L2 & L3 The Action Potential and Properties of Nerve Fibers

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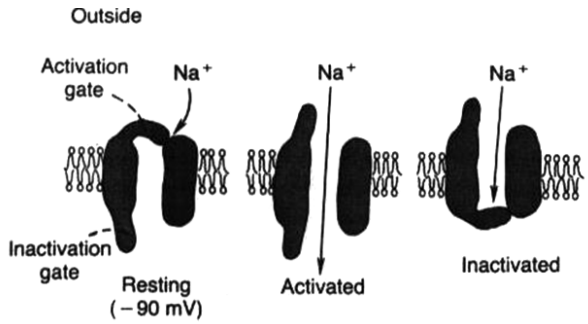
Voltage-Gated Ionic Channels

These are channels that open when a stimulus depolarizes the nerve membrane to values between the values -70mV to -50 mV .

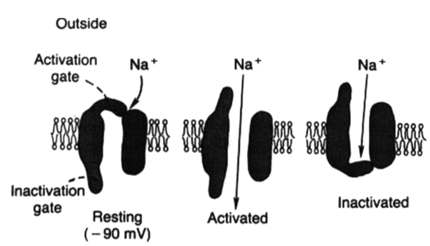
The Voltage-Gated Na+ Channel (1)



- Has 2 gates : one on the outer side of the membrane and is called the activation gate , and another one on the inner side of membrane called the inactivation gate .
- And this channel has 3 states :
- (1) Resting state : in the resting cell , when the MP = RMP = -90 mV , → the activation gate is closed → this prevents entry of Na+ to the interior of the cell via this gate.

The Voltage-Gated Na+ Channel (2)

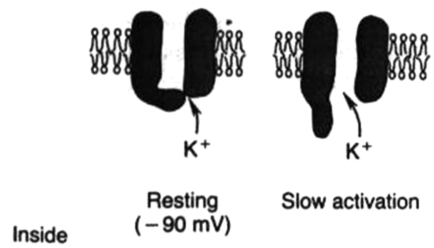
- (2) Activated state : when a stimulus makes the MP less negative than the RMP , and takes it to the range -70 to -50 mV (threshold level) , this flips the activation gate suddenly to the open position → this is called the activated state (where both gates are open) → permeability to Na+ becomes increased 500 to 5000 times → N+ pours into the cell in large amounts , depolarizing it .
- After one AP , the inactivation gate will not open (& the cell becomes refractory) until the MP has gone back to the resting level (-70 to -90mV).

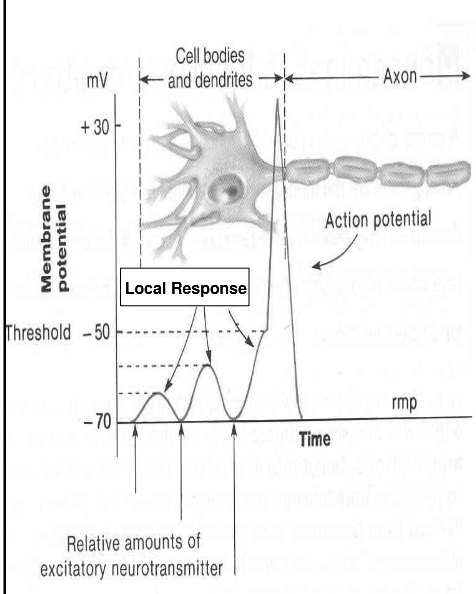


- (3) Inactivated state : A few milliseconds after the activation gate opens , the channel becomes inactivated :→ while the activation gate is still open , the inactivation gate is closed .

The Voltage-Gated Potassium Channel

- During the resting state , the gate of the potassium channel is closed , and K+ can not enter through it .
- Shortly after depolarization , when the sodium channel begins to be inactivated , the potassium channel opens .
- Thus , the simultaneous decrease in sodium entry into the cell , and increase in potassium exit from the cell → greatly speed the repolarization process .





- When the cell is inactive (resting) → we call the MP : Resting Membrane Potential (RMP) .
- When the cell is stimulated → a small (subthreshold) stimulus can produce a <u>Local Response</u> (which is graded and does not propagated).
- However , if the stimulus is strong enough to exceed Threshold Level (the level in MP between local response and action potential) → an action potential is generated .
- The AP differs from local response in that it is (1) not graded obeys All-or None Law) , and (2) propagated (conducted for long distances .

The Action Potential (AP)

(nerve impulse & muscle AP)

A/ ELECTRICAL CHANGES DURING THE AP

(1) We need to start from the baseline i.e., Resting state of the membrane potential (RMP) : the resting membrane potential(RMP) .

(2) Depolarization phase of the AP

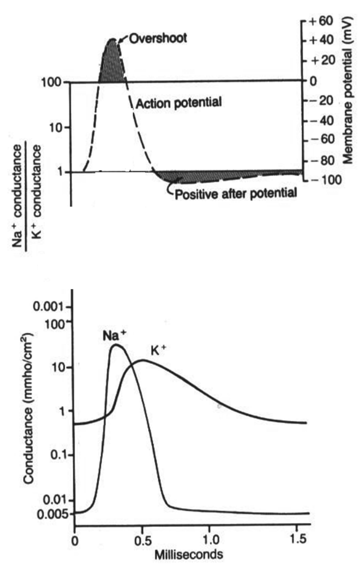
(3) Repolarization phase of the AP .

The Nerve Action Potential (Nerve Impulse) (1)

As mentioned before, in a resting cell the membrane permeability to K+> Na+ (due to K+ leak channels) & the RMP= -90 mV.

(1) A stimulus strong enough to carry the MP to the threshold level (-65 mV) causes explosive activation of voltage-gated Na+channel → 5000 fold increase inNa+ conductance (permeability) →massive Na+ influx (inflow)→depolarization.

- Then overshoot (reversal of MP) occurs as the inside of the cell becomes +ve ; & the peak of AP is reached at +35 - +40 mV.

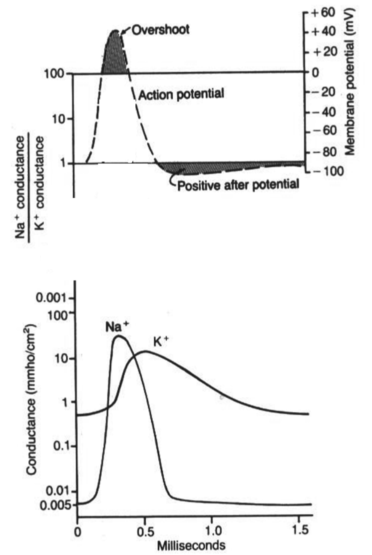


The Nerve Action Potential (Nerve Impulse) (2)

(2) Repolarization phase is due to delayed opening of K+ channels (Na+ channels are already inactivated) → rapid K+ efflux (outflow) → the MP quickly returns toward the resting level .

(3) In some nerves there is a Positive After Potential, due to continued outflow of K+, which causes the membrane to becomes hyperpolarized

- However , the Na+-K+ pump soon restores the MP to the resting (RMP) level .



Excitability Changes During the AP

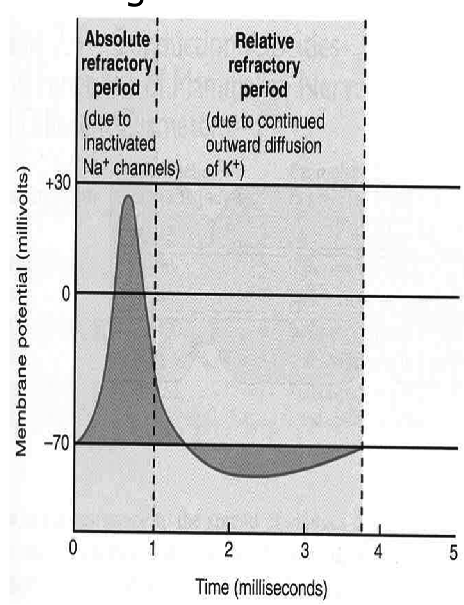
Immediately after an AP there is :

(1) Absolute Refractory Period : where no stimulus , however strong , can produce a second AP . It is due to inactivation of Na+ channels .

(2) Relative Refractory Period : a stimulus higher than threshold is needed to produce an AP . Due to continued outflow of K+ .

ALL-or-Nothing (None) Law

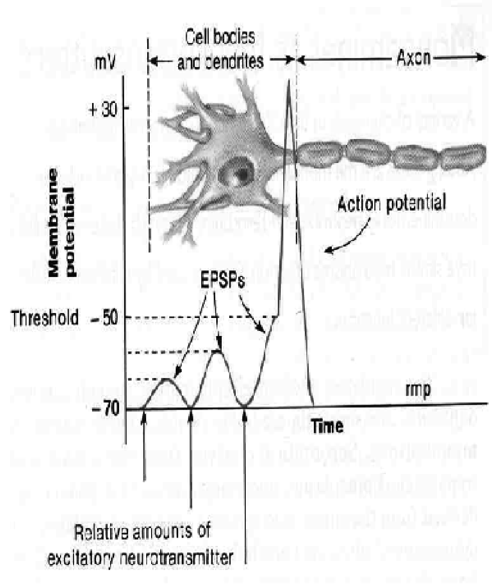
A stimulus , if threshold, produces a full AP , otherwise no AP is produced (there are no half solutions , but a local potential can be producd by a subthreshold stimulus .) .



ALL-or-Nothing (None) Law

A stimulus , if threshold, produces a full AP , otherwise no AP is produced (there are no half solutions , but a local response (EPSP) can be producd by a subthreshold stimulus .) .

- Therefore , the AP obeys All-or –None Law , but the Local response does not obey this law .



Types of Nerve Fibers

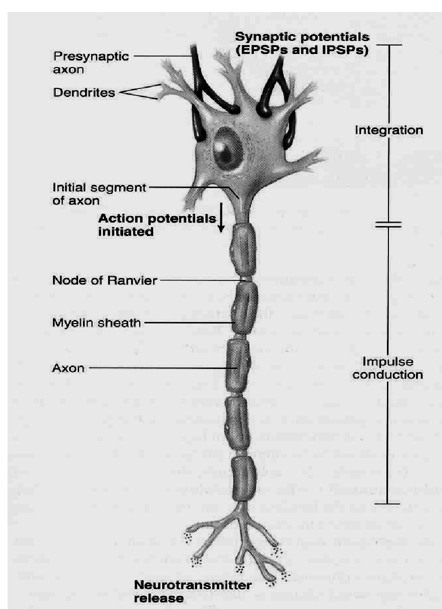
Classification According to Myelination

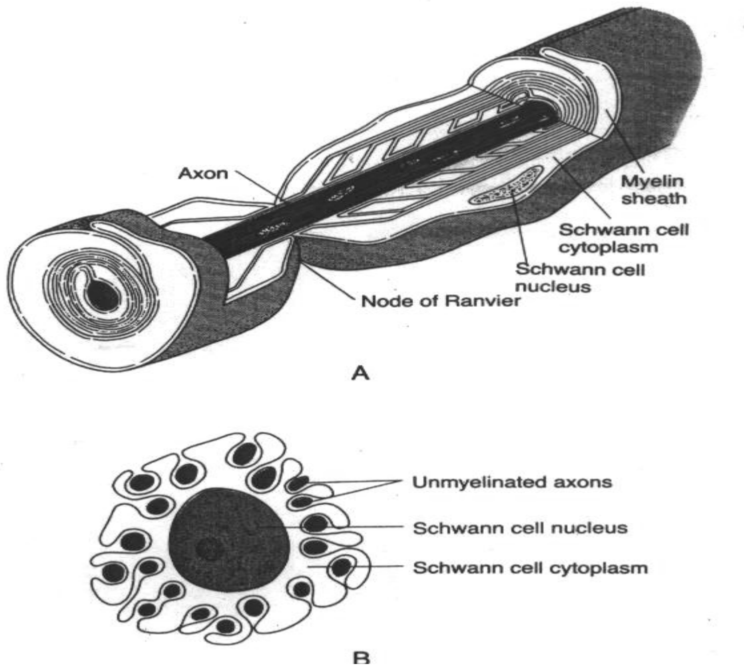
(1) Myelinate (have myelin sheath) and
(2) Unmyelinated

- In both myelinated and unmyelinated fibers impulses are propagated (conducted) by Ionic current Flows .
- However , in unmyelinated fibers these currents are local , and in myelinated ones they are saltatory (jumping) from one Node of Ranvier to the next one .

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
- A and B are myelinated
- C are unmyelinated





- Myelin is an excellent insulator : it makes ion flown across the membrane much more harder than otherwise →
- decreases ion leakage (Na+ to inside and K+ to outside) and loss by a factor of 5000 times , hence it makes the myelinated nerve
- (1) more economical (because it prevents loss/dissipation of membrane charge

  {RMP } , which is due to accumulation of Na+ outside and K+ inside) ,and

  (2) faster-conducting (because ionic currents need to “ jump ” over relatively long distances (from one node of Ranvier to the next) .

Saltatory Conduction (propagation) of APs in myelinated nerves

(A) Myelin sheath is absent at the Nodes of Ranvier , each of which is about 2 – 3 microns (micrometer) wide.

- ✓ Therefore ionic flow (& consequently flow of ionic currents) can easily take place only at the Nodes of Ranvier .

(B) Moreover , voltage-gated channels are present only at the Nodes of Ranvier .

- Therefore , APs can develop only at the Nodes of Ranvier → Where

(1) ions can relatively easily flow in & out

(2) there are voltage-gated channels .

Contiguous (Continuous) Conduction in Unmyelinated nerves

(A) Myelin does not completely wrap around & cover the axon →

- Consequently , ionic flow can take place anywhere along the membrane at much less difficulty than in myelinated fibers .

(B) Voltage-gated channels are present all along the membrane

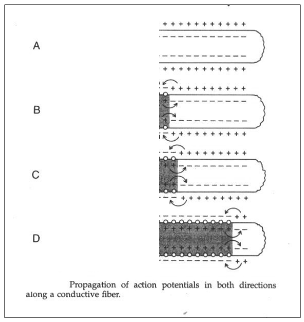
- Consequently an AP can develop anywhere along the membrane under suitable conditions (if the threshold potential is reached).

(N.B. in myelinated nerves threshold potential can only be reached at the Nodes of Ranvier).

Propagation (Conduction) of AP :By Circular Current Flows

In unmyelinted fibers : propagation of AP is by Contiguous Conduction → i.e., by Local Circular Currents, & conduction velocity(CV) = 0.25-3.0 m/s.

In myelinated nerves : Saltatory Conduction (Long Distance Currents) → impulses jump from one node of Ranvier to another) which is (1) Faster (2) Economical : conserves energy for the axon .



Point-to –Point conducti in unmyelinated nerve

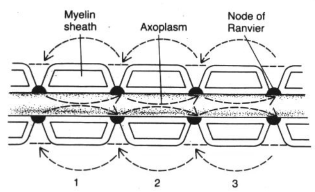
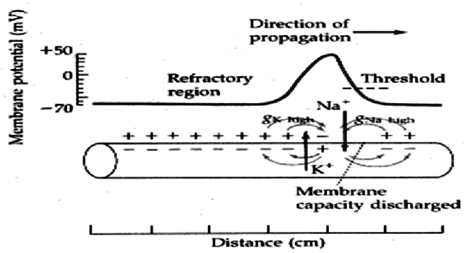
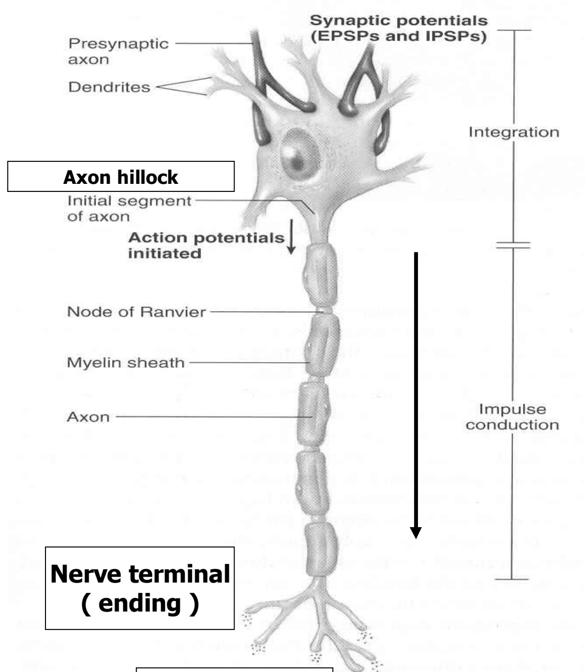


Figure 5–12 Saltatory conduction along a myelinated axon.



- NB : In the laboratory , if we electrically stimulate a nerve fiber at a point , the AP travels in both direction .This is , of course , NOT a normal way , but artificial stimulation .
- However , normally the AP travels along the nerve fiber along one direction only : from its origin at the axon hillock (in the cell-body) → towards the nerve ending (terminal) .



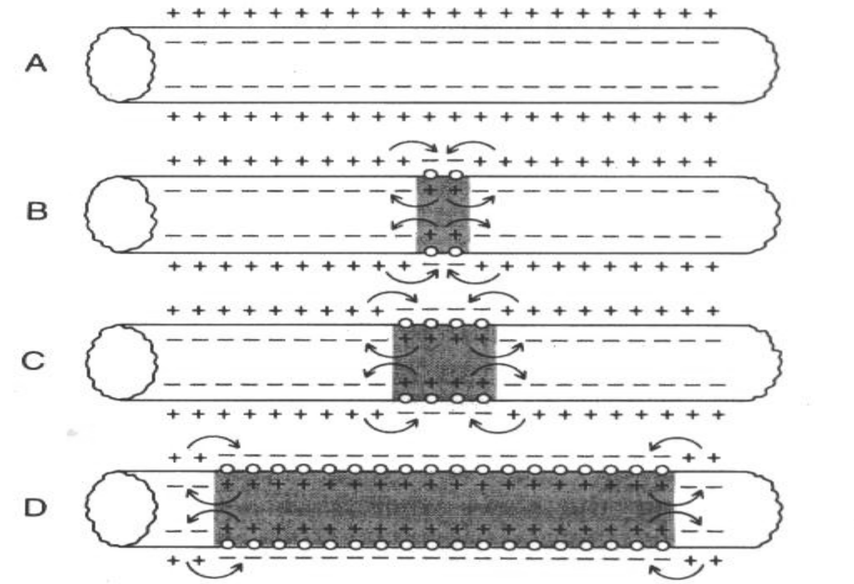


Figure 5–8 Propagation of action potentials in both directions along a conductive fiber. → **Under Artificial condition of electrical stimulation in the laboratory**

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