Human Physiology

Lecture 7 – Wednesday 2/3/2016

"Action Potential" with Dr. Esraa' Kiwan

(Slides are on e-learning)

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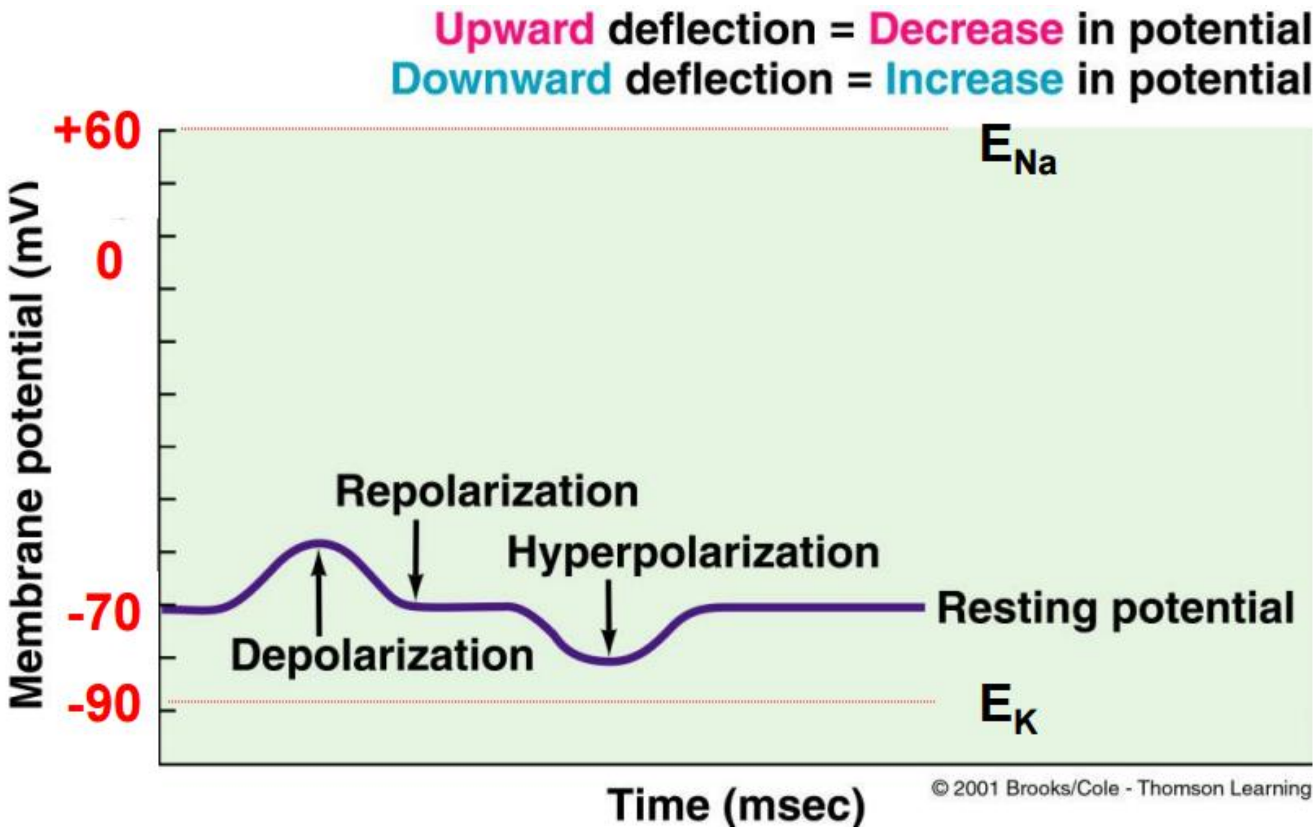
PSU

Note: (F) means a question that could come in the first exam.

Reminder**: Membrane potential** (الجهد الغشائي) is the separation of opposite charges across the plasma membrane.

What do we call the changes that happen to resting membrane potential?

- Reminder: All cells have resting membrane potential.
  However, only excitable cells can change the resting membrane potential.
  The excitable cells are muscle and nerve cells.
- The function of nerve cells is to transmit messages across the body, that's why nerve cells need to change resting membrane potential (in order to transmit electrical signals), the function of muscle cells is to perform muscle contraction, that's why they need to change resting membrane potential.



- **Polarization (الاستقطاب):** Separation of charges (separating negative and positive charges). An example of polarization is resting membrane potential (as
- **Depolarization (إزالة الاستقطاب):** decrease in negativity (e.g. from -70mV to -50mV), when the charge starts to move towards 0mV.
  (F) Depolarization is also called an **upward deflection** on the graph

(“upward” because we are moving from a negative number like -70mV to a less negative number like -50 mV)

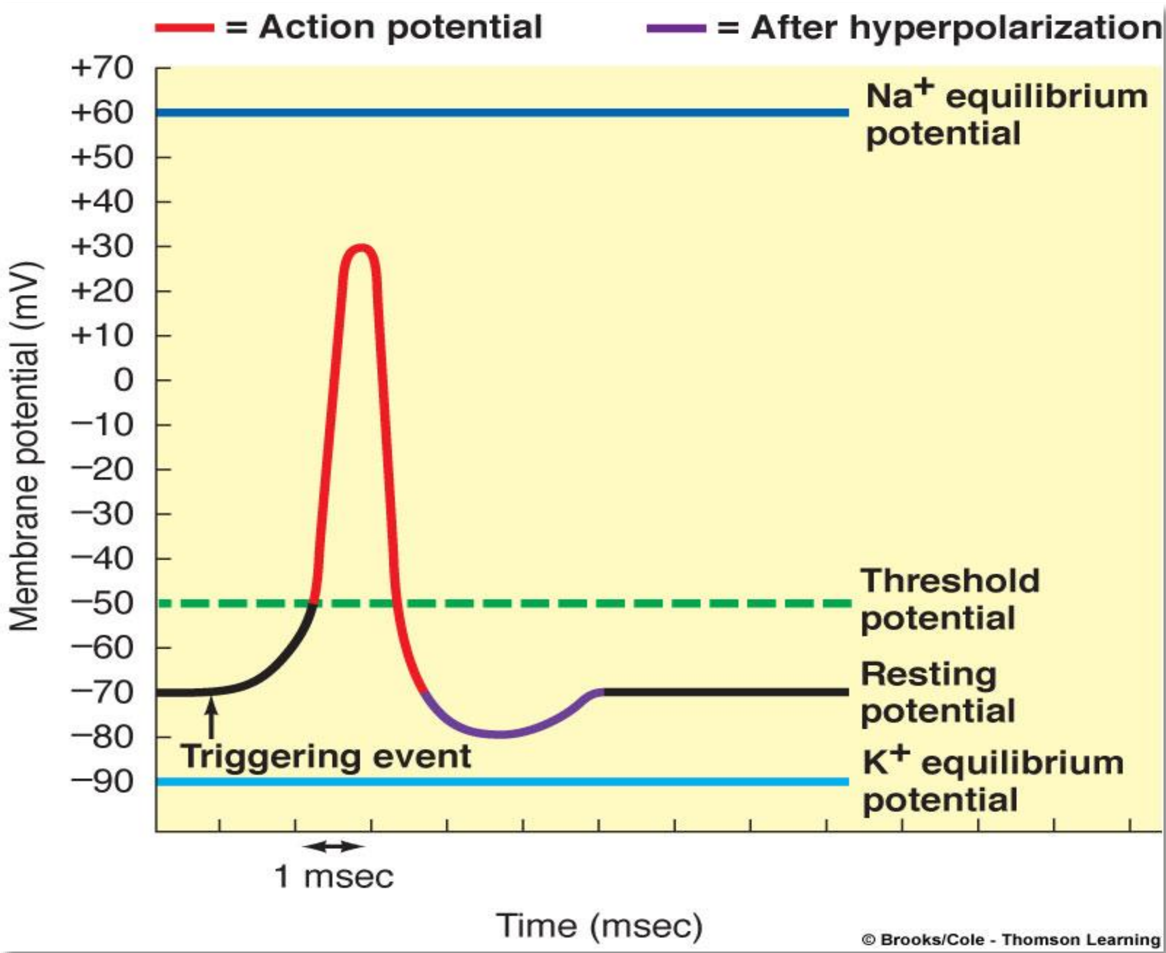
- **Repolarization (عودة الاستقطاب):** when the membrane starts to return to the resting state (e.g. from -50mV to -70mV)
- **Hyperpolarization:** an increase in the negativity of the membrane that causes it to become more negative than the resting state (resting state is at -70mV, so hyperpolarization makes it go from -70mV to e.g. -80mV).
  (F) Hyperpolarization is also called a **downward deflection** on the graph (“downward” as the cell becomes more negative//because the potential increases)

How does the change in polarity happen?

- Reminder: inside the cell, we have A- (negatively charged intracellular proteins). This A- has 0 permeability, meaning the negative charge will ALWAYS be inside the cell // we cannot bring it outside. This means that the only type of charge that can enter/leave the cell membrane is positive (K^+/Na^+).
- To achieve depolarization, we need to increase the permeability of the positive ions so that they can move inside the side. Meaning decrease the negativity inside of the cell // we want to cause an **influx** (تدفق) of positive ions to the cell.
- To achieve hyperpolarization, we need to increase the negativity the cell inside of the cell. This happens when the permeability of ions from inside to the outside increases // we want to cause an **efflux** (خروج) of positive ions to the outside of the cell.

There are two types of changes to resting membrane potential: Action potential & Graded potential. This lecture we will only study **action potential**.

- Action potential is a brief/rapid (very fast, for a short amount of time) change to the membrane potential.
- During action potential, the inside of the cell becomes more positive than the outside. The membrane potential reaches +30mV.



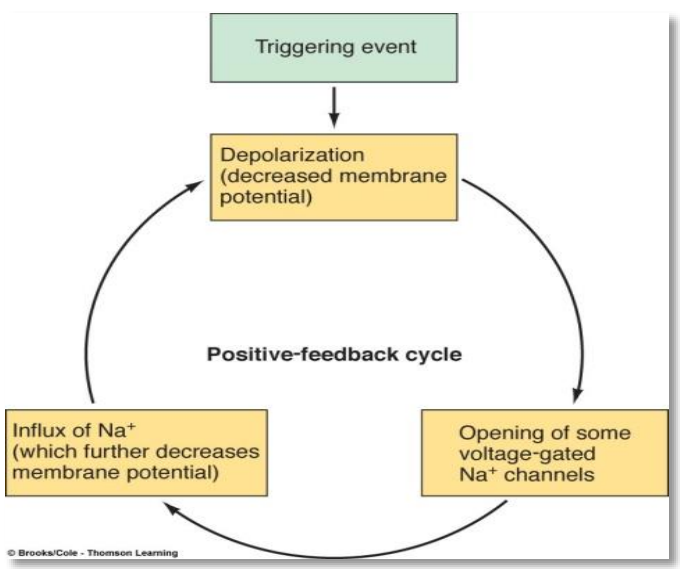
- First step: the triggering event (leads to decrease in potential/negativity from -70mV to -50mV)
  the triggering event is stimulation of the cell. For example, you are exercising and your muscle cells need to contract. This stimulates the cell, and causes it to begin with action potential.
- Second step: threshold potential (very fast decrease in negativity)
  the negativity will keep decreasing slowly from step 1, until it reaches a point called "threshold potential" (threshold = عتبة). Once it reaches the threshold, the negativity will decrease at a very fast pace until it reaches the positive peak of +30mV. **Depolarization** happens in this step.
- Third step: returning to resting state (very fast increase in negativity)
  after it reaches +30mV, the cell's negativity will quickly start to increase in order to

return to resting state.
Repolarization happens in this step.

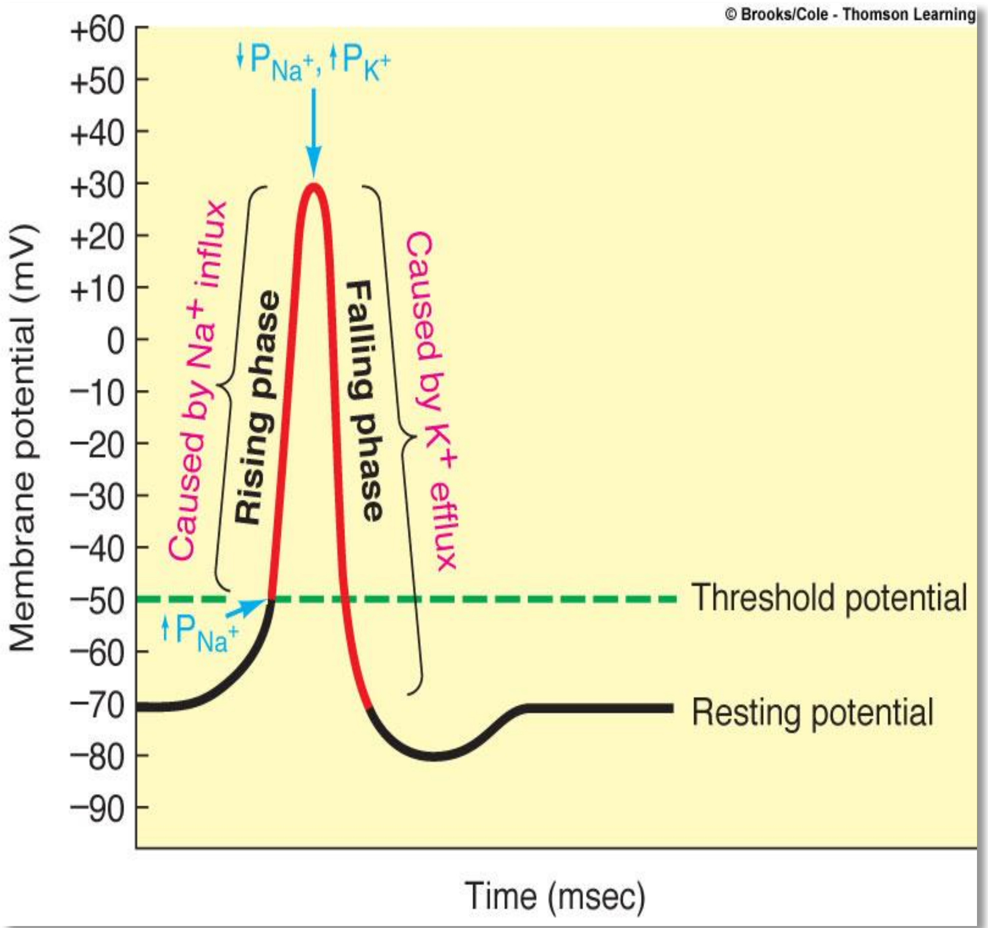
- Action potential is the red color in the graph.

Why does depolarization/repolarization happen?

- The reason depolarization & repolarization happen is due to a change in membrane permeability (نفاذية الخلية).
- We know that the permeability of K^+ is 50-75 times greater than the permeability of Na^+. However, during action potential this permeability changes because of the opening of **voltage-gated ion channels** (voltage gated Na^+ channel & K^+ channel)
- From the name: "voltage" gated ion channels, are channels that depend on the voltage of the cell. Action potential causes these voltage gated channels to open (**at resting state they are all closed**).
- A triggering event causes stimulation of the cell // and this causes <u>some</u> of the voltage gated Na^+ channels to open.
  Since Na^+ is found outside of the cell, depolarization of the cell causes Na+ to start to move inside (influx) through these channels.
- As Na^+ starts to move inside, the negativity of the cell starts to decrease. This causes more voltage gated Na^+ channels, which also lets more Na^+ inside (causing a larger decrease in negativity of the cell).



- This is an example of a positive feedback cycle (ارتجاع ايجابي): (1) opening of some voltage gated channels lets some Na^+ ions inside. (2) These ions cause a lot of Na^+ channels to open, which causes an influx of Na^+. The permeability of Na^+ is 600 times greater than that of K^+ at this point. (3) The influx of Na^+ causes depolarization of the cell membrane, and this cycle repeats.

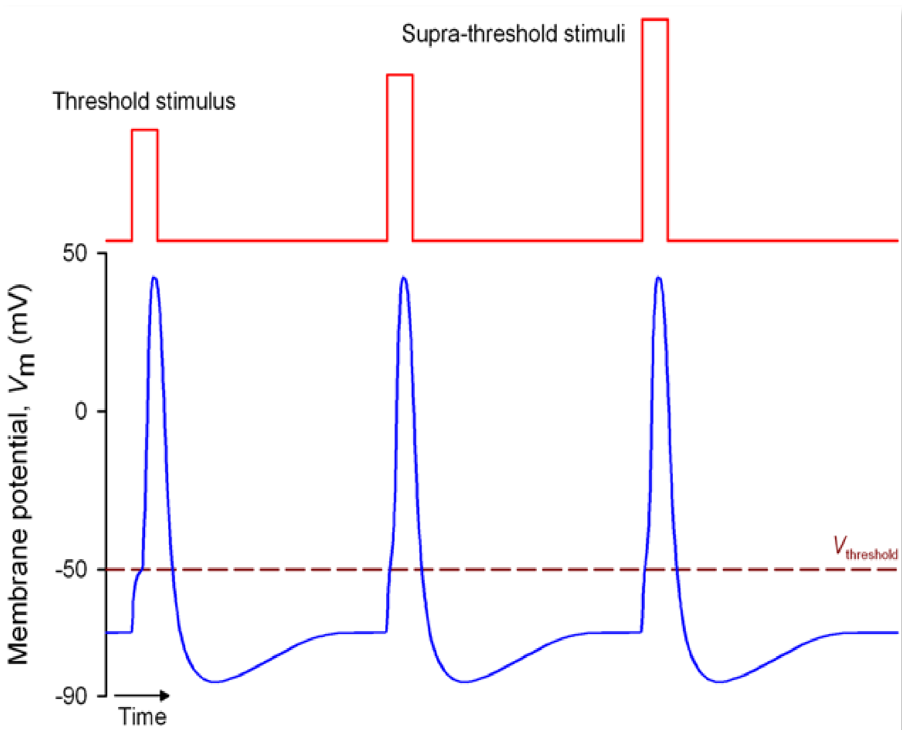


- **The rising phase**: due to Threshold potential (the explosive increase in permeability of Na^+ // the permeability of Na^+ becomes 600 times greater than that of K^+), the membrane potential will decrease in negativity & reach about +30mV. This number is close to E_{Na+} (Na^+ equilibrium potential at +60mV).
  (F) Rising phase is caused by an influx of Na^+.
- However, before reaching the peak potential (+30mV), voltage gated Na^+ channels will start to close/inactivate which stops the Na^+ from entering the cell.
- **The falling phase**: the closing of Na^+ channels causes the opening of K+ channels, which lets K^+ leave or go outside of the cell. This causes an increase in negativity (repolarization), and this increase in K^+ causes more K^+ channels to open. This causes an explosion in permeability of K^+ // the permeability of K^+ becomes 300 times greater than that of Na^+. The membrane potential starts to become closer to E_{K+} (K^+ equilibrium potential at -90mV)
  (F) Falling phase is caused by an efflux of K^+.

- **(F)** The Na/K pump maintains the balance between the cations inside & outside of the cell // Na/K pump restores the distribution of ions.
- Hyperpolarization occurs after action potential is done, as a result of the time needed to close all the voltage gated K^+ channels.
  (closing all the K^+ channels takes time, and a result more K^+ will leave the cell causing the cell to become more negative than resting state // hyperpolarization)

Properties of action potential

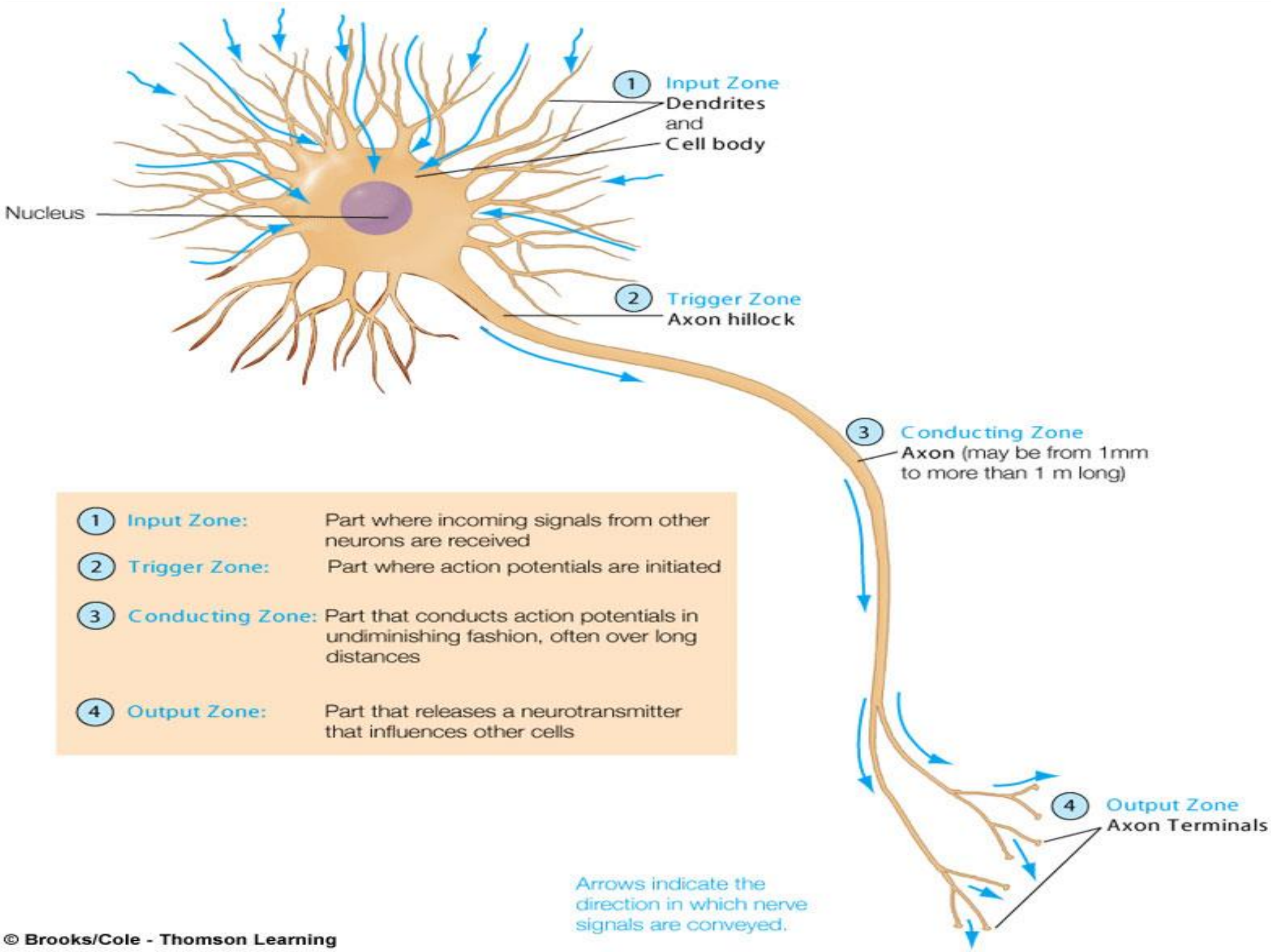
- **(F)** Action potential works by the "all or none" law.
  Either it reaches threshold potential (action potential happens), or it does not reach threshold potential.
- Action potential has the same magnitude no matter how strong the stimulus is:



As you can see from this graph, action potential reaches the same peak (+30mV), even if the stimulus is stronger. Why? Because action potential goes by the "all or none" law.

- How do we find the magnitude of the action potential? It starts at -70mv. It reaches +30mV. (30 – (-70)) = 100. As you can see from the graph above, they all have the same magnitude (100).
- However, a stronger stimulus leads to the frequency becoming stronger. A higher frequency means more cells will reach the threshold potential.

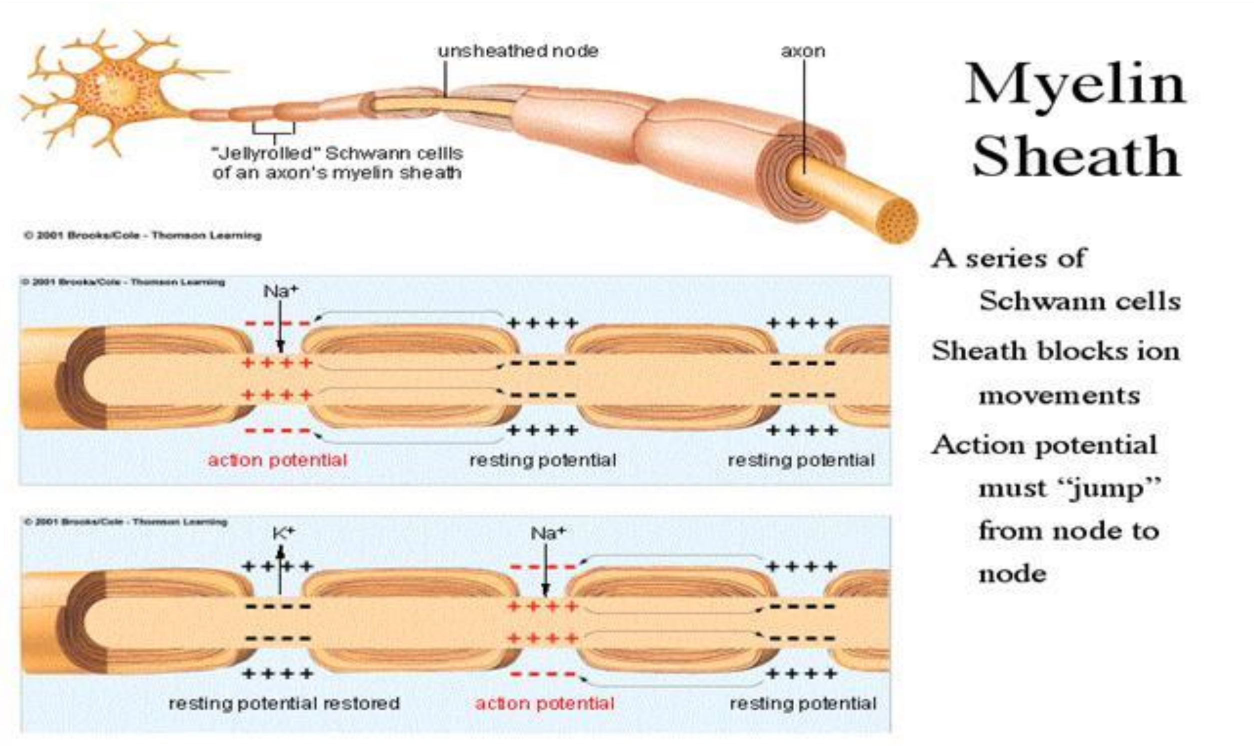
- Action potential is propagated/transmitted (منقول) through nerve fibers.
  The action potential spreads through the membrane by a non-decremental fashion.
  "Non-decremental": This means that the magnitude of action potential does not change when it is being transferred. Example: At the beginning of the nerve fiber the magnitude is 100, and at the end of the nerve fiber the magnitude is still 100.



- This is a diagram of a **neuron**, a specialized cell that carries nerve impulses (or messages) through the body.
- **Input zone**: the dendrite & the cell body – the parts that receive the stimulation.
- **Trigger zone**: "axon hillock" – the site of action potential production
- **Conducting zone**: the axon – the part that carries the action potential
- **Output zone**: the axon terminals
  so the action potential is carried in one direction from the hillock to the terminals.

The conduction of action potential depends on the type of neuron.

- There are **myelinated** neurons and un-myelinated neurons.

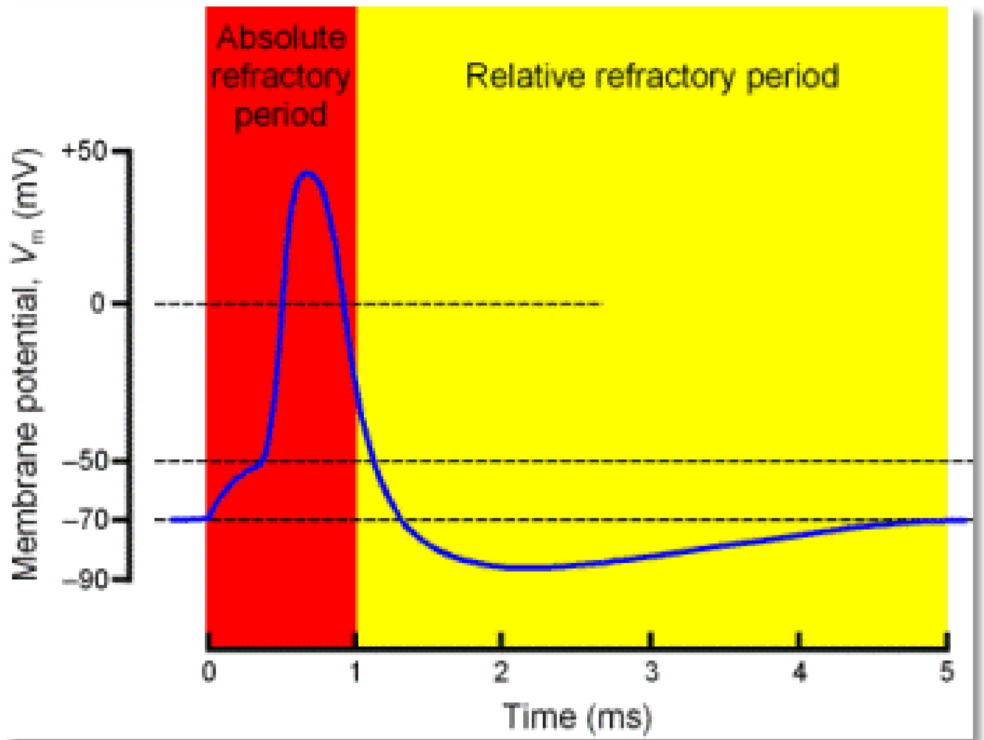


Myelinated neurons are neurons that have myelin sheath surrounding the axon Myelin sheath insulates the axon. In between each myelin sheath is Ranvier nodes.

- In myelinated neurons, the action potential jumps from one Ranvier node to the next one. This jumping causes very fast conduction of action potential & this is known as **saltatory conduction.**
- In unmyelinated neurons, the action potential does not jump // it travels straight through the axon. This is much slower, and is known as **contiguous conduction.**

The refractory period (فترة الجموح)

- It is a period of time in which the membrane is unable to respond to other stimuli // the membrane already undergone an action potential.
- There are two phases of refractory phases:



  - Absolute: the membrane cannot respond to any stimulus, no matter how strong.
  - Relative: the membrane only responds to very strong stimulus.

Quick summary of action potential properties:

- "All or none" law – either it passes threshold or it doesn't.
- It is propagated through the nerve fibers in non-decremental fashion.
- Has a refractory period (stimulation does not produce action potential)
- Has a fixed amplitude (does not change in magnitude).