Electrical Properties of Cell

Resting Membrane Potential, Action Potential, Signal propagation

Lecture from the Medical Physiology

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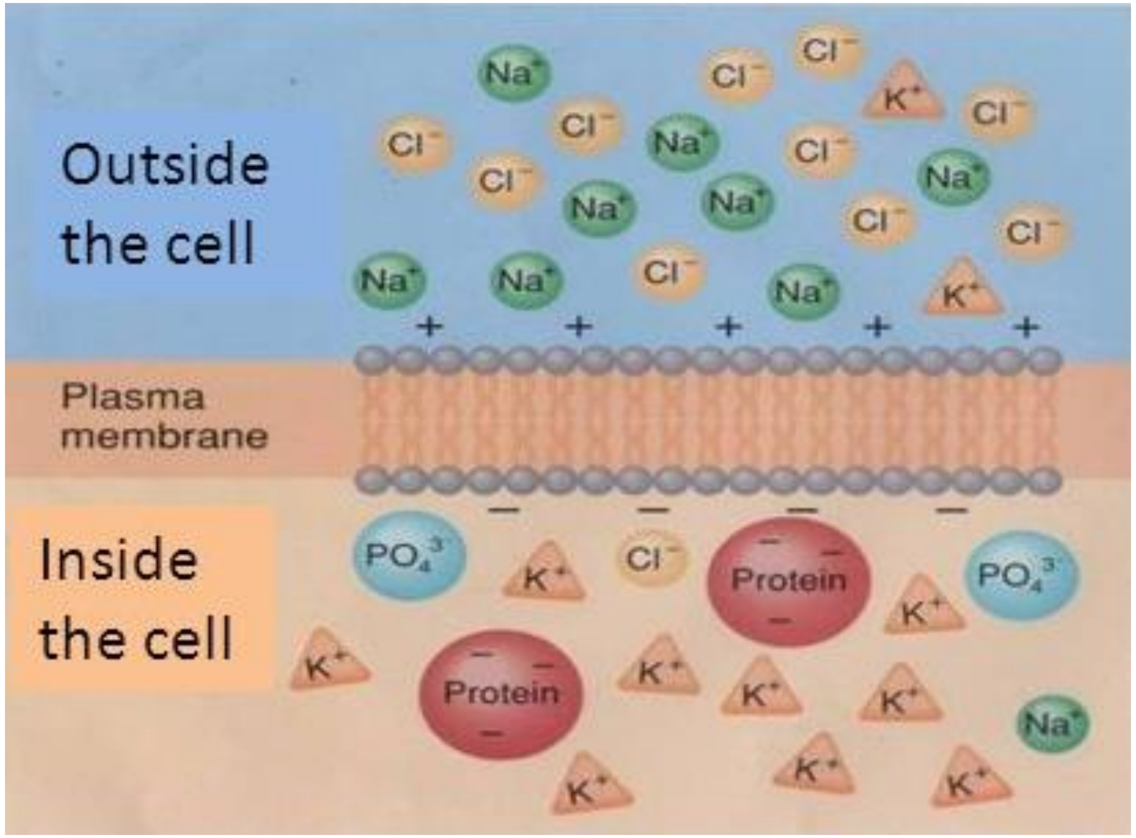
Resting membrane potential

Na^+- K^+ pump
Extrudes 3 Na^+ ions
Brings 2 K^+ ions in

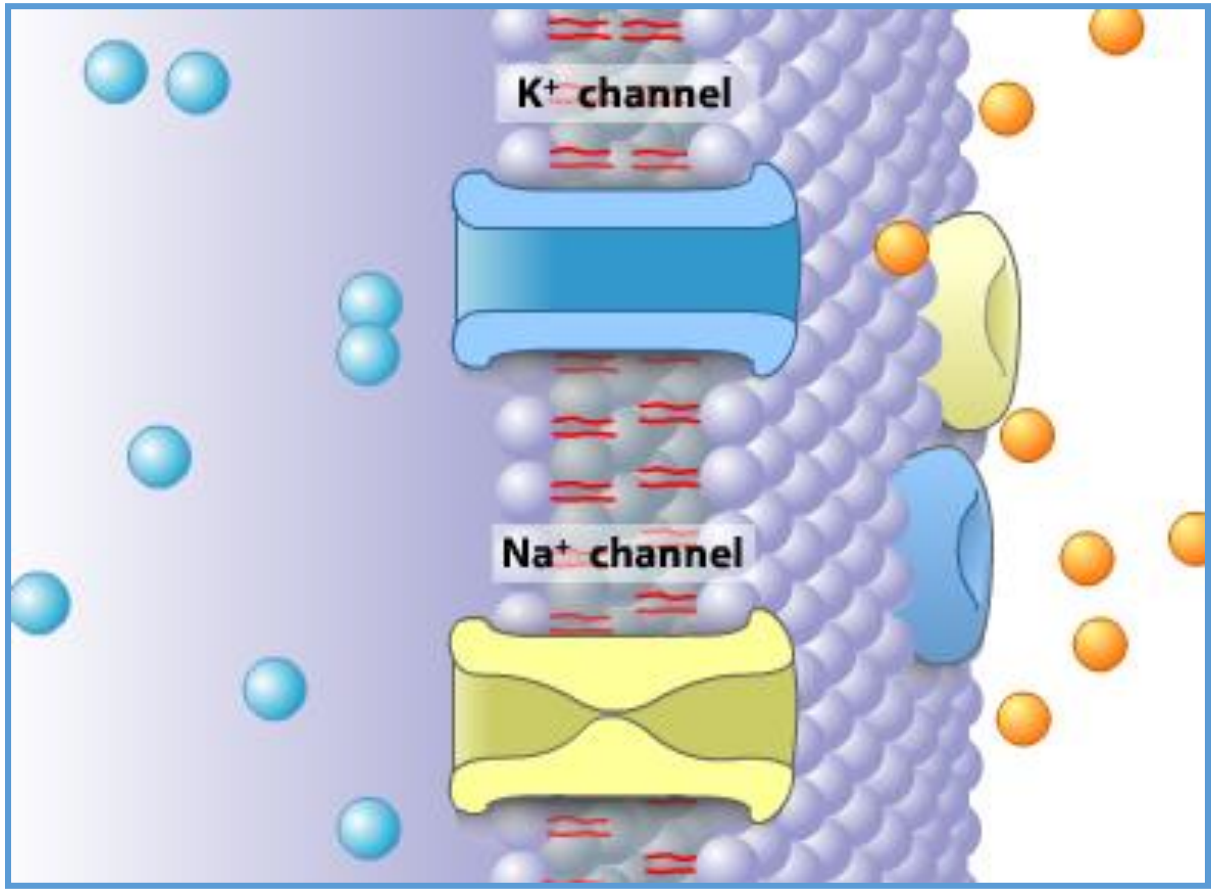
Unequal distribution of ions
Na^+ and Cl^- extracelullary
K^+ and A^- intracelullary

Intracellular concentration [mmol/l]		Extracellular concentrace [mmol/l]	
Na^+	12	Na^+	145
K^+	155	K^+	4
Ca^{2+}	0,0002	Ca^{2+}	2
Cl^-	4	Cl^-	120
HCO_3^-	8	HCO_3^-	27
proteins (A^-)	155	proteins (A^-)	0



The equilibrium membrane potential for K^+

Model 1: Membrane is permeable for K^+ only



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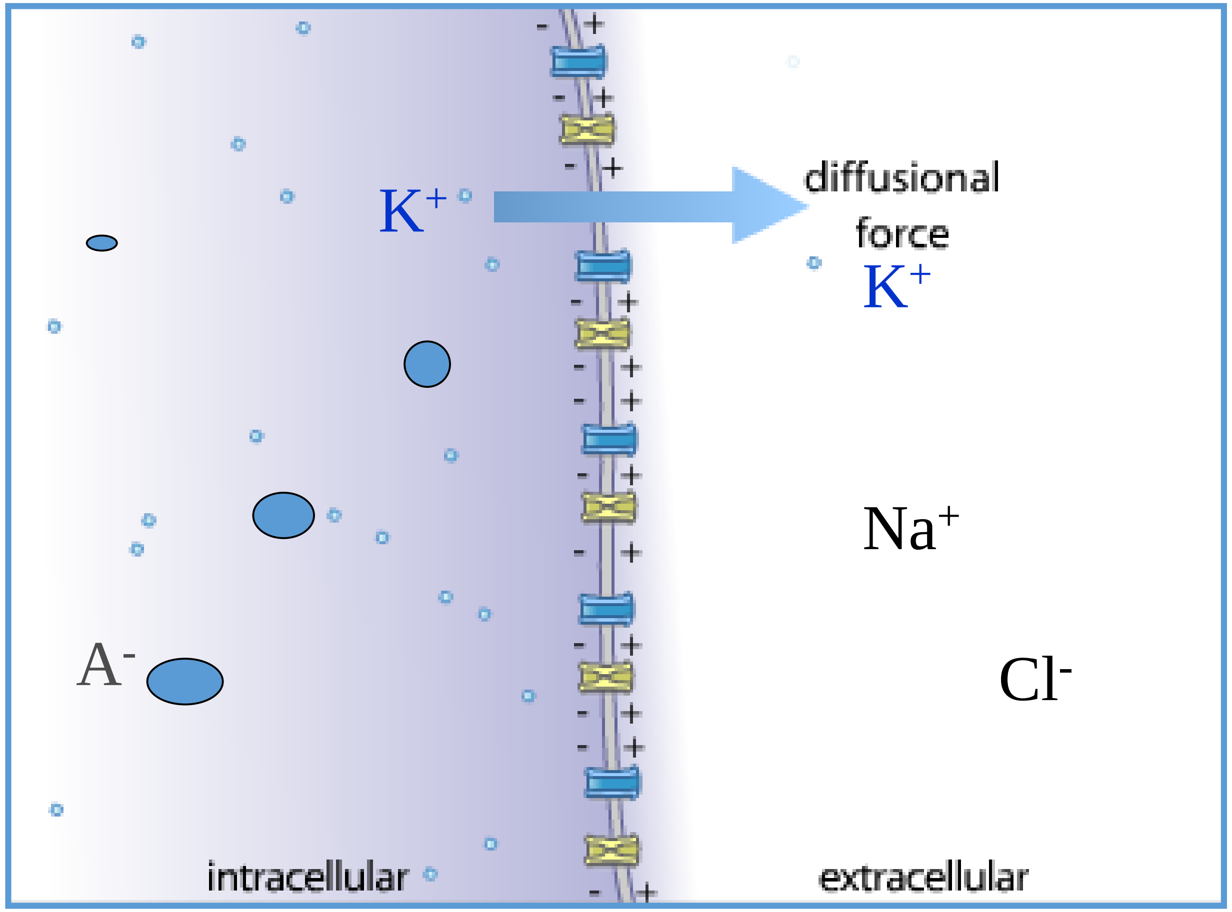


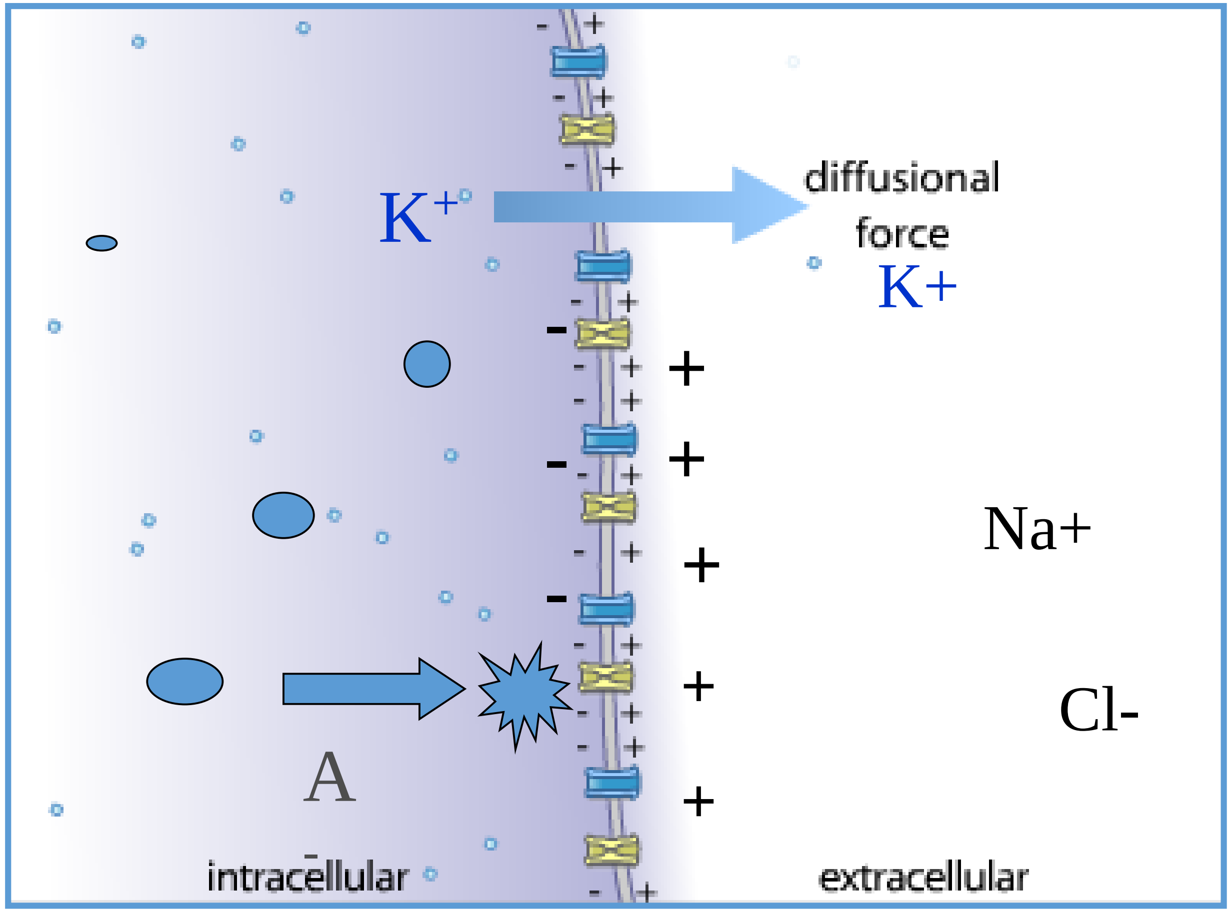
Chemical driving force

Diffusion

- Outward movement of K+

The equilibrium membrane potential for K^+

Model 1: Membrane is permeable for K^+ only



K^+ escapes out of the cell along concetration gradient

A^- cannot leave the cell

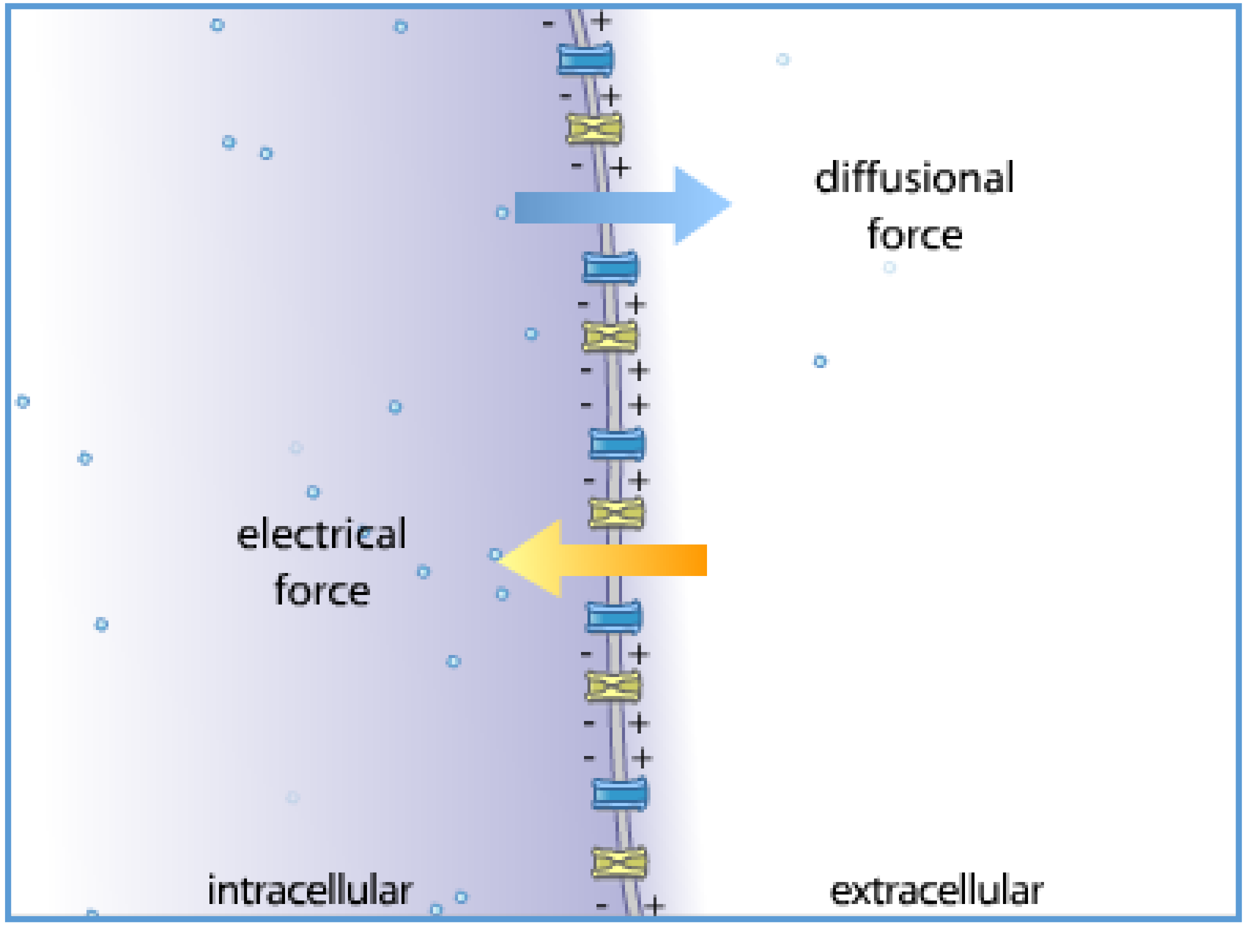
Greater number of positive charges is on the outer side of the membrane

On the inner more negative charges

electrical driving force emerges,

The equilibrium membrane potential for K^+

Model 1: Membrane is permeable for K^+ only



Electrical Gradient

Inward movement of K^+

The equilibrium membrane potential for K^+

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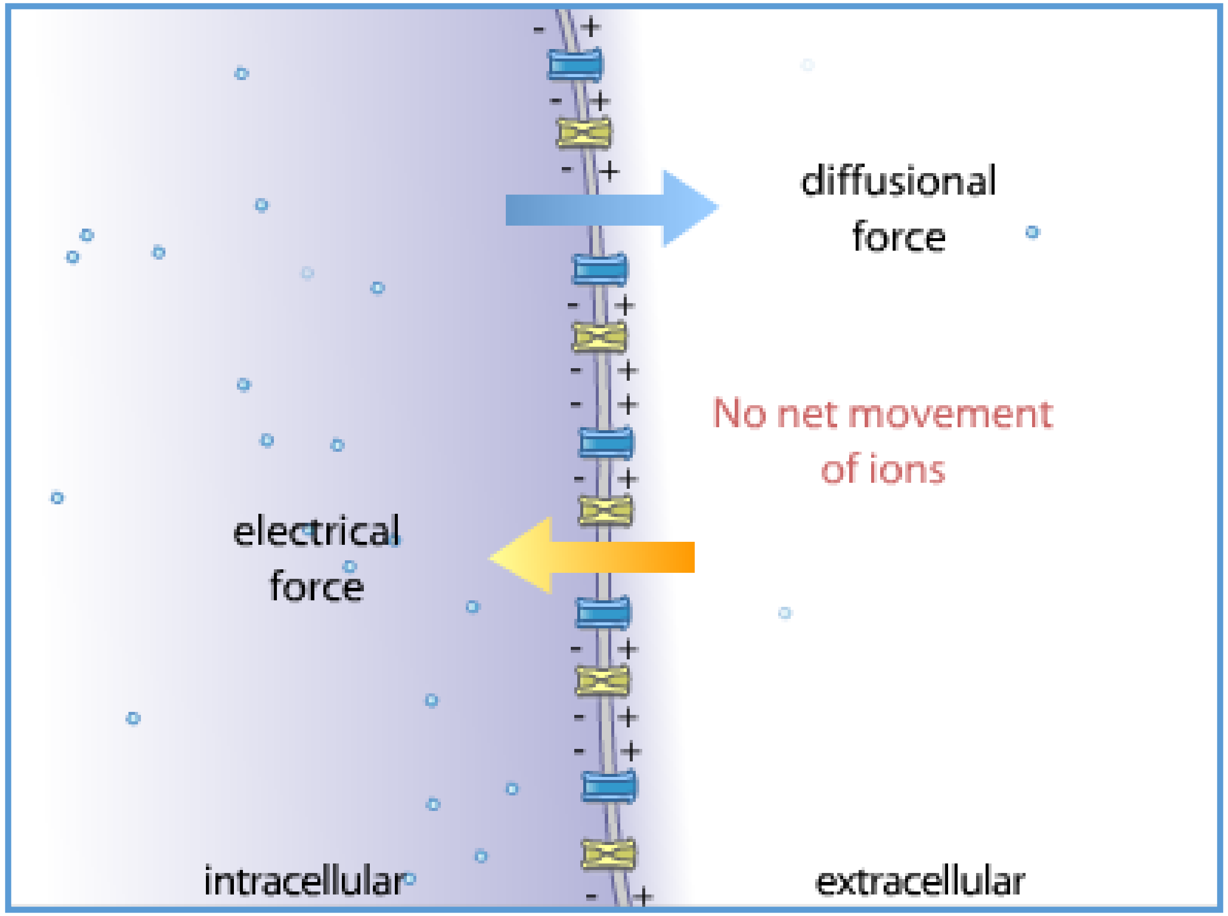


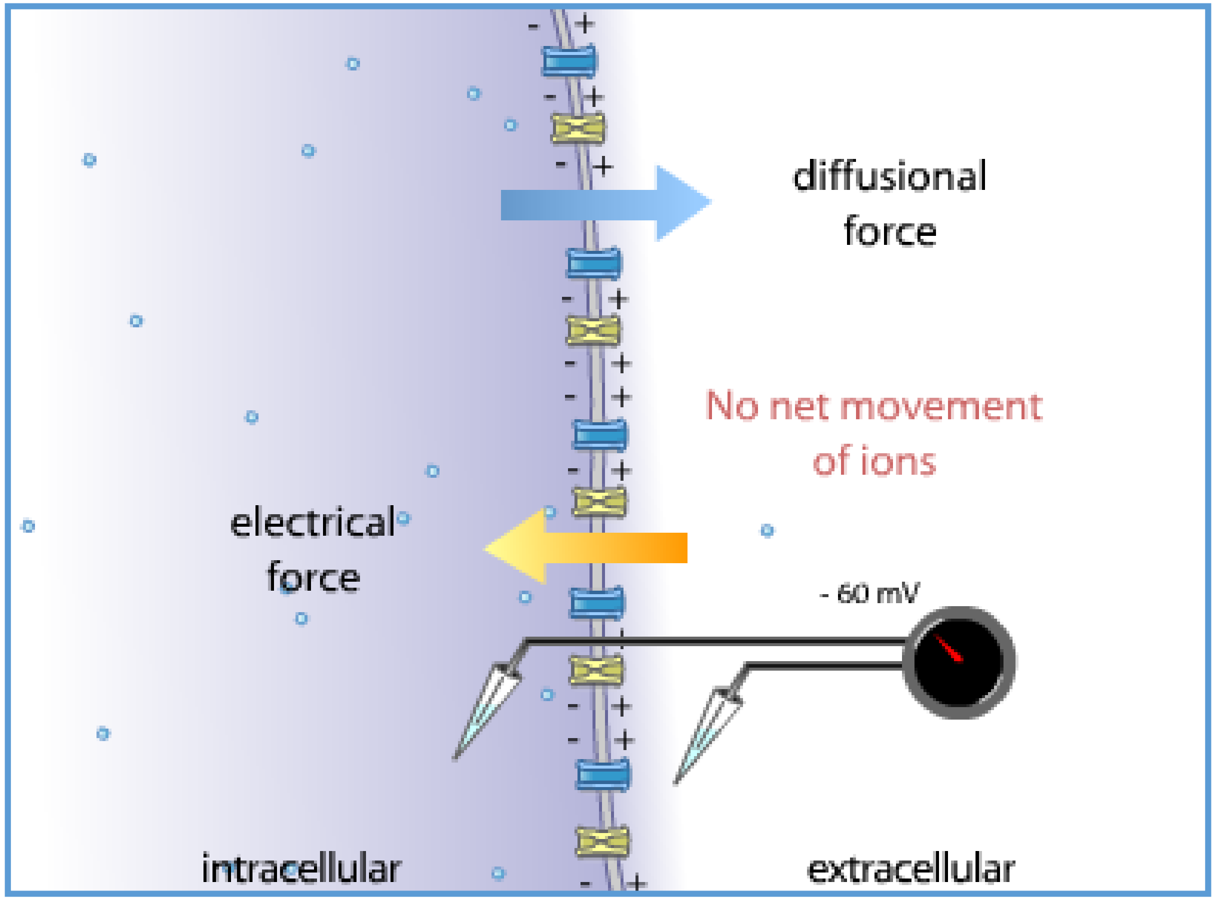
Chemical gradient equals electrical gradient

No net movement of ions

Steady state is balanced

The equilibrium membrane potential for K^+

Model 1: Membrane is permeable for K^+ only

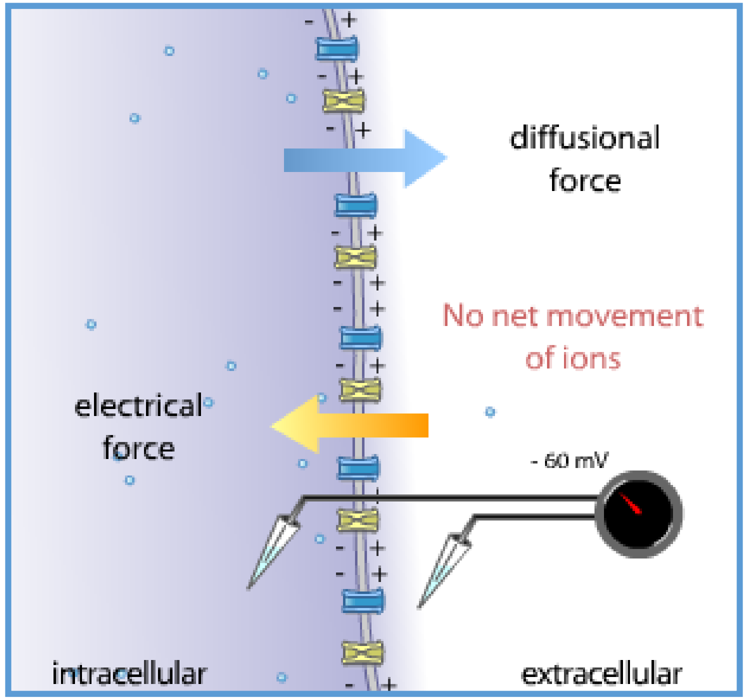


Negative membrane potential

Equilibrium membrane potential for potassium is negative

The equilibrium membrane potential for K^+

How to calculate the magnitude of the membrane potential



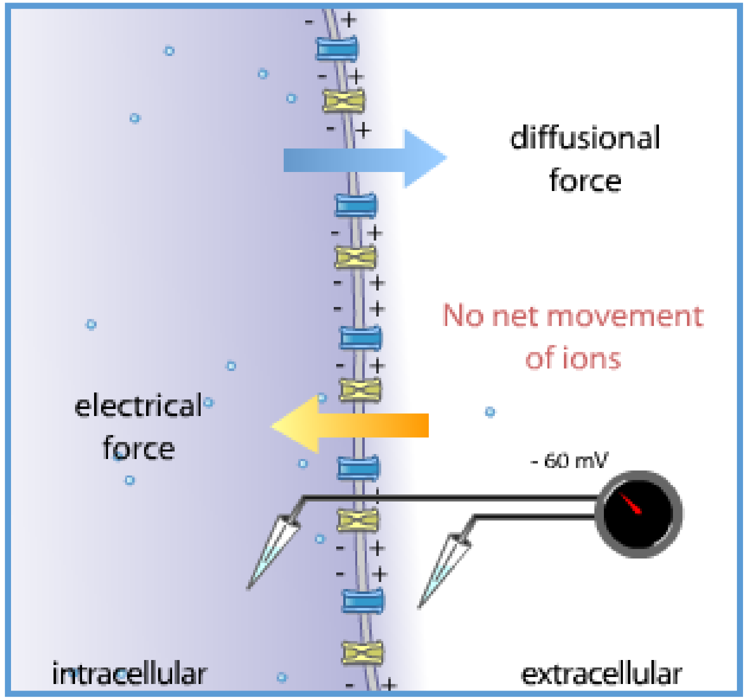
Osmotic work
The work, which must be done to move 1 mol of the substance from concentration C_e to concentration C_i
A_o= R.T.ln $[C_e]/[C_i]$

Electric work
The work, which must be done to move 1 mol of the substance across the potential difference E
A_e = E. n. F

R – universal gas constant
T – absolute temperature
Ce , Ci – ion concentration
E – potential difference
n – charge of ion
F – Faraday's constant

The equilibrium membrane potential for K^+

How to calculate the magnitude of the membrane potential



When the system is in balance then osmotic work equals electric work

$A_o = A_e$

$R.T.\ln [C_e]/[C_i] = E.\ n.\ F$

E =

Nernst equation

$E = RT/nF\ .\ \ln [C_e]/[C_i]$

(natural logarithm)

R – universal gas constant
T – absolute temperature
Ce , Ci – ion concentration
E – potential difference
n – charge of ion
F – Faraday's constant

The equilibrium membrane potential for K^+

How to calculate the magnitude of the membrane potential

Nernst equation

$E = -62/n \cdot \log [C_i] / [C_e]$

(decimal logarithm)

The equilibrium membrane potential for K^+

Count if $K^+e = 4$ mM/l

$K^+i = 155$ mM/l

-98 mV

Resting membrane potential

Real cell

Membrane permeability

K^+	**:**	**Na^+**	**:**	**Cl^-**
1	**:**	**0,03**	**:**	**0,1**

Resting membrane potential

Real cell

Real cell membrane permeability

Resting membrane potential

Goldmanova equation

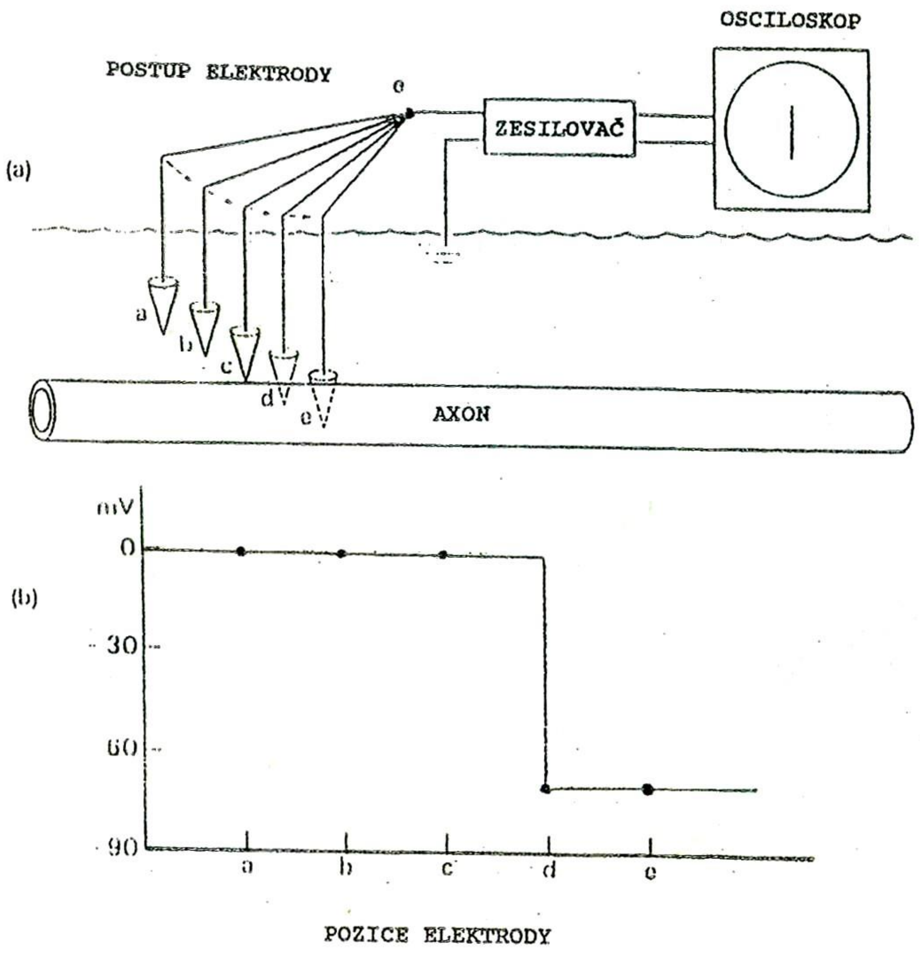
K^+	:	Na^+	:	Cl^-
1	:	**0,03**	:	**0,1**

$$V = \frac{RT}{F} \ln \frac{P_{K^+}[K_o^+] + P_{Na^+}[Na_o^+] + P_{Cl^-}[Cl_i^-]}{P_{K^+}[K_i^+] + P_{Na^+}[Na_i^+] + P_{Cl^-}[Cl_o^-]}$$

Resting membrane potential

Every living cell

in the organism



Resting membrane potential

Membrane potential is not a potential. It is a difference of two potentials so it is a voltage, in fact.

The equilibrium membrane potential for other ions

Nernst equation

$E = -62/n \cdot \log [C_i] / [C_e]$

Intracellular concentration [mmol/l]		Extracellular concentrace [mmol/l]	
Na^+	12	Na^+	145
K^+	155	K^+	4
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proteins (A^-)	155	proteins (A^-)	0

The equilibrium membrane potential for other ions

The equilibrium membrane potential for Na^+

For Ca^{2+}

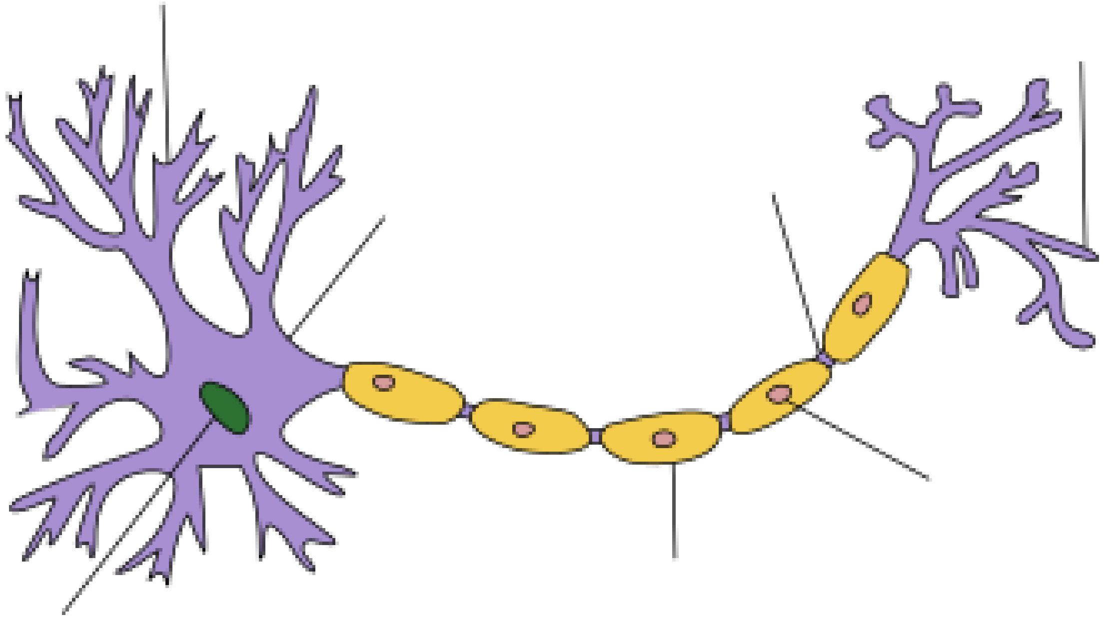
For Cl^-

https://create.kahoot.it/

Log in – e mail: ustav.fyziologie@gmail.com

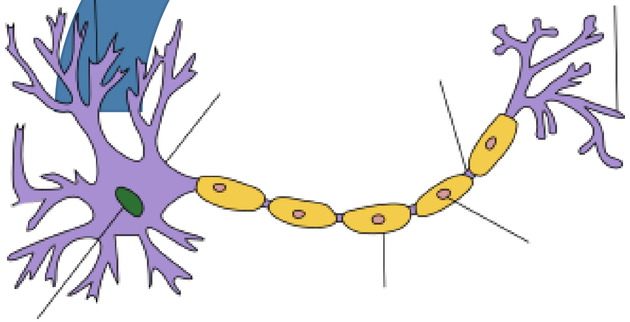
Signal propagation

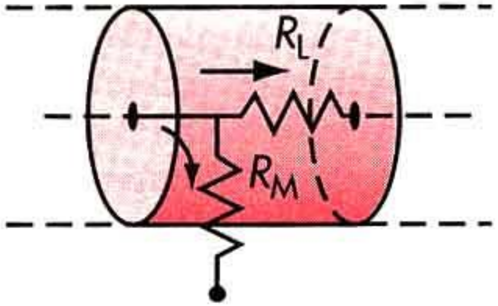
Neuron

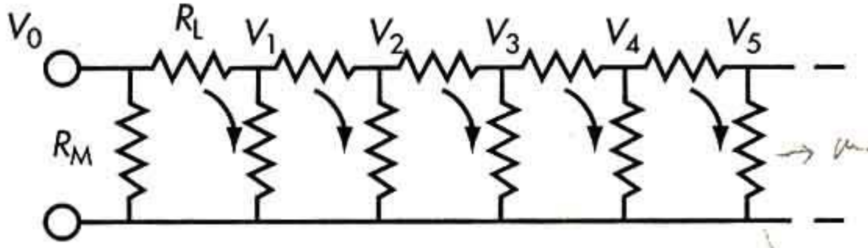


Signal propagation

Dendrites and Neuron Soma







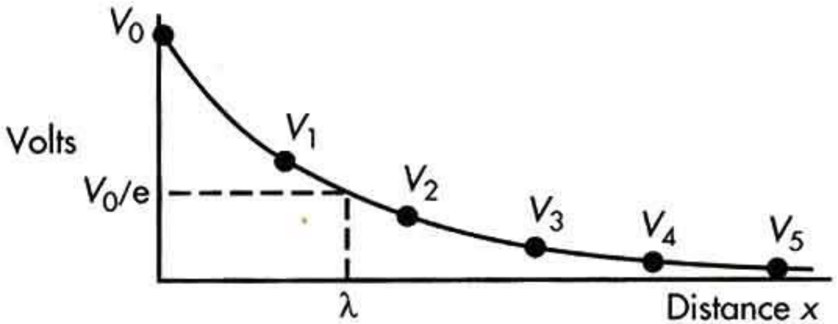
Passive spread of electrical current
along the axon
Electrotonic propagation

Equivalent electrical circuit

R_M transverse or membrane resistance

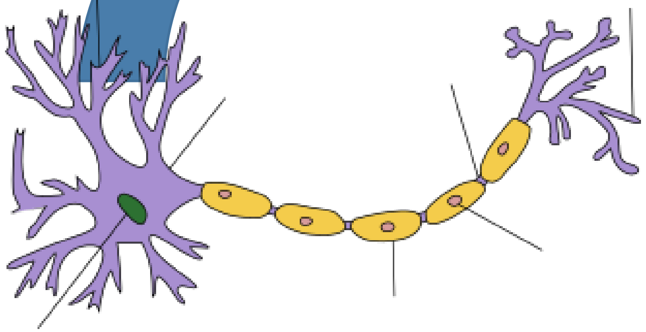
R_L longitudinal resistence (axoplasm)

ECF resistance is negligible.



Signal propagation

Dendrites and Neuron Soma

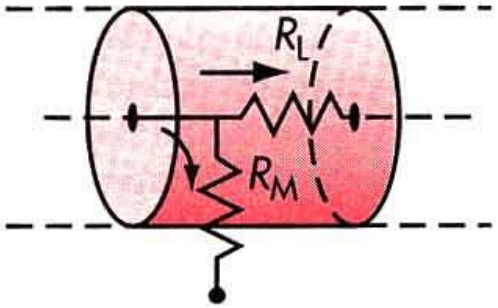


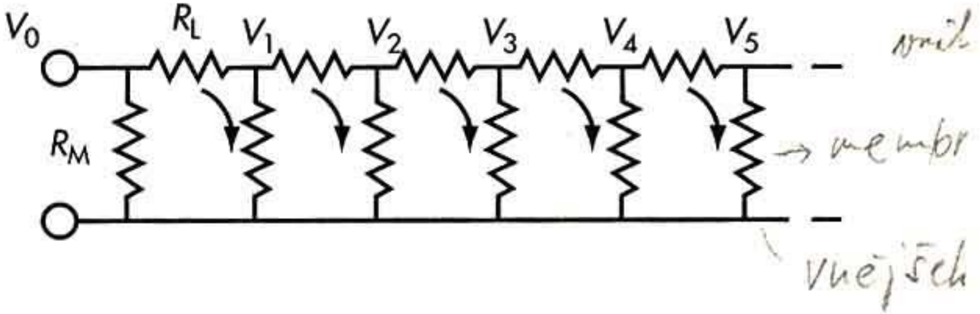
Space constant γ

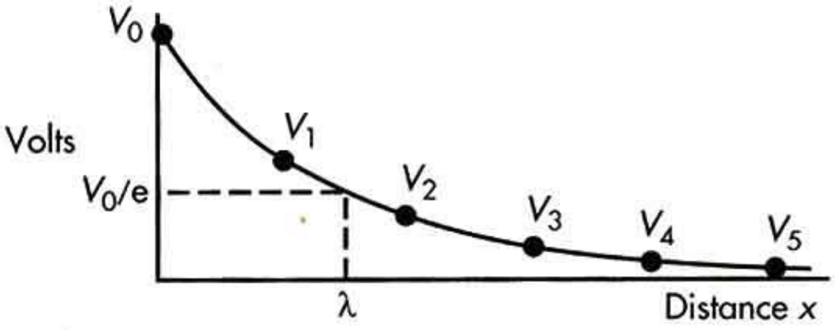
Potential seen at each compartment will fall in a fixed ratio (at a rate that will dependent on the ratio R_M / R_L)

Exponential decline in voltage

γ = the distance you have to go before voltage V_0 has dropped to 37% of its original value.





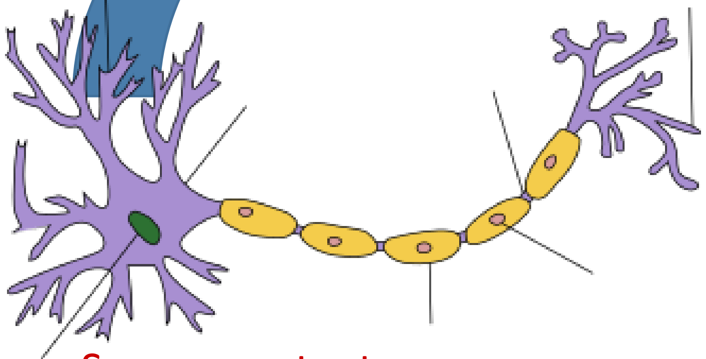


$\gamma = \sqrt{(R_M / R_L)}$

(square root of the ratio)

Signal propagation

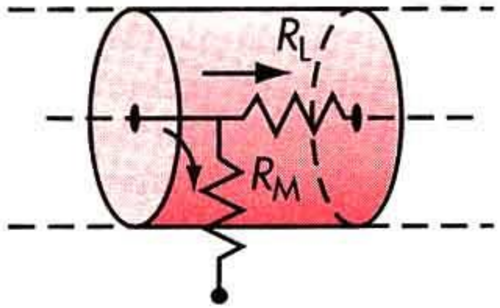
Dendrites and Neuron Soma

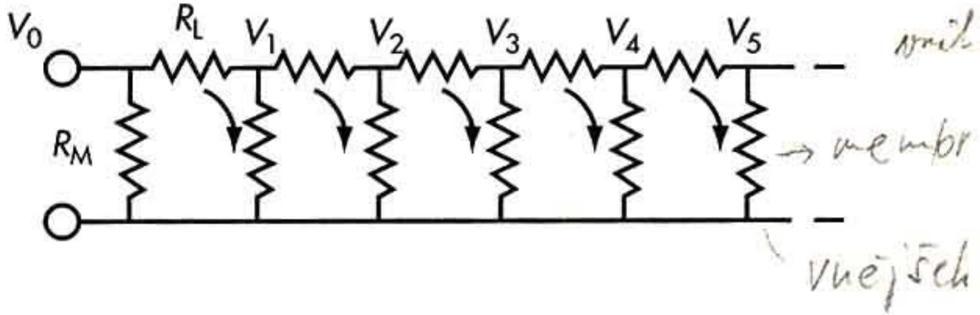


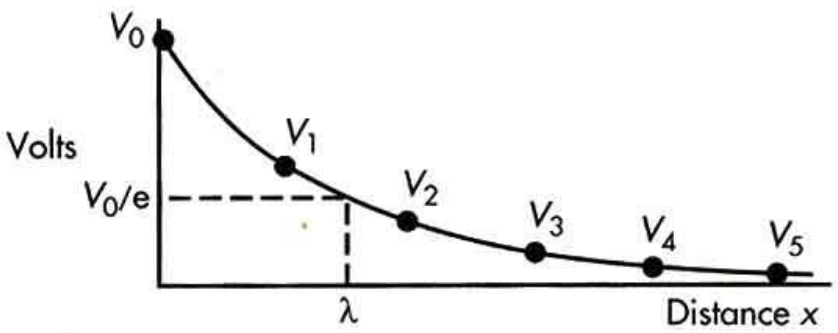
Space constant γ

= cca 1 mm

How to ensure long distance signal propagation?!?





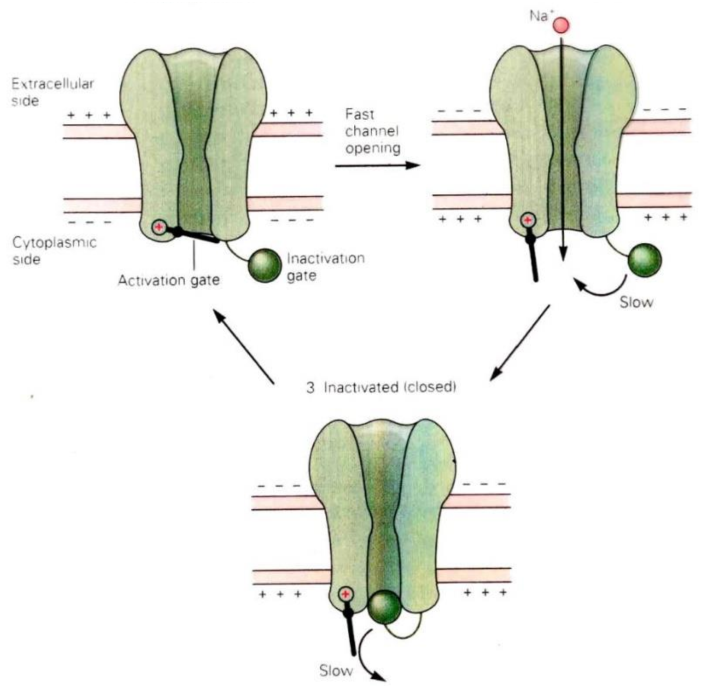


Action potential

voltage dependent sodium channel

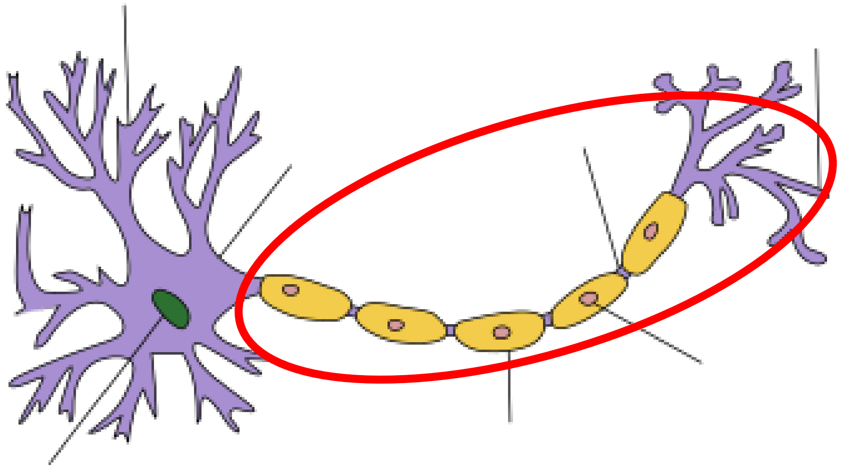
Closed but available

Activated (open)

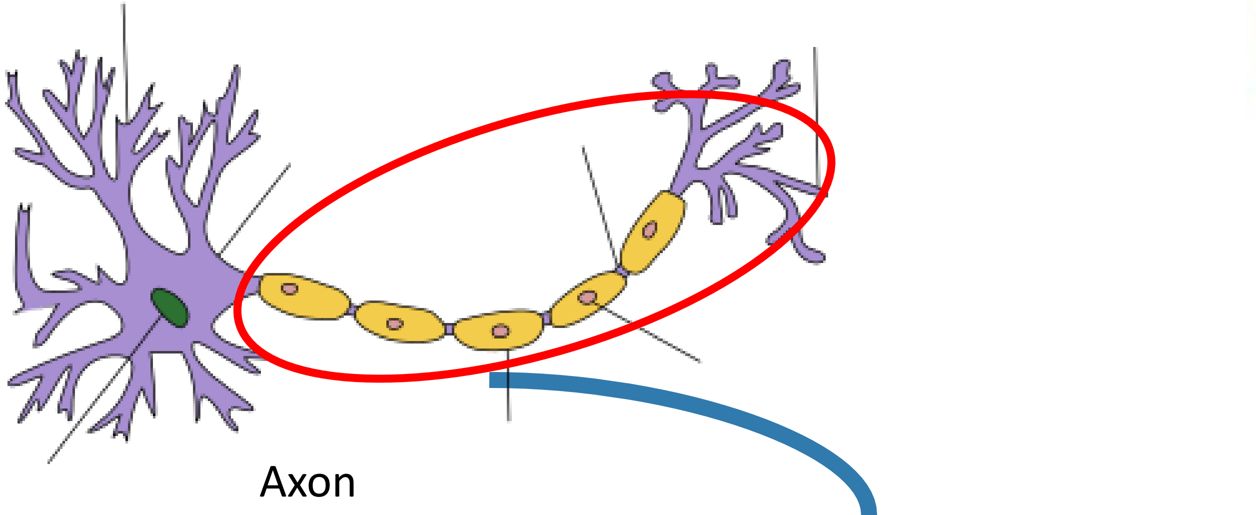


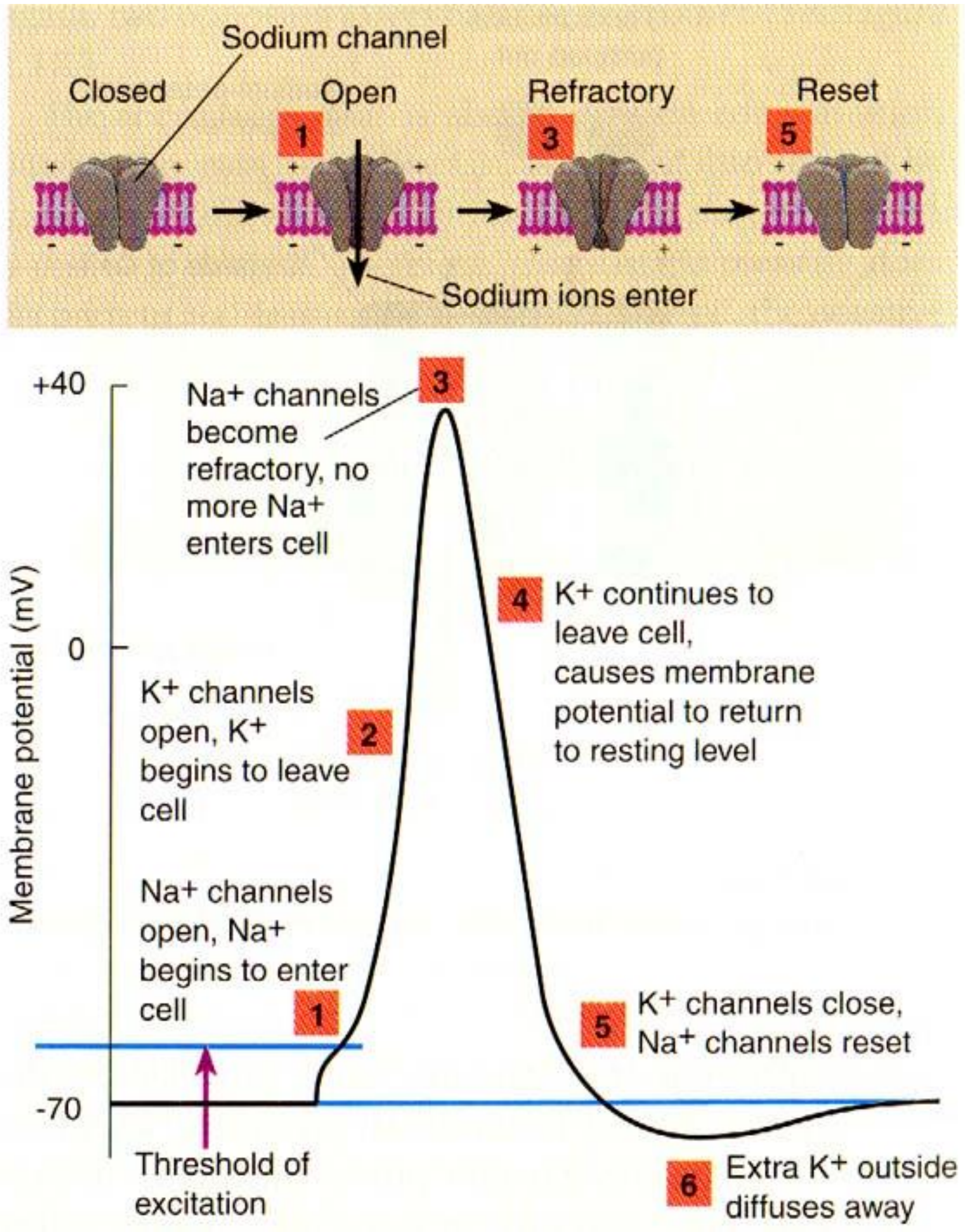
Inactivated

Conductive Membranes:
Axon of neurons
Skeletal muscle fibre
Smooth muscle cell
Heart muscle



Action potential





Action potential

Membrane permeability

K^+	**:**	**Na^+**	**:**	**Cl^-**
1	**:**	**15**	**:**	**0.1**

Action potential

Changes in membrane potential

Depolarization

Repolarization

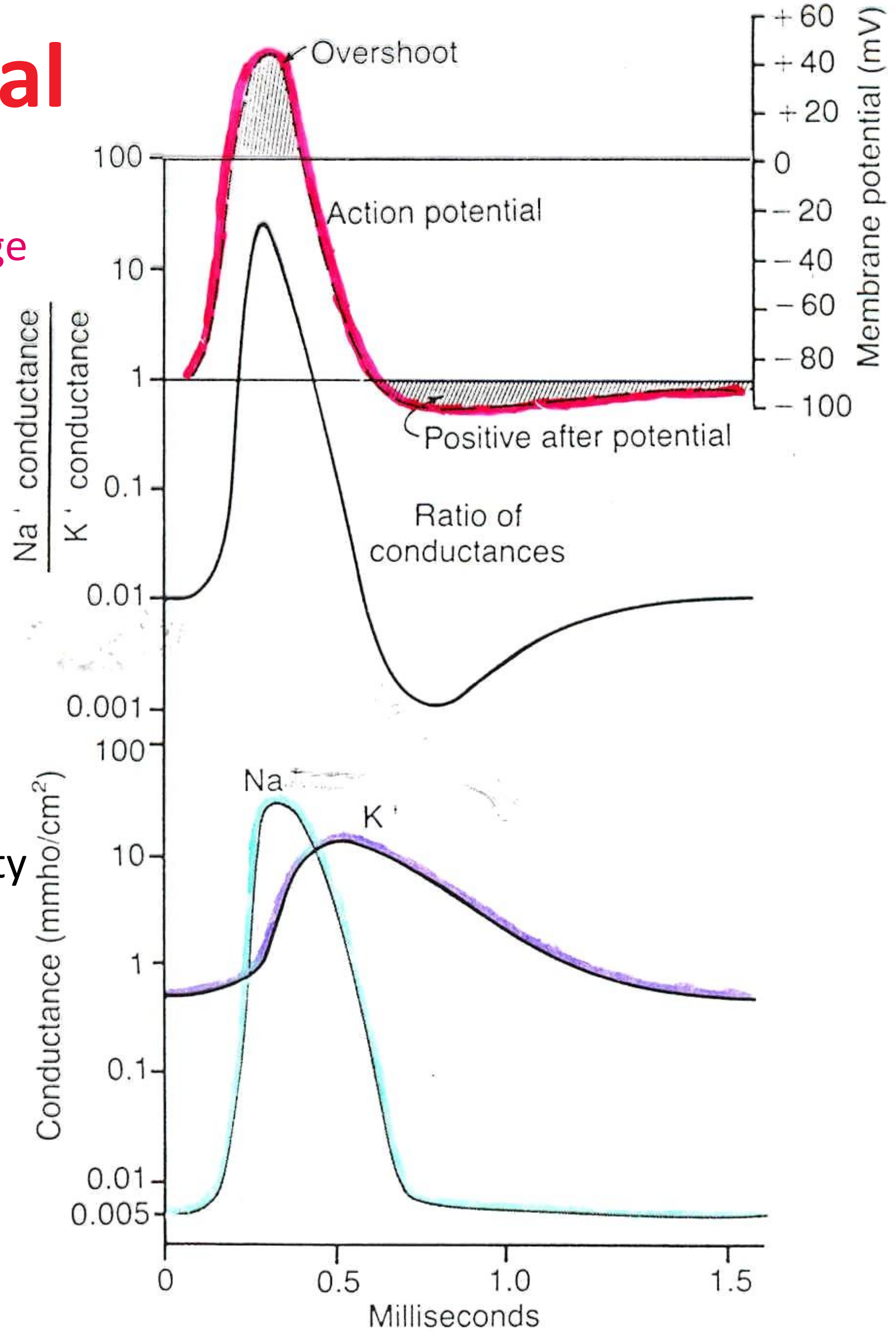
Hyperpolarization

Votage

Permeability

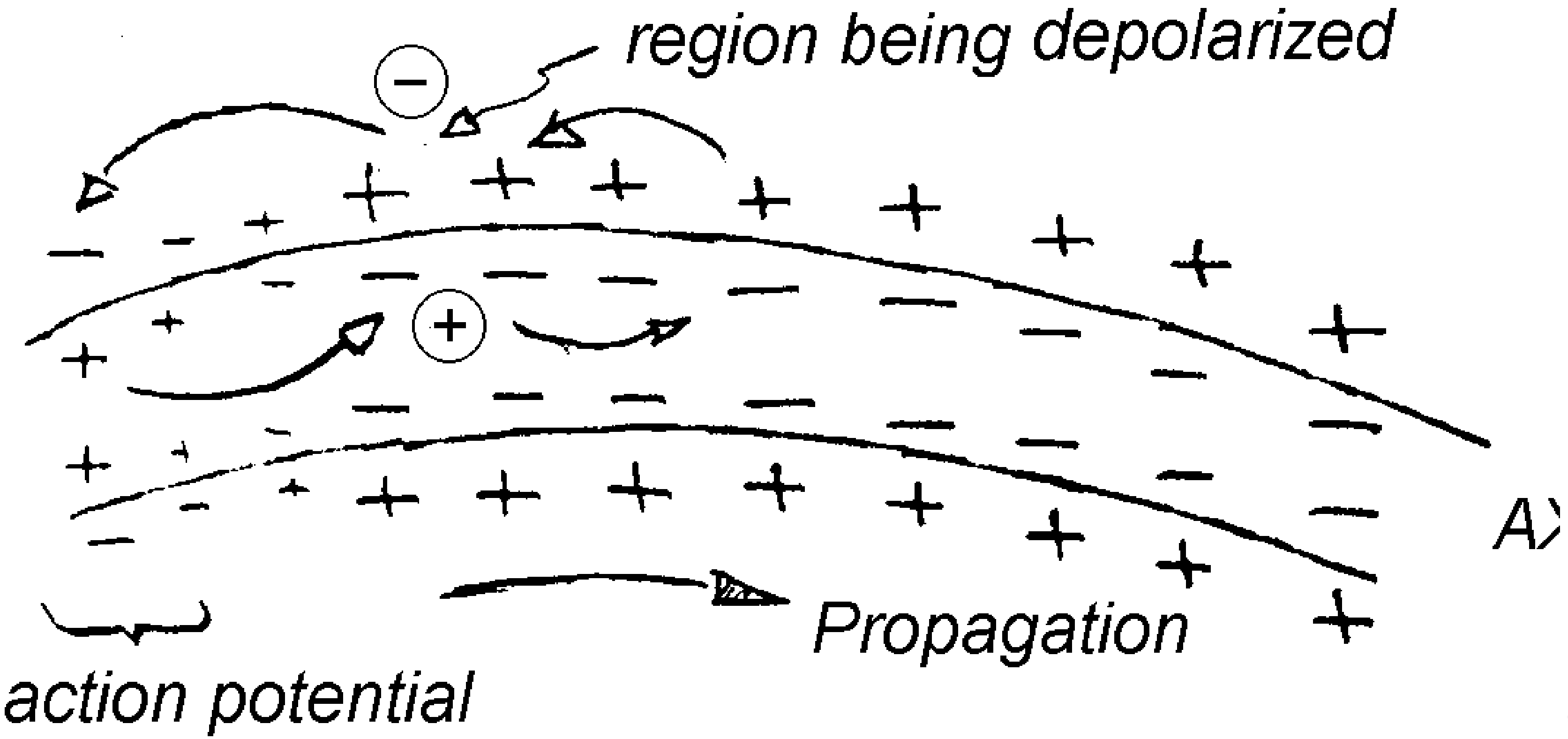
Na^+

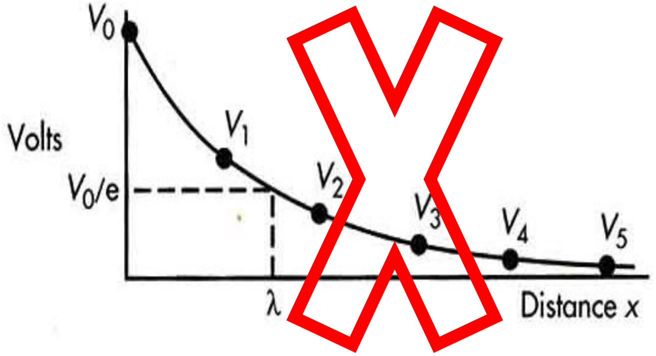
K^+

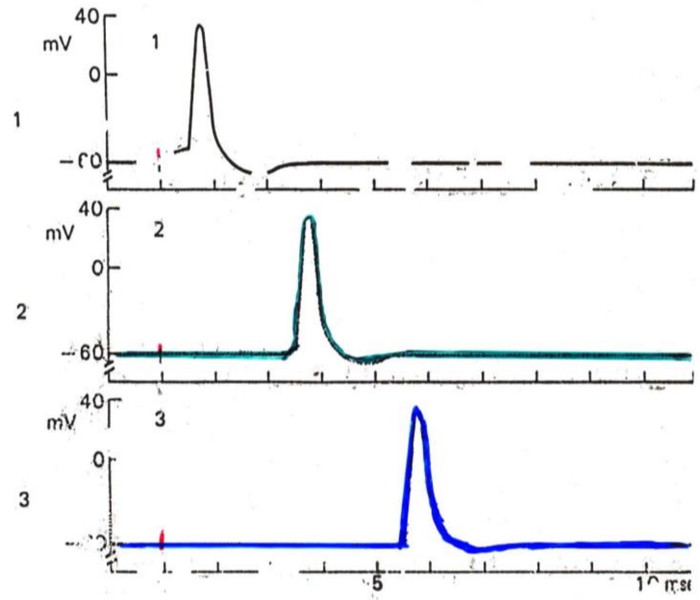


Signal propagation - Action potential

Propagation of the action potential along the axon



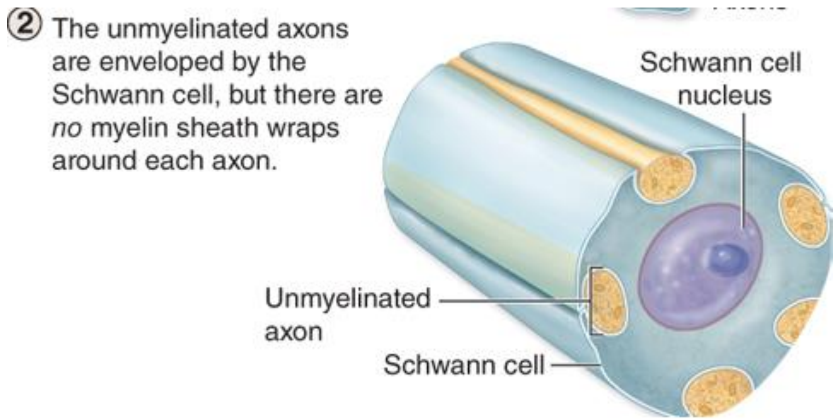


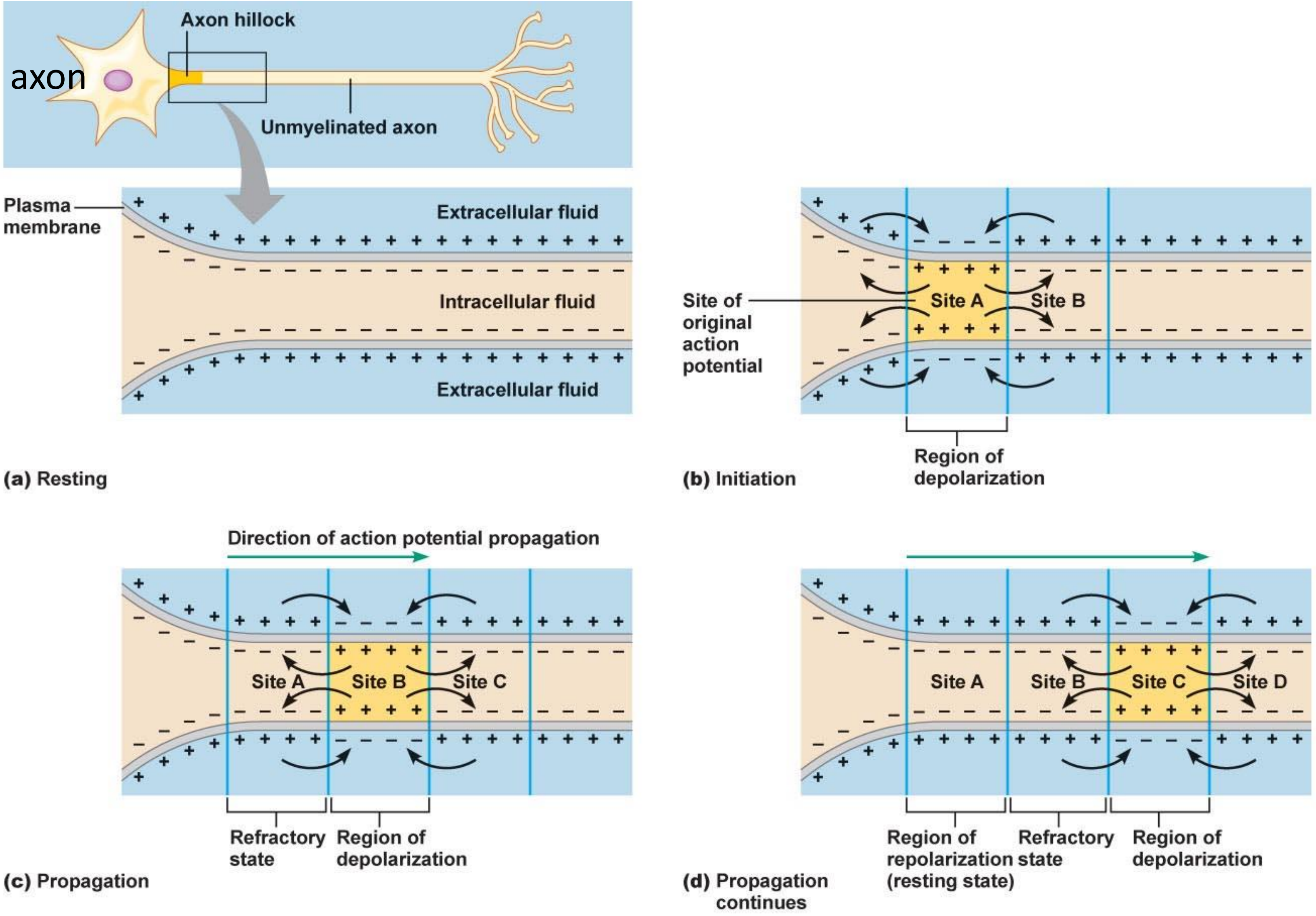


Signal propagation - Action potential

Propagation of the action potential along the axon

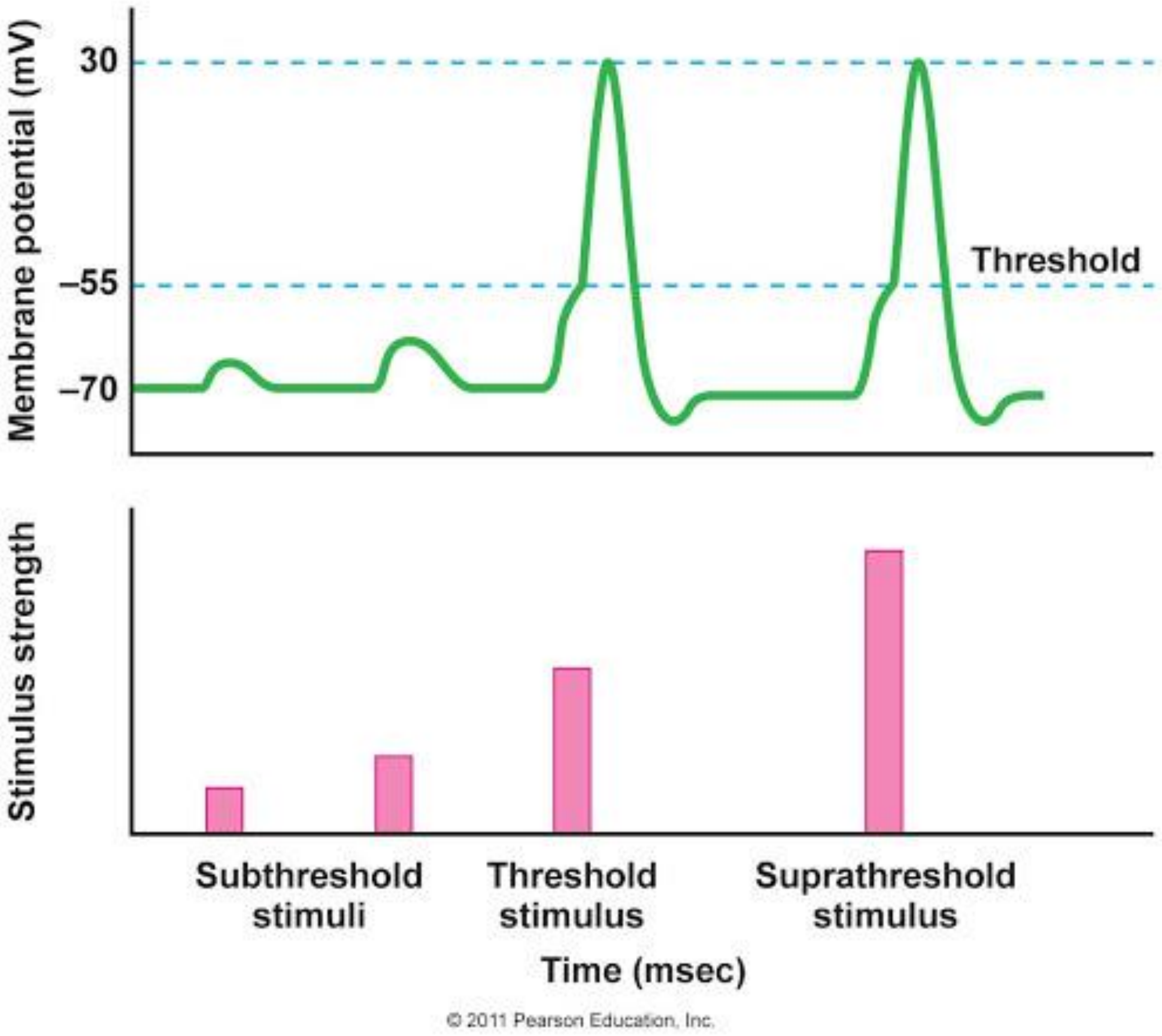
Unmyelinated axon





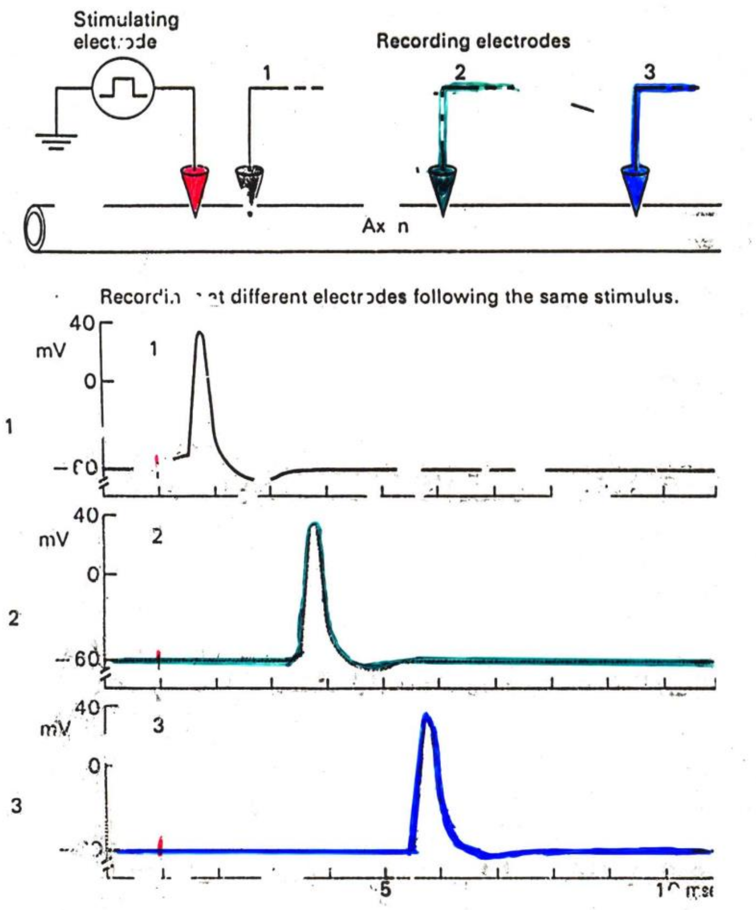
Action potential

The all-or-nothing law



Action potential

Propagation without decrement
(no loss)

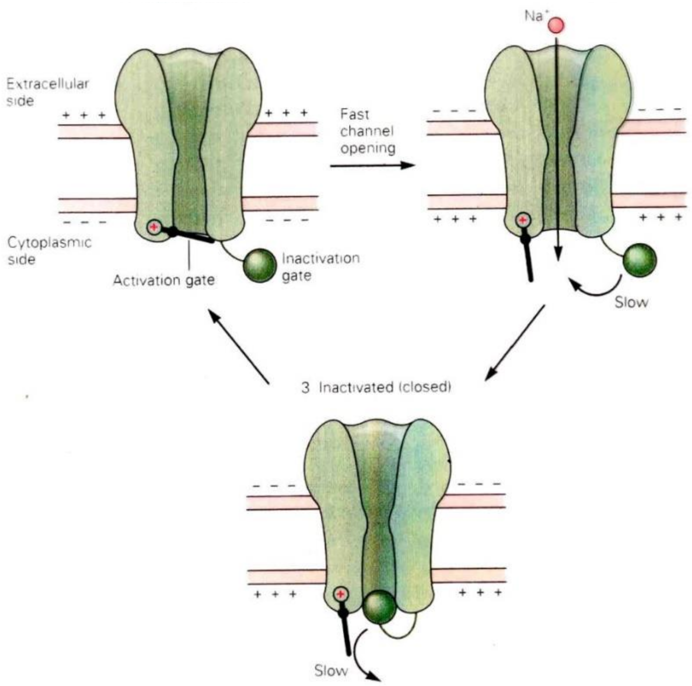


Action potential

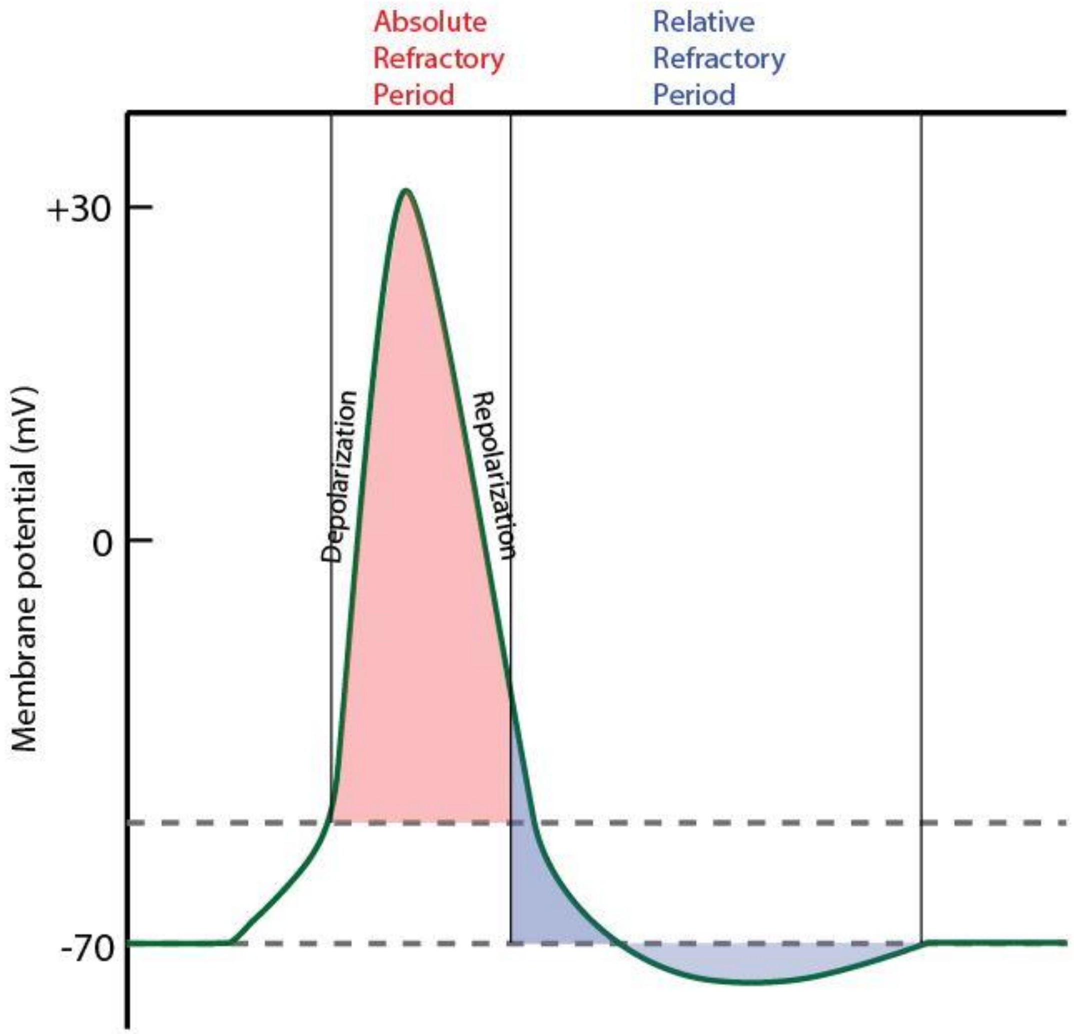
Absolute and relative refraktectory period

The period of time when an AP cannot be elicited

Closed but available   Activated (open)

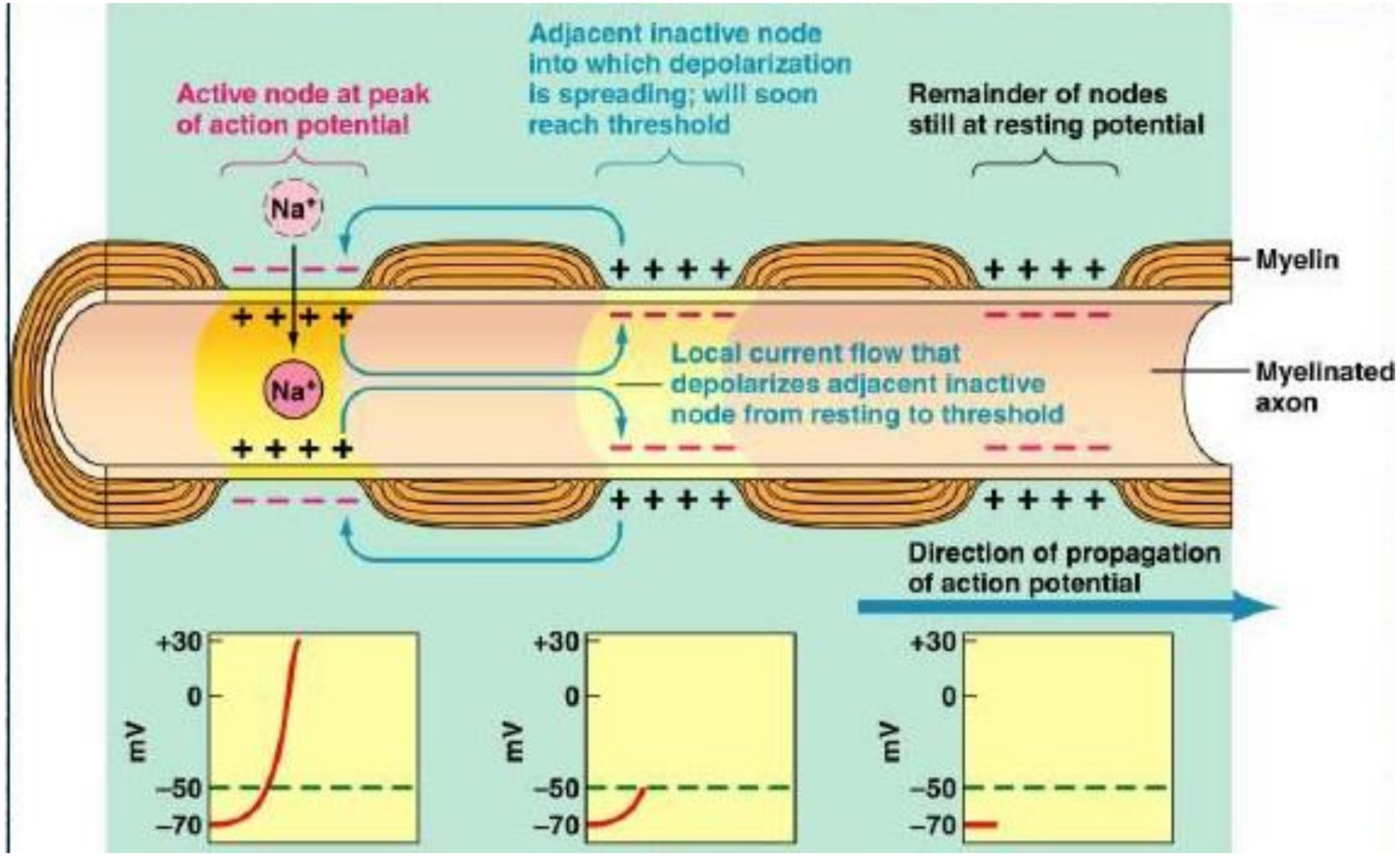


Inactivated



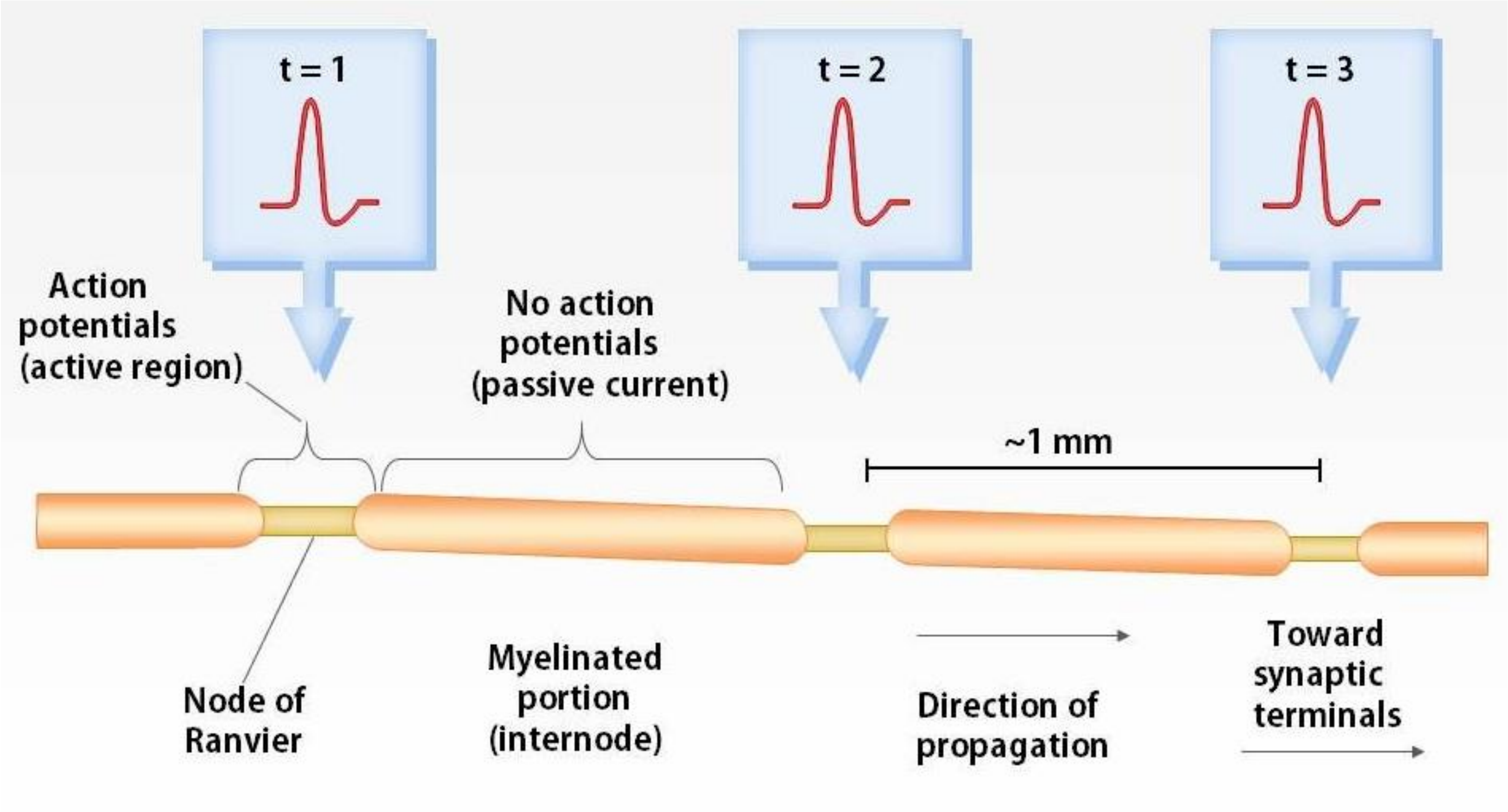
Action potential

Saltatory Conduction
myelinated axon



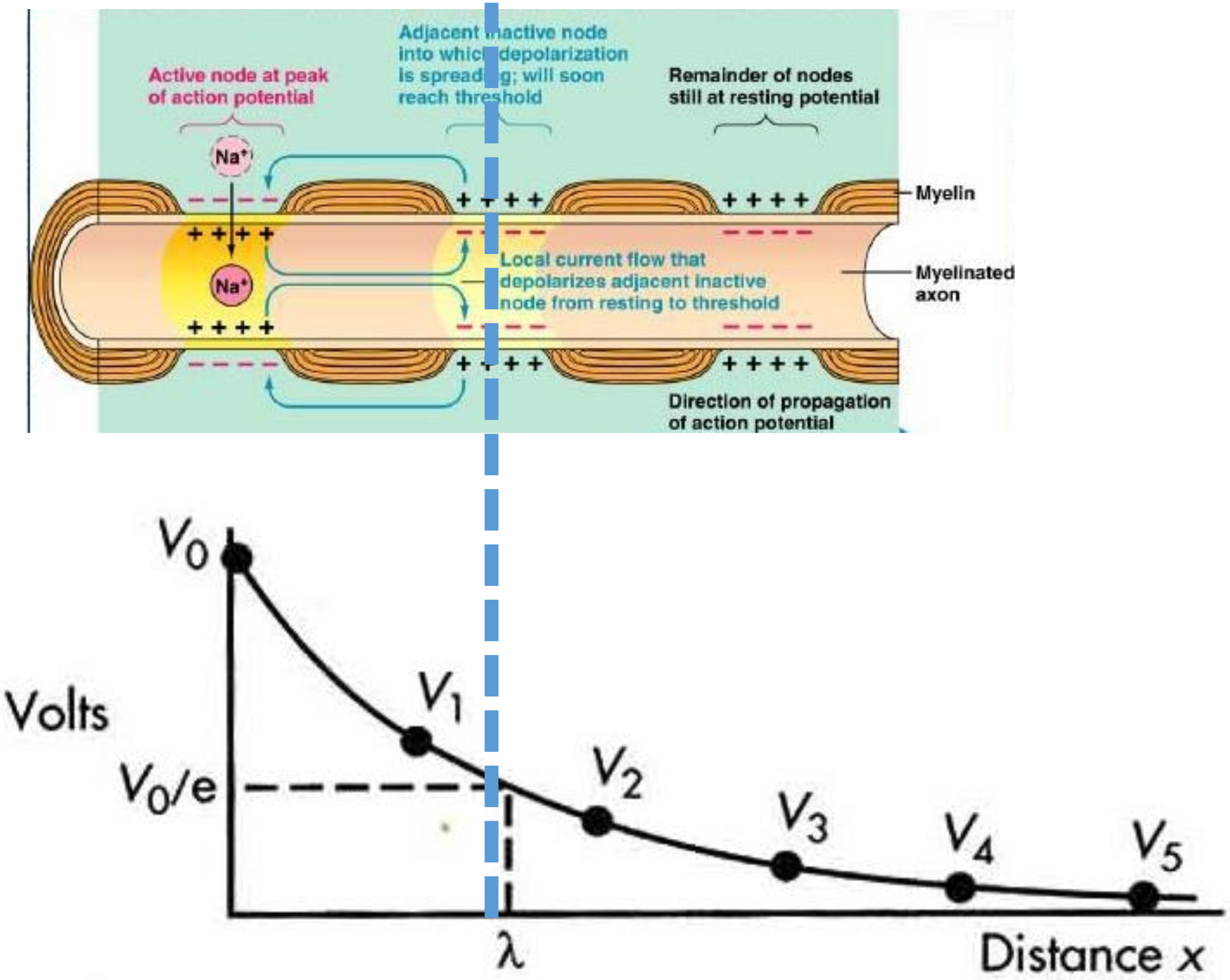
Action potential

Saltatory Conduction
myelinated axon



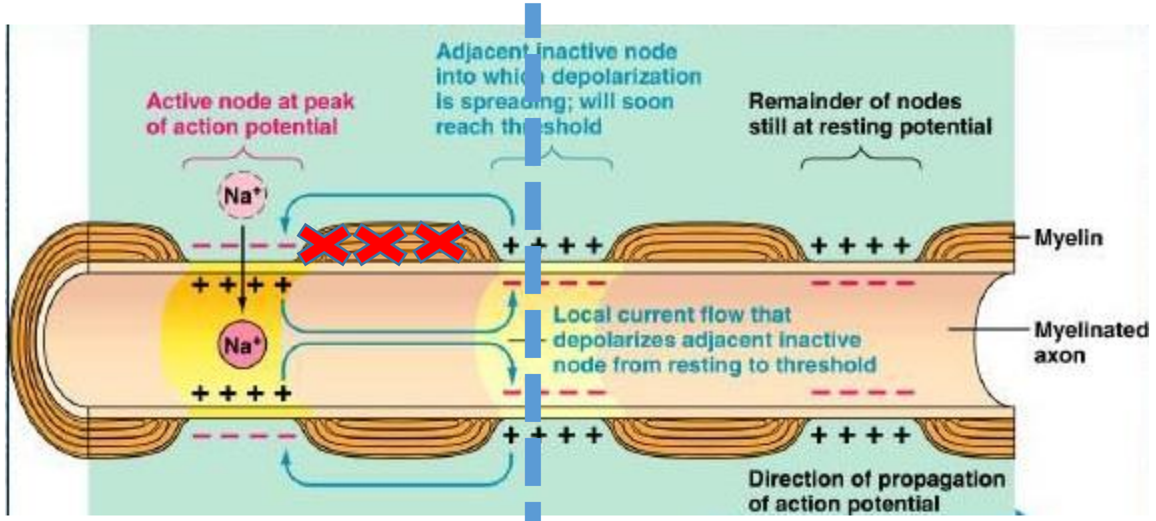
Action potential

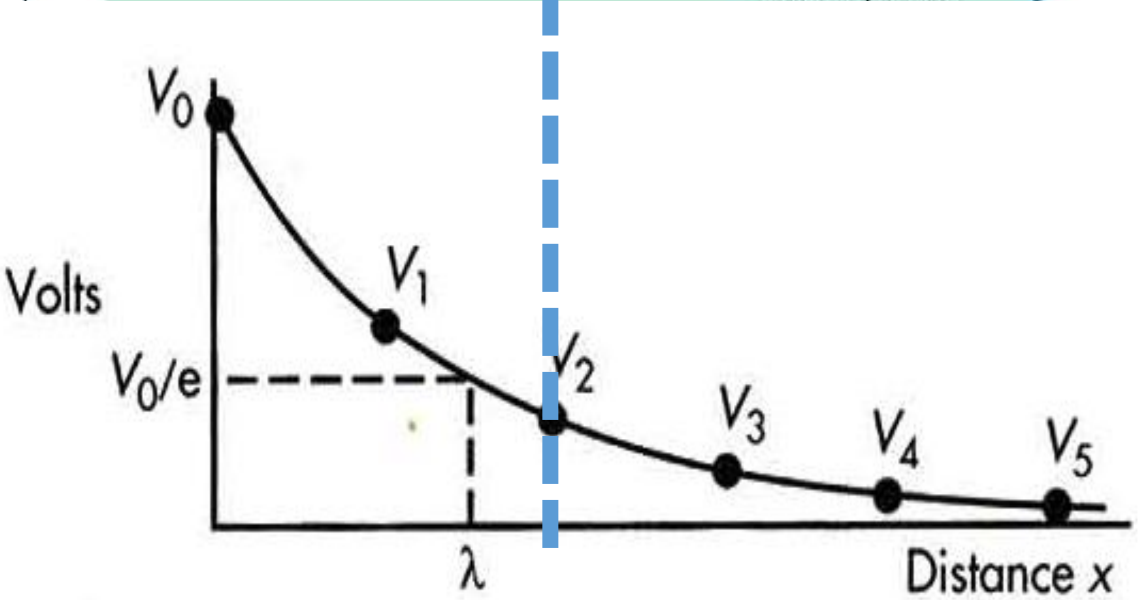
Normal
myelinated axon



Action potential

Multiple sclerosis
unmyelinated axon





Signal propagation

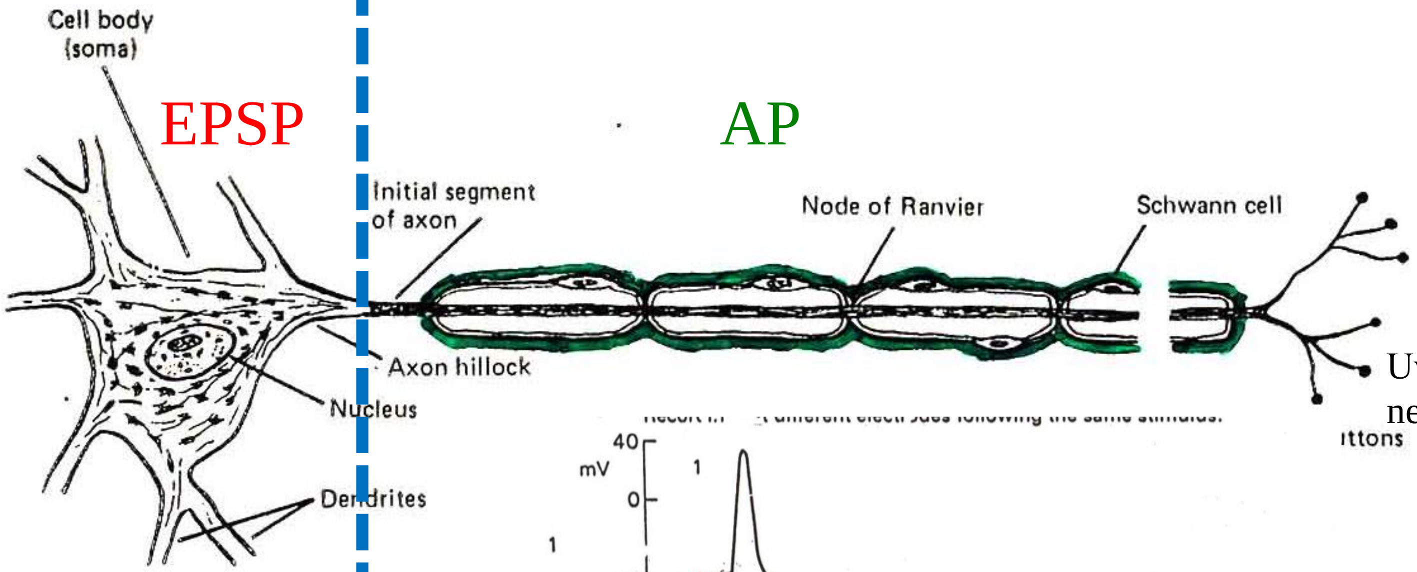
Nervous system

Elektrotonic potencial

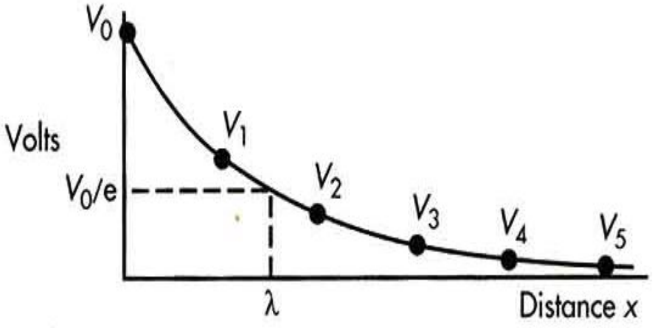
Action potential

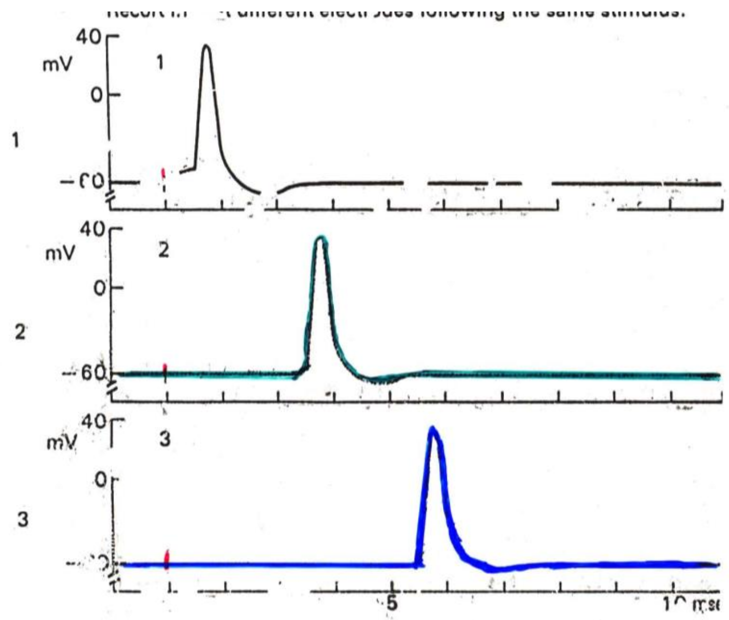
EPSP

AP



Uvolnění neurotransmiteru

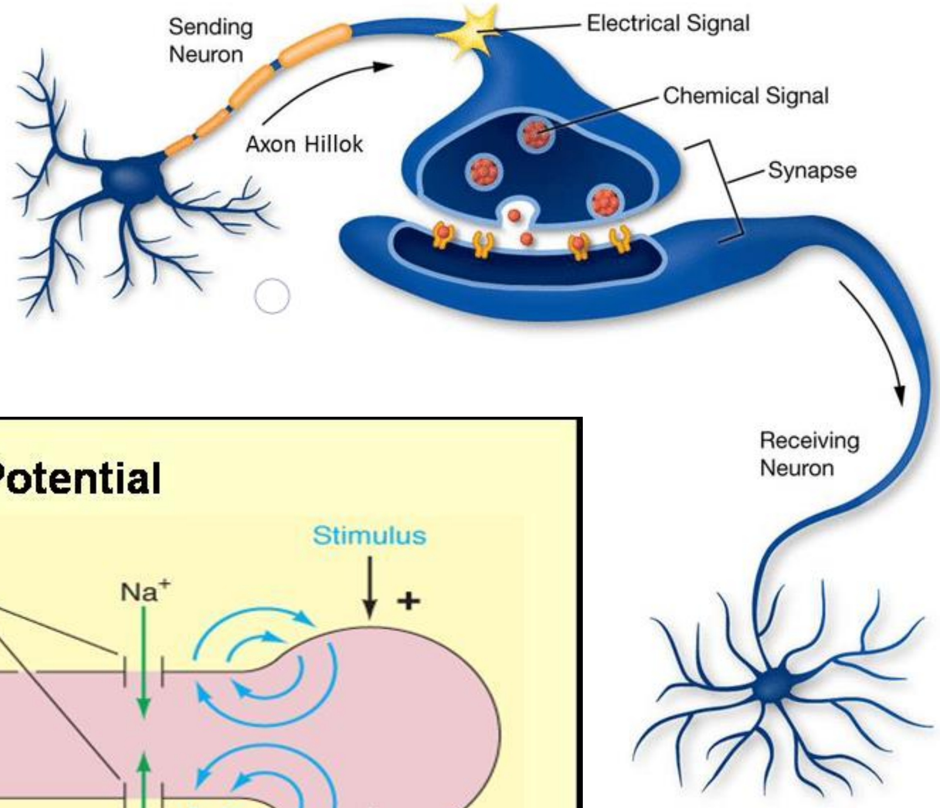


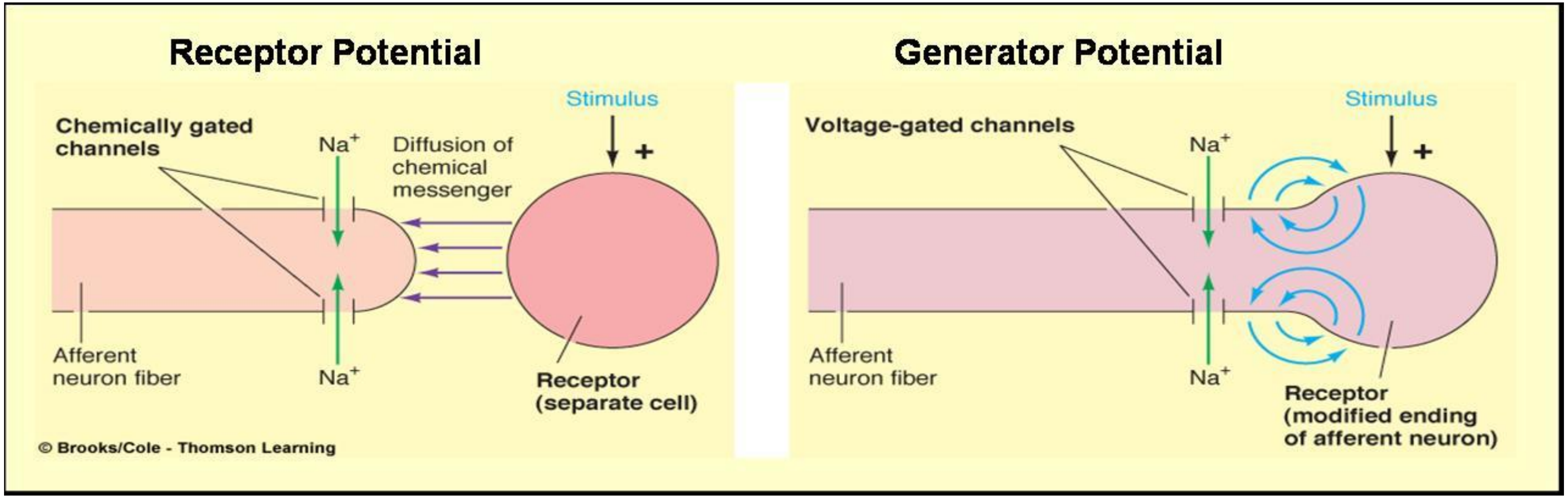


Signal generation

Sensory receptors

Synaptic transmission



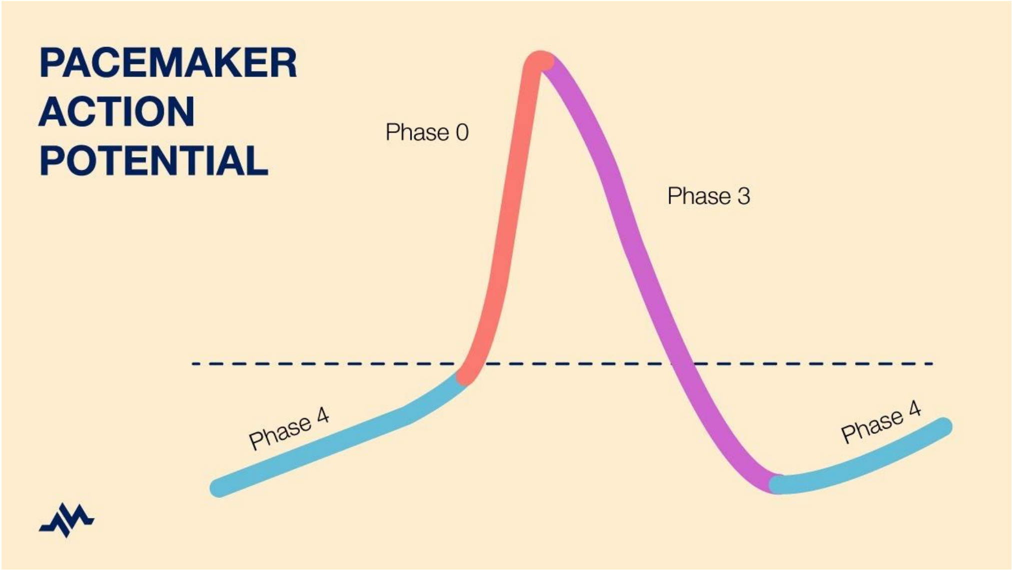


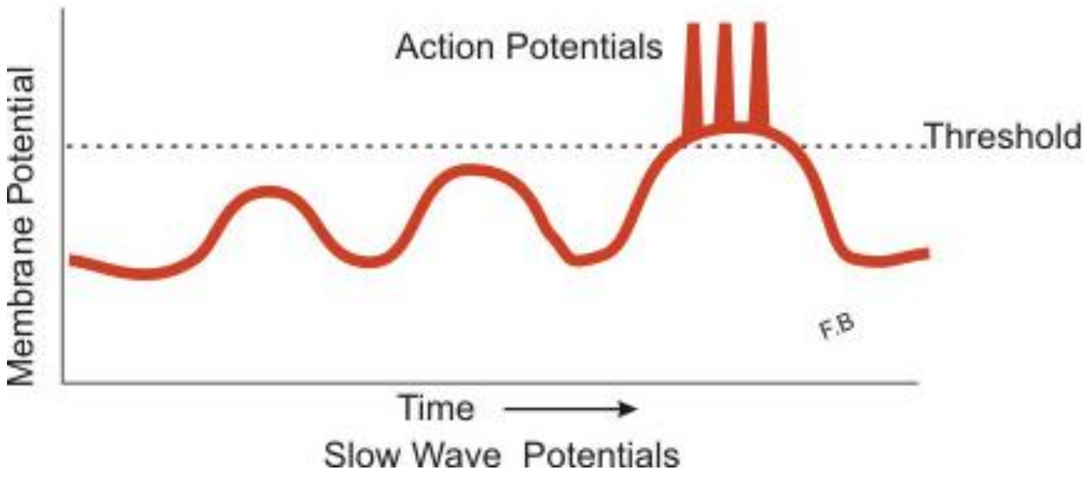
Signal generation

Pacemaker activity

Heart
Sinoatrial node

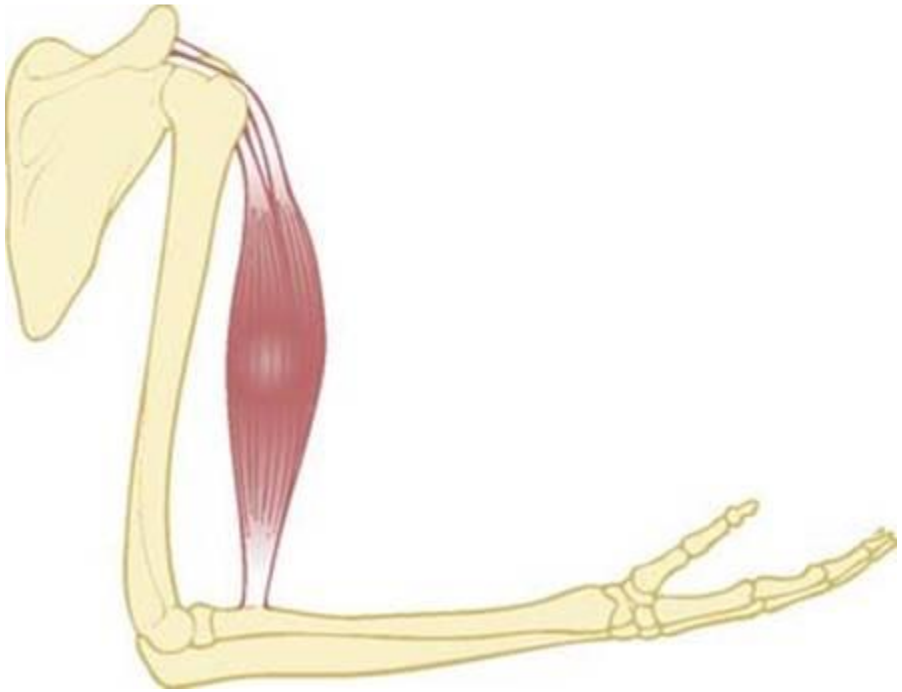
Smooth muscle
GIT – interstitial cells of Cajal

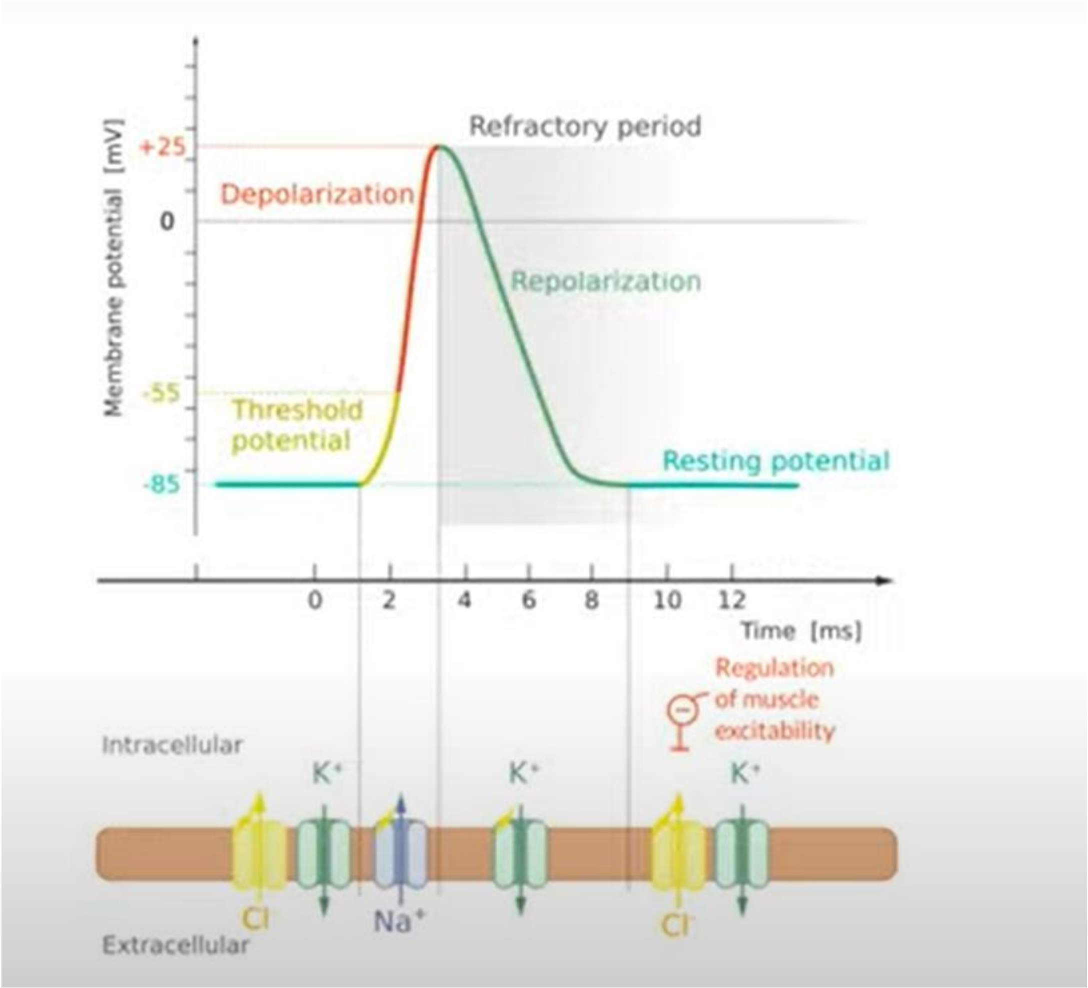




Skeletal Muscle

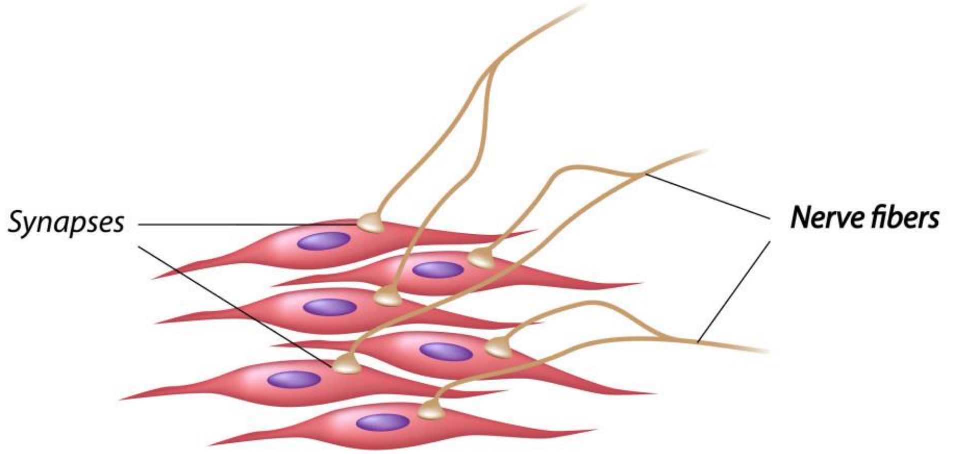
https://www.youtube.com/watch?v=4VOMadMSbrc





Smooth Muscle

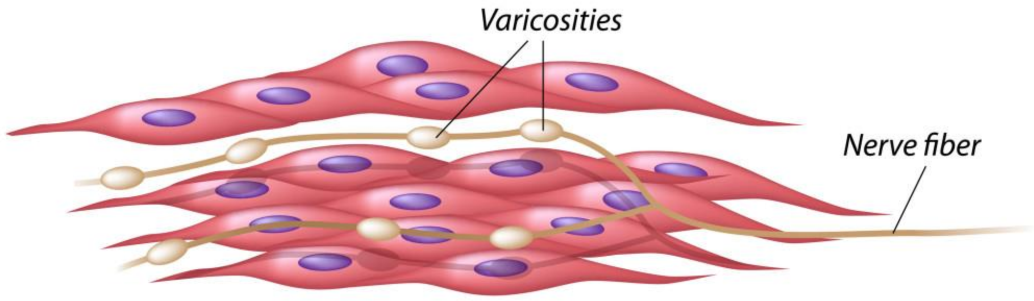
Multiunit
each smooth-muscle cell receives its synaptic input. This allows for multi-unit smooth muscle to have much finer control. Multi-unit smooth muscle is found in the airways of the lungs, large arteries, and ciliary muscles of the eye.



Multiunit Smooth Muscle

Single unit (unitary) –

Urinary tract, digestive tract, vessels

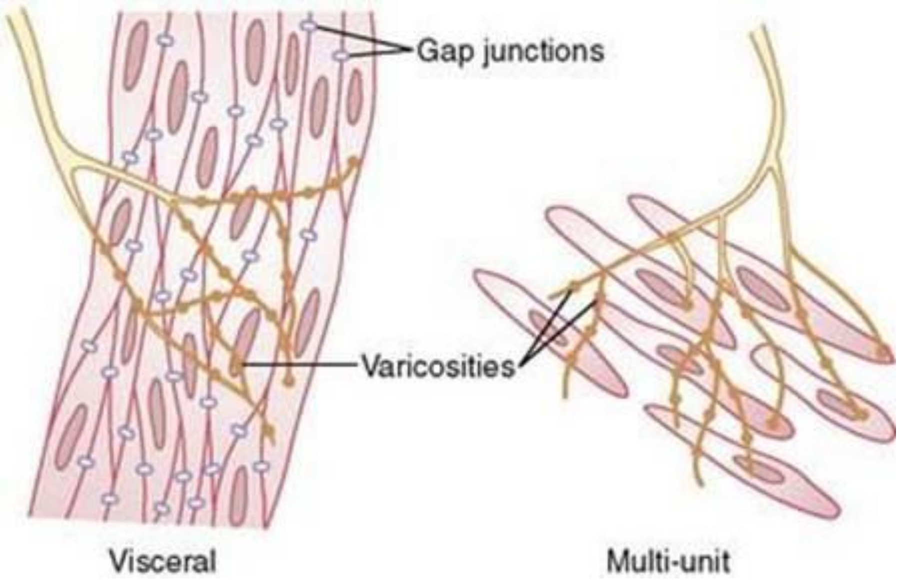


Single-unit Smooth Muscle

Smooth Muscle

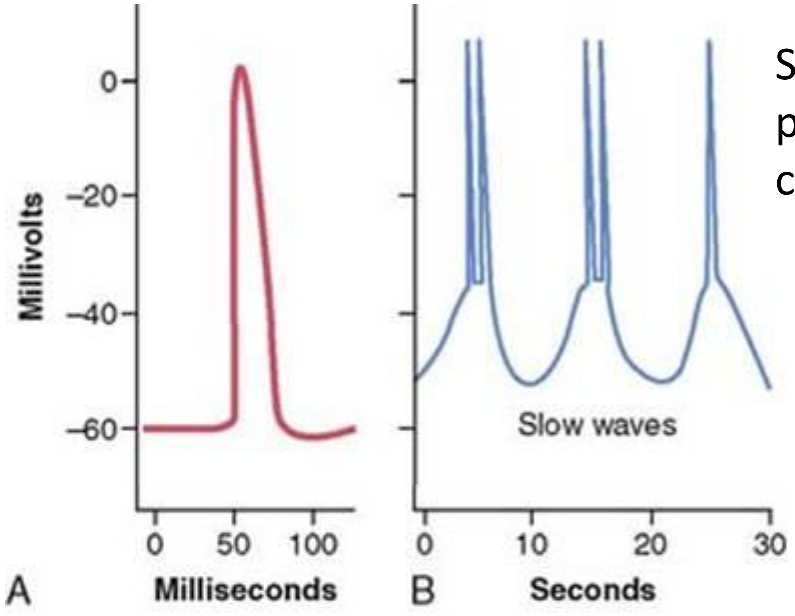
Smooth muscle

Single unit (unitary) – Nerve fiber - varicosity
Receptors on the muscle surface
gap junctions

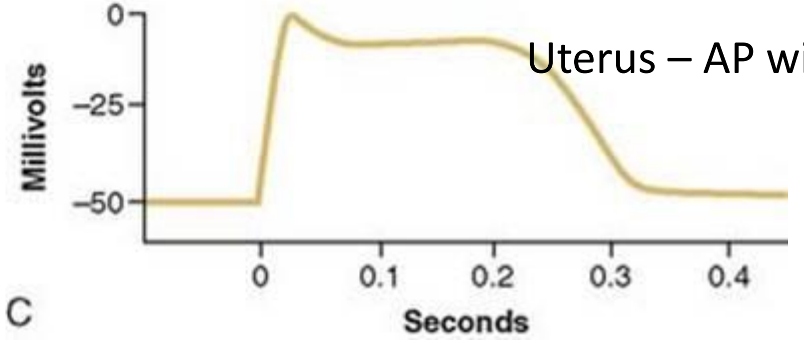


Smooth muscle action potential

Slow waves of Intestinal wall

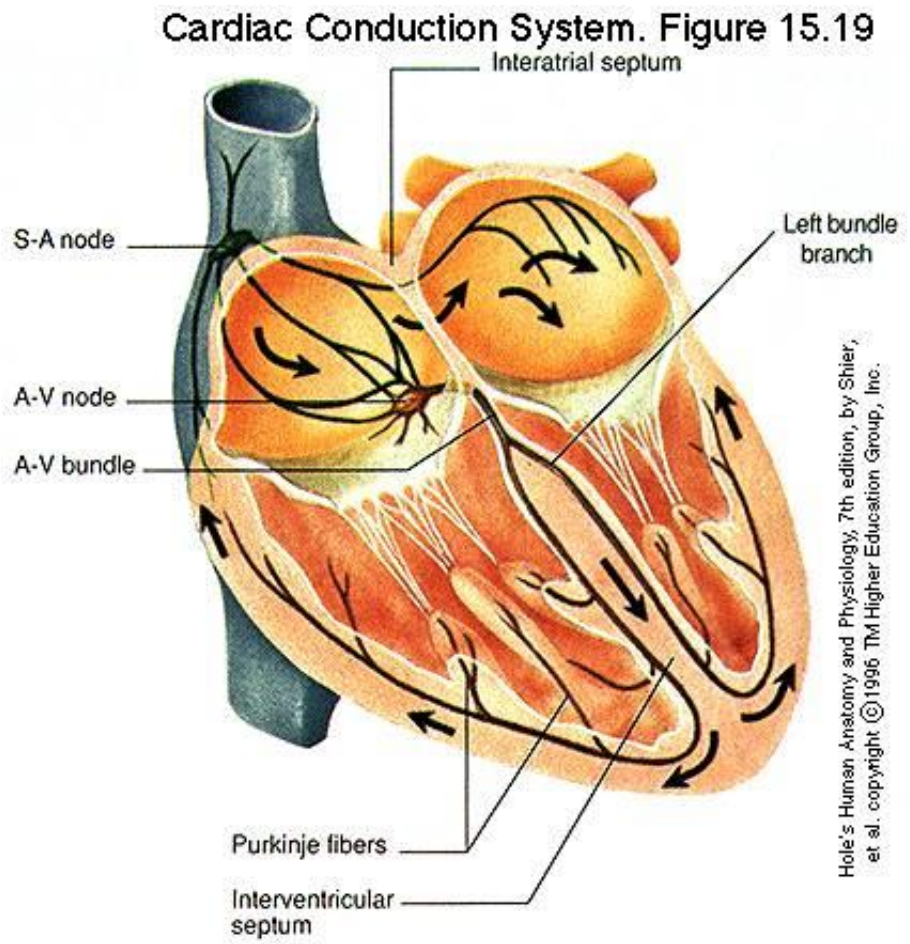


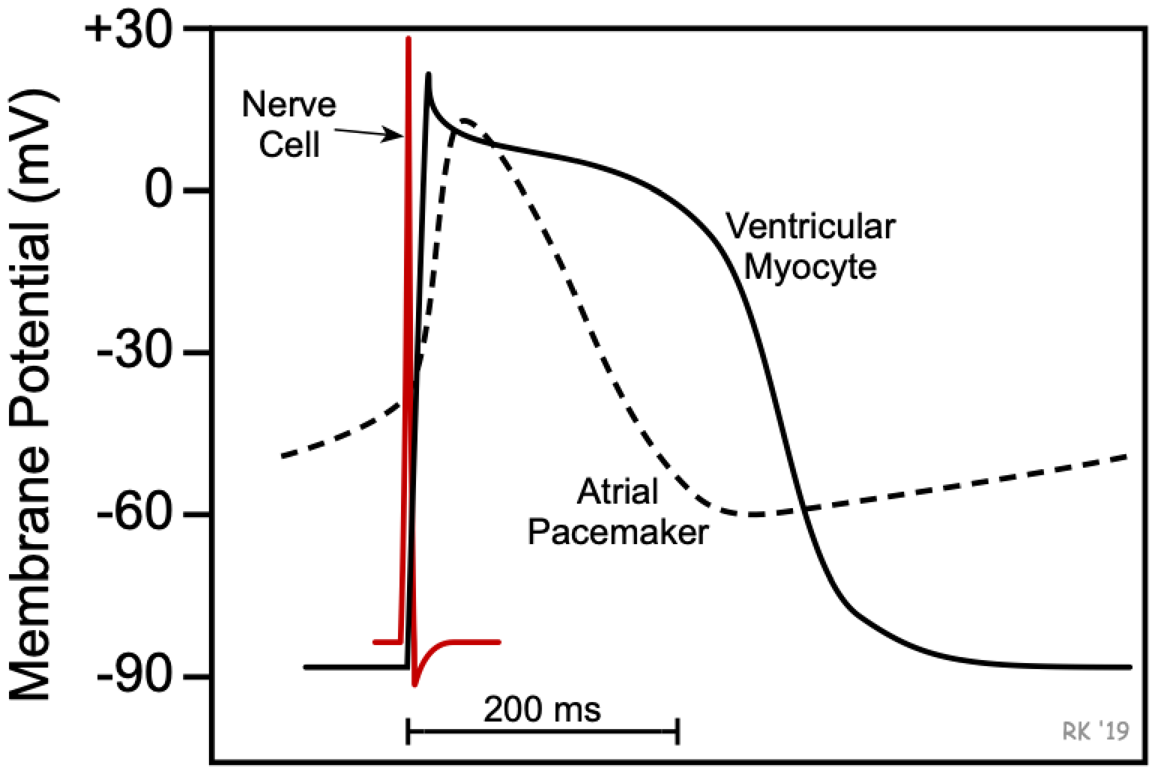
Spontaneous pacemaker - cells of Cajal



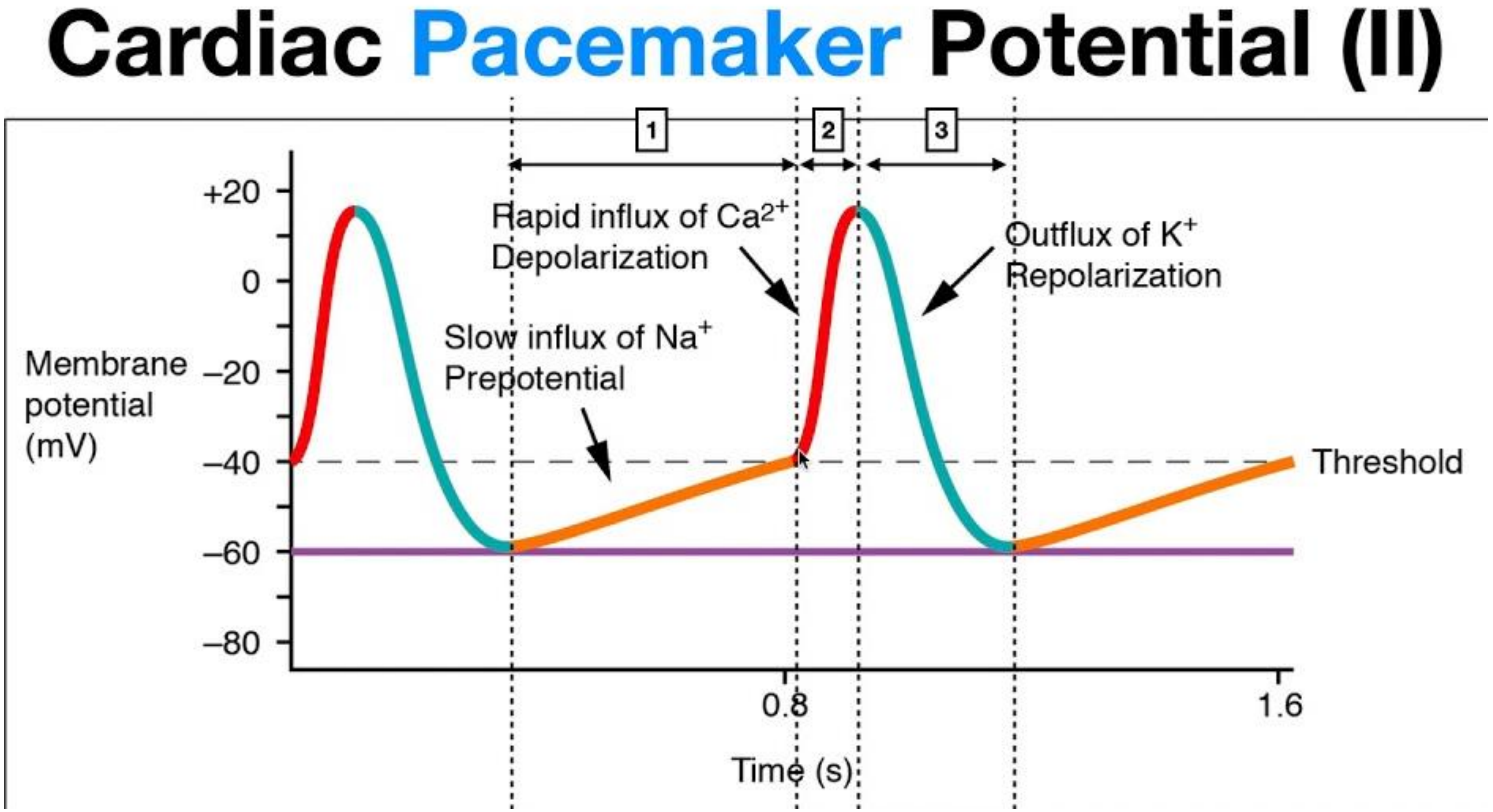
Uterus – AP with a plateau

Heart

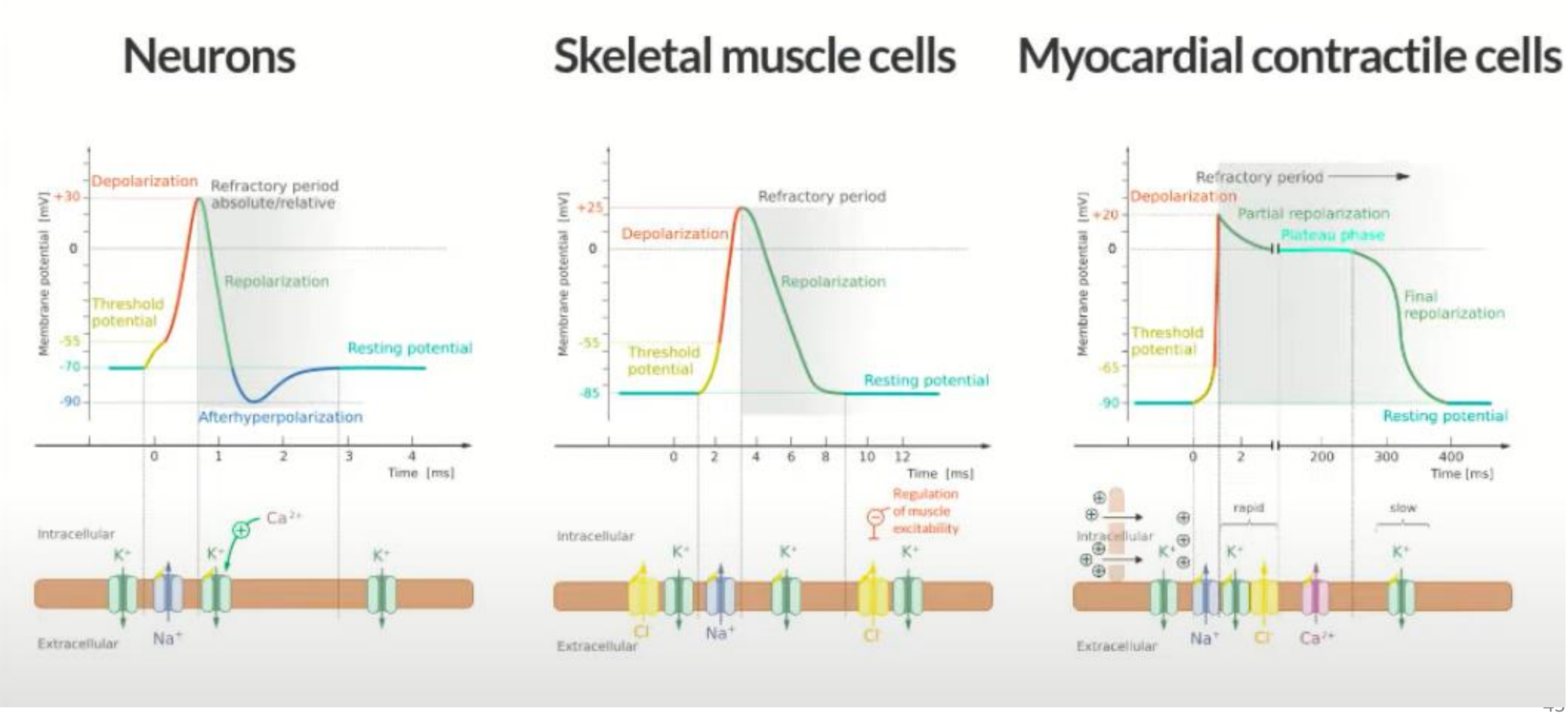

Cardiac Conduction System. Figure 15.19
Interatrial septum
S-A node
Left bundle branch
A-V node
A-V bundle
Purkinje fibers
Interventricular septum
Hole's Human Anatomy and Physiology, 7th edition, by Shier, et al. copyright ©1996 TM Higher Education Group, Inc.


+30
0
-30
-60
-90
Membrane Potential (mV)
Nerve Cell
Ventricular Myocyte
Atrial Pacemaker
200 ms
RK '19

Heart – sinoatrial node



Action potential - comparison



Thanks for your attention

The seed was planted ☺

Questions ???

Comments ???