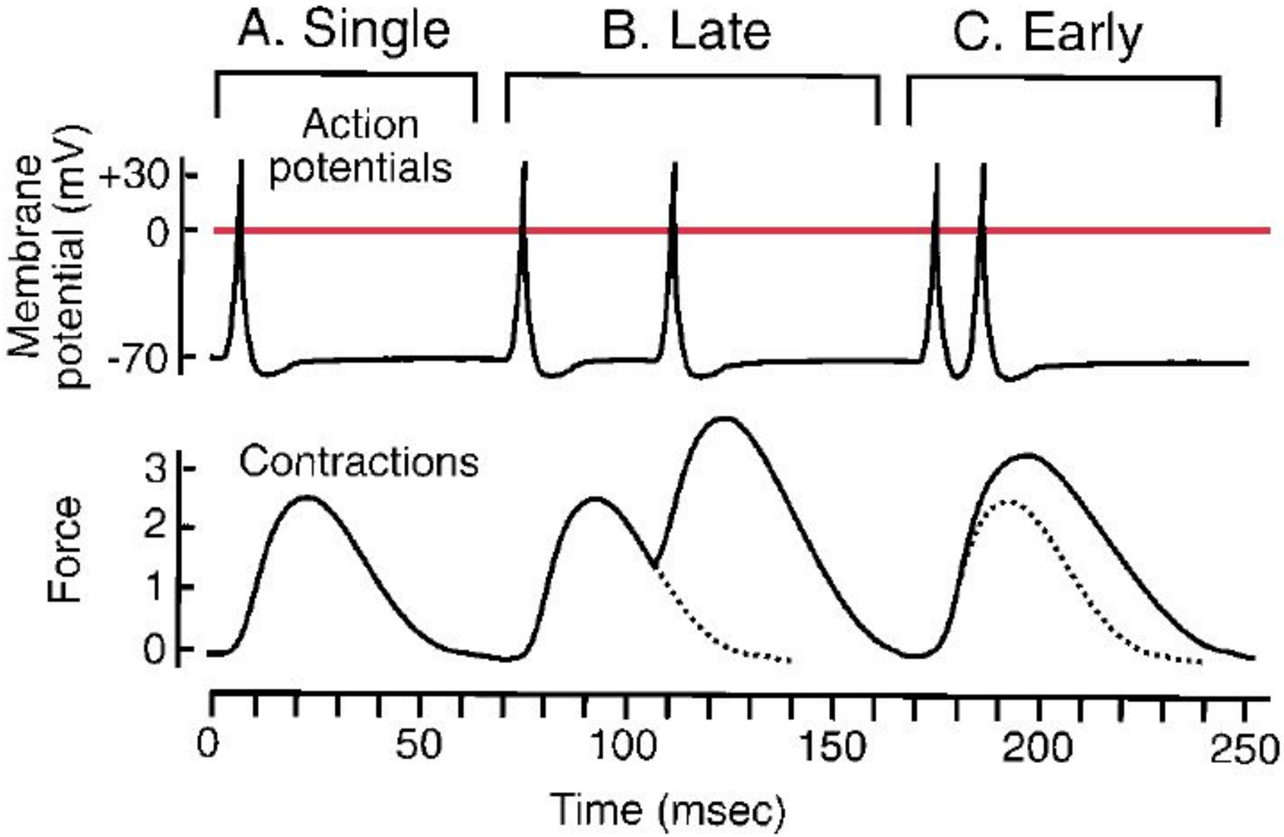



**FIGURE 9.4** **Temporal summation of muscle twitches.** A, The first contraction is in response to a single action potential. B, The next contraction shows the summed response to a second stimulus given during relaxation; the two individual responses are evident. C, The last contraction is the result 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.

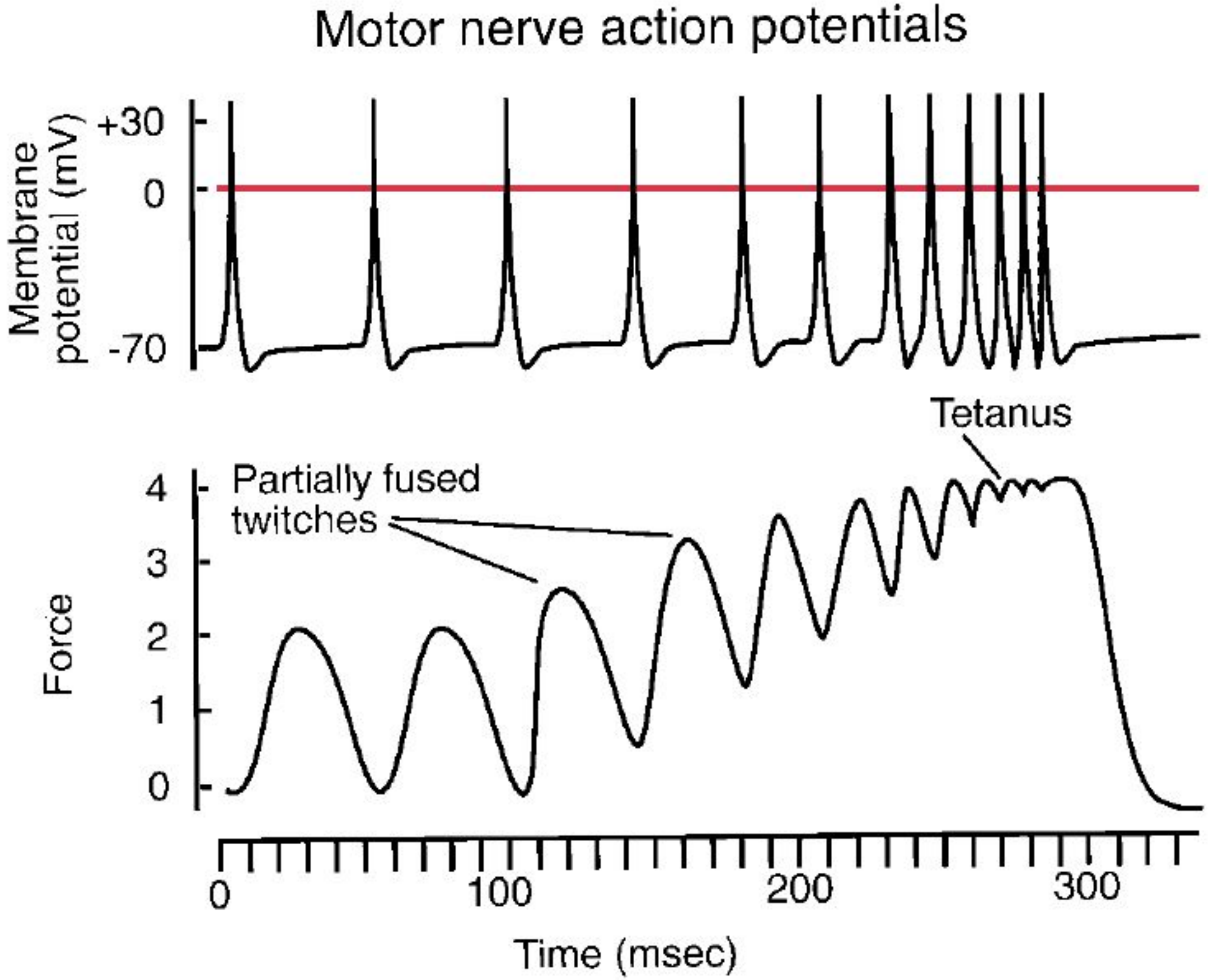



**FIGURE 9.5** **Fusion of twitches into a smooth tetanus.** The interval between successive stimuli steadily decreases until no relaxation occurs between stimuli.

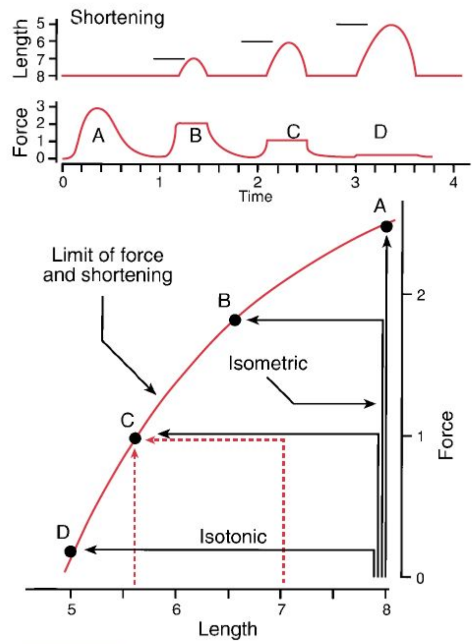



**FIGURE 9.12** **The relationship between isotonic and isometric contractions.** The top graphs show the contractions from Figure 9.11, with different amounts of shortening. The bottom graph shows, for contractions B, C, and D, the initial portion is isometric (the line moves upward at constant length) 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.)

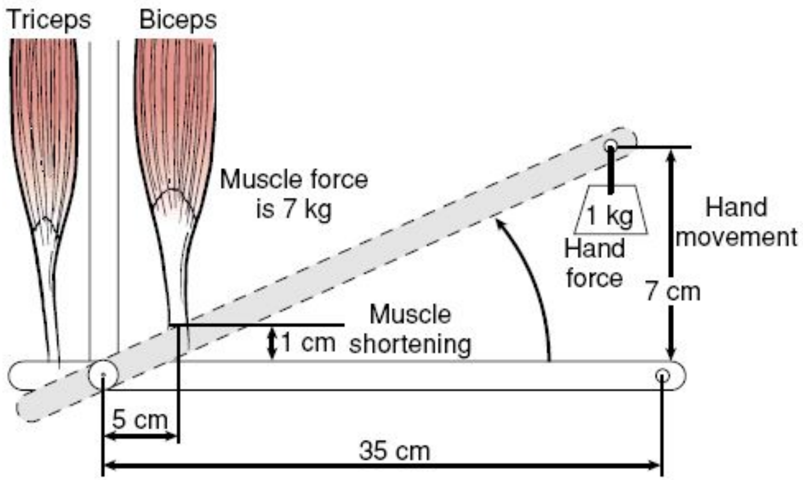



FIGURE 9.13 **Antagonistic pairs and the lever system of skeletal muscle.** Contraction of the biceps muscle lifts the lower arm (flexion) and elongates the triceps, while contraction of the triceps lowers the arm and hand (extension) and elongates the biceps. The bones of the lower arm are pivoted at 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**

| | Fast Twitch | | Slow Twitch |
|---|---|---|---|
| Metabolic Type | 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 |

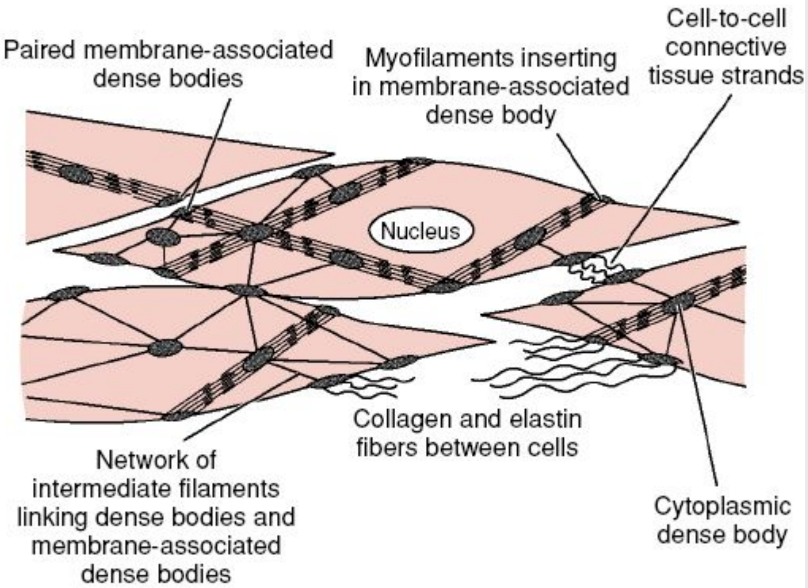



**FIGURE 9.15** **The contractile system and cell-to-cell connections in smooth muscle.** Note regions of association between thick and thin filaments that are anchored by the cytoplasmic and membrane-associated dense bodies. A network of intermediate filaments provides some spatial organization (see, 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.)

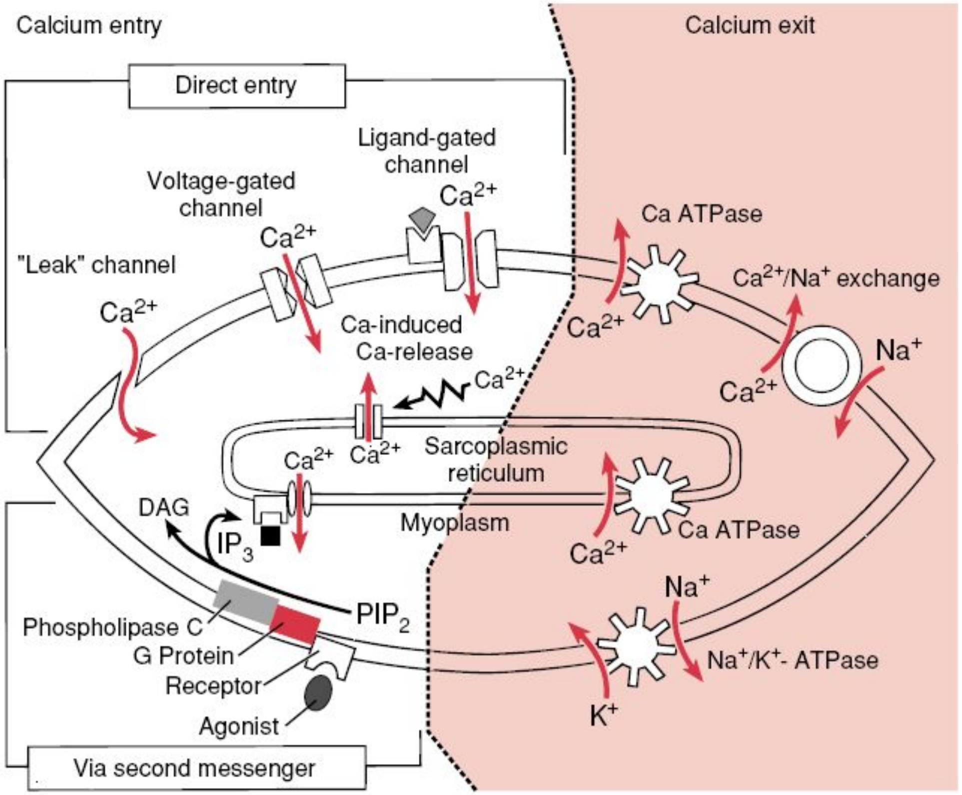
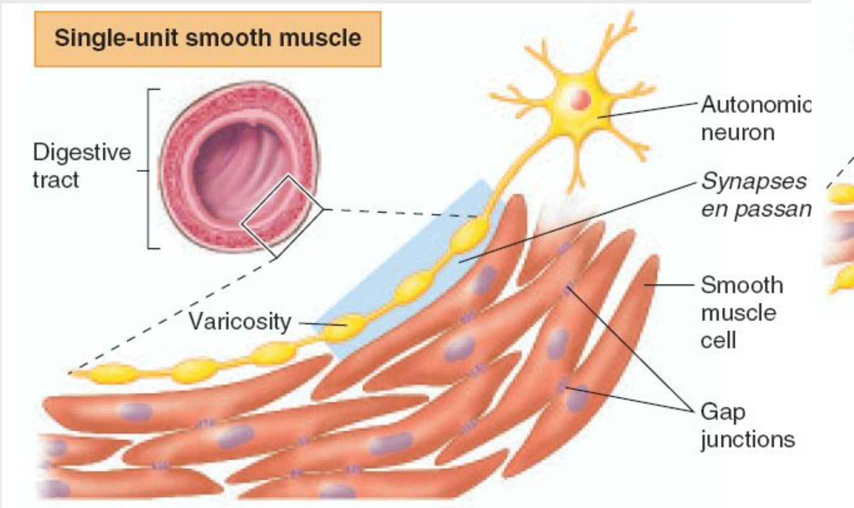



**FIGURE 9.16 Major routes of calcium entry and exit from the cytoplasm of smooth muscle.** The ATPase reactions are energy-consuming ion pumps. The processes on the left side increase cytoplasmic calcium and promote contraction; those on the right decrease internal calcium and cause relaxation. $PIP_2$,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



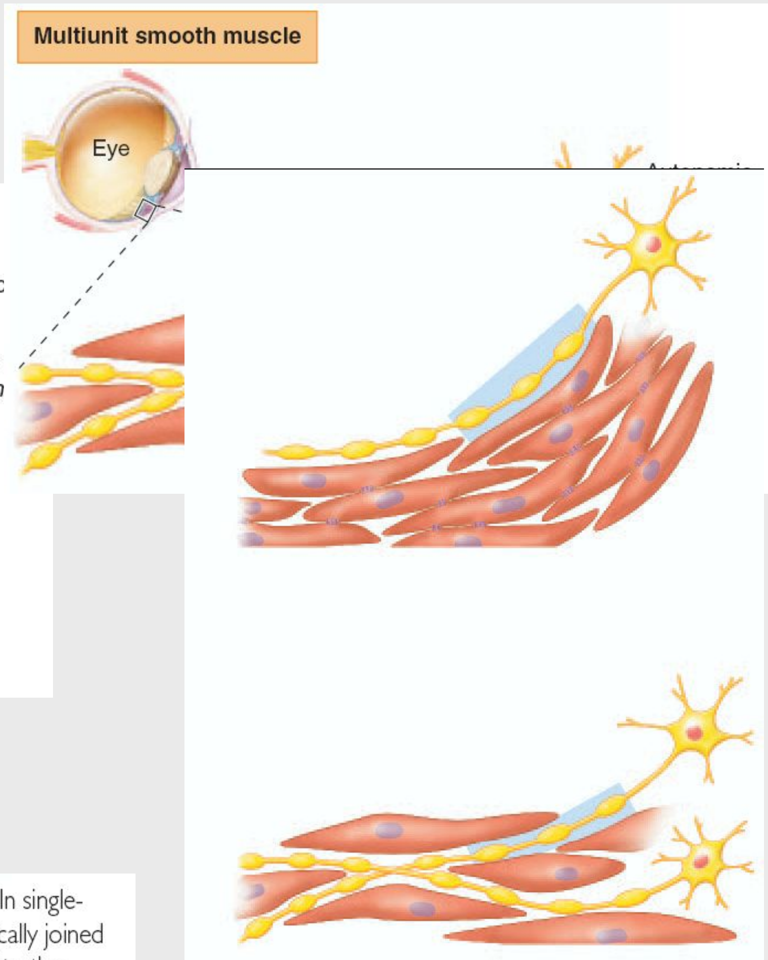
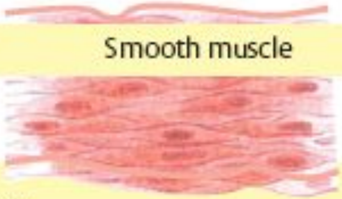
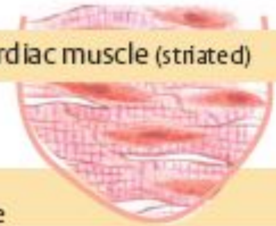
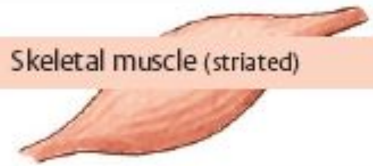




**Figure 12.35** **Single-unit and multiunit smooth muscle.** In single-unit smooth muscle, the individual smooth muscle cells are electrically joined by gap junctions, so that depolarizations can spread from one cell to the next. In multiunit smooth muscle, each smooth muscle cell must be stimulated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



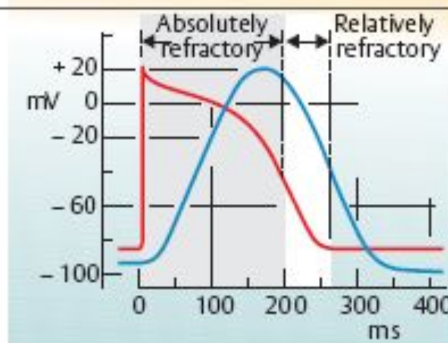




| Structure and function | Smooth muscle | Cardiac muscle (striated) | Skeletal muscle (striated) |
|---|---|---|---|
| Motor end-plates | None | None | Yes |
| Fibers | Fusiform, short (≤ 0.2 mm) | Branched | Cylindrical, long (≤ 15 cm) |
| Mitochondria | Few | Many | Few (depending on muscle type) |
| Nucleus per fiber | 1 | 1 | Multiple |
| Sarcomeres | None | Yes, length ≤ 2.6 µm | Yes, length ≤ 3.65 µm |
| Electr. coupling | Some (single-unit type) | Yes (functional syncytium) | No |
| Sarcoplasmic reticulum | Little developed | Moderately developed | Highly developed |
| $Ca^{2+}$ "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 |
| Tetanizable | Yes | No | Yes |
| [redacted] | Length-force curve [redacted] | In rising length-force curve (see 2.15E) | At peak of [redacted] |

[redacted] to stimulus

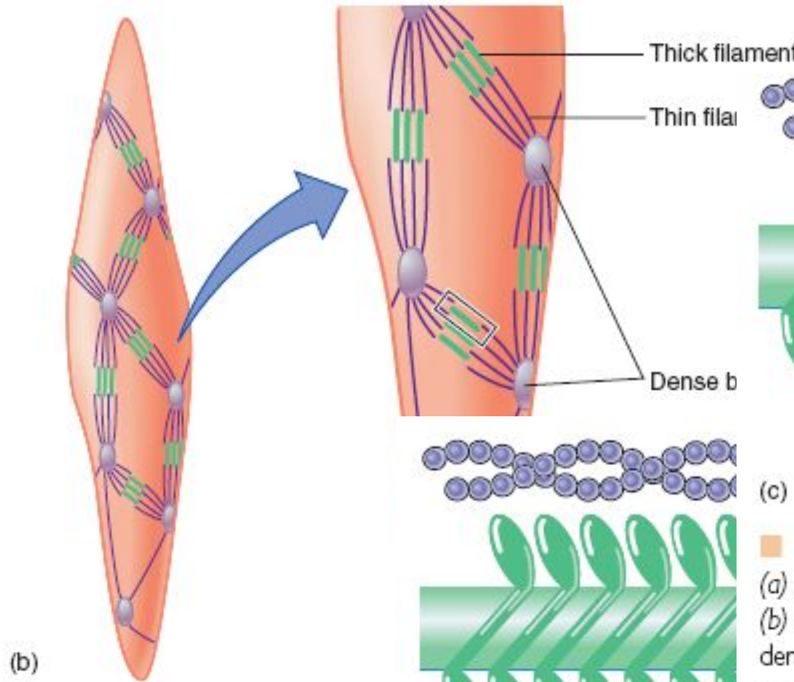
[redacted]



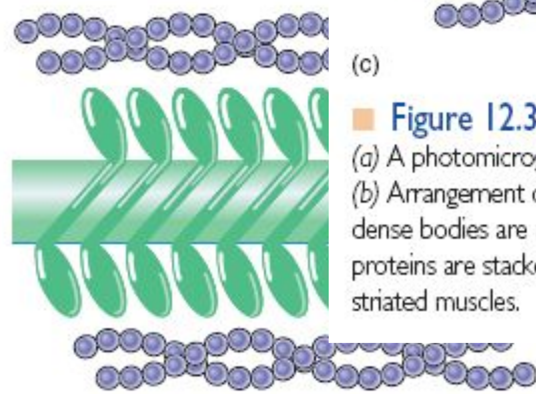

[redacted]

Potential

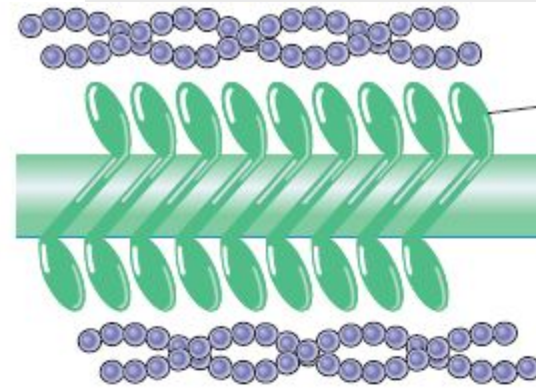
Muscle tension




(b)

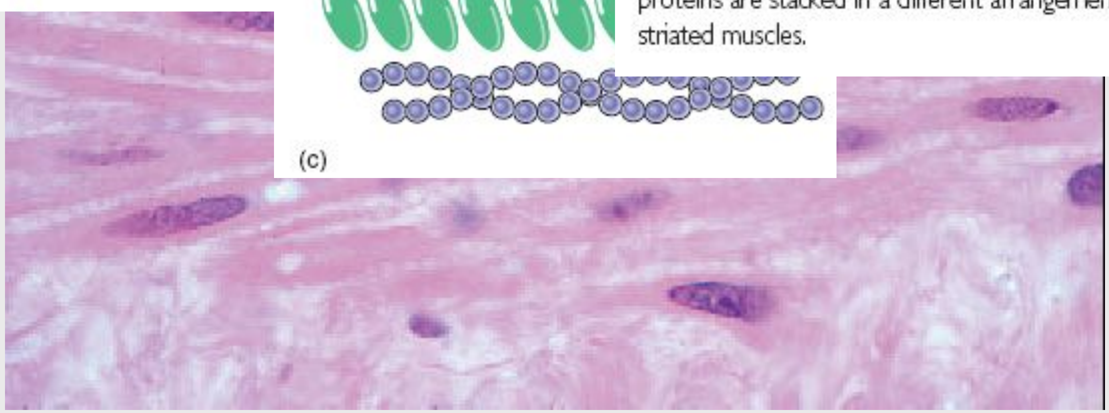


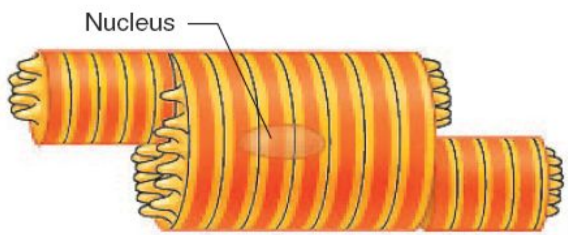
(c)



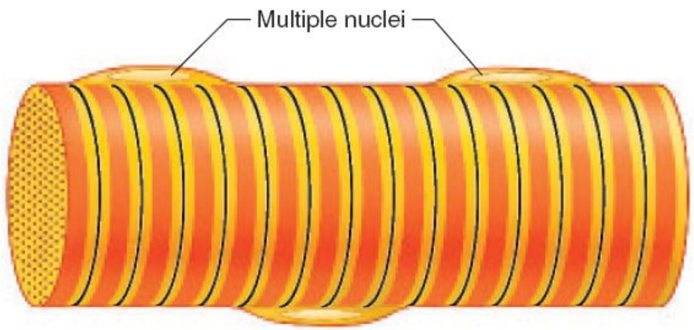

(c)

**Figure 12.33** Smooth muscle and its contractile apparatus. *(a)* A photomicrograph of smooth muscle cells in the wall of a blood vessel. *(b)* Arrangement of thick and thin filaments in smooth muscles. Note that dense bodies are also interconnected by intermediate fibers. *(c)* The myosin proteins are stacked in a different arrangement in smooth muscles than in striated muscles.






**Cardiac muscle cell**




**Skeletal muscle fiber**


**Smooth muscle cell**