Resting membrane potential & action potential

TEXTBOOK OF MEDICAL PHYSIOLOGY

GUYTON & HALL 13TH EDITION

UNIT II CHAPTER 5

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Objectives

At the end of this lecture the student should be able to:

- Discuss the resting membrane potential and its genesis.
- Know the ionic channels involved in resting membrane potential.
- Describe the function Na+-K+ pump and the stages of action potential.
- Explain the threshold Potential, local Response and action Potentials.
- Describe the electrical changes in membrane potential during the action potential, their chemical bases and excitability changes.
- Describe conduction along nerve fibers, role of myelination and how nerve fibers are classified.

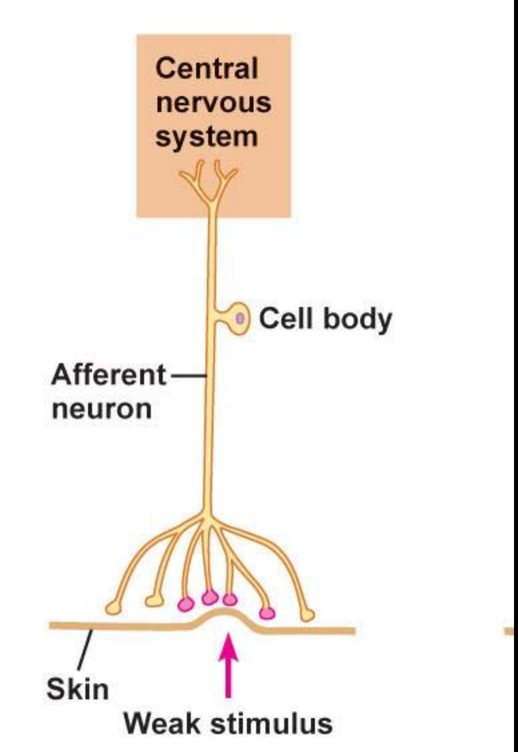
- **What are excitable tissues?**
- **Definition of resting membrane potential (RMP).**
- **Measurement and normal value of RMP.**
- **Origin of RMP: contribution of K+, Na+, and Na-K pump**

What are excitable tissues?

Nerve and muscles.

What does that mean?

The tissue has the capability to respond to an adequate stimulus.



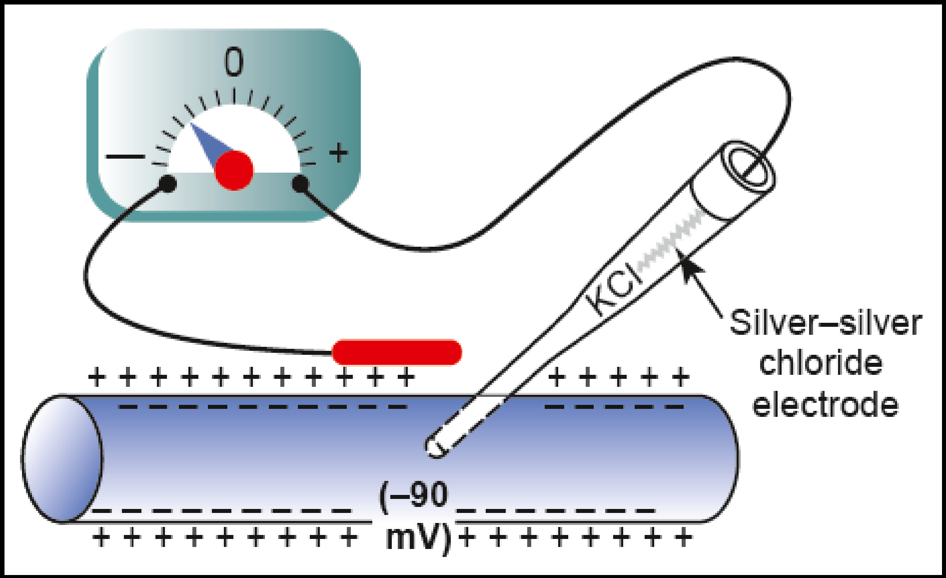
(a) Single sensory unit stimulated

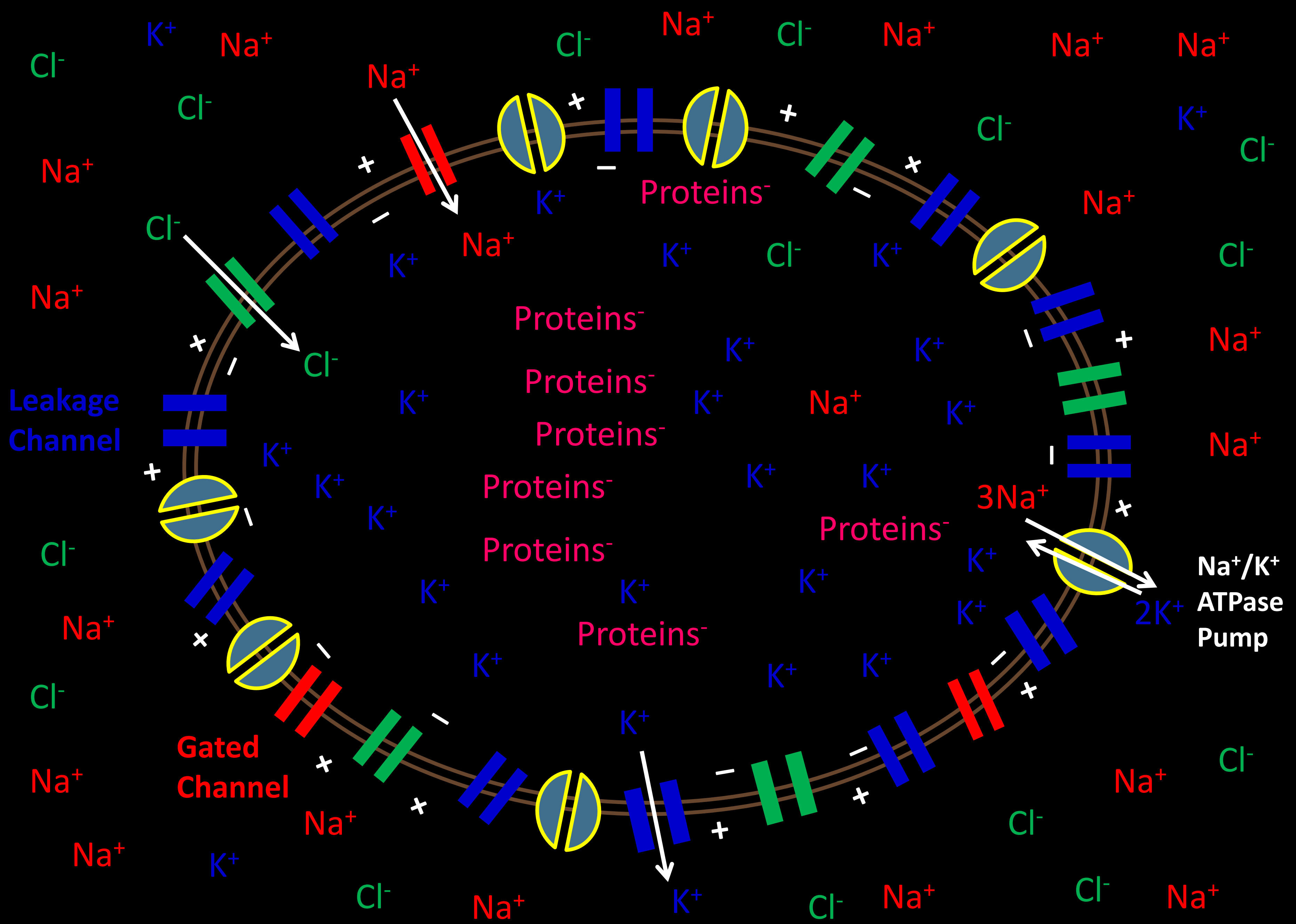
RESTING MEMBRANE POTENTIAL (RMP)

DIF: it is the potential difference across the membrane during rest (without stimulation) between the inner side & outer side of the membrane, and it is relatively –ve inside.

Measurement of RMP: Using **VOLTMETER.**

Normal Values: - 70 mV in medium sized nerve and -90 mV in large sized nerve.





Leakage
Channel
Gated
Channel
Na+/K+
ATPase
Pump
3Na+
2K+
Proteins-
Cl-
K+
Na+

Origin of RMP:

1- Contribution of K+ diffusion potential:-

K+ diffusion contributes far more to membrane potential

K+ leak channels: K+ OUTFLUX to the OUTSIDE causing –ve inside from high concentration inside to outside carrying +ve charge with it → electropositivity outside & electronegativity inside.

$$\text{E.M.F (mV)} = -\frac{61}{z} \log \text{K+} \frac{\text{Conc. Inside}}{\text{Conc outside}} = -94 \text{ mV K+}$$

2- Contribution of Na+ diffusion potential:-

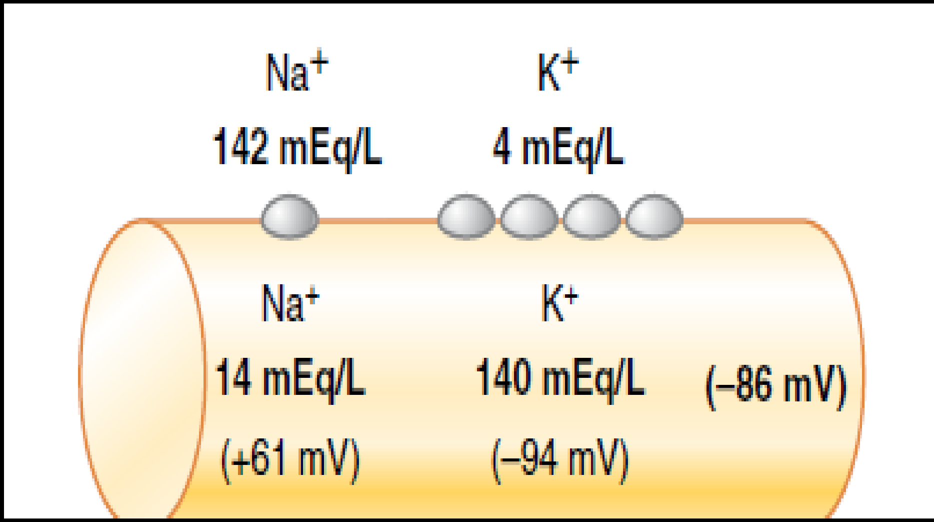
Na+ leak channels :- **Slight membrane permeability to Na ions in leak channels from outside to inside.(why slight?)**

E.M.F (mV) = +61 mV Na+

Using this value in the **Goldman equation** gives a potential inside the membrane of **−86 millivolts**.

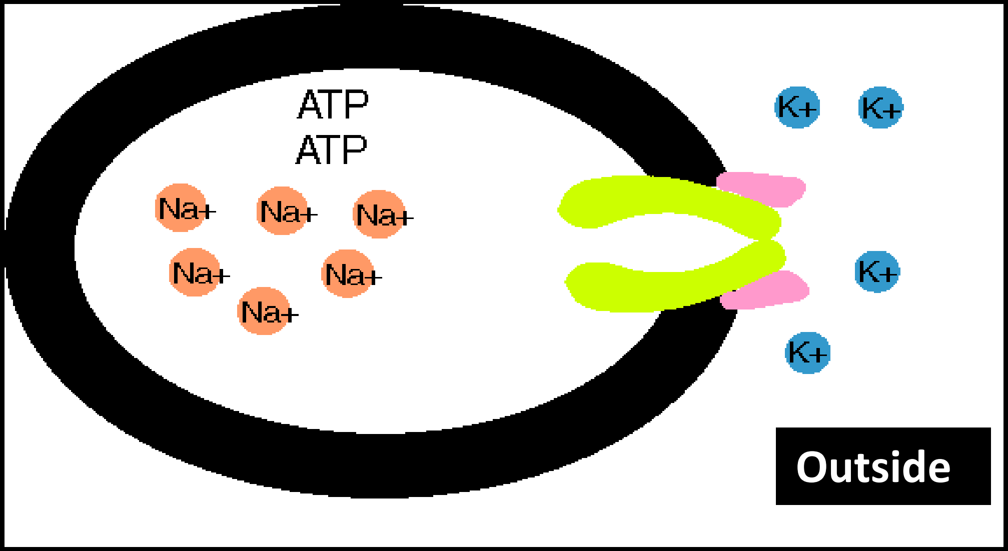
EMF (millivolts)

$$= -61 \times \log \frac{C_{Na_i^+} P_{Na^+} + C_{K_i^+} P_{K^+} + C_{Cl_o^-} P_{Cl^-}}{C_{Na_o^+} P_{Na^+} + C_{K_o^+} P_{K^+} + C_{Cl_i^-} P_{Cl^-}}$$



3- Contribution of Na+-K+ PUMP:

- This is a powerful ***electrogenic pump*** on the cell membrane.
- **It pumps 3 Na+ to outside & 2 K+ to inside, causing what?**
- **A net loss of +Ve ions from inside, returning the nerve fibre to the resting state (-4 mV).**

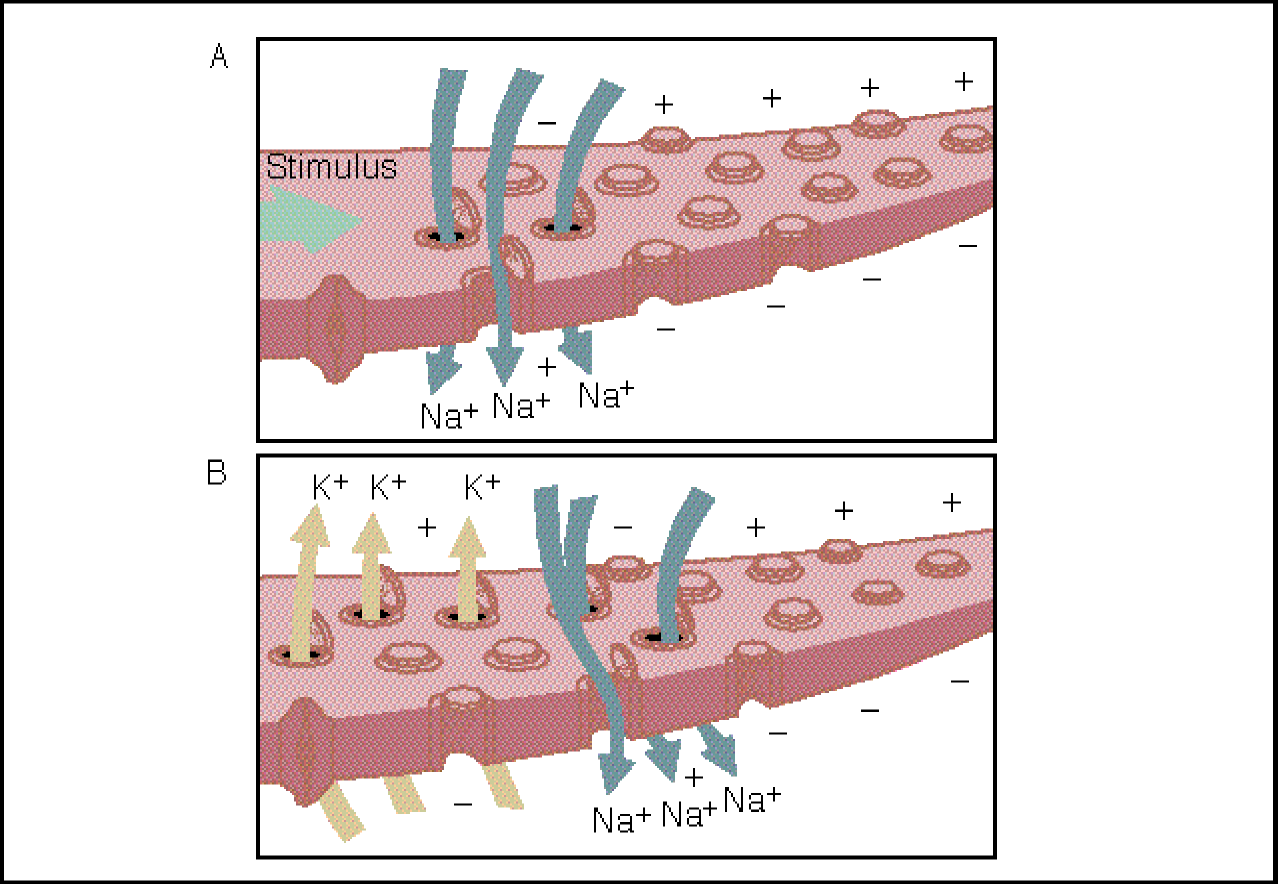


- **So the NET MEMBRANE POTENTIAL would be :-**

Diffusion potential (caused by K+ & Na+ diffusion) + *Electrogenic* Na+/K+ pump

(-86 mV) + (- 4mV) = -90 mV

Neuron Action potentials



The action potential

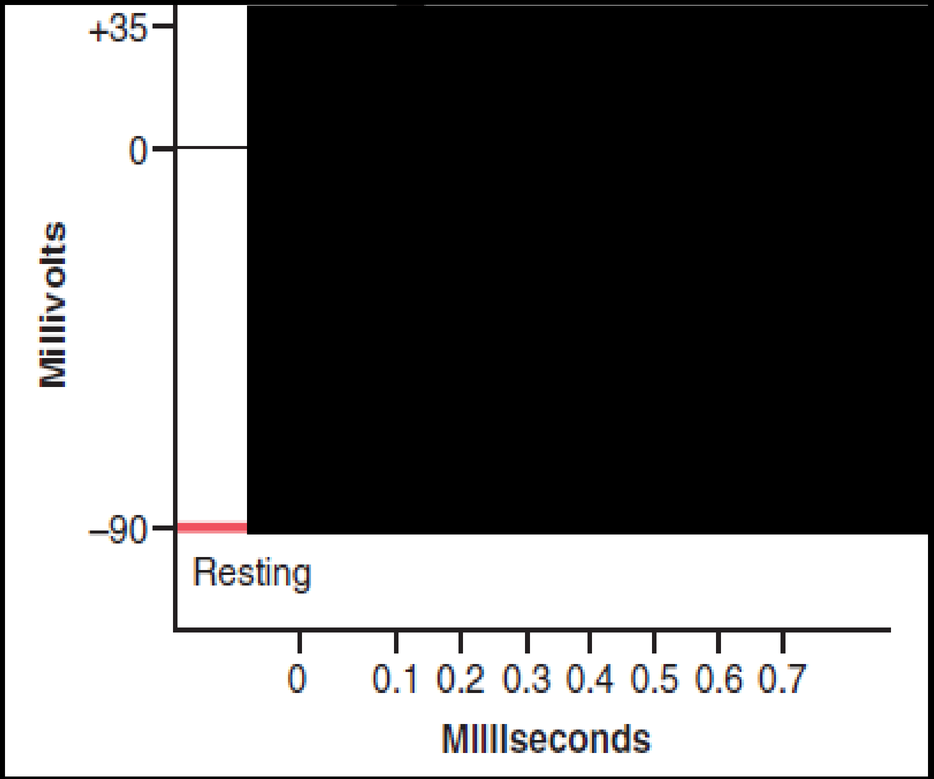
Nerve signals are transmitted by ***action potentials**, which* are rapid changes in the membrane potential that spread rapidly along the nerve fiber membrane to produce physiological effects **such as:**

- Transmission of impulse along nerve fibres
- Release of neurotransmitters
- Muscle contraction
- Activation or inhibition of glandular secretion

Each action potential begins with a **sudden change** from the normal resting negative membrane potential to a positive potential and ends with an almost equally rapid change back to the negative potential.

Stages of the action potential:

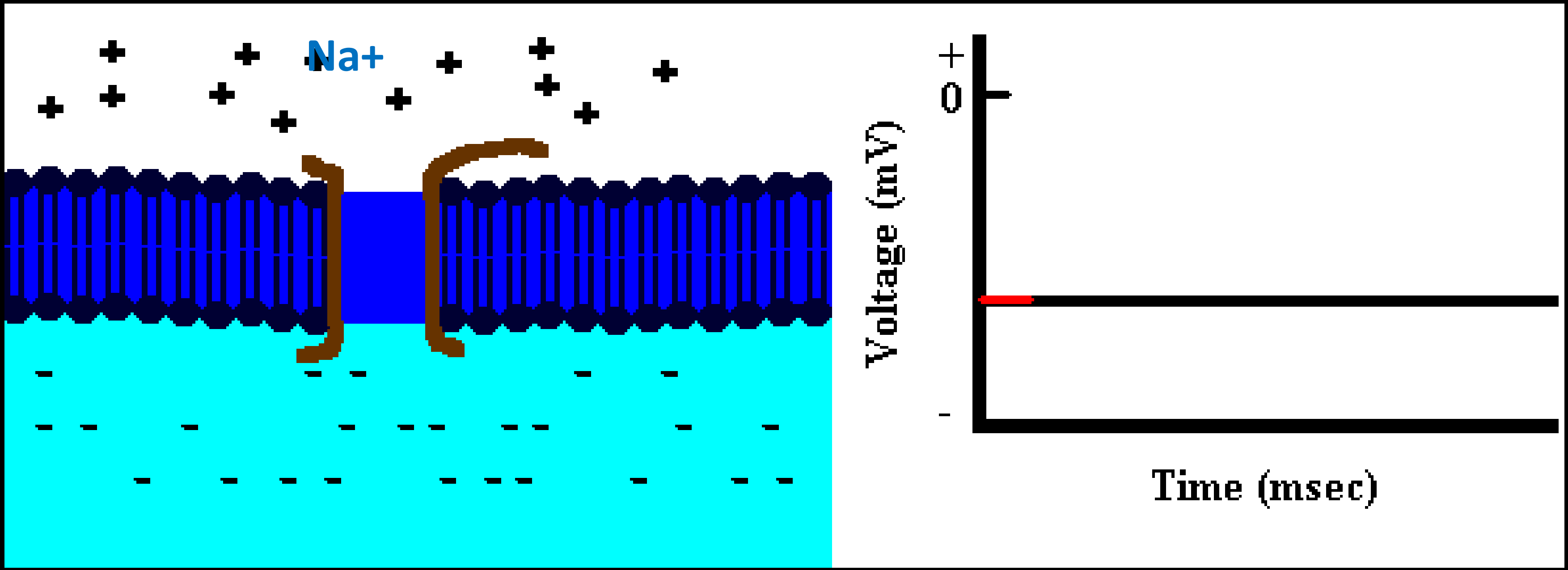
Resting Stage. It is the resting membrane potential before the action potential begins. The membrane is "polarized".



Depolarization Stage.

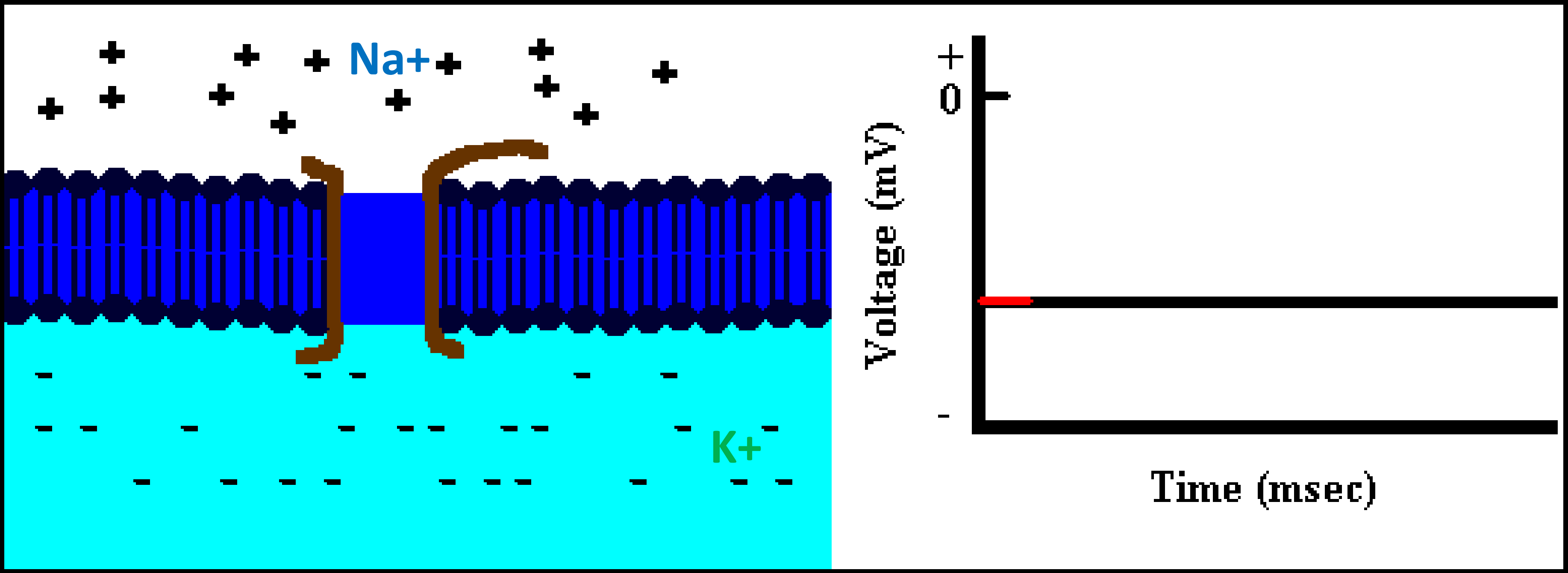
Repolarization Stage.

Depolarization



Depolarization: The membrane suddenly becomes permeable to **Na+** ions, allowing tremendous numbers of positively charged **Na+** to diffuse to the interior of the axon (Upstroke).

Repolarization



Repolarization: Na+ channels begin to close and the K+ channels open. Rapid diffusion of K+ ions to the exterior re-establishes the normal negative resting membrane potential.

Threshold stimulus:
The membrane potential at which occurrence of the action potential is inevitable.

Acute subthreshold potential:
Stimulus that results only in local depolarisation (*acute local potentials*) when stimulus is below the threshold.

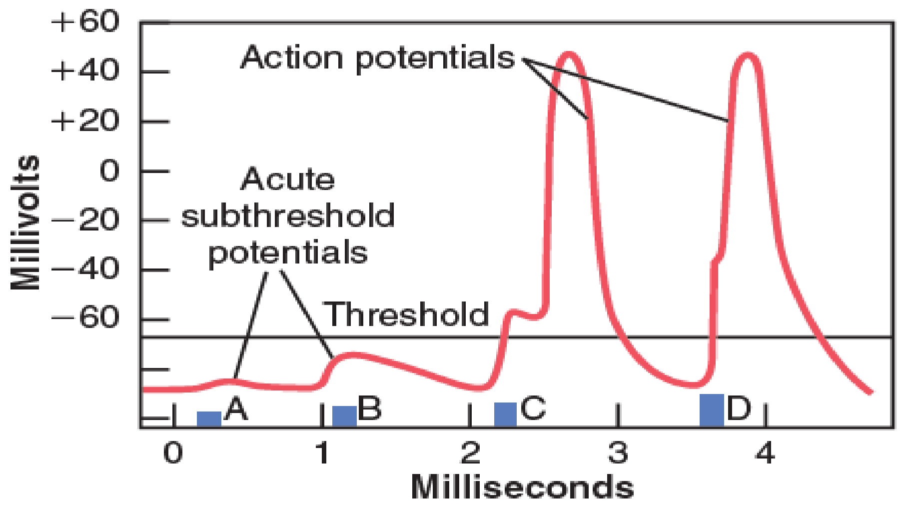


Figure 5-18. Effect of stimuli of increasing voltages to elicit an action potential. Note development of acute subthreshold potentials when the stimuli are below the threshold value required for eliciting an action potential.

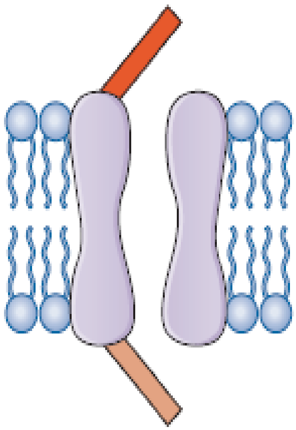
All-or-nothing principle:

Once threshold value for excitation is reached a full AP is produced, its intensity can not be increased by increasing stimulus intensity.

Types of transport channels through the nerve membrane:

- **Voltage gated Na+ channels**
- **Voltage gated K+ channels**

Voltage gated Na+ channels



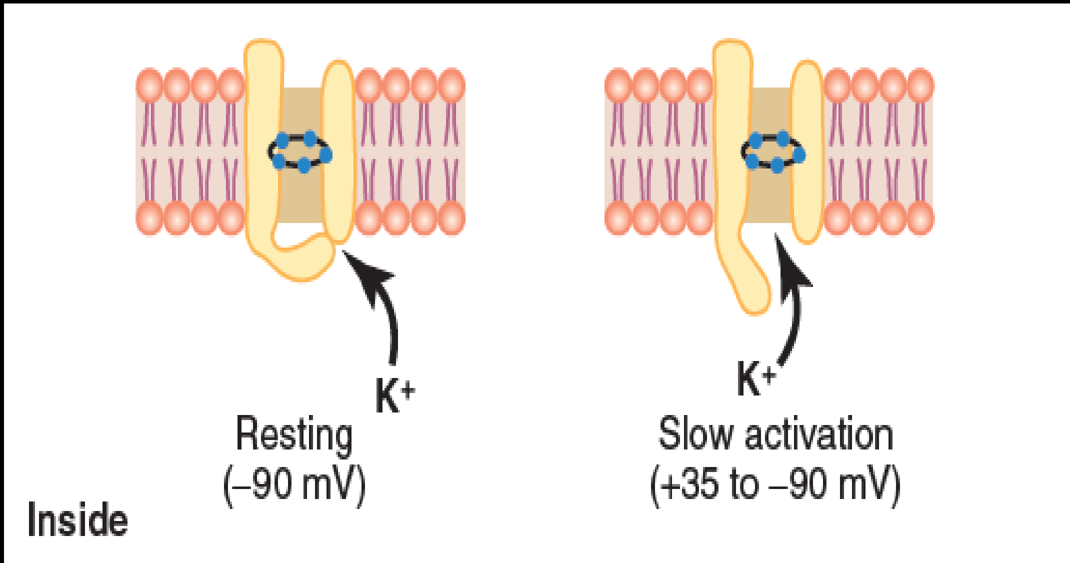
Functions of activation and inactivation gates on the nerve Na^+ channel. At rest, the activation gate is closed and the inactivation gate is open. During the upstroke of the action potential, both gates are open and Na^+ flows into the cell down its electrochemical potential gradient. During repolarization, the activation gate remains open but the inactivation gate is closed.

The Voltage-Gated K+ Channel

- Has one gate only .
- During the resting state, the gate of the potassium channel is closed and potassium ions are prevented from passing through this channel to the exterior.
- Shortly after depolarization, when the sodium channel begins to be inactivated, the potassium channel opens.

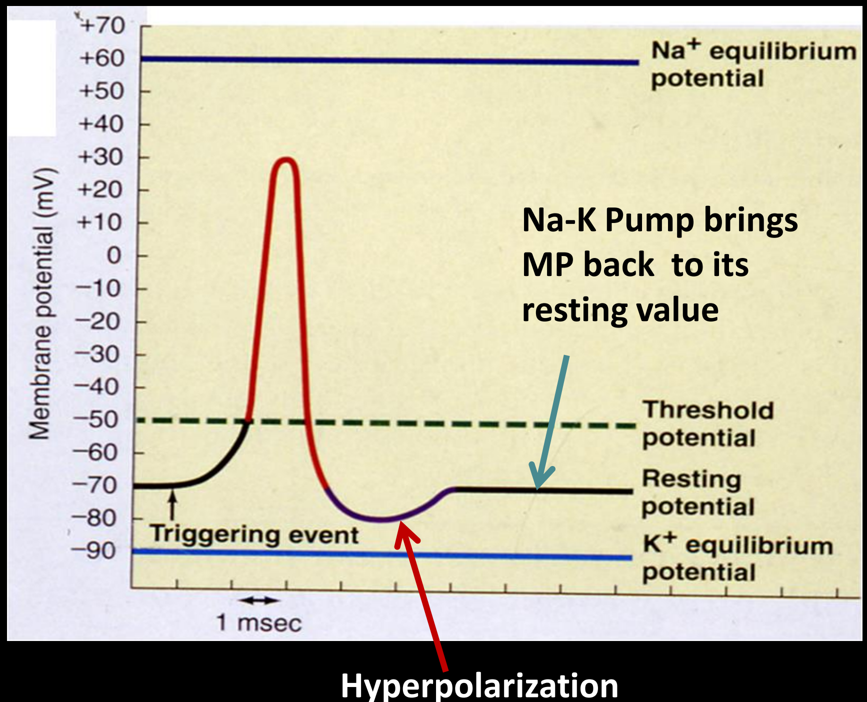
→ K+ exits (Efflux) →

Repolarization



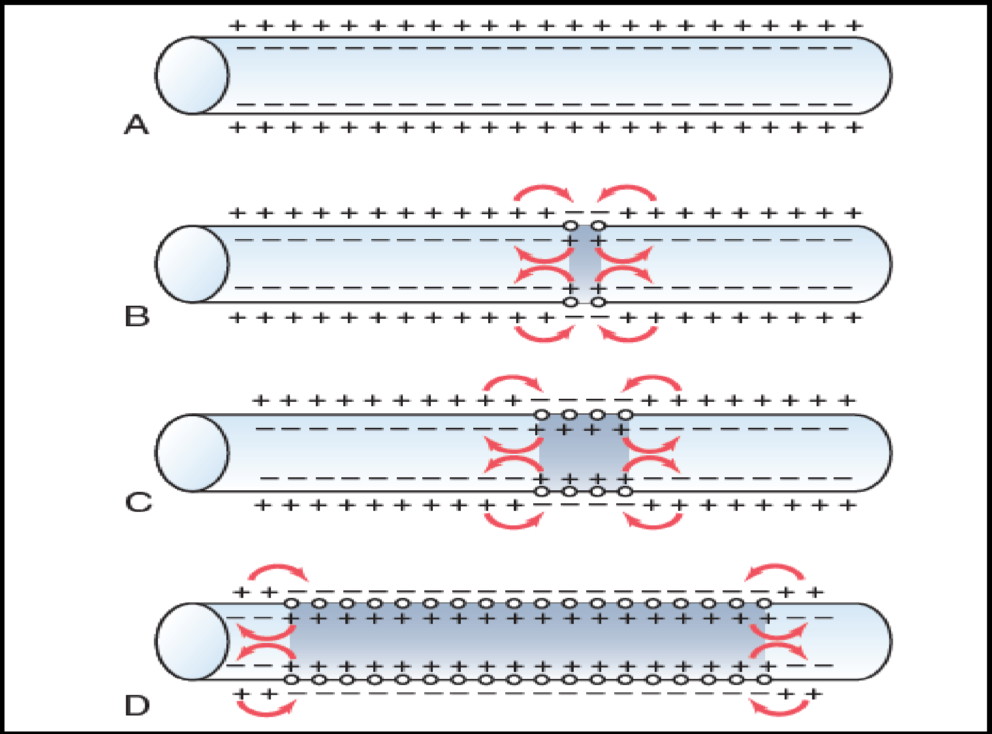
Hyperpolarization: **Why?**

- For a brief period following repolarization, the K+ conductance is higher than at rest.
- **<u>Na-K pump</u>** now starts to move Na+ out & K+ in against their concentration gradient.



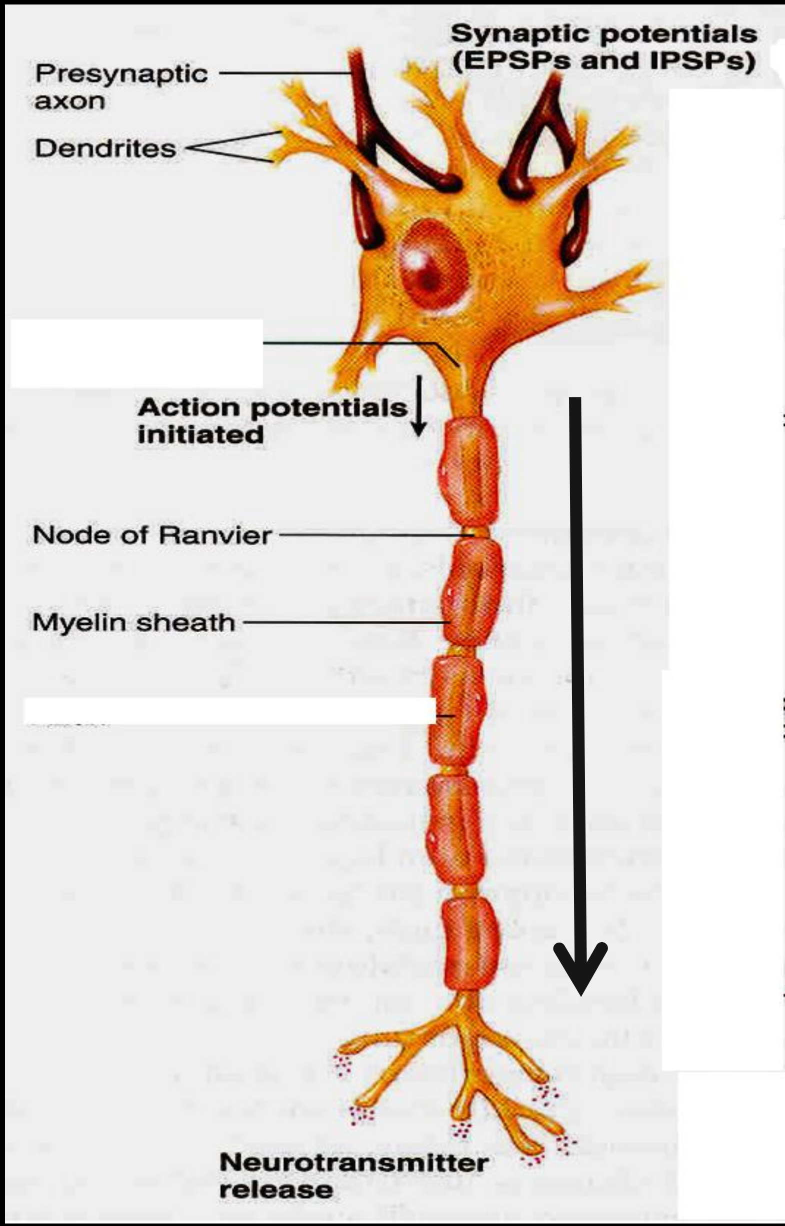
Propagation of the action potential

Artificial Electrical Stimulation



✓Under Artificial condition of electrical stimulation in the laboratory, the AP propagates in both directiions .

✓But normally AP starts in axon hillock & propagates distally in one directions



Refractory Period

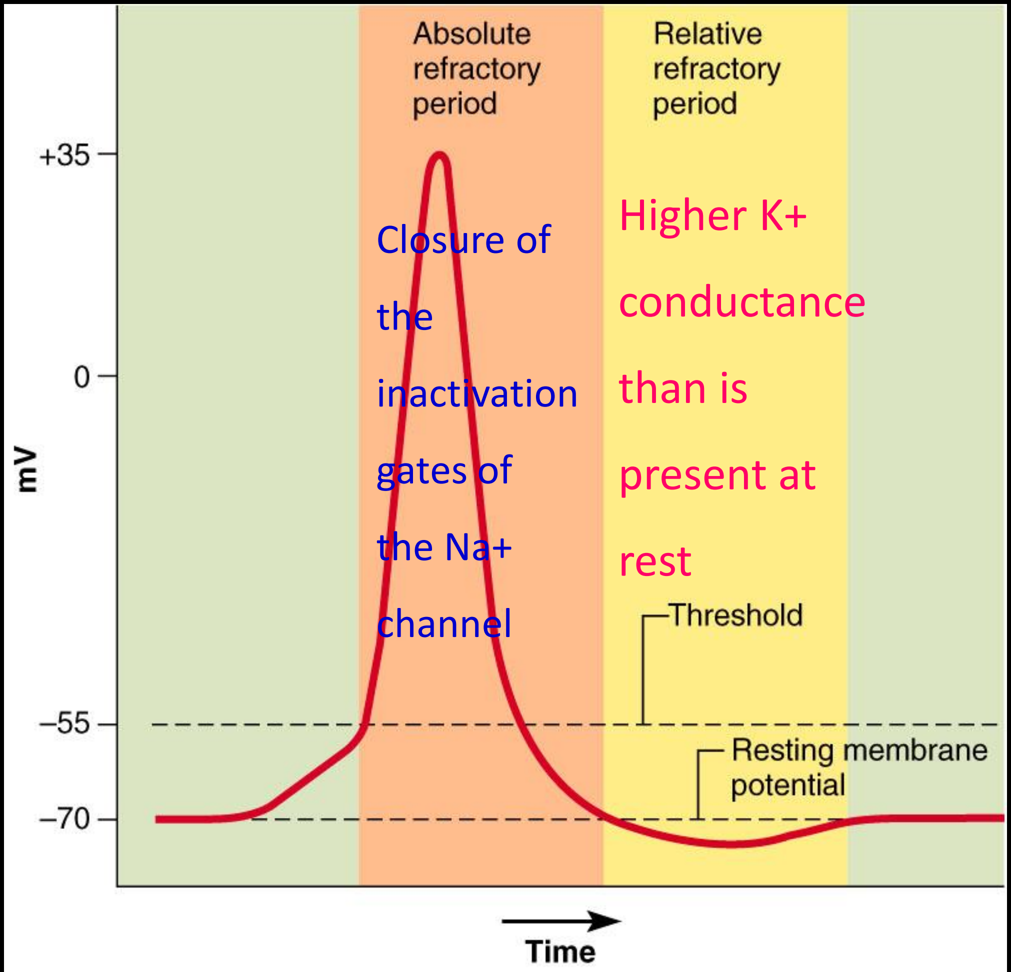
Two stages

- **Absolute refractory period**

The period during which a second action potential cannot be elicited, even with a strong stimulus.

- **Relative refractory period**

Can trigger new action potential if stimulus is very strong.



Conduction Velocity

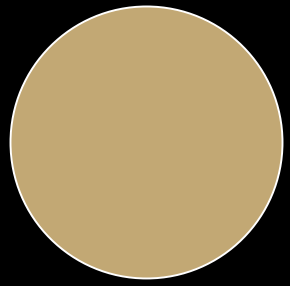
It is the speed at which action potentials are conducted (propagated) along a nerve or muscle fiber.

Mechanisms that increase conduction velocity along a nerve:

1- Nerve diameter.

The larger the diameter, the faster the transmission, **Because:**

-Large fiber offers Less resistance to local current flow & more ions will flow.



Faster conduction

Slower conduction

Conduction Velocity

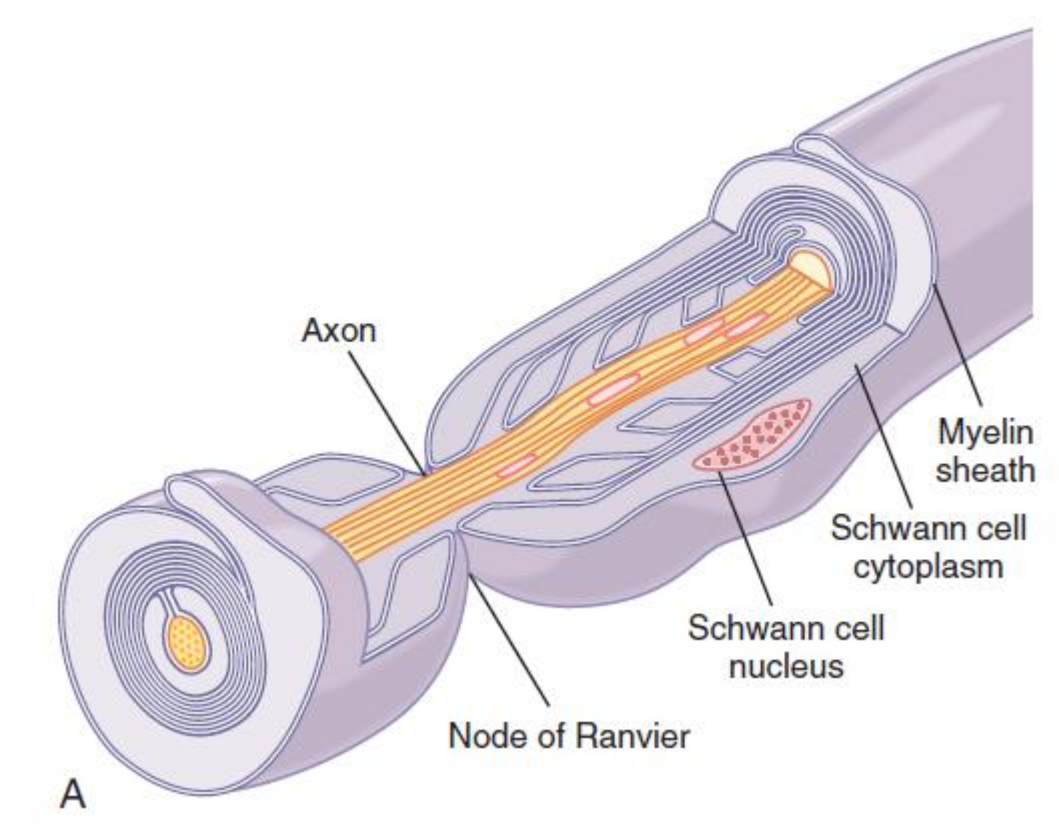
Mechanisms that increase conduction velocity along a nerve:

2- Myelination.

Myelin is an *insulator* that makes it more difficult for charges to flow between intracellular and extracellular fluids.

-The layers of Schwann cell membrane contain the lipid substance sphingomyelin which is excellent electrical insulator that decreases ion flow through the membrane.

- **Node of Ranvier:** small uninsulated area where ions can flow with ease.



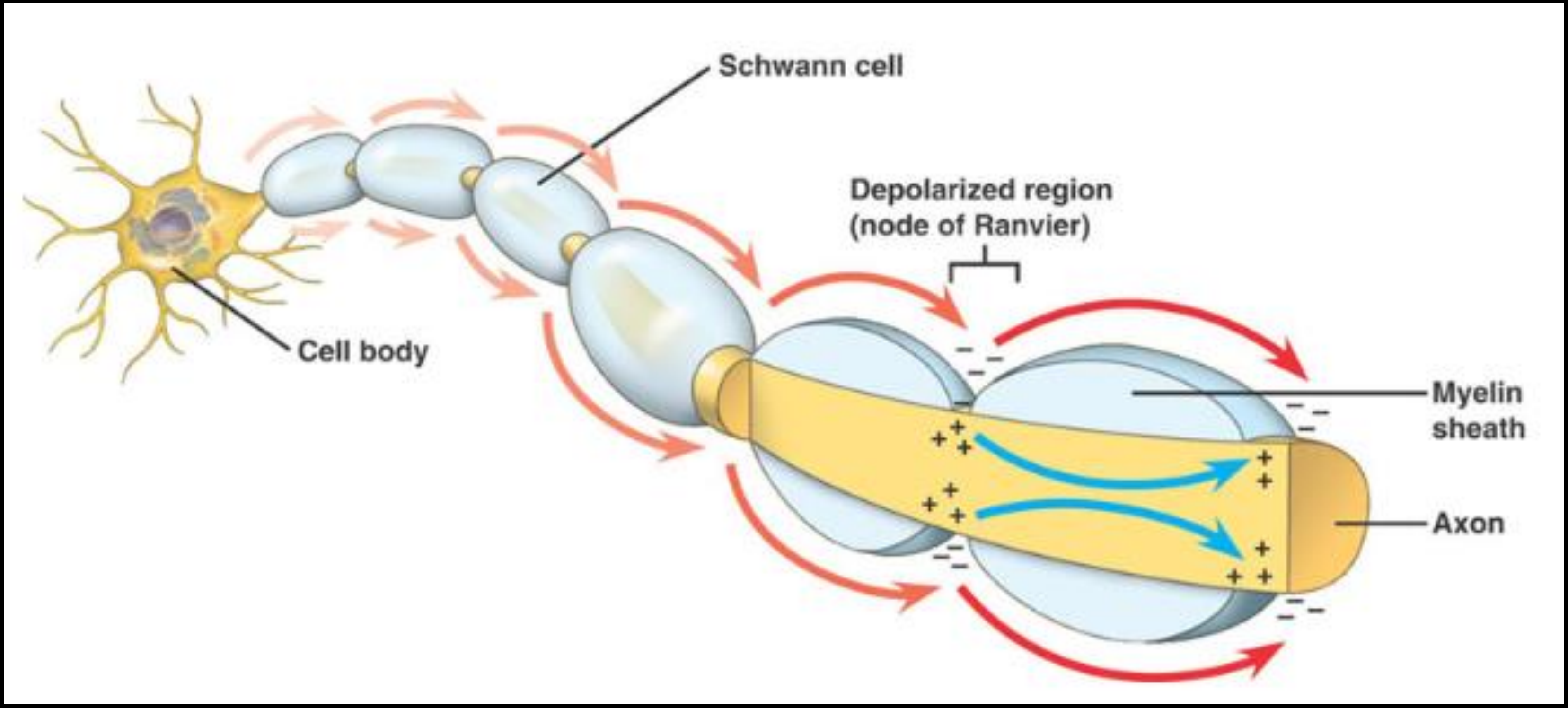
Saltatory Conduction

It is the jumping of action potentials from one node of ranvier to the next as they propagate along a myelinated fiber.

Value:-

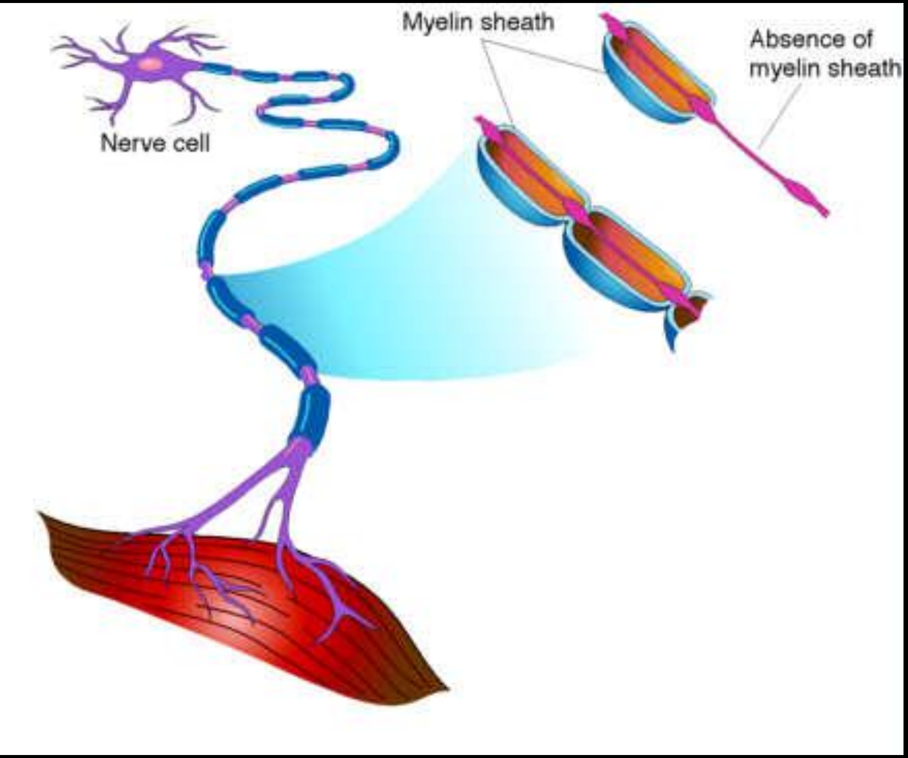
1- Increases conduction velocity.

2- Conserves energy for axon because only nodes depolarize.



What happens if myelination is lost?

- Multiple sclerosis
  - Autoimmune disease (Immune system attacks the myelin sheaths surrounding axons as well as the axons themselves).
  - Usually young adults
  - Blindness, problems controlling muscles
    - Ultimately paralysis
  - Scar tissues (scleroses) replaces some damaged cells.



- The End