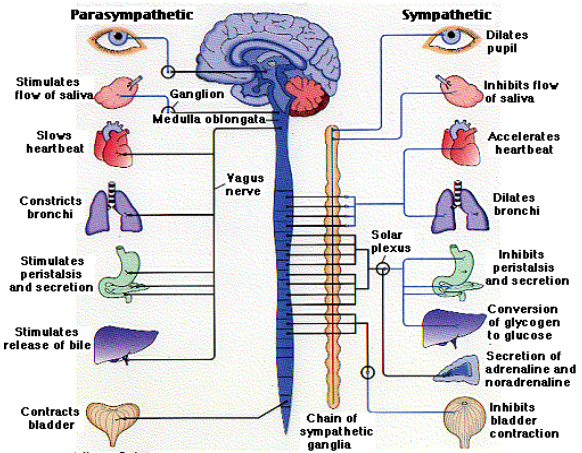
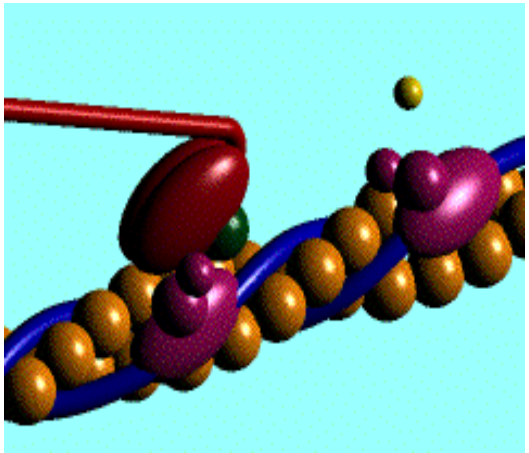
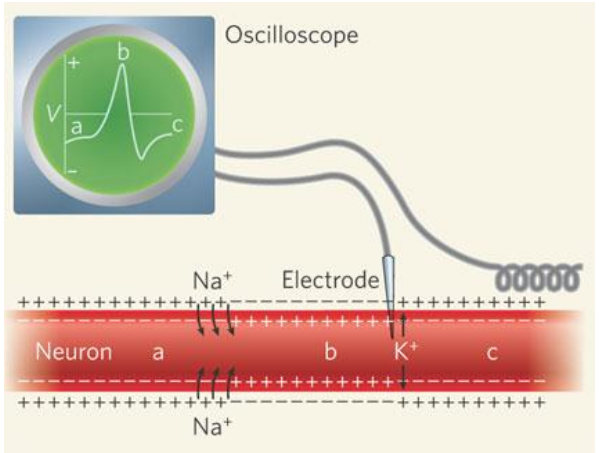
Lecture 2

(Physiology of Nerve and Muscle)
and
(Autonomic Nervous System)

Prof. Dr. Osama M. Ahmed







Contents

Excitable cells are those which can respond to stimuli to produce action potentials. They includes neurons and muscle fibres.

Excitability is the ability to receive and respond to stimulus or the ability of the cell or tissue to generate and propagate action potentials.

Neurons

Neurons are the structural and functional units of the nervous system. They form with glia (neuroglia) cells the neural tissue. The percent of neurons to glia cells is

10:90% as number and 50:50% as volume.

Glia cells includes:

1) oligodendroglia which form the meylin sheath in CNS (compare with Shwann cells which form myelin sheath outside CNS).

2) astroglia which maintain the homeostasis of components in the extracellular fluid between neurons, secrete growth factors and also connect neurons with blood vessels.

3) micoglia cells which are involved in the phagocytosis of unwanted substances; engulf microbes like bacteria and cellular debris).

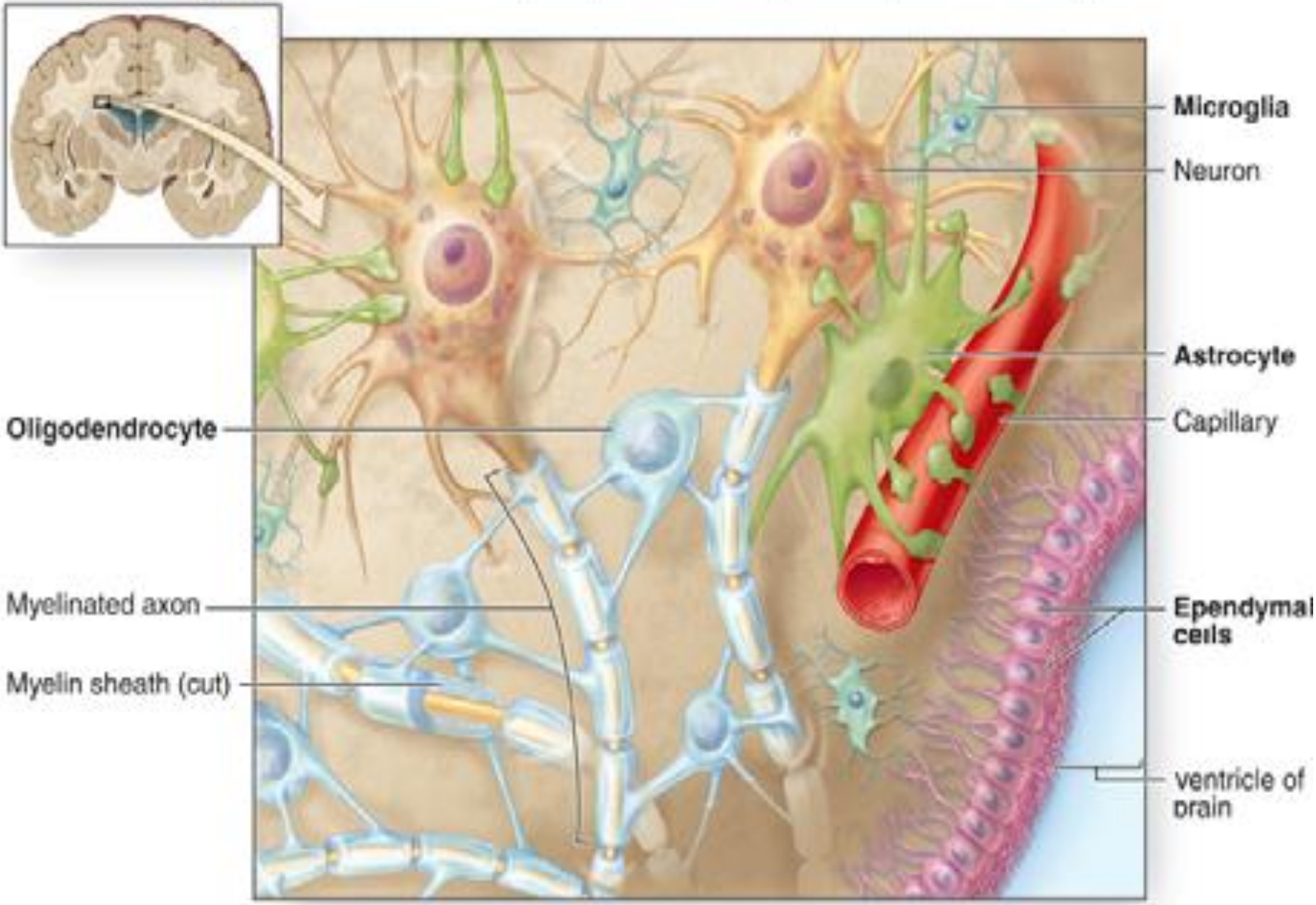
Properties of neurons

1- mature neurons can not divide or proliferate

2- they have high metabolic rate

3- they depend mainly on glucose to obtain energy

4- they need high amounts of oxygen.

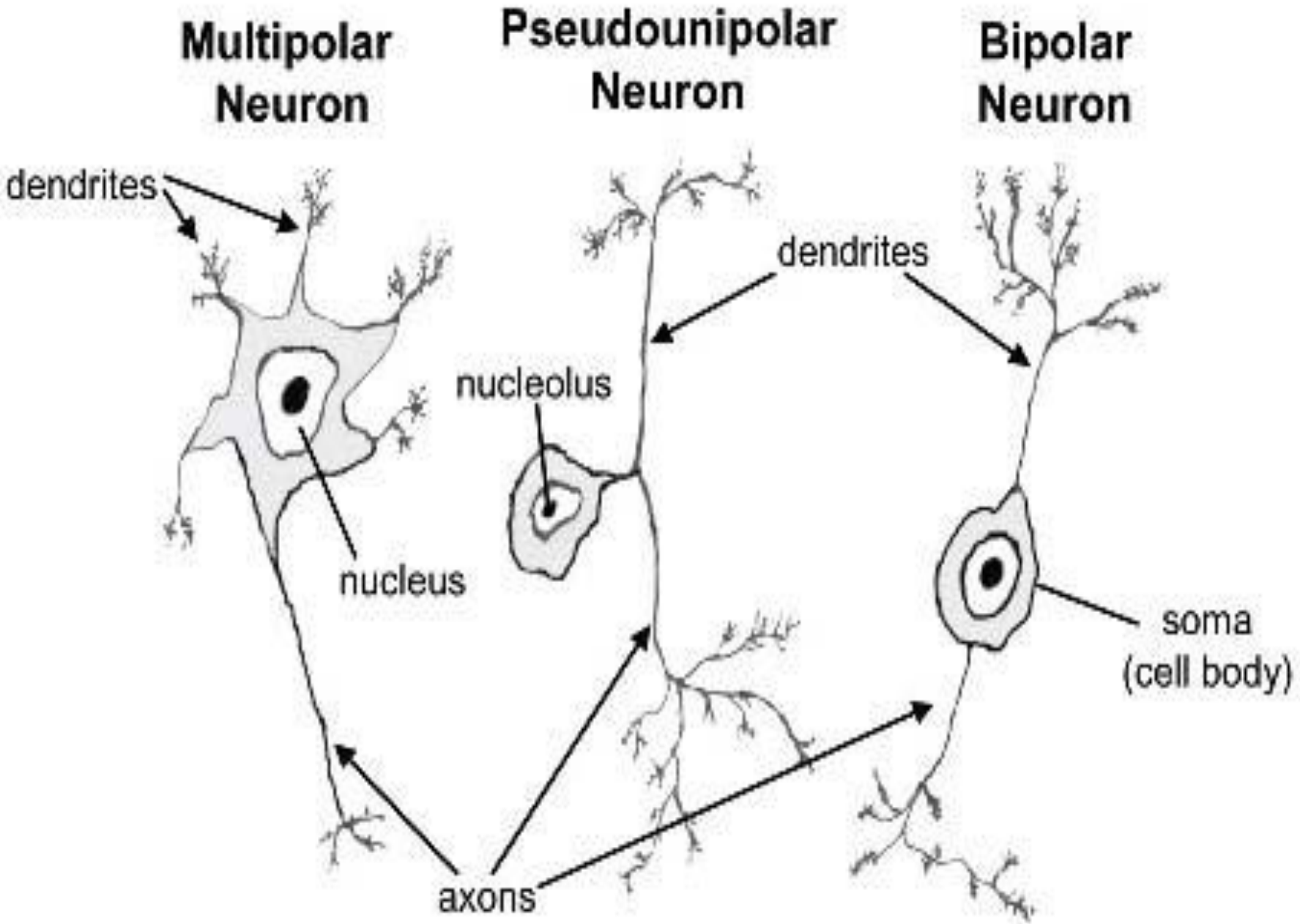


Structural Types of Neurons:

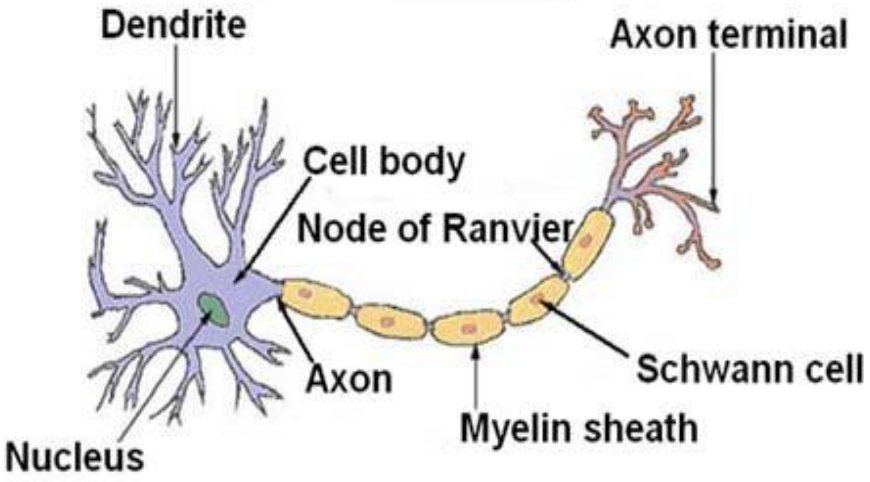
- Unipolar neurons: **These neurons have a single nerve fiber. A short distance from the cell body, this fiber divides into two branches, peripheral and central processes. Example: sensory neuron in the sensory ganglia outside brain and spinal cord.**

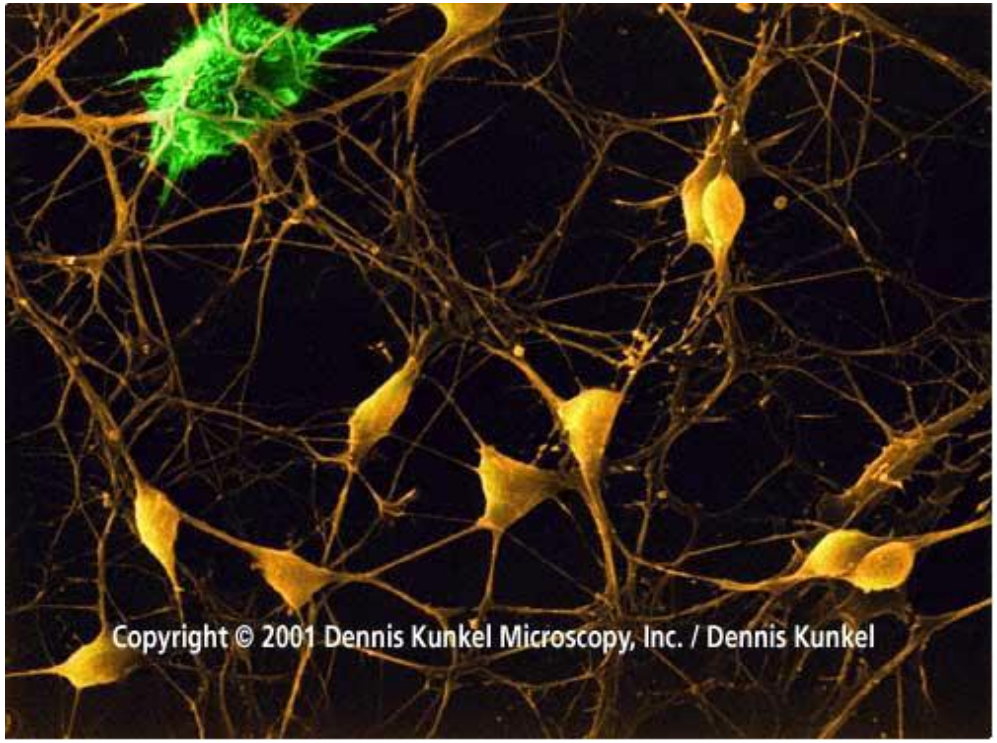
- Bipolar neurons: **each has two nerve fibers. One is known as dendrite and the other as axon. Example: bipolar neuron in the retina of eye.**

- Multipolar neurons: **they have many nerve fibers. One fiber is an axon and the others are dendrites. Examples: most neurons whose cell bodies lie within the brain and the spinal cord are of this type.**


Multipolar Neuron
Pseudounipolar Neuron
Bipolar Neuron
dendrites
dendrites
nucleolus
nucleus
soma (cell body)
axons

Structure of a Typical Neuron





Caption: Cortical neurons growing in culture. Note the large, round, textured, astrocytic glial cell (central nervous system).
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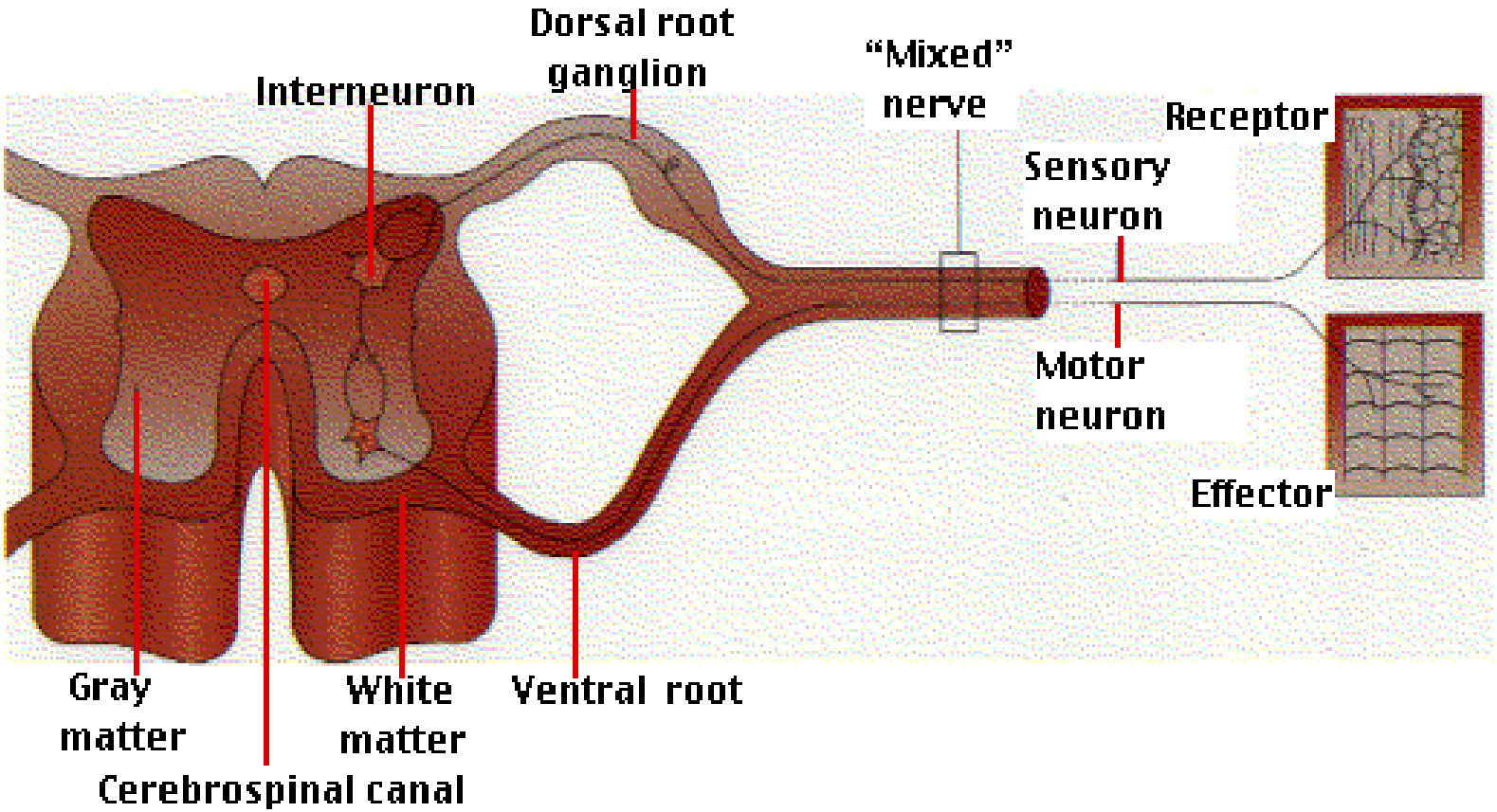
Functional Types of Neurons

1) Sensory neurons – receive an impulse from a receptor and transmit it to the CNS

2) Motor neurons – send an impulse to another neuron or effector organs.

3) Interneurons – (association neurons or connecting neurons) they carry impulses from neurons to one another within CNS.


Dorsal root ganglion
Interneuron
"Mixed" nerve
Receptor
Sensory neuron
Motor neuron
Effector
Gray matter
White matter
Ventral root
Cerebrospinal canal

Nervous System

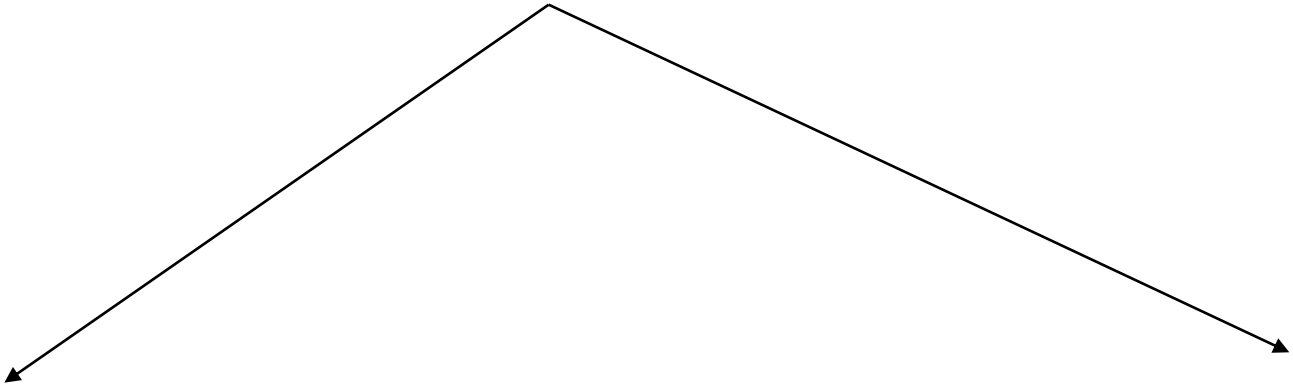
Central nervous system consists of brain and spinal cord.

Peripheral nervous system consists of cranial nerves (12 pairs), spinal nerves (31 pairs) and autonomic n. s.

1- Afferent nerve fibres
2- Efferent nerve fibres

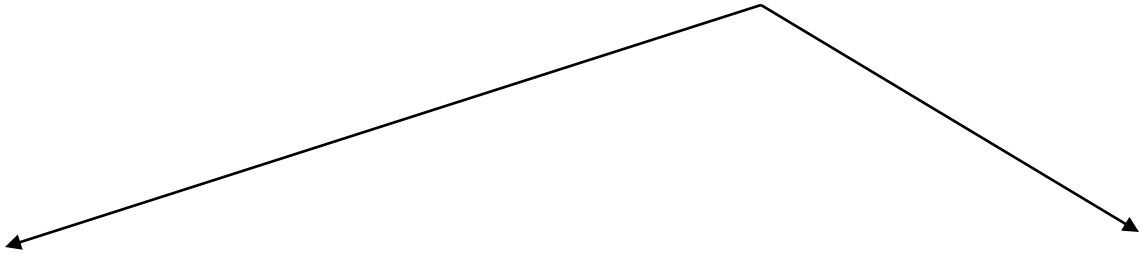
Cranial Nerve	Type	Function
Olfactory (I)	Sensory	Olfaction
Optic (II)	Sensory	Vision
Oculomotor (III)	Motor	Eyelid and eyeball muscles
Trochlear (IV)	Motor	Eyeball muscles
Trigeminal (V)	Mixed	Sensory: Facial and mouth sensation Motor: Chewing
Abducens (VI)	Motor	Eyeball movement
Facial (VII)	Mixed	Sensory: Taste Motor: Facial muscles and salivary gl.
Auditory (VIII)	Sensory	Hearing and balance
Glossopharyngeal (IX)	Mixed	Sensory: Taste ’Motor: Swallowing
Vagus (X)	Mixed	Main nerve of parasympathetic NS
Accessory (XI)	Motor	Swallowing; moving of head and shoulder
Hypoglossal (XII)	Motor	Tongue muscles

Efferent nerve fibres



Somatic nervous system. It controls voluntary motor organs

Autonomic nervous system. It is involuntary



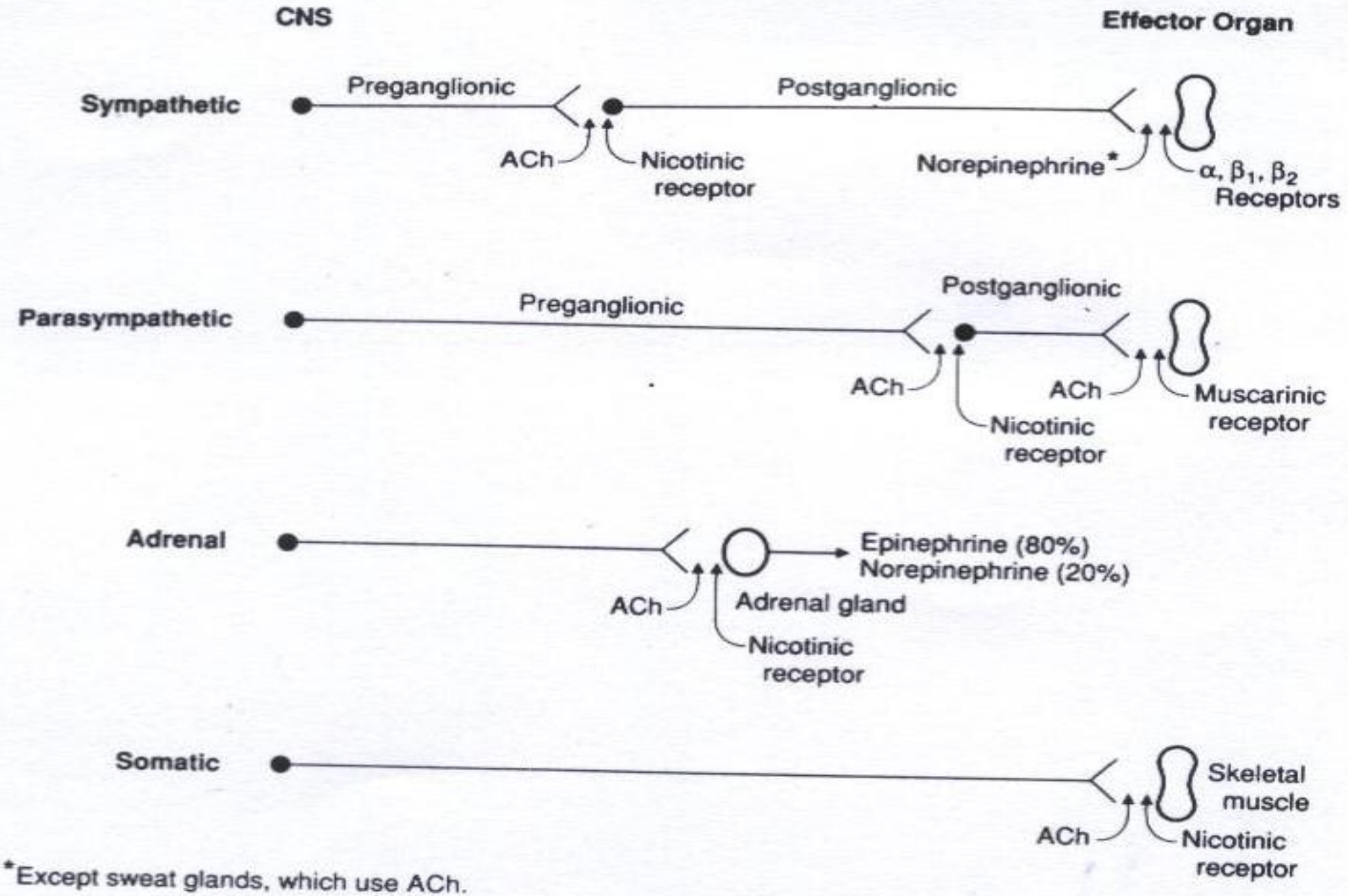
Sympathetic nervous system

Parasympathetic nervous system

Table . Organization of the Autonomic Nervous System

Characteristic	Sympathetic	Parasympathetic	Somatic*
Origin of preganglionic nerve	Nuclei of spinal cord segments T1–T12; L1–L3 (thoracolumbar)	Nuclei of cranial nerves III, VII, IX and X; spinal cord segments S2–S4 (craniosacral)	
Length of preganglionic nerve axon	Short	Long	
Neurotransmitter in ganglion	ACh	ACh	
Receptor type in ganglion	Nicotinic	Nicotinic	
Length of postganglionic nerve axon	Long	Short	
Effector organ	Smooth and cardiac muscle; glands	Smooth and cardiac muscle; glands	Skeletal muscle
Neurotransmitter in effector organ	Norepinephrine (except sweat glands, which use ACh)	ACh	ACh (synapse is neuromuscular junction)
Receptor type in effector organ	α_1, α_2, β_1, and β_2	Muscarinic	Nicotinic

*Somatic nervous system has been included for comparison.



*Except sweat glands, which use ACh.

Figure 1 Organization of the autonomic nervous system.

The stimulation of sympathetic nervous system

1- stimulates the release of adrenaline and noradrenaline from adrenal gland

2- increases the heart beating rate

3- elevates the blood pressure

4- dilates the eye pupil

5- dilates the trachea and bronchi

6- stimulates the conversion of liver glycogen into glucose

7- stimulates the conversion of liver triglycerides into fatty acids

8- shunts blood away from the skin and viscera to the skeletal muscles, brain, and heart

9- inhibits peristalsis and secretion of the gastrointestinal (GI) tract

10- inhibits contraction of the urinary bladder and rectum and constricts sphincters.

Parasympathetic stimulation causes:

1- slowing down of the heart beating rate

2- lowering of the blood pressure

3- constriction of the eye pupil

3- increase in blood flow to the skin and viscera

4- increase in peristalsis and secretions of the GI tract

5- increase in contraction of the urinary bladder and relaxation of sphincter.

6- increase in constriction of the bronchi and decrease in the respiratory rate.

In short, the parasympathetic system returns the body functions to normal after they have been altered by sympathetic stimulation.

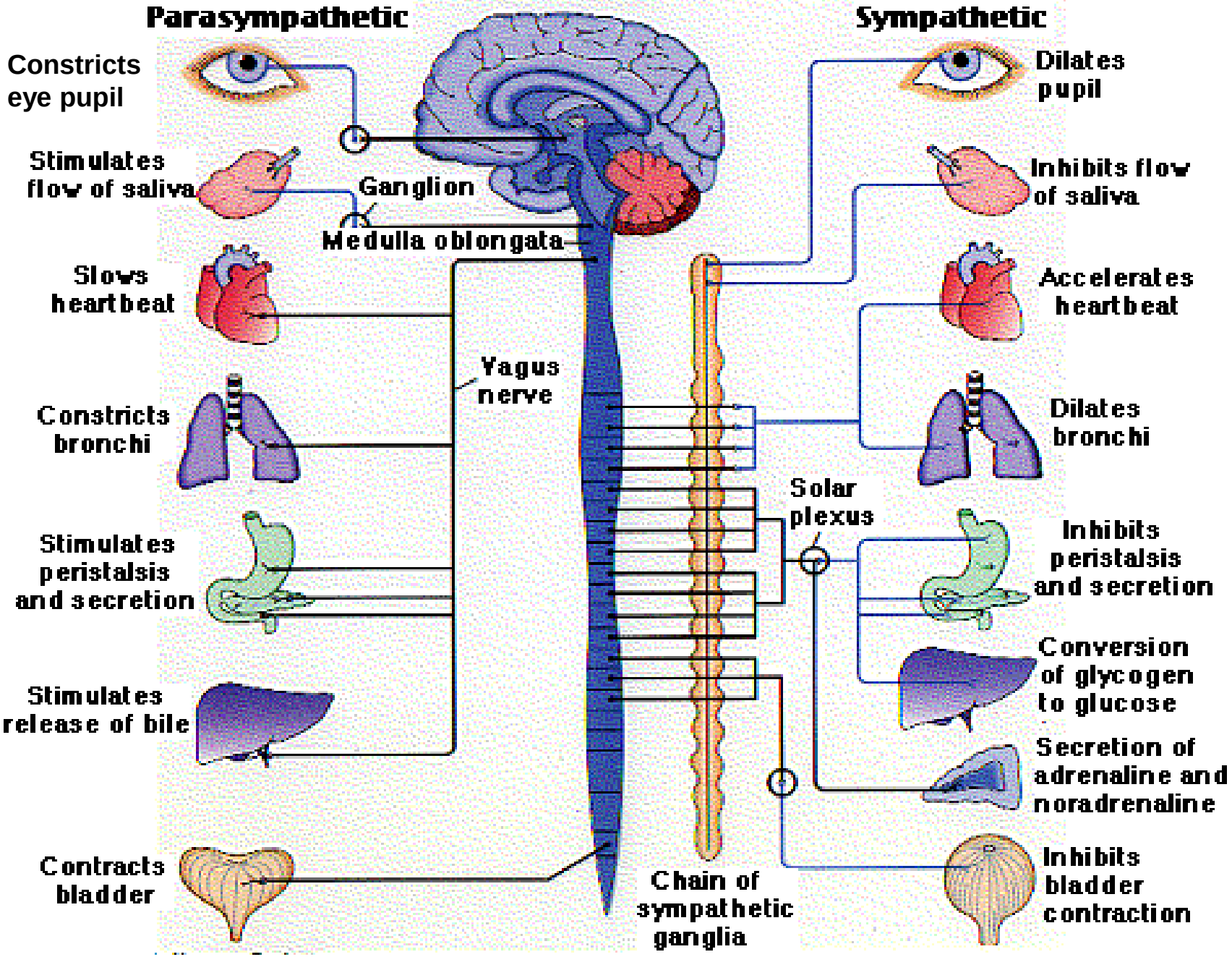


Figure showing the functions of sympathetic and parasympathetic nervous systems

Electrical Changes Across Excitable cells

Resting membrane potential and polarization: **In such condition, the membrane has +ve charges outside the nerve or muscle fibre and have –ve charges inside. The cause of polarization state: it is as a result of increase in K^+ conductance. Resting membrane potential is -70 mV.**

Depolarization: **the membrane have –ve charges outside and +ve charges inside. It results from the increase of Na^+ conductance due to dislocation of Ca^{2+} that bind Na^+ channel on the outer side or due to conformational change that open Na^+ channel.**

Action Potential: **it follows all or none law. When depolarization reaches threshold potential (-55mV) or more, it will give action potential that is able to propagate through nerve or muscle fibres.**

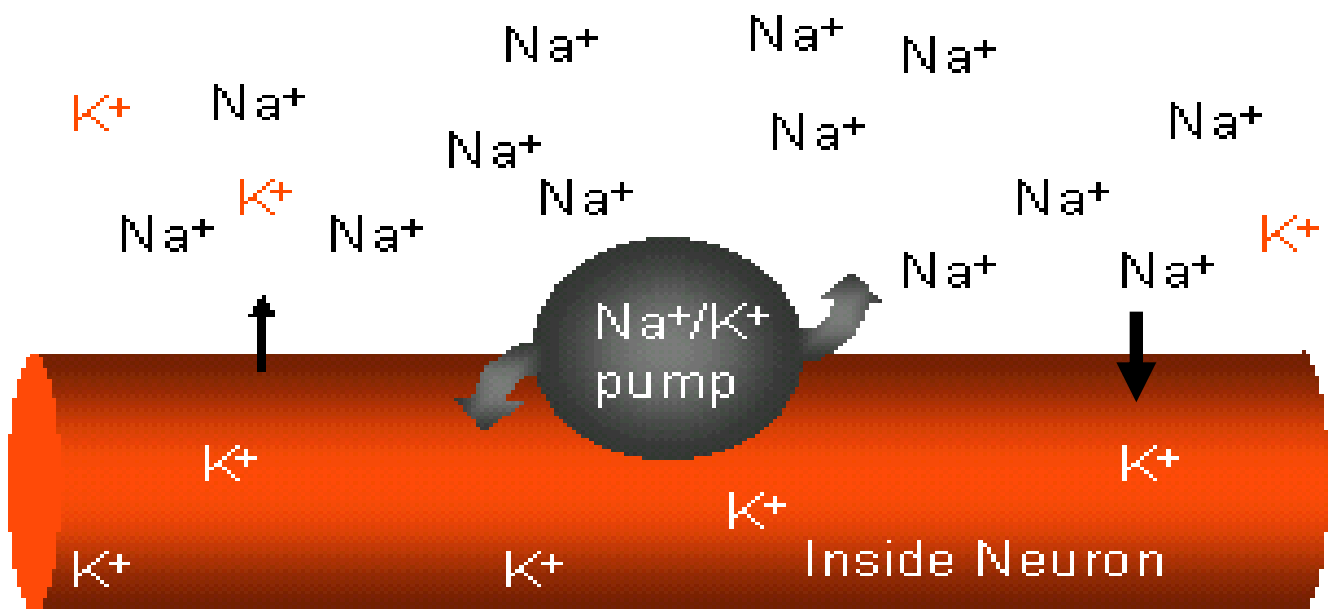
Repolarization: **it results from the increase in the output of K^+ again.**

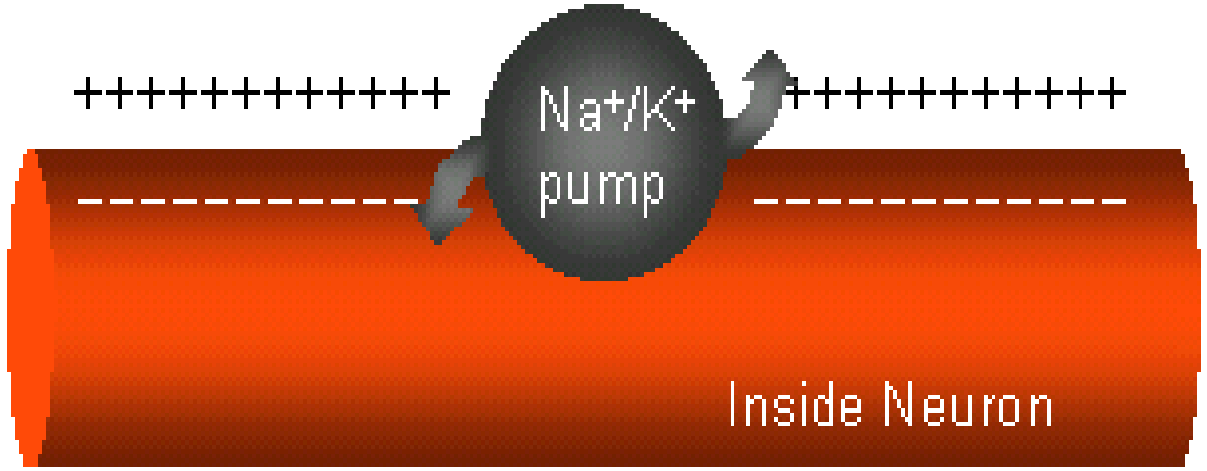
Ions transport through nerve and muscle membrane.

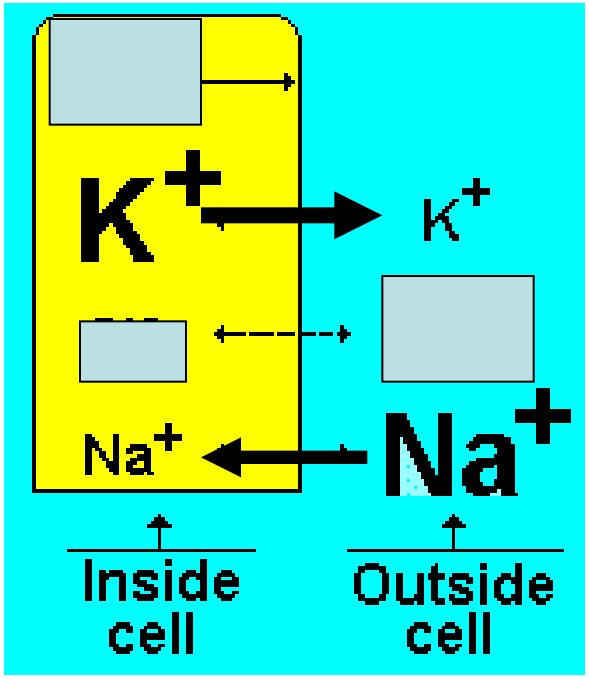
Na^+ diffusion through Na^+-channel (downhill; with the concentration gradient).

K^+ diffusion through K^+-channel (downhill; with the concentration gradient).

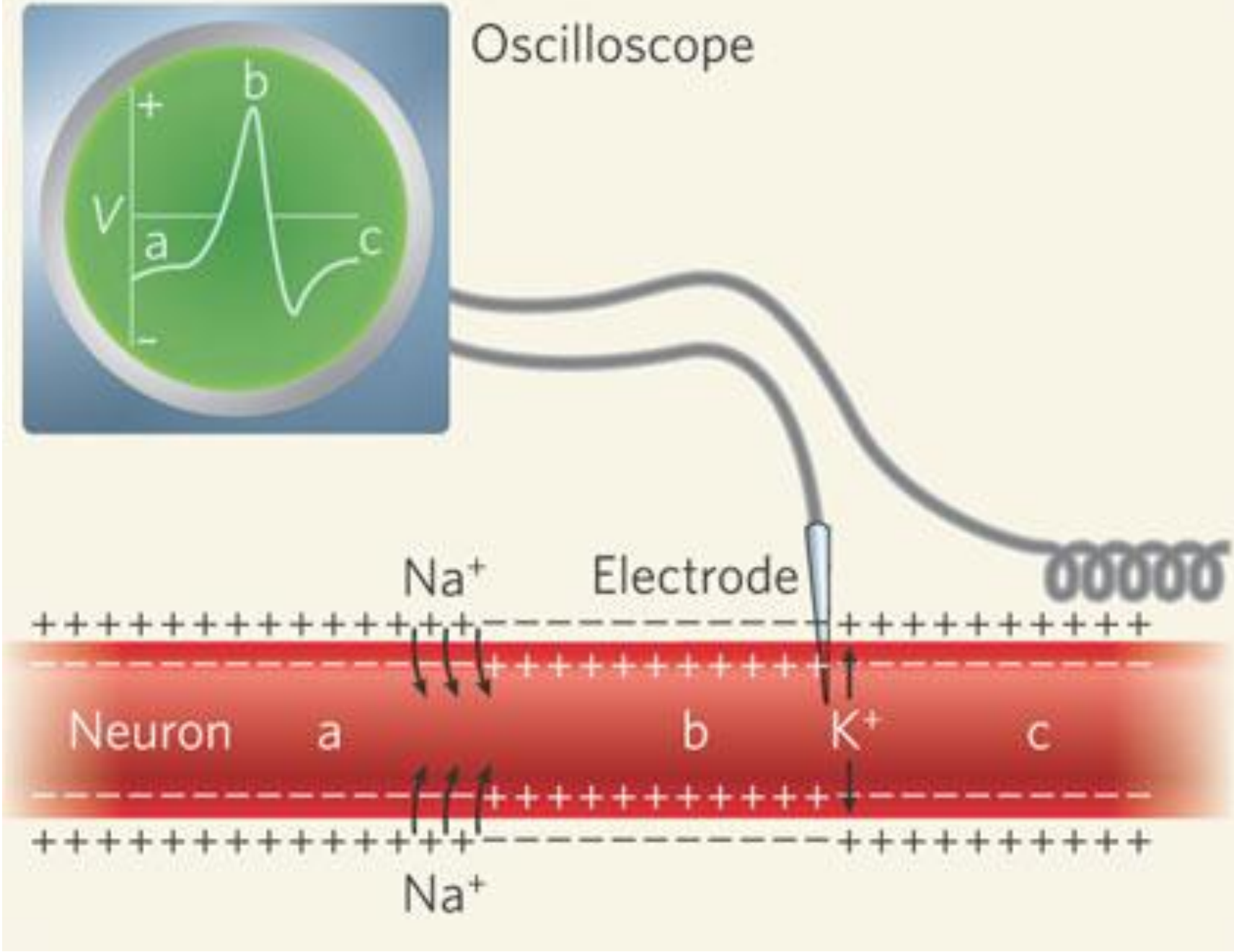
Na^+-K^+ pump (uphill; against concentration gradient): It is necessary to maintain the high concentration of sodium outside the membrane and high concentration of potassium inside. It needs energy and carriers.







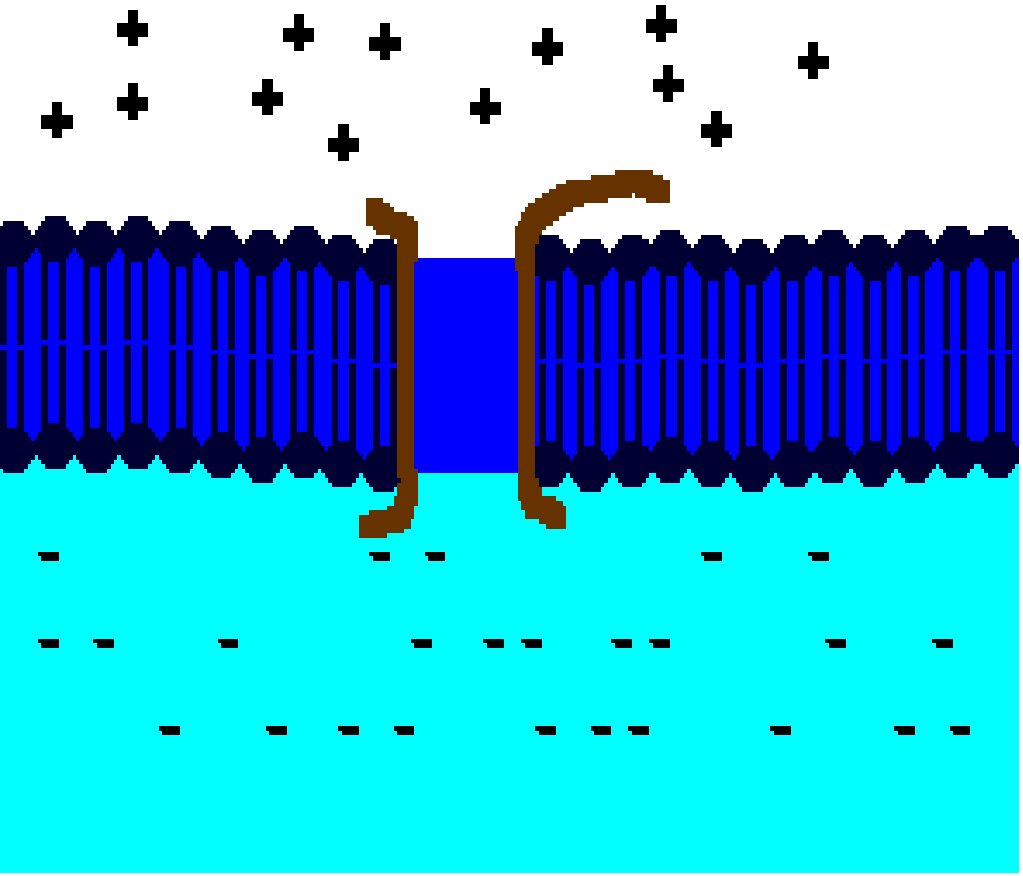
Polarized State

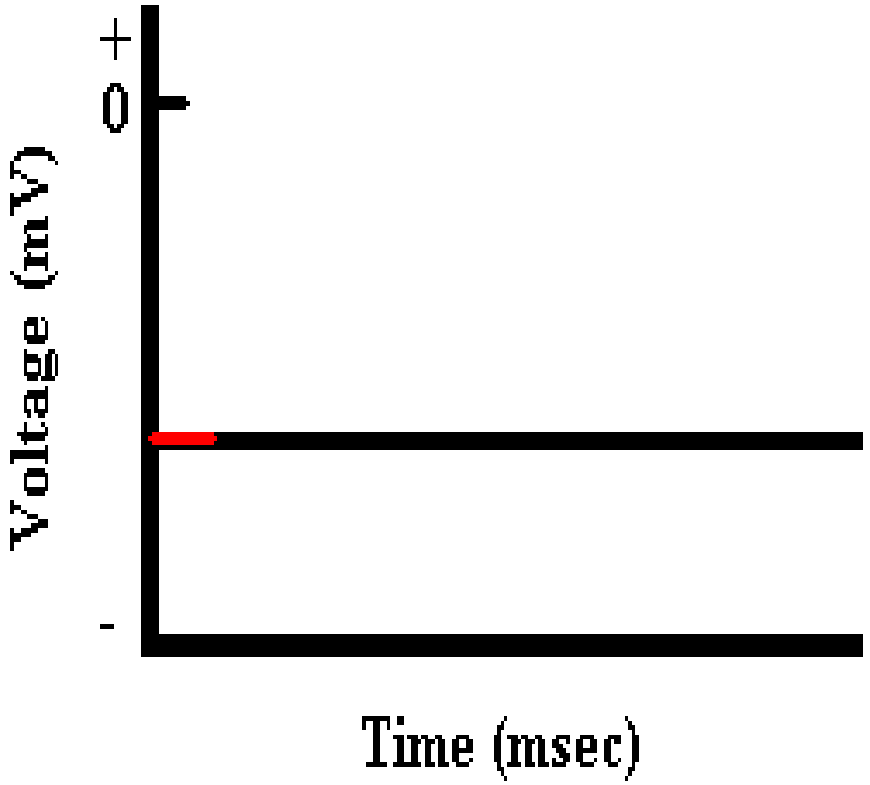

Oscilloscope
+
V
−
a
b
c
Na+
Electrode
Neuron
a
b
K+
c
Na+

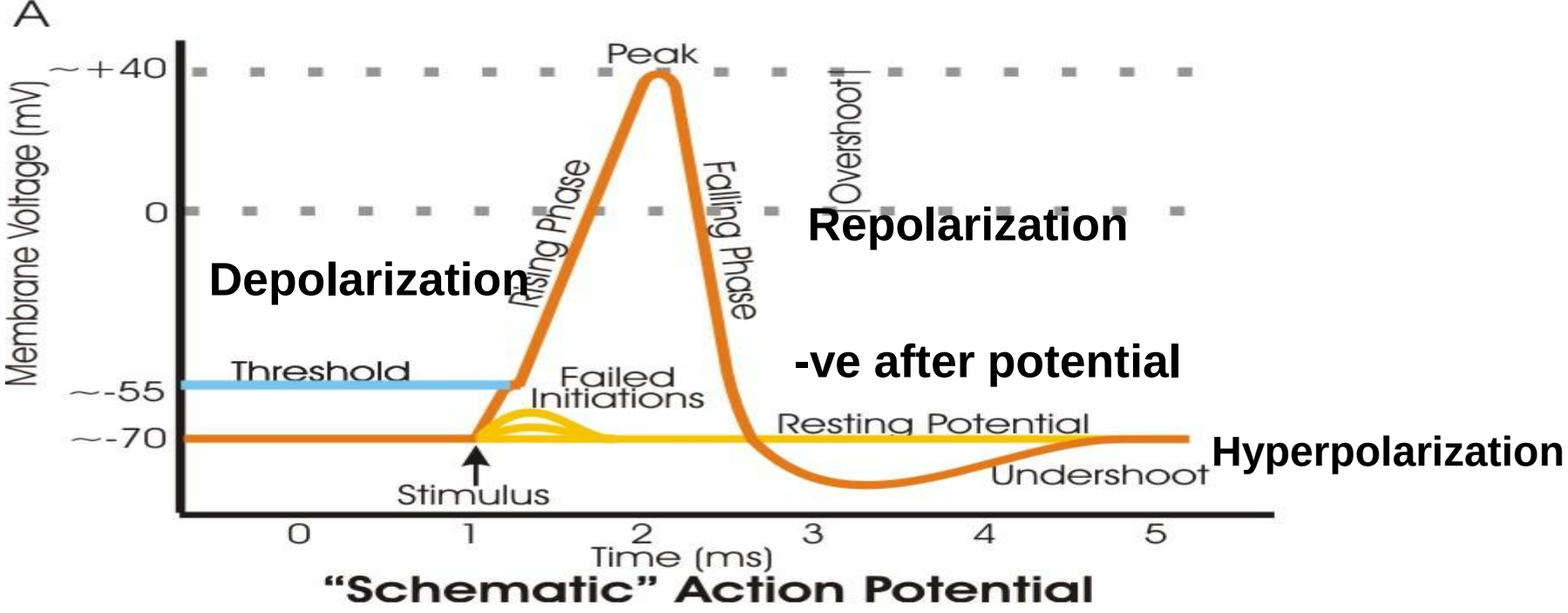
Polarization: K^+ conductance is 30-50 times higher than Na^+ conductance.
Depolarizatin: Na^+ conductance higher than K^+ conductance.
Replorization: K^+ conductance is higher than Na^+ conductance.

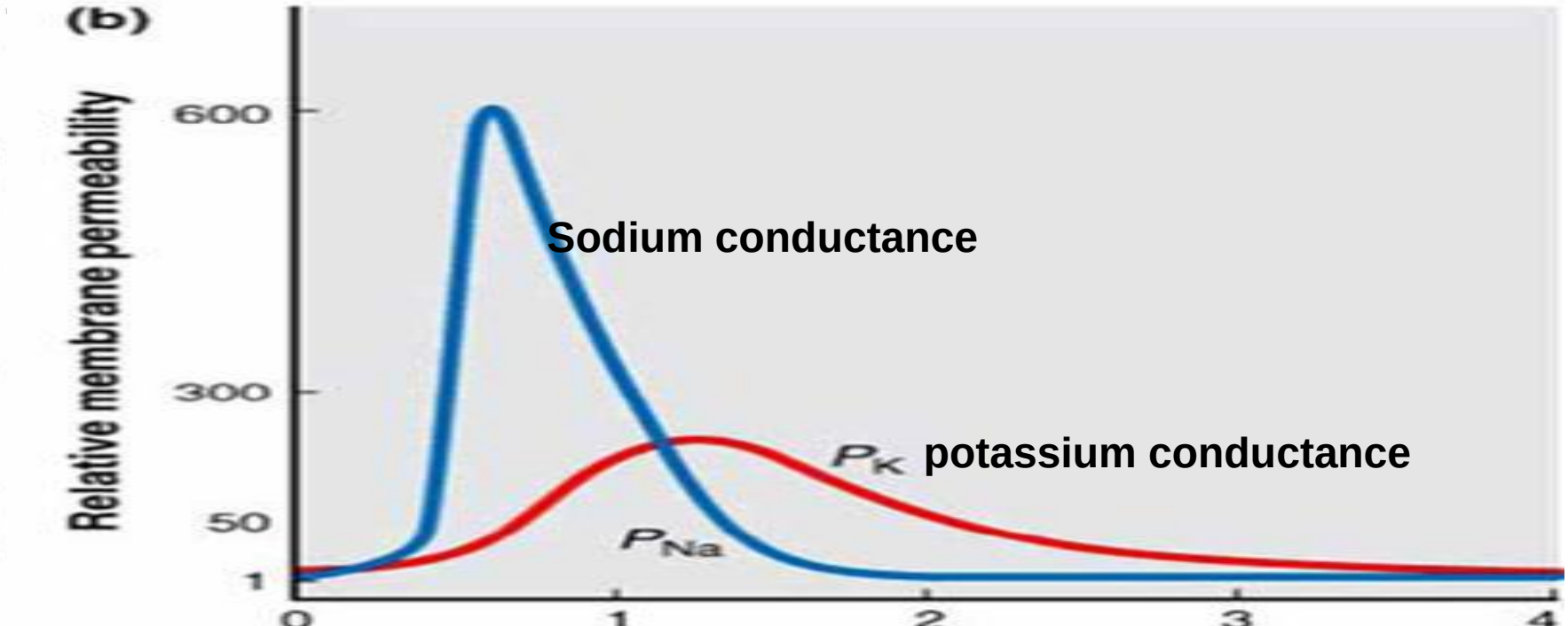
-ve after potential: delay in K^+ conductance
+ve after potential: activated Na^+ pump.

Depolarization

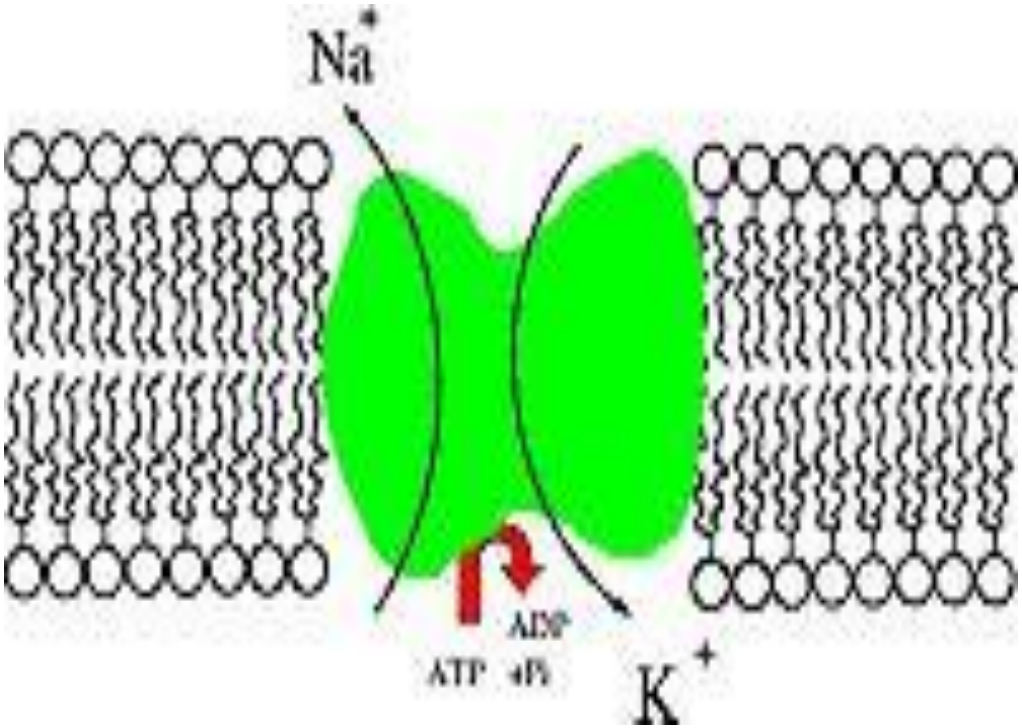





A
Membrane Voltage (mV)
~+40
0
~-55
~-70
Peak
Rising Phase
Falling Phase
Overshoot
Repolarization
Depolarization
-ve after potential
Threshold
Failed Initiations
Resting Potential
Hyperpolarization
Undershoot
Stimulus
0
1
2
3
4
5
Time (ms)
"Schematic" Action Potential


(b)
Relative membrane permeability
600
300
50
1
Sodium conductance
P_K potassium conductance
P_{Na}
0
1
2
3
4

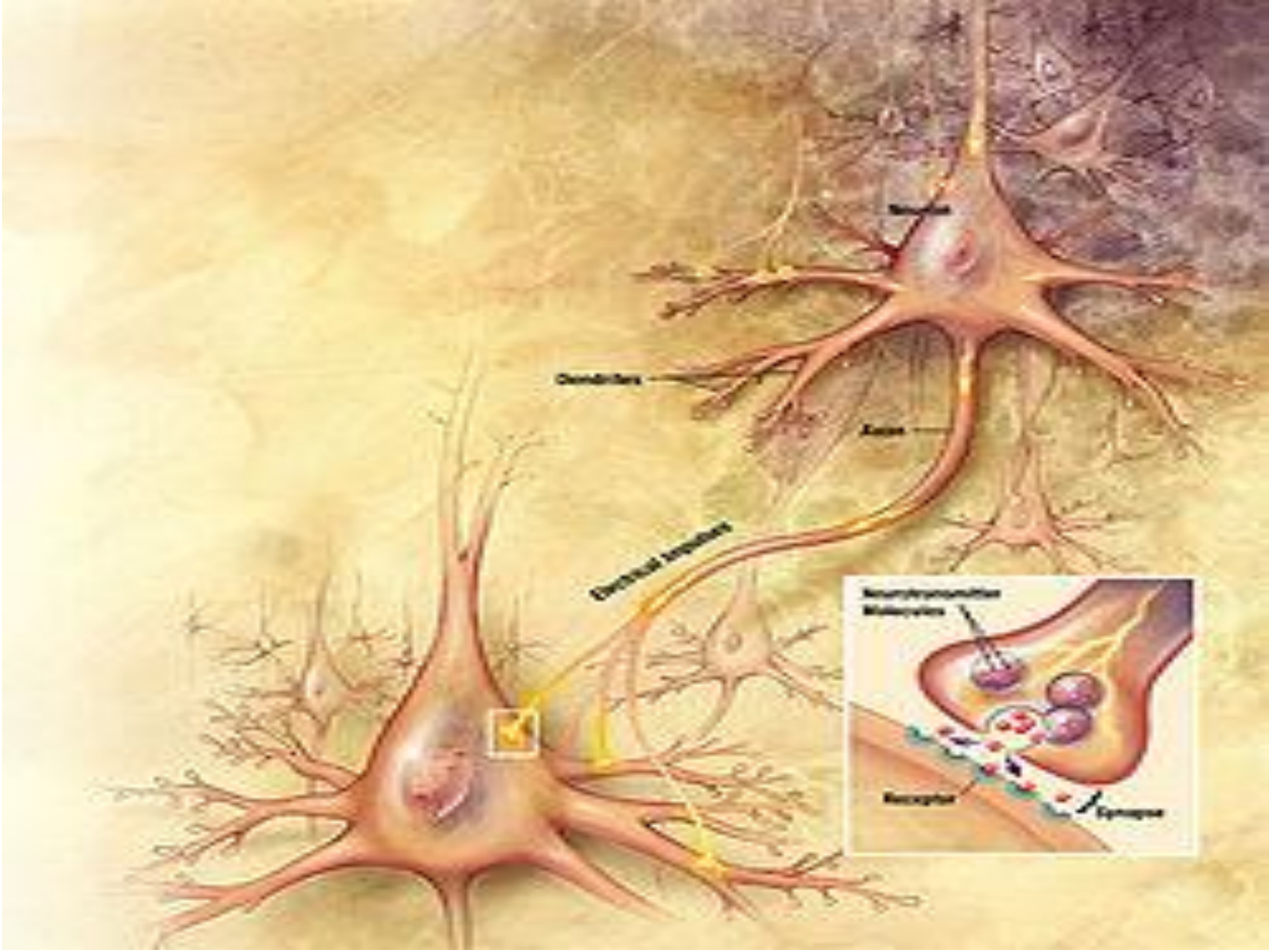
Sodium-potassium pump

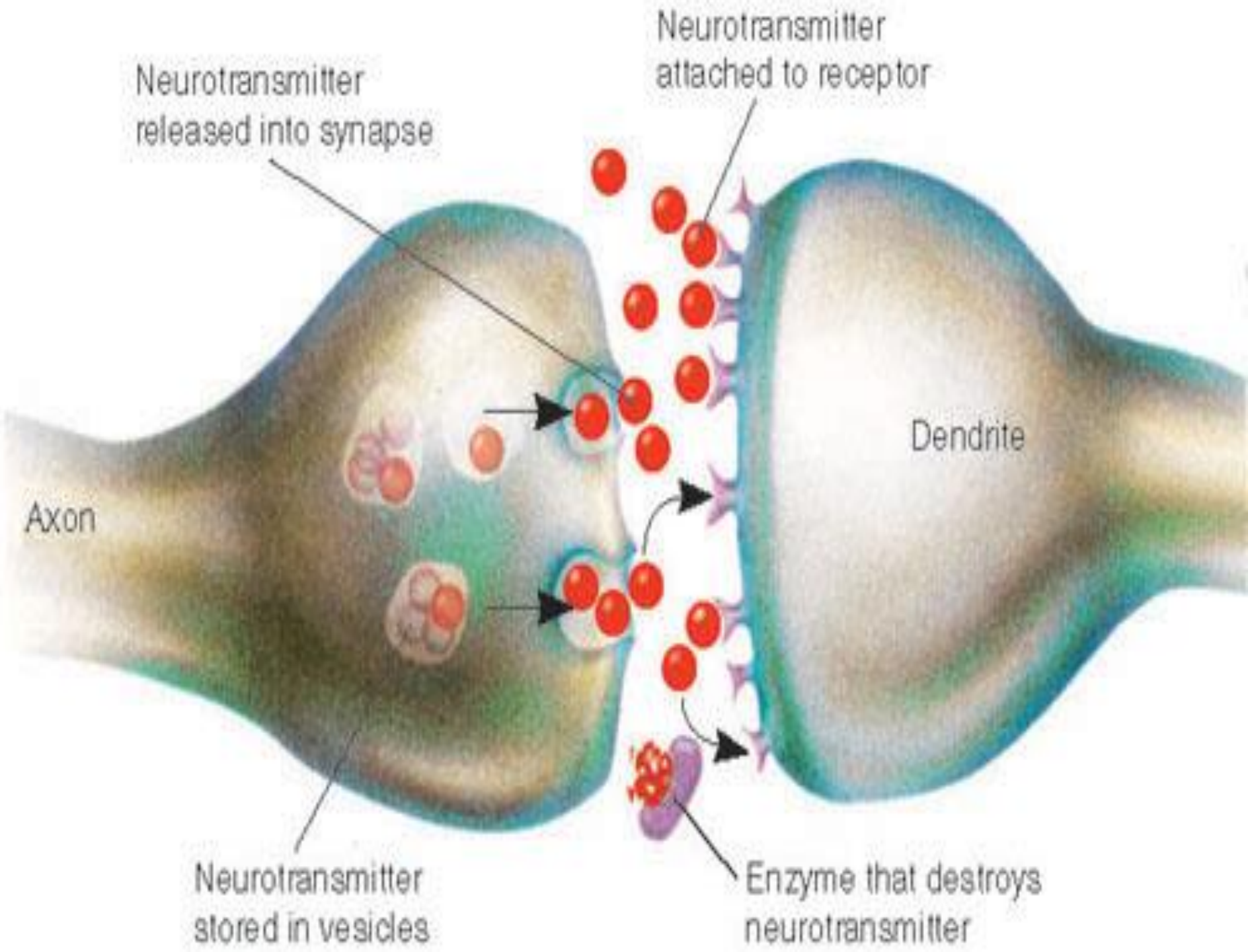


- Synaptic transmissions and Interaction between neurons:

A nerve impulse travels from dendrite or cell body along the axon to the presynaptic membrane at its end. The process by which impulse in the pre-synaptic membrane signals the postsynaptic neuron is called synaptic transmission. The nerve impulse is transmitted chemically by release of neurotransmitter from axon terminal button to bind its receptors on the postsynaptic membrane. The binding of neurotansmitter to its receptors is considered as a stimulus to the postsynaptic membrane leading to its depolarization. The neurotransmitter is released by exocytosis.

Convergence: one neuron or dendrite receives signals from many incoming fibres.
Divergence: many output fibres receive signals from one axon terminal.



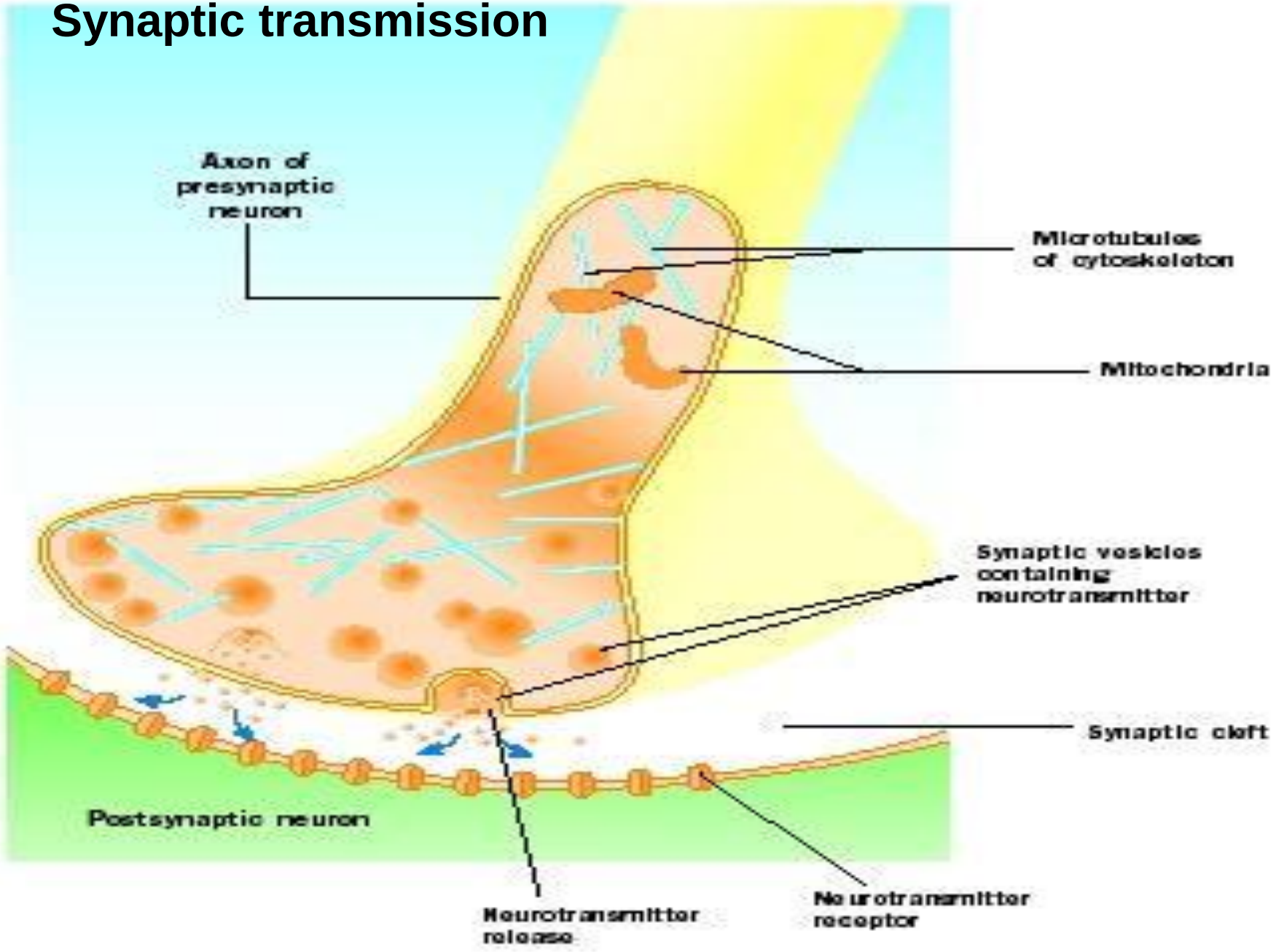

Neurotransmitter released into synapse
Neurotransmitter attached to receptor
Dendrite
Axon
Neurotransmitter stored in vesicles
Enzyme that destroys neurotransmitter

Neuromuscular Junction

It is the junction between axon terminals and the sarcolemma of mucle fibres. Also, a neurotransmitter mediates the transmission between pre and postsynaptic membranes.

End plate potential: depolarization and generation of action potential in the postsynaptic membrane at the neuromuscular junction, mediated by acetylcholine, in response to action potentials arriving at the endings of presynaptic motor neurons.

Synaptic transmission



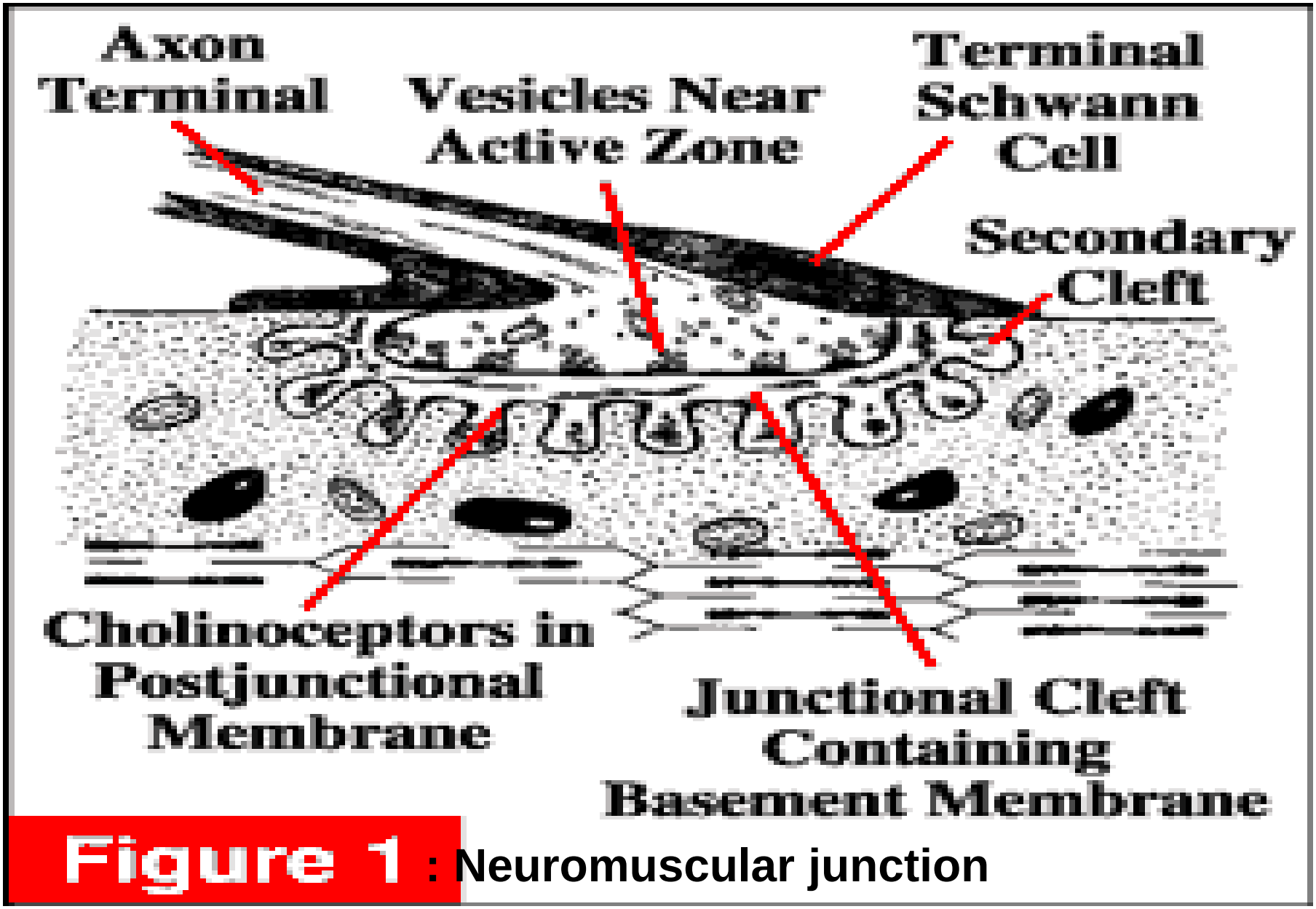


Figure 1 : Neuromuscular junction

Types of muscular tissue

The muscular tissue is classified into the following three types

1. Smooth muscle (involuntary, unstraited): it is found in blood vessels, alimentary canal etc.

2. Skeletal muscle (voluntary, striated): it is connected with the skeleton.

3. Cardiac muscle (involuntary and stiated): it is found in the heart.

Muscle fibres

- **Muscular** tissue is composed of many elongated cells called muscle fibres (or myoneme) which consist of many myofibrils. Each myofibril is composed of two types of proteinaceous myofilaments: actin (thin filament) and myosin (thick filament). –Under the electronic microscope, light and dark bands can be observed in every muscle fibre.

Organization of muscles

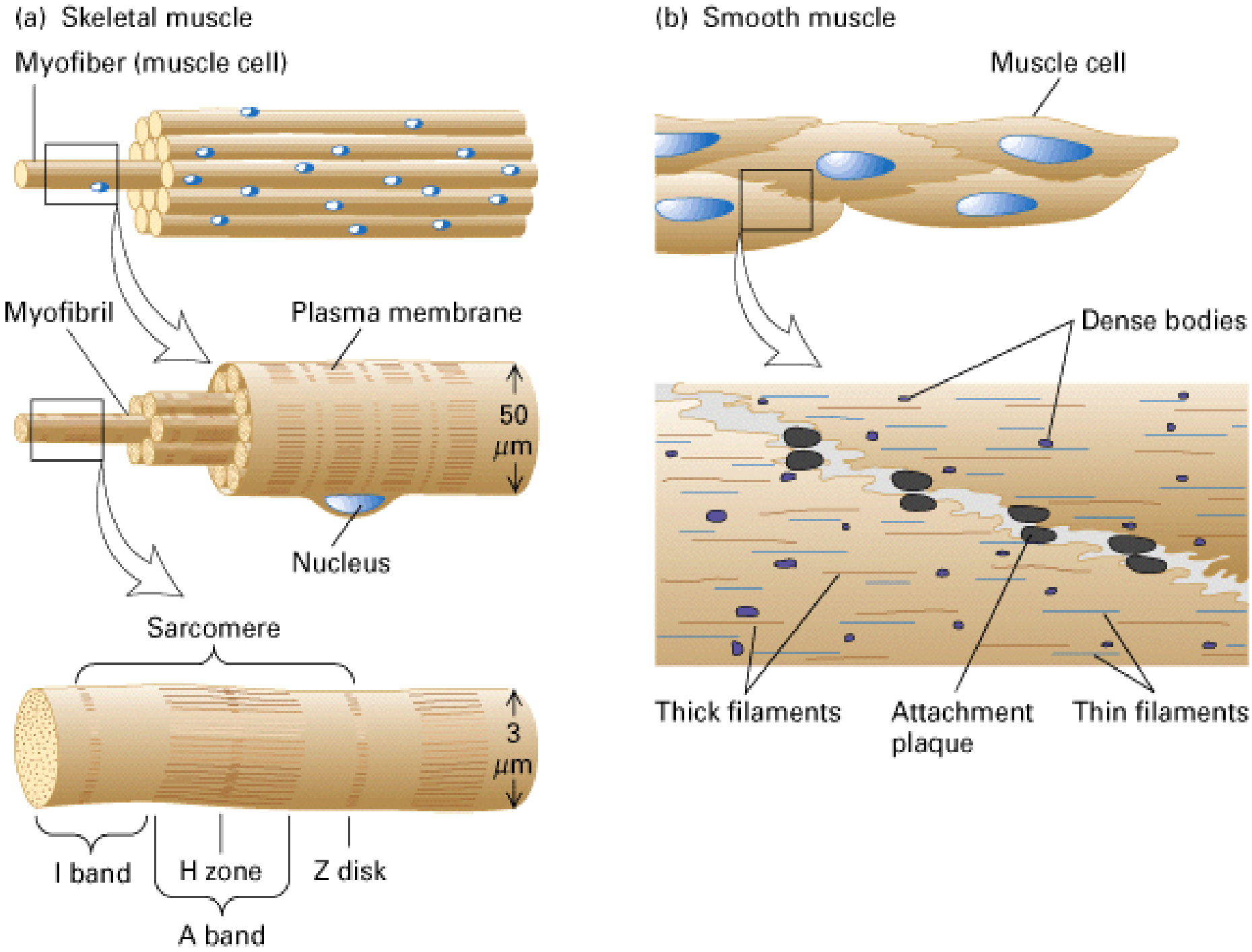
Muscle - muscle fibres – myofibrils – myofilaments which include thin and thick filaments.

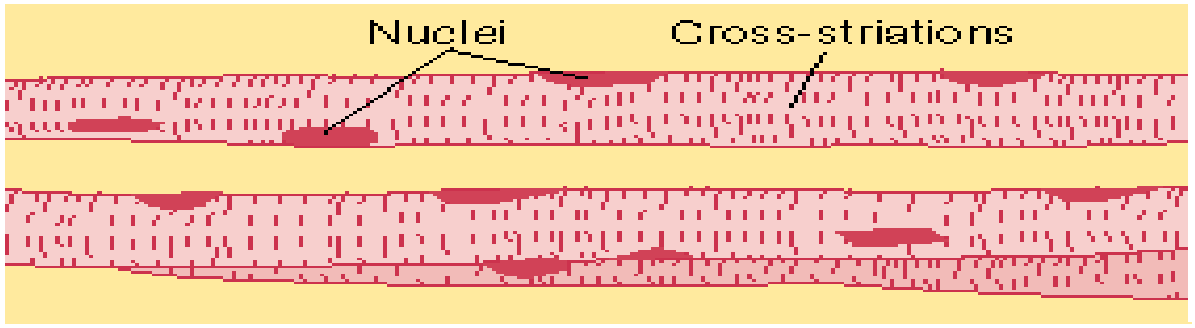
Thick filament consist of myosin

Thin filaments consists of actin, troponin (Tc, Tt and Ti) and tropomyosin.

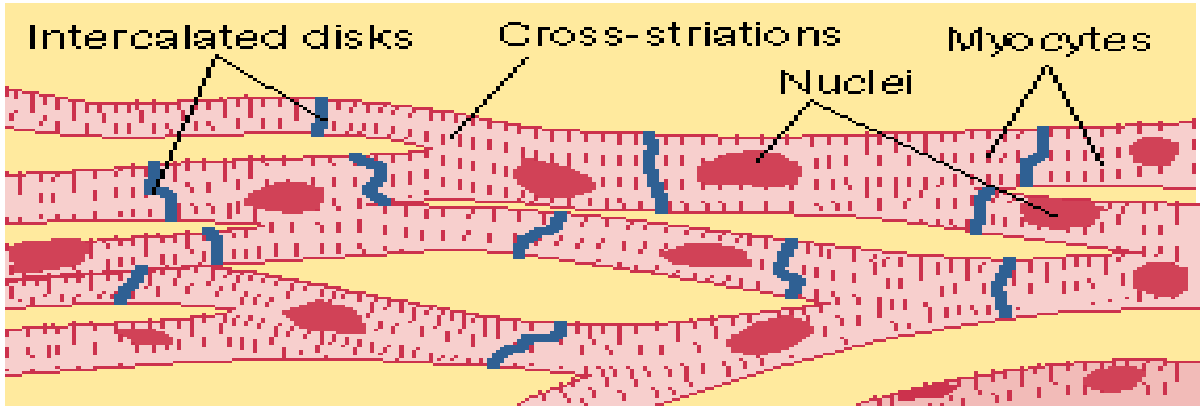
Skeletal muscle fibers

- Sarcolemma (cell membrane)
- Sarcoplasm (muscle cell cytoplasm)
- Sarcoplasmic reticulum (modified ER)
- T-tubules and myofibrils aid in contraction
- Sarcomeres – regular arrangement of myofibrils (area of muscle fibre between two z-lines)

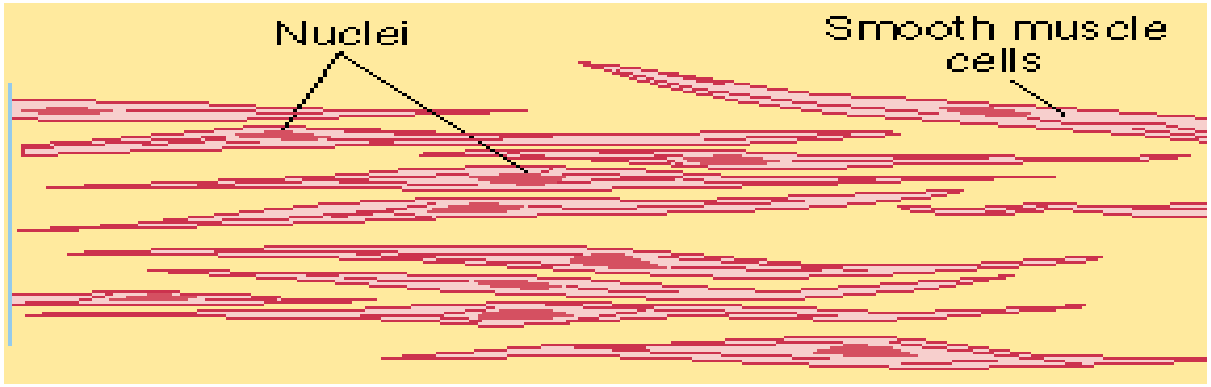

(a) Skeletal muscle
Myofiber (muscle cell)
Myofibril
Plasma membrane
50 μm
Nucleus
Sarcomere
3 μm
I band
H zone
Z disk
A band
(b) Smooth muscle
Muscle cell
Dense bodies
Thick filaments
Attachment plaque
Thin filaments



Skeletal muscle

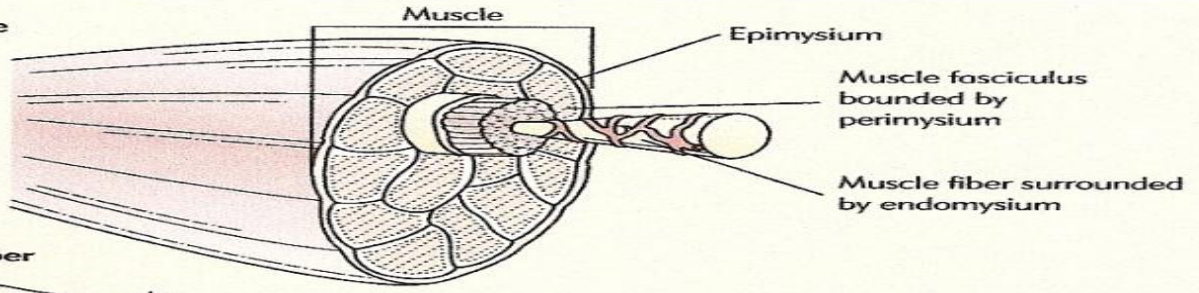


Cardiac muscle

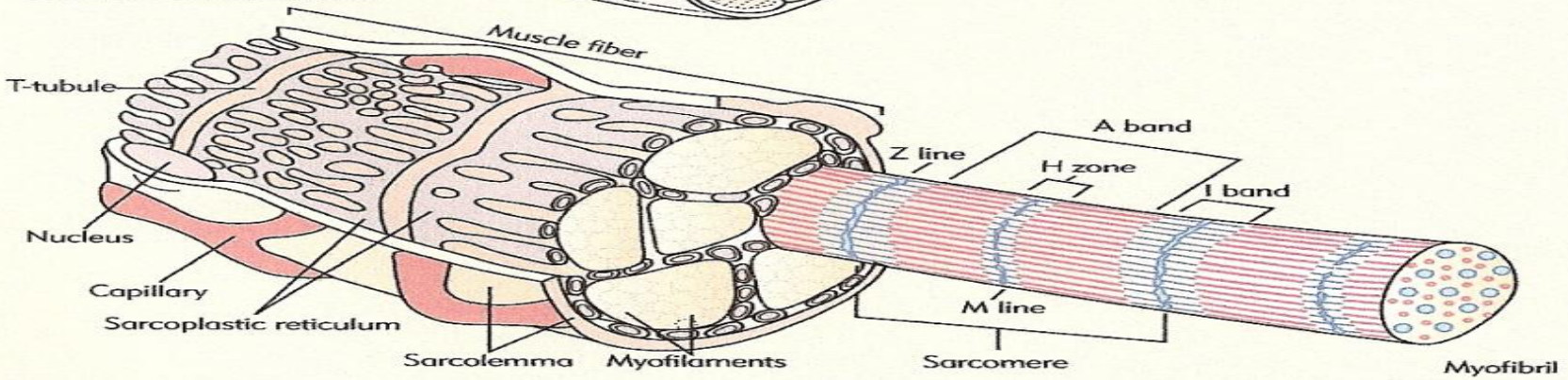


Smooth muscle

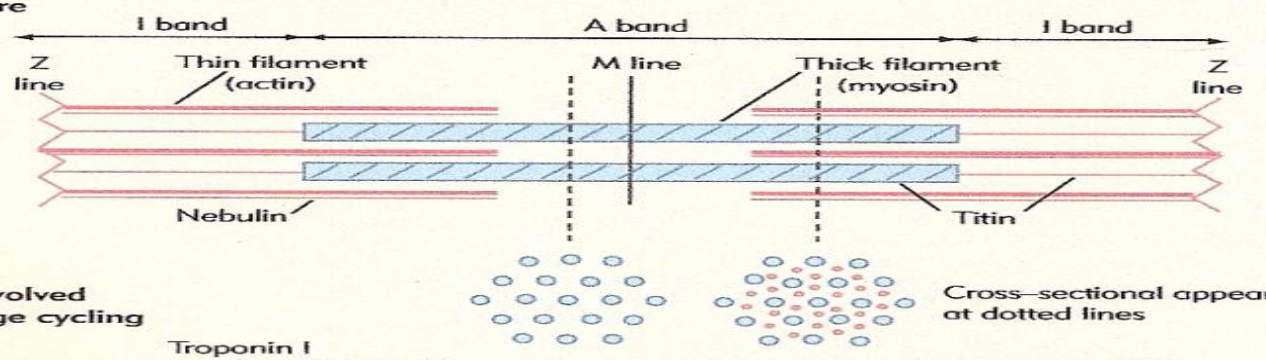
Gross muscle structure



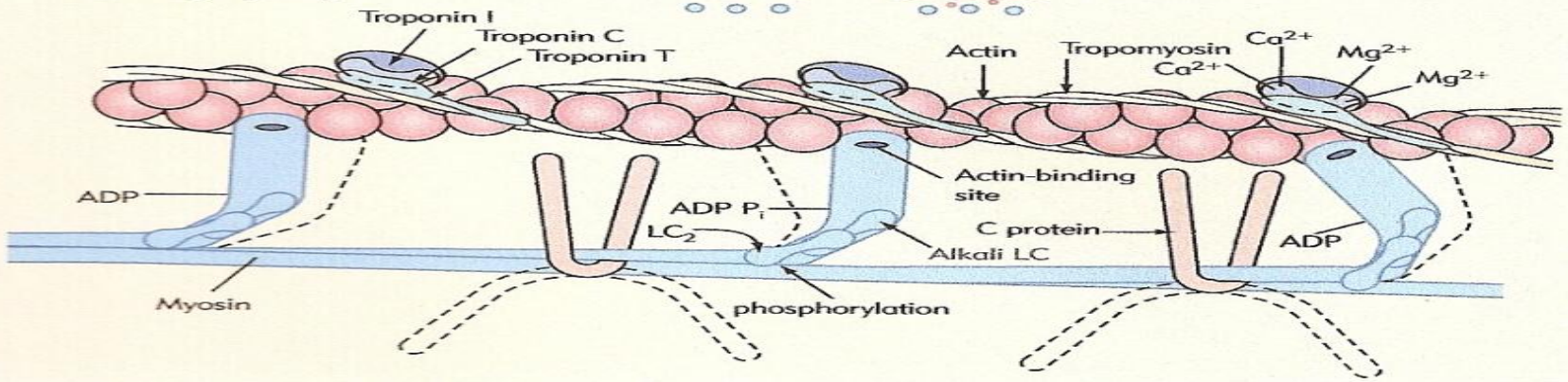
Structure of muscle fiber

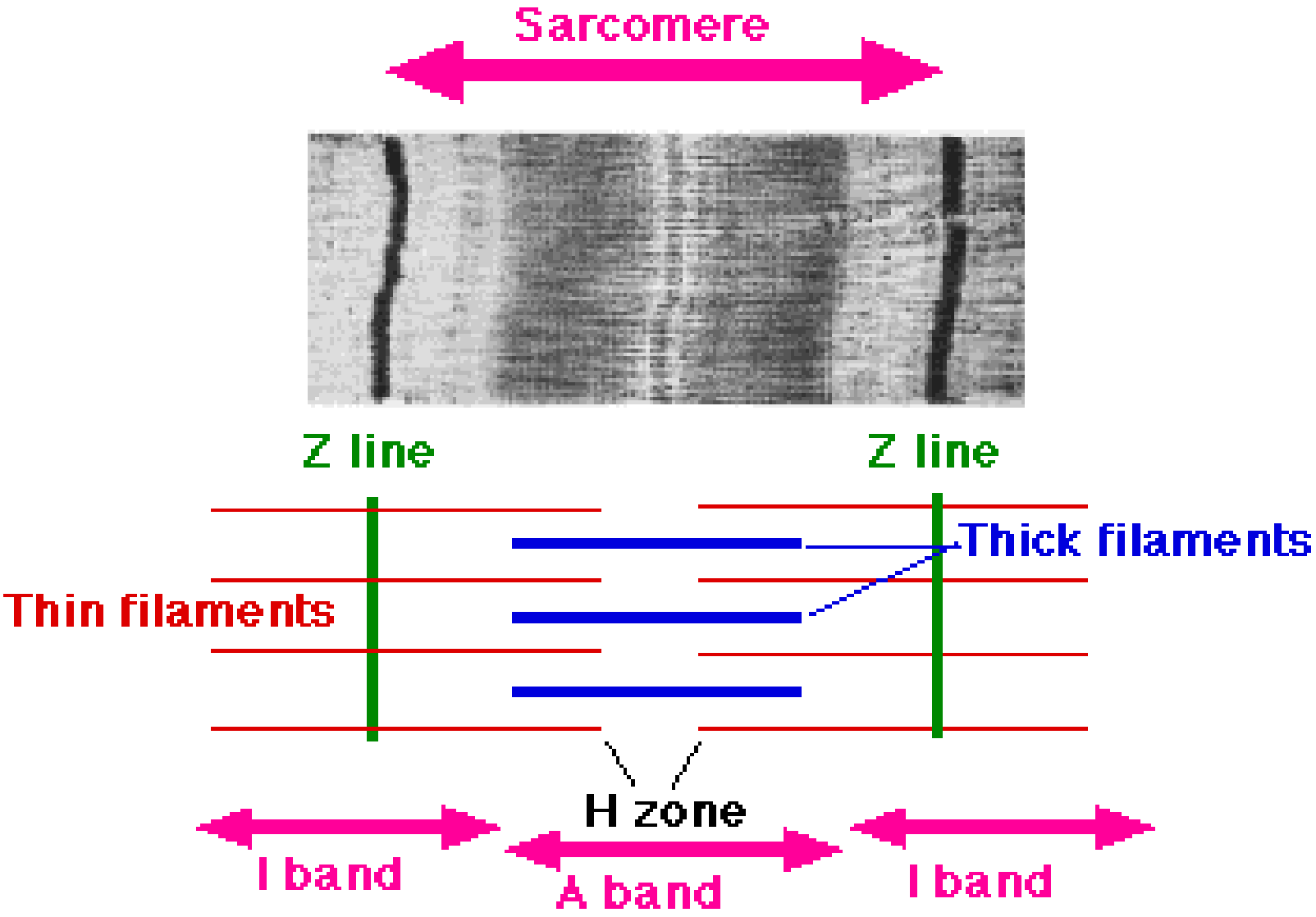


The sarcomere

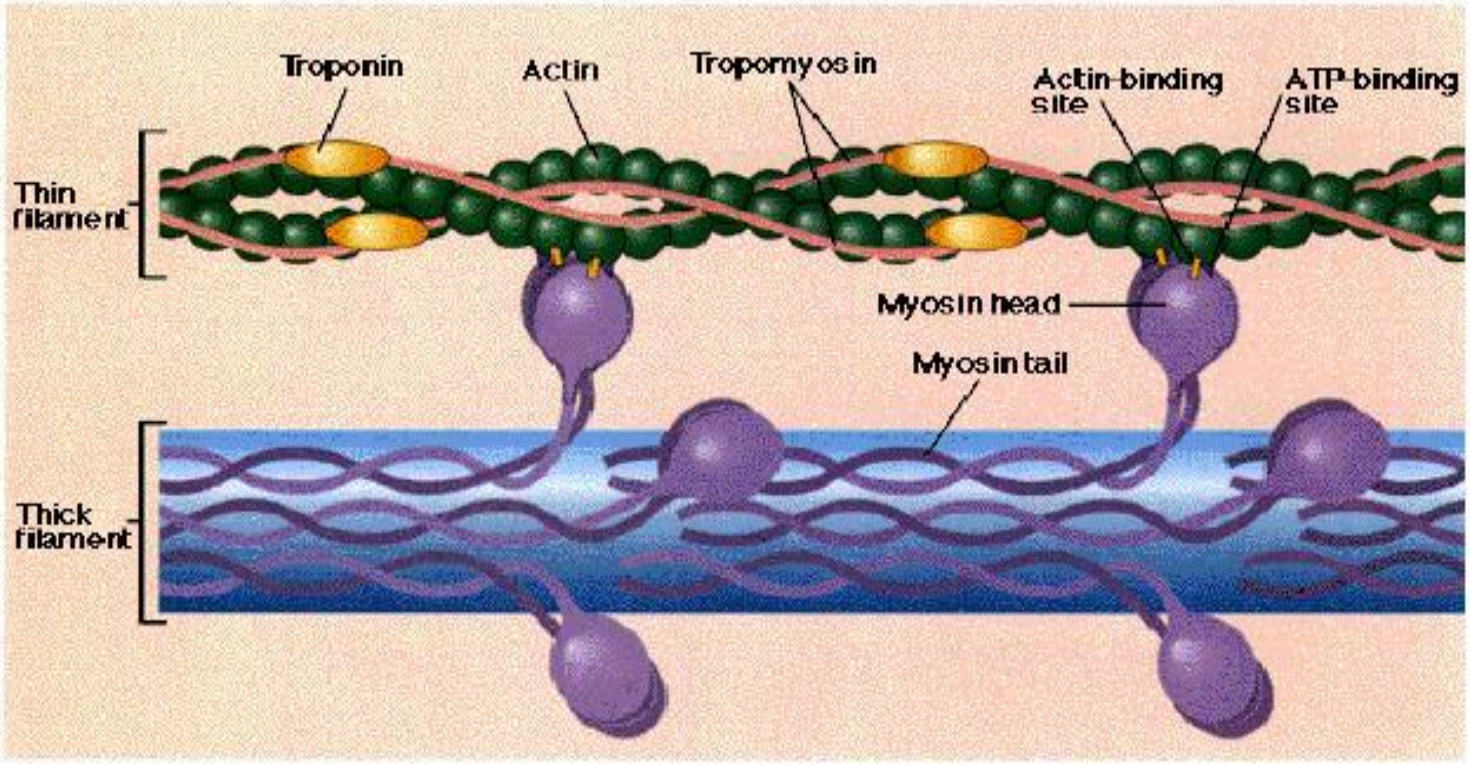


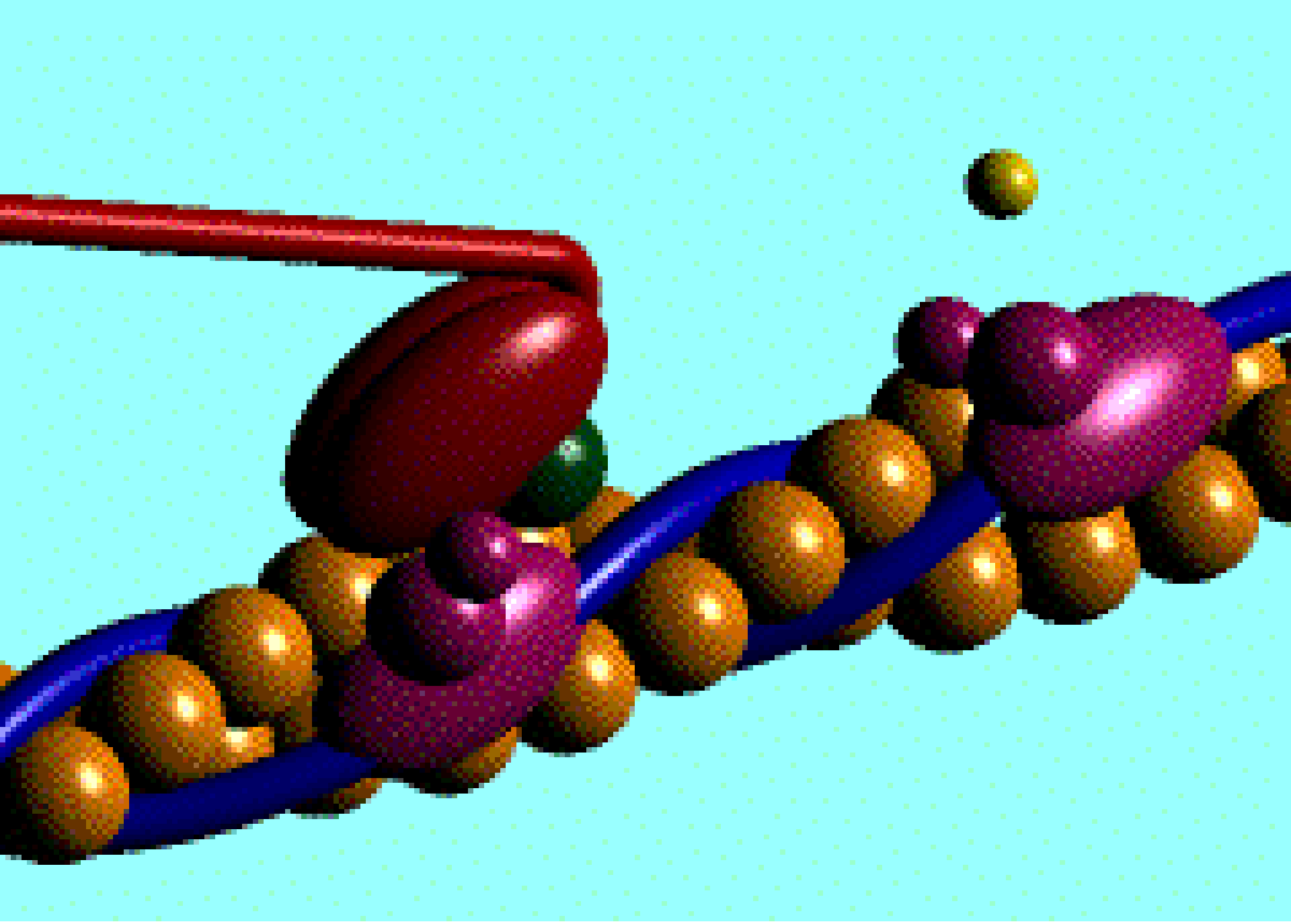
Structures involved in cross–bridge cycling




Sarcomere
Z line
Z line
Thick filaments
Thin filaments
H zone
I band
A band
I band

Myosin & the Thick Filament



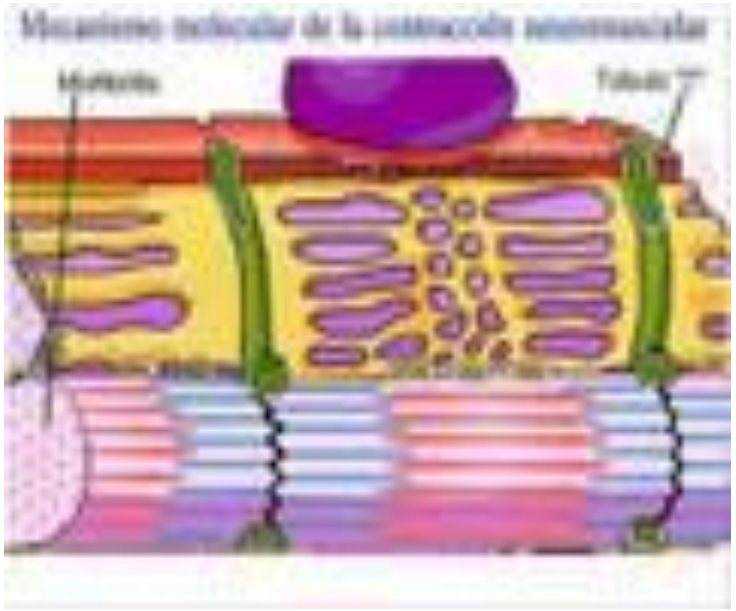


Mechanism of muscle contraction

The following steps take place in sequence:

1) Nerve impulse is chemically transmitted to sarcolemma by neurotransmitter.
2) Sarcolemma is depolarized
3) Action potential spreads out and reaches the sarcoplasmic reticulum through T system (T tubule).
4) Impulse stimulates the release of Ca^{2+} from sarcoplasmic reticulum to sarcoplasm.
5) Ca^{2+} binds to troponin.
6) Displacement of tropomyosin and exposing mysion head binding site on actin.
7) ATP-ase is activated in myosin heads to hydrolyze ATP and produce energy.
8) Binding of myosin heads with their binding site on actin.
9) Hydrolysis of ATP in association with formation of cross bridge provides power stroke to pull the actin filaments towards Z line.
9) Sliding of actin on myosin **(Sliding filament theory)**
10) Length of sarcomeres is shortened and resulted in muscle contraction.
11) Ca^{2+} is actively pumped back to SR and myosin heads bind to another ATP.
12) Cross-bridge is broken and actins and myosins return to orignial conformation as in resting state.

Mechanism of muscle contraction- Animations



Action potential animation

http://www.youtube.com/watch?v=m79HiApDJ2I&feature=related