



**Musculoskeletal Physiology**  
**(I) Physiology of Excitable  
Tissues : Nerve and Muscle  
( namely Skeletal Muscle )**

**by**

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# Lecture 4&5

## The Action Potential and Properties of Nerve Fibers

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## **Lecture 2&3 :- nerve action potential & properties of nerve fibers**

### **Objectives**

- By the end of this lecture, the student should be able to:**
- Appreciate Changes that occur through the nerve after stimulation by threshold (effective) stimulus**
- Define and draw giving membrane potential in mv and time course in msec and label all components such as threshold level(firing level), depolarization , spike overshoot, repolarization and positive after potential**
- Identify different types of voltage –gated channels**
- Correlate the conductance changes with opening (activation) or closing (inactivation) of relevant gates.**
- Distinguish between a local potential and an action potential.**
- Define absolute and relative refractory period on basis of excitability changes**
  
- Classify neurons by using letters or numbers on basis of diameters and velocity.**
- Define myelin sheath, myelinated and unmyelinated nerve fibers**
- Describe differences in the propagation of action potential in myelinated and unmyelinated nerve fibers.**
- Define all and none law.**
- Differentiate monophasic, biphasic and compound action potential.**

# Types of Nerve Fibers

## Classification According to Myelination

**1- myelinated** : have myelin sheath  
(diameter more than 1 $\mu$ m)

**1-type A fibers**

-( as somatic (motor) nerves to skeletal muscles)

**2-type B fibers**

-( as preganglionic autonomic nerves).

**2- unmyelinated** have no myelin sheath  
(diameter less than 1 $\mu$ m )

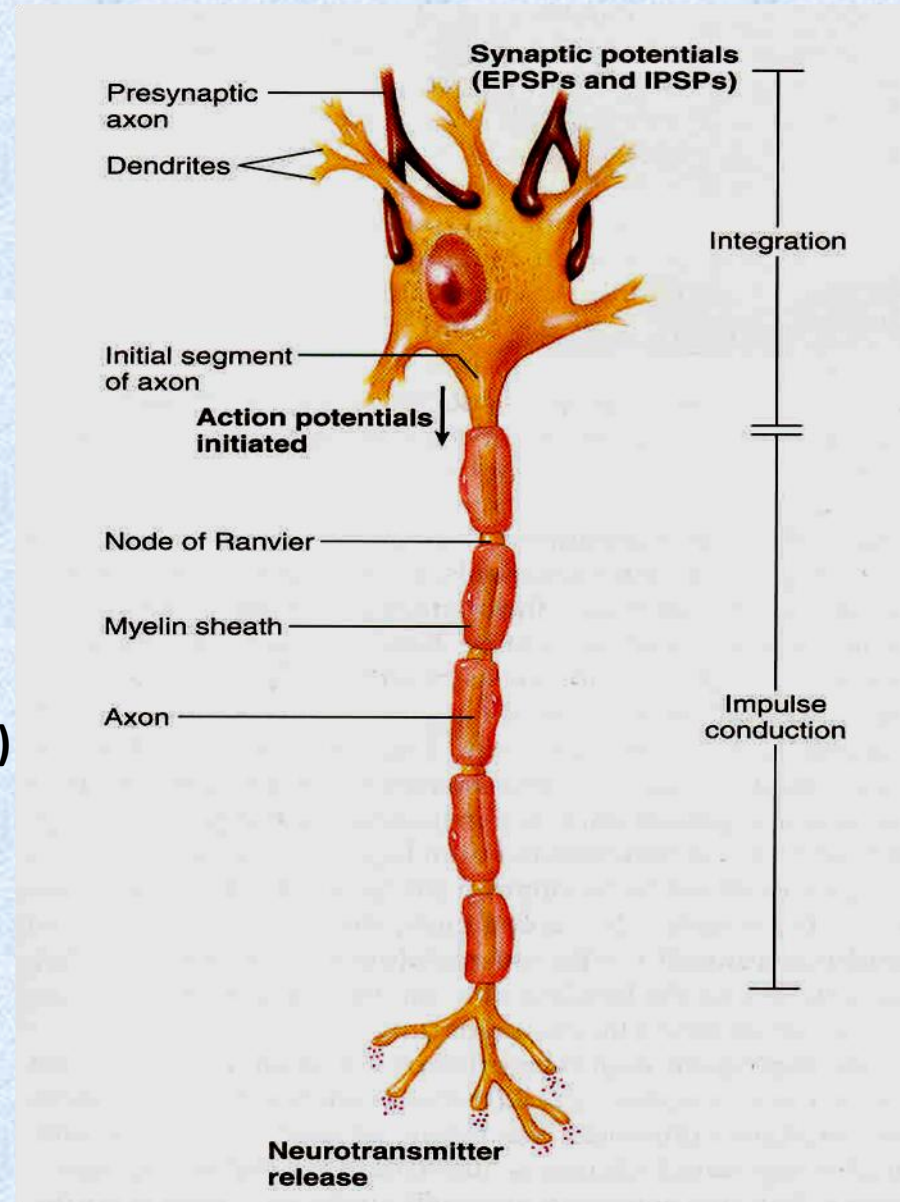
**-type C** ( postganglionic autonomic & pain fibers)

## Classification According to Diameter

A, B & C fibers

Diameter : A > B > C

Because conduction velocity depends upon diameter , A are fastest and C are slowest



- **-Myelin sheath** is formed by schwann cell which deposit lipid substance called **sphingomyelin around the nerve fiber**
- **-Interrupted at nodes of Ranvier (2-3 micron) at the junction between 2 cells.**

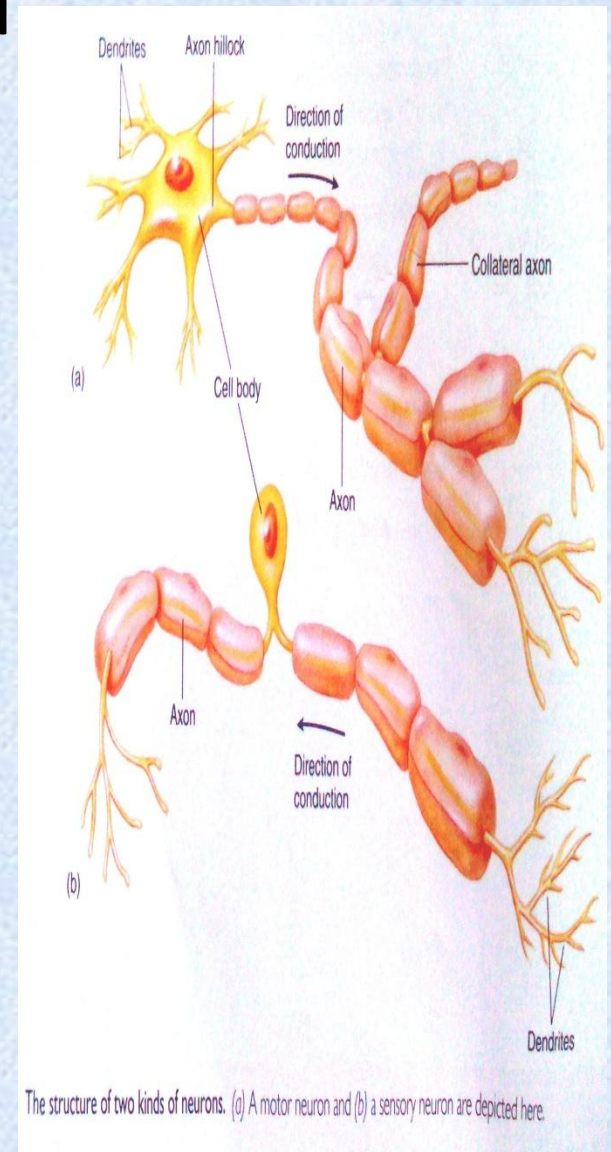
### **Functions of myelin sheath**

**1-insulator/** makes ion flow across the membrane much more harder & decrease ion flow through the membrane (decreases ion leakage )

**3- increase conduction velocity** ( because ionic currents need to “ jump ” ( from one node of Ranvier to the next )

**4-protection**

**5- conserve energy during transmission of AP**



The structure of two kinds of neurons. (a) A motor neuron and (b) a sensory neuron are depicted here.

Changes that occur in the nerve after stimulation by an effective stimulus are:-

1-Electrical changes

2- Excitability changes

3-Thermal changes

4-Chemical changes

# • 1- Electrical changes

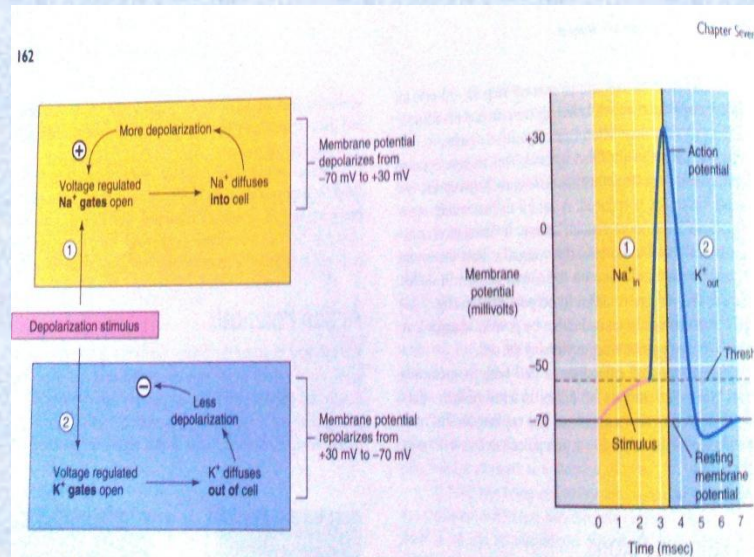


Figure 7.13 Depolarization of an axon affects Na<sup>+</sup> and K<sup>+</sup> diffusion in sequence. (1) Na<sup>+</sup> gates open and Na<sup>+</sup> diffuses into the cell. (2) After a brief

# The nerve action potential

## -The nerve action potential

It is potential difference along nerve membrane after stimulation by (Threshold = effective) stimulus

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-Nerve signals (impulses) are transmitted as nerve action potentials conducted along the nerve fiber as a wave of depolarization to its end.

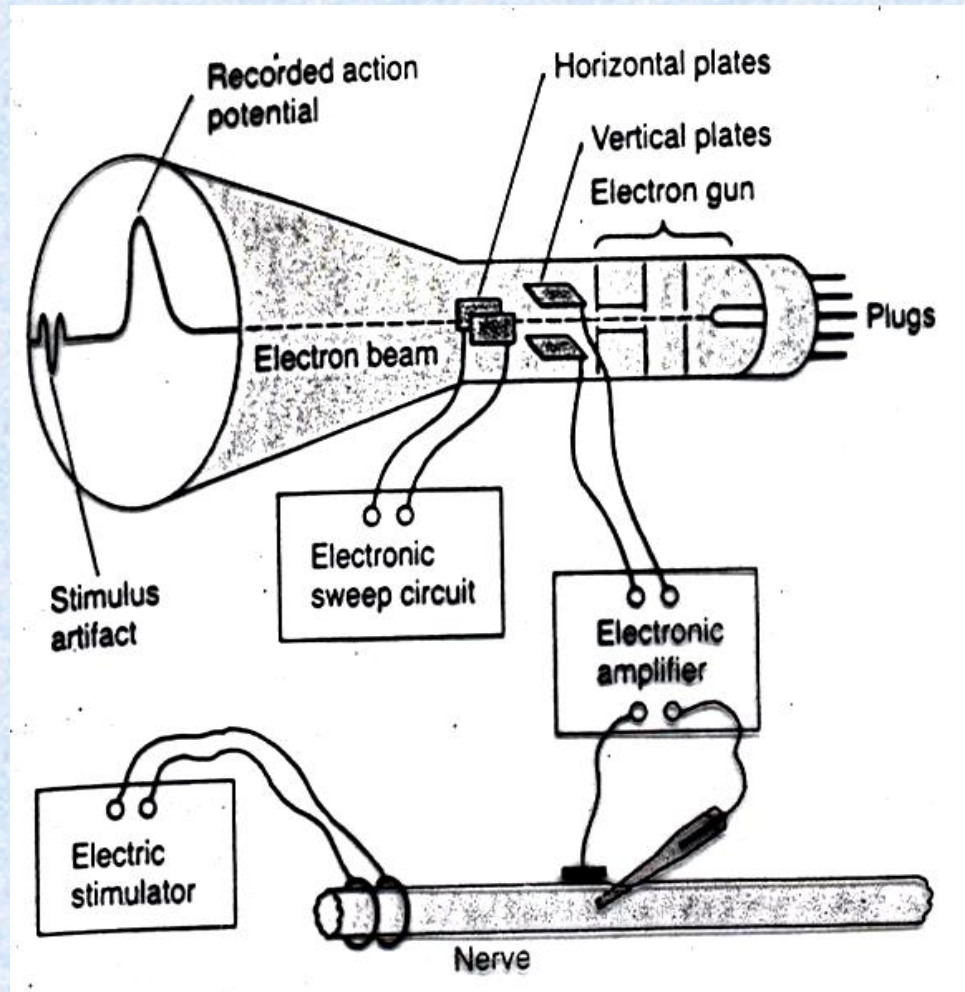
-The channels necessary for nerve action potential are:-

Voltage gated Na<sup>+</sup> & k<sup>+</sup> channels

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During action potential we use oscilloscope to measure rapid changes in membrane potential

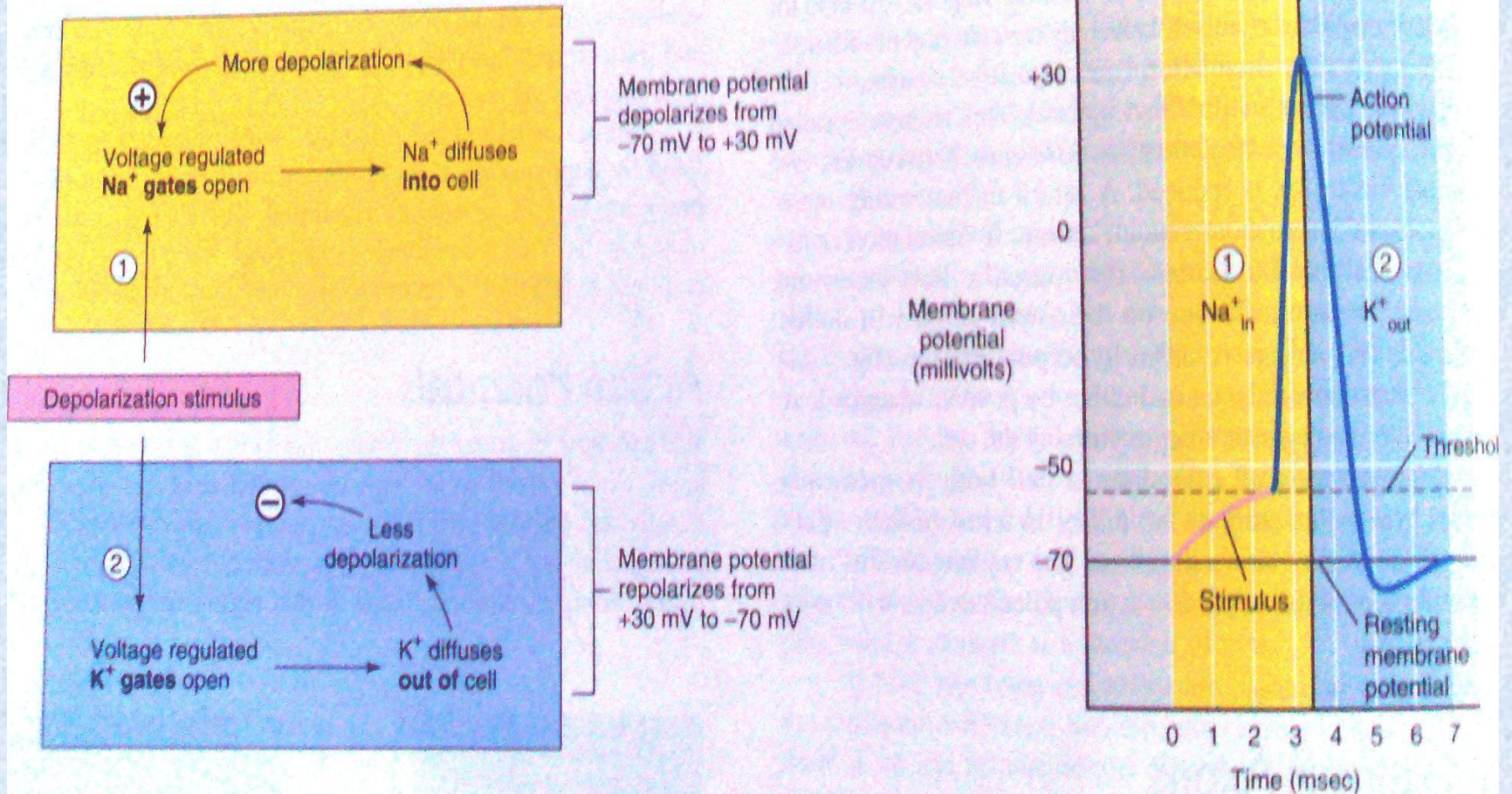


## Summary of stages of action potential are:-

**1-RMP**:-At the resting state( no stimulation) the membrane is **polarized** ( -ve inside = -90 mv)

**2-Depolarization**:- sudden **Na inflow (influx)**  
→ polarized state **is lost** & potential rises to positive values (reach zero & **overshoot** to +ve values).

**3-Repolarization**:- Na channels close & K channels open & **K outflow (outflux)** to outside → restoration of the normal -ve RMP.



**Figure 7.13** Depolarization of an axon affects Na<sup>+</sup> and K<sup>+</sup> diffusion in sequence. (1) Na<sup>+</sup> gates open and Na<sup>+</sup> diffuses into the cell. (2) After a brief

## Summary of events that causes AP (spike potential):-

### 1-Initiation of Action Potential (AP)& +ve feedback vicious circle that opens Na channels CAUSING DEPOLARIZATION STAGE

#### a- Gradual depolarization stage:-

- **Threshold stimulus** (An effective stimulus strong enough )->>>>> >to cause voltage gated Na channels to open & Na influx to inside nerve membrane >>>>>>rises resting potential from-90 towards zero
- Rise of membrane potential >>>>> open more Na channels & more Na influx (+ve feedback vicious circle) until all voltage gated Na channels open.
- The increase in membrane potential from -90 to -65 mv cause explosive opening of all Na channels & Na conductance is 5000 times great → massive Na<sup>+</sup> influx  
so -65mv is called firing level.

## b-Depolarization stage:-

- Sharp & rapid depolarization occurs & membrane potential reach zero value & then overshoot to reach +35 mv (reversal of polarity) occurs & the inside of the cell becomes +ve
- The peak of AP is reached at (+35 to +40 mV).
- At this value all Na<sup>+</sup> channels become refractory (begin to close suddenly & no more Na<sup>+</sup> entry)

& Depolarization ends

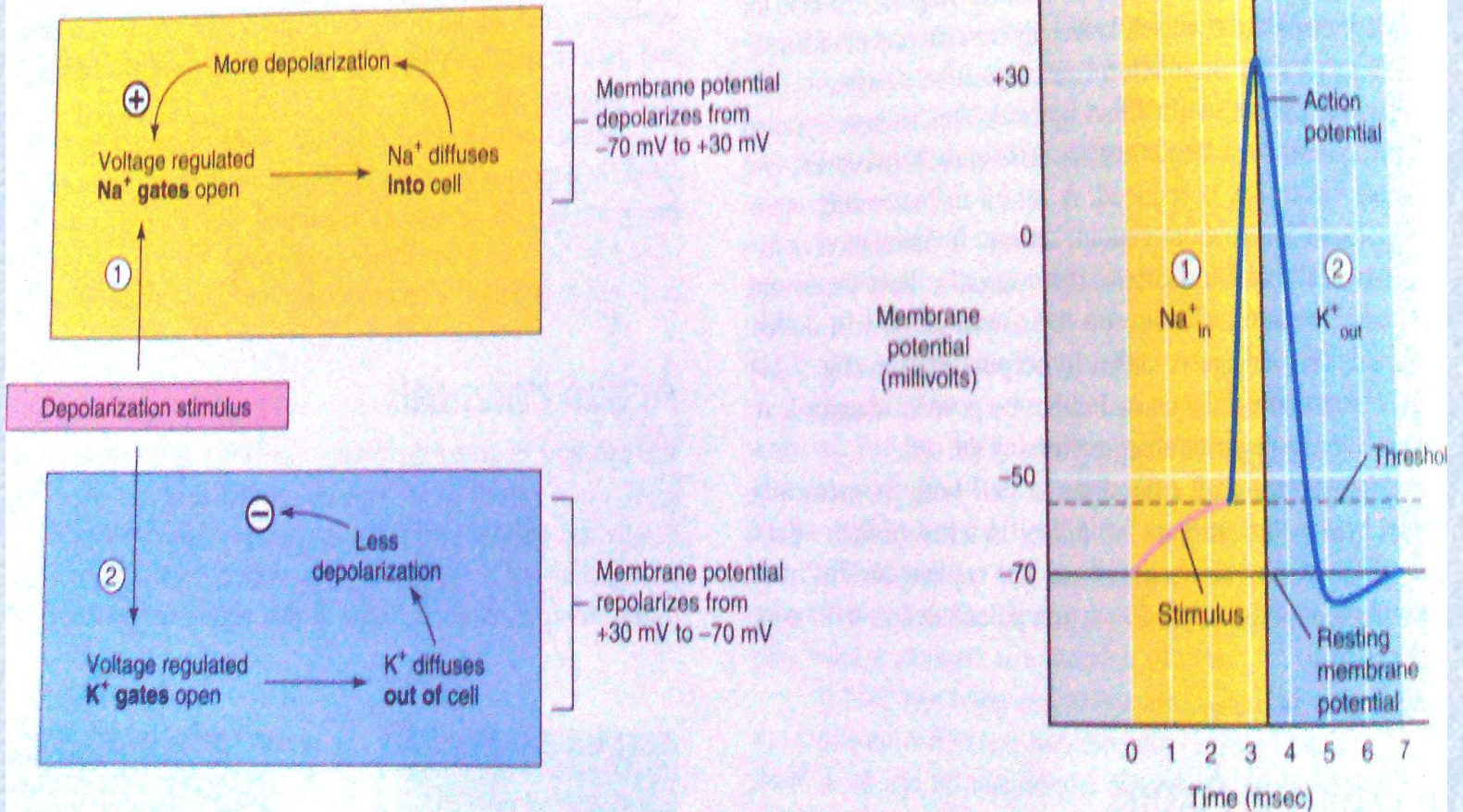
## c-Repolarization (return to polarized state):-

Cause:- due to high K conductance( flow) to outside of nerve membrane by opening of all K channels >>>>> (K outflux carrying positivity to outside & raising negativity inside)

(Also zero flow of Na to inside as all Na channels close)


 causes negativity inside

- Membrane returns to resting potential ( drop from +35mv towards zero then to negative resting potential -90 mv)



**Figure 7.13** Depolarization of an axon affects Na<sup>+</sup> and K<sup>+</sup> diffusion in sequence. (1) Na<sup>+</sup> gates open and Na<sup>+</sup> diffuses into the cell, (2) After a brief

**D- Positive after potential** (In some nerves)  
membrane potential becomes more negative  
than resting level

(because many K channels remain open & K  
outflux continue-  causing more -ve  
inside = hyperpolarized state)

-(positive after potential is wrong terminology it is historical one)

.



**E- Re-establishment of Na & K ionic gradients & return to resting membrane potential:-**

**a- Na that had influxed in & K that had outfluxed out returned to original state by Na-K pump ( active process - need ATP & ATPase)**

**b- Closure of some K channels so keep some K<sup>+</sup> inside(raise positivity inside)**

**-Gain of these two processes is:-**

**K remain inside causing some positivity to raise potential towards -90 mv**

–Duration of nerve action potential is 1-1.5 ms

The factors necessary for depolarization & repolarization are :-

1-Na voltage –gated channels important for both depolarization & repolarization

2- K voltage –gated channels important for repolarization

## A- Voltage-gated Na channels:-

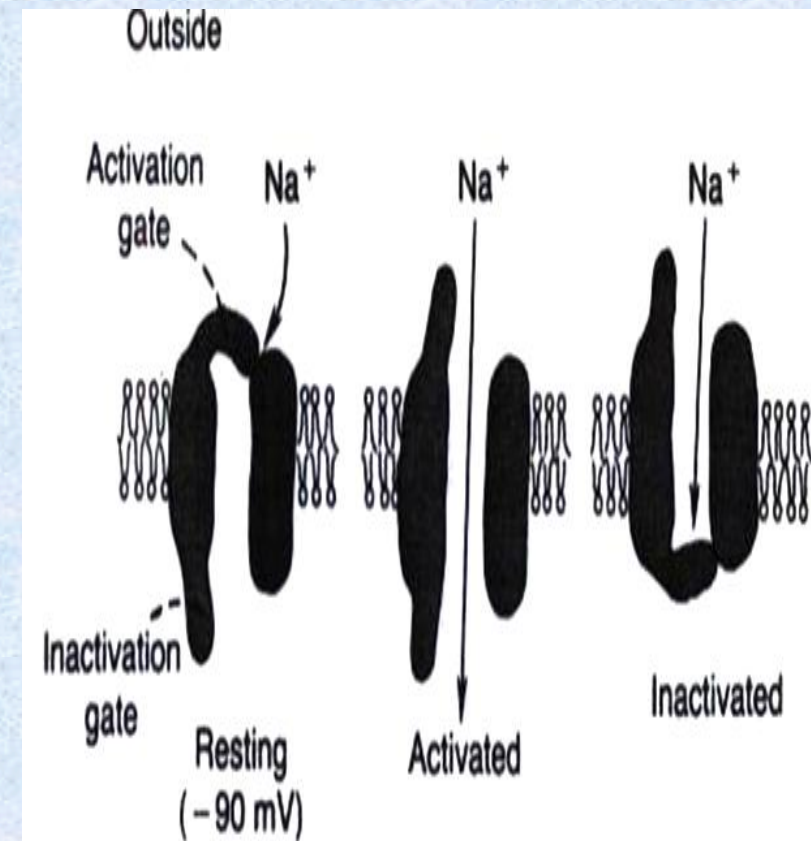
- -Outer activation gates & inner inactivation gates.

- 1-Resting state:-at RMP -90 mv activation gates close & inactivation gates open →

- No Na entry.

- 2- Activated state:-after stimulation, the membrane potential rises at a voltage between -90 to -65mv, **conformational change** occur & activation gates open (now both gates are open) & Na influx causing depolarization

- 3- Inactivation state:- inactivation gates close slowly while the activation gate is still open & they close completely at + 35 mv & stops Na influx & repolarization begins.

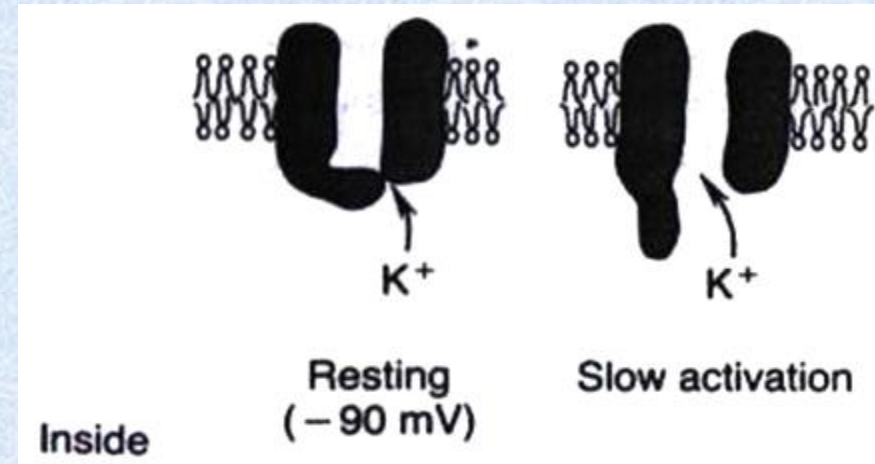


## B -Voltage –gated K channels:-

### 1- Only one gate,

a-at RMP (resting state ) the gate of K is closed & no K pass to out.

- b- after stimulation & between -90 to zero mv, the potassium channel opens slowly & K outflux begins slowly
- - They open completely only when Na gates close & when Na influx stop) causing rapid repolarization

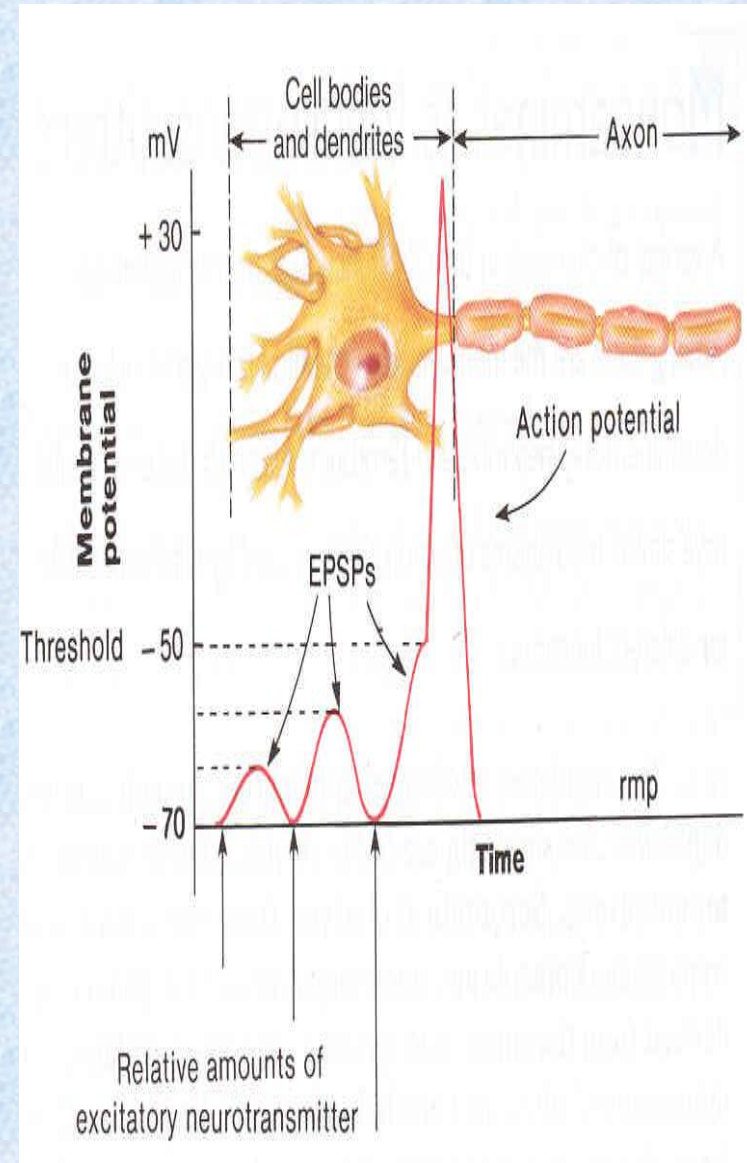


## -Acute local potential (acute local response):

A very weak stimulus ( not threshold) can cause local change in membrane potential e.g from -90 to -85 mv which is not sufficient for generation of AP, this is acute subthreshold potential ( which is graded متدرج and does not propagate ). It should increase to threshold level to produce AP.

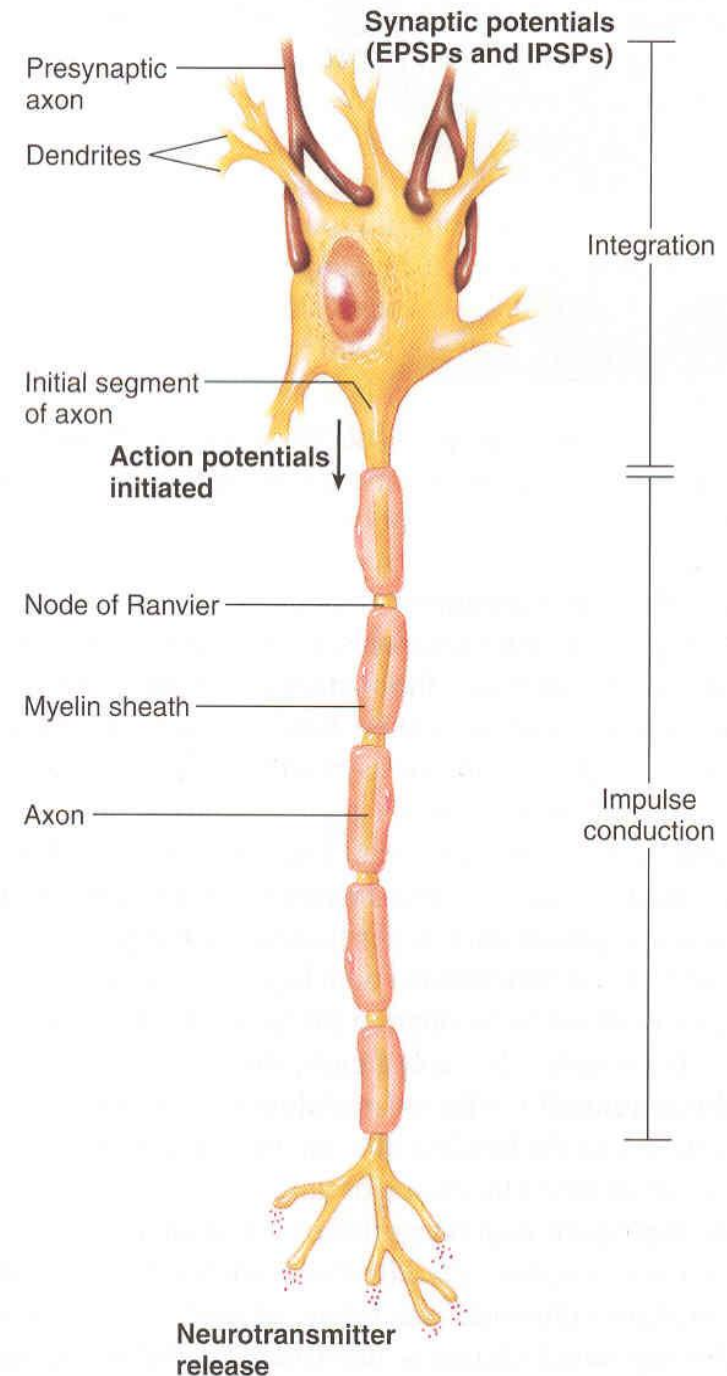
-The AP differs from local response in that AP is:-

- (1) not graded
- (2) obeys All-or None Law
- (2) propagated (conducted for long distances .



# All or nothing principle:-

- The nerve respond to a threshold stimulus maximally or does not respond at all ( there are no half solutions)
- Once threshold stimulus applied, it gives AP spread all over the nerve fiber
- -its intensity ( peak amplitude) can not increase by increasing stimulus intensity ( or by suprathreshold)
- subthreshold stimulus can not elicit action potential (but produce a local response which does not obey this law)



## Direction of propagation of AP:-

- In one direction from axon hillock to nerve terminal

- (experimentally) if nerve stimulated at its midportion, AP pass in both directions

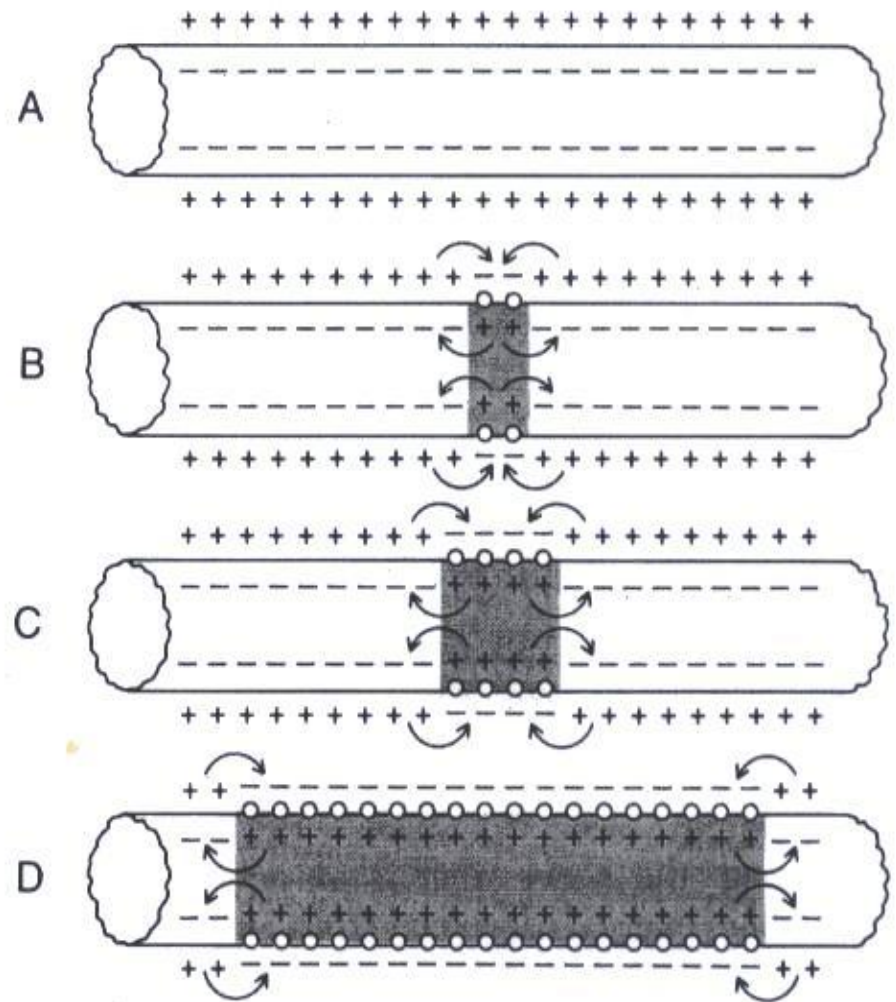


Figure 5-8 Propagation of action potentials in both directions along a conductive fiber.

Under Artificial condition of electrical stimulation  
in the laboratory

## Na & K conductance (flow) during action potential:-

1-At resting state , before AP:-

K conductance through K leak channels is 50-100 times as Na.

2- At onset of action potential:-

Voltage gated Na channels activated & Na conductance is 5000 folds, at the same time voltage gated K channels begin to open slowly

3- During depolarization :- Na conductance / K conductance >1000 fold

4- At peak of AP :- Na channels close & voltage gated K channels open &

K conductance increase

- At repolarization:- the ratio Na conductance/ K conductance decreases.

4-At end of AP :-return to -ve potential , close voltage gated K channels & no K+ conductance



## **2-Excitability changes**

# the ability to respond to a second stimulus

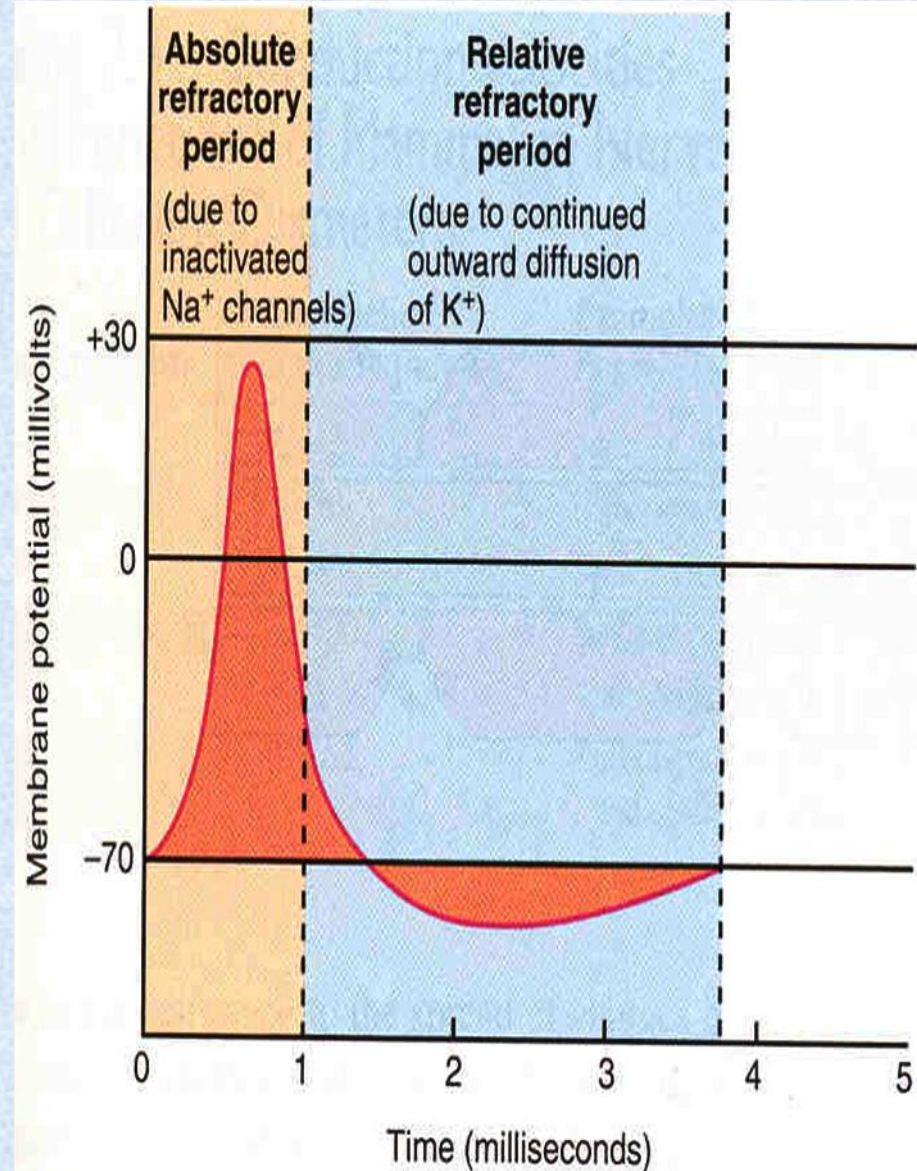
## 1-Latent period

## 2-absolute refractory (متمرد) period

- During depolarization & early repolarization

- during it the nerve can not be excited by a a second stimulus & a second spike action potential can not be elicited whatever strength of the stimulus (even suprathreshold)

-(because all Na channels are already opened & Na influx occurred & a new stimulus can not open further Na channels



### 3- Relative refractory period:-

-It is during the late third of repolarization ( $\frac{1}{2}$  to  $\frac{1}{4}$  absolute refractory period in its duration)

-it is the period during which a second action potential of low amplitude can be elicited by stimulus stronger than normal suprathreshold)

Why suprathreshol stimulus?

because :\_\_

1- Na channels still inactive so need stronger stim to open

2- rapid flow of K to outside during repolarization oppose any stimulation to occur ( so need stronger stim to cause a new AP.)

**Propagation of action potential (Transmission of depolarization process along a nerve = spread of nerve impulse**

**1- in myelinated nerve fibers by:-**

**Saltatory conduction ( jumping)**

**✓ - AP occurs at nodes of Ranvier & directed from node to node, through axoplasm inside & ECF outside by jumping**

**APs can develop only at the Nodes of Ranvier → Where**

- (1) ions can relatively easily flow in & out**
- (2) there are voltage-gated channels**

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## Value:-

**1-↑ velocity of conduction (100 m/sec in large myelinated nerve fibers in comparison to 0.25 m/sec in small unmyelinated nerve fibers)**

**2-Conserve energy for axon because only nodes depolarize ( need little energy for re-establishment of Na&K ions).**

**3-Insulation by myelin sheath allow repolarization to occur rapidly (with many K channels have not open)**

## 2- Non- myelinated nerves by :-

local circuits=Continuous Conduction =point to point

- depolarization pass by local circuits.
- depolarization in an area, + ve charge carried inward by Na ions flow for several 1-3 mm in the axon core & increases the voltage inside the nerve to threshold value to cause depolarization in a new area & Na channels open & depolarization spread to new areas

## **Recording of AP:-by cathode ray oscilloscope**

**1-Monophasic AP:-one microelectrode outside & one inserted into nerve fiber**

**2-Biphasic AP:-2 microelectodes placed on outside of nerve fibers( biphasic means one in one direction then second in second direction**