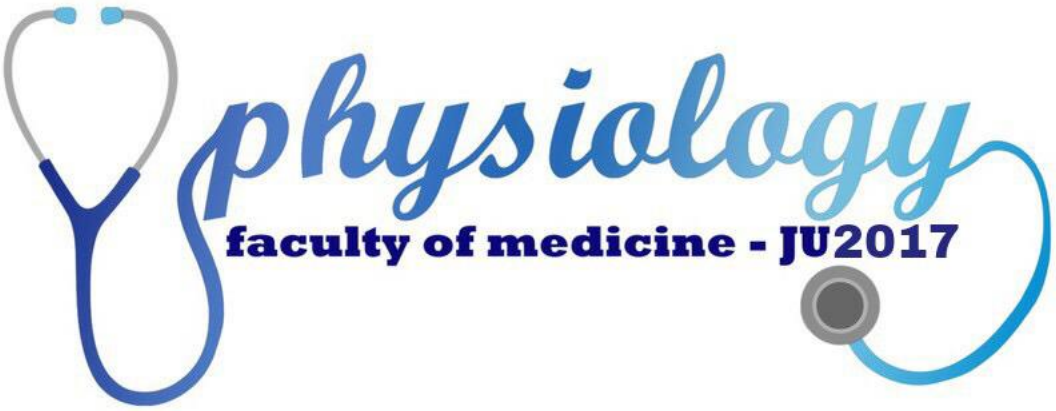


◉ Sheet ○ Slides

Number

10

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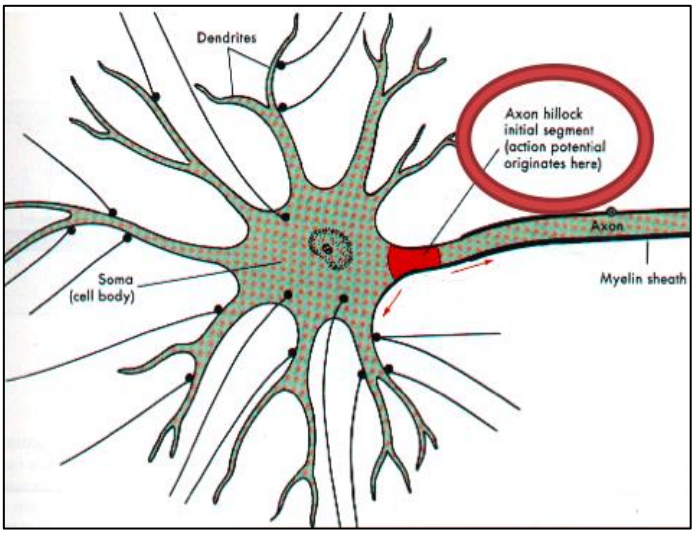
# Generation of Action Potential in Neural Cells:

- Our nervous system consists of neurons and supportive cells. A **neuron** is an electrically excitable cell that receives, processes, and transmits information through electrical and chemical signals. The neuron has three basic parts, **the cell body** (soma), **dendrites** (increase surfaces area), and the **axon** (nerve fiber).

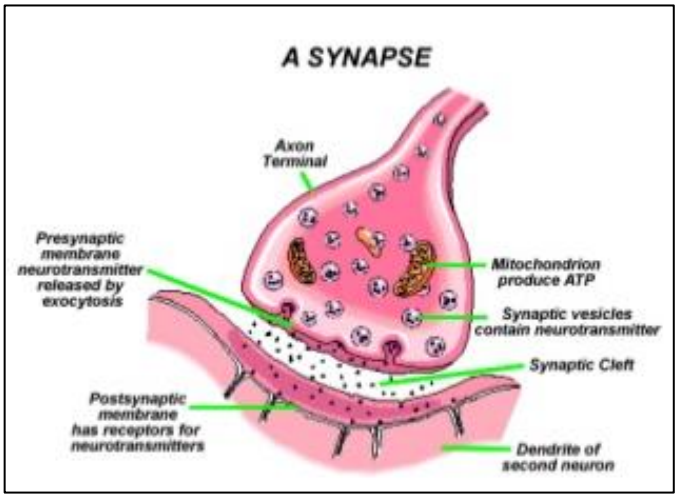
- The function of a neuron (neural cell) to generate action potential which leads to the release of neurotransmitters. The generation of action potential occurs at the axon hillock. The **axon hillock** is a specialized part of the cell body that connects it to the axon. The impulse (generation of action potential) is initiated at the junction between the axon hillock and the initial segment of the axon. The axon ends at into long fine processes called the **axon terminals**.




- Found at the axon terminals of a neuron are a series of bulb shaped structures (**synaptic knobs**) which store neurotransmitters in vesicles. Once the impulse reaches the axon terminal there is a release of neurotransmitters from the presynaptic membrane into the synaptic cleft. These two structures (presynaptic membrane and the synaptic cleft) are part of the synapse. The **synapse** is the site of functional contact between two neurons at which an electric impulse is transmitted from one neuron to the next. The synapse contains the following:

1. **Presynaptic Membrane**

- Membrane of synaptic knob, where neurotransmitters fuse and are released by exocytosis to the synaptic cleft.




2. **Synaptic Cleft**

- A small space between the presynaptic and postsynaptic membranes, separating the axon terminal from the dendrites of the next cell.

3. **Postsynaptic Membrane**

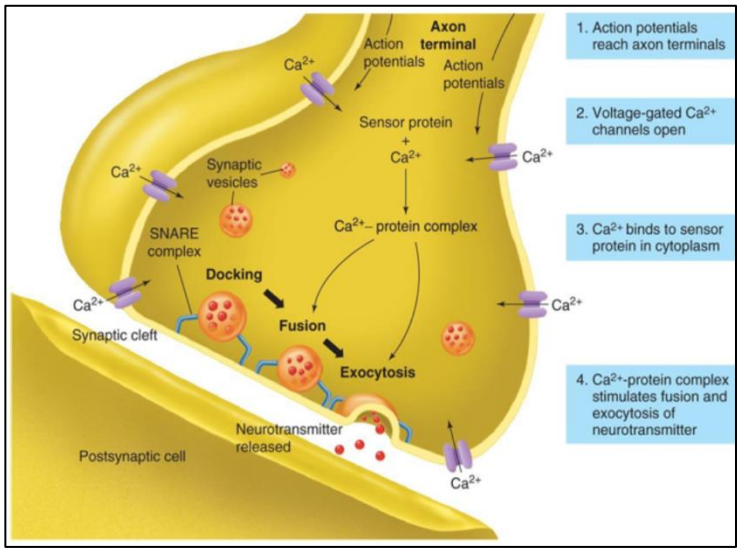
- its Where the neurotransmitters bind to receptors on the second neuron, thus allowing the action potential to proceed to the next neuron.

Watch this video for more illustration: https://www.youtube.com/watch?v=mItV4rC57kM

**Dendrodendrites (Dendrodendritic synapses):**

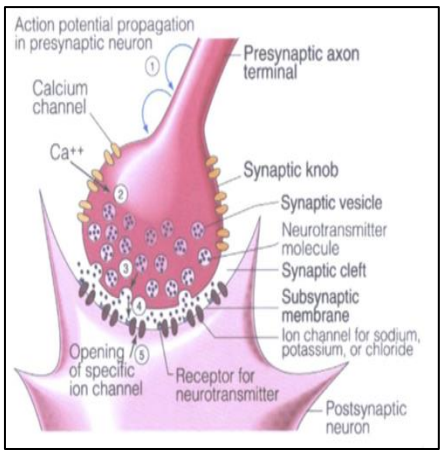
Most synapses are made of presynaptic axon, synaptic cleft and postsynaptic terminals as previously mentioned, but we can also find a type of dendrodendritic synapses which are formed by the joining of dendrites of different neurons by gap junctions.

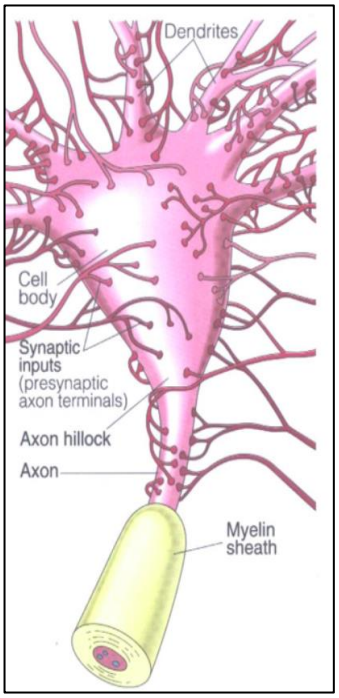
**What happens at the Synapse?**

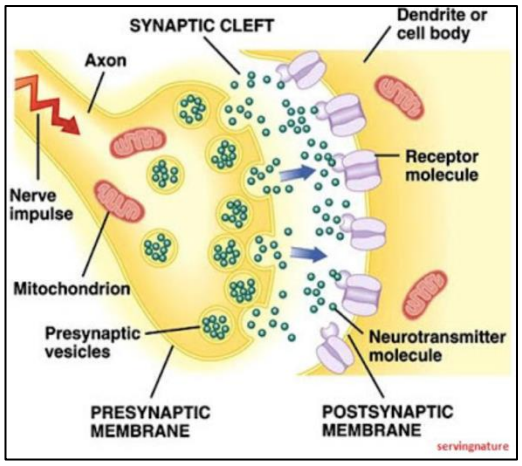



-Synapses operate in one direction. They allow the transmission of signals from one neuron to its neighboring neuron.

1. Once the impulse reaches synaptic knob via the presynaptic neuron, the activation of voltage gated Ca++ channels occurs (these channels are a part of the membrane of the presynaptic neuron.)
2. The concentration of Ca++ outside the axon terminal is much higher than the concentration of it inside the axon terminal. This creates a steep concentration gradient for Ca++, thus allowing an influx of Ca++ into the synaptic knob.
3. This increase in Ca++ concentration inside the axon terminal triggers the release of neurotransmitters into the synaptic cleft (by exocytosis).
4. These neurotransmitters bind to the specific receptors on the postsynaptic membrane.

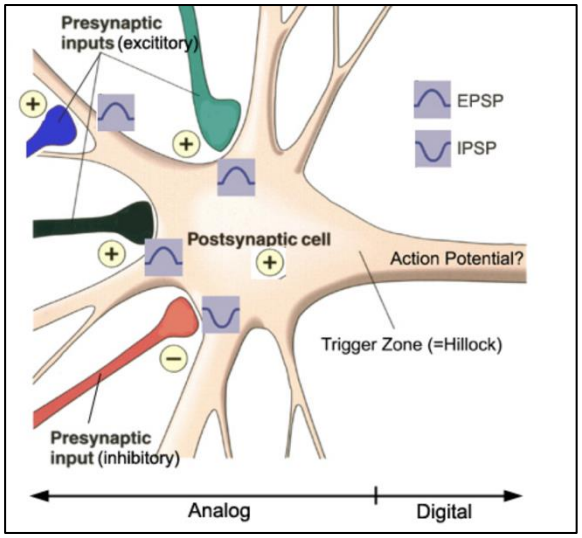





5. When the neurotransmitters bind onto the receptors, depending on the type of ligand gated channels present in the postsynaptic membrane, this will either trigger the activation of Na+ ligand gated channels which allows an influx of Na+ (into the postsynaptic neuron) and leads to depolarization. This is called **Excitatory Post Synaptic Potential** (EPSP). These are not action potentials, but small depolarizations (subthreshold potentials).

**Note**: The doctor told us that he will use the term "**Depolarization"** for the increase in the cell's potential before threshold and the term "**Firing Phase"** after threshold.

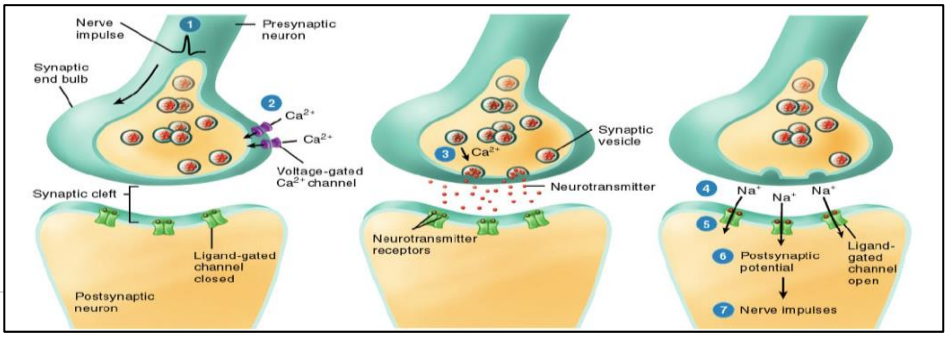



6. Or, it might trigger the activation of K+ ligand gated channels, if present, which allows an efflux of K+ (out the postsynaptic membrane) and leads to hyperpolarization or decrease in membrane potential (more negative). This is called **Inhibitory Post Synaptic Potential**. (IPSP) IPSPs, can also be induced by the activation of Cl- ligand gated channels which hold the membrane at the resting potential and prevent depolarization.

**So, the link between a specific type of ligand with a specific type of receptor determines the potential we will have (IPSP/EPSP).**

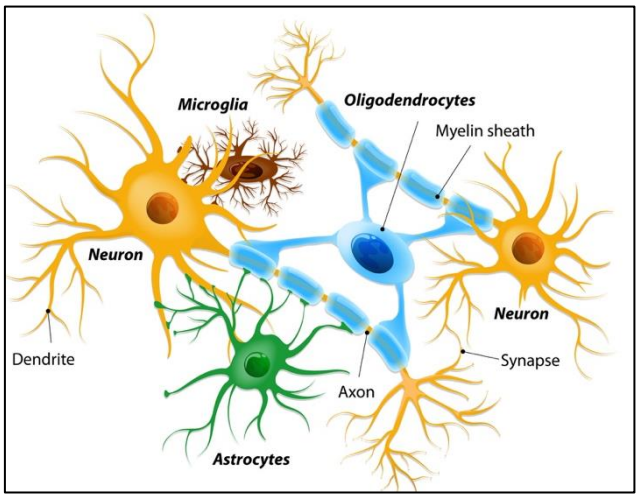
- low concentration of neurotransmitters ⟶ less chance to bind to receptors ⟶ Lower number of Na+ channels activated.
  High concentration of neurotransmitters ⟶ higher chance to bind to receptors ⟶ Higher number of Na+ channels activated.

This is an example of EPSP, due to the activation of Na+ ligand gated channels.

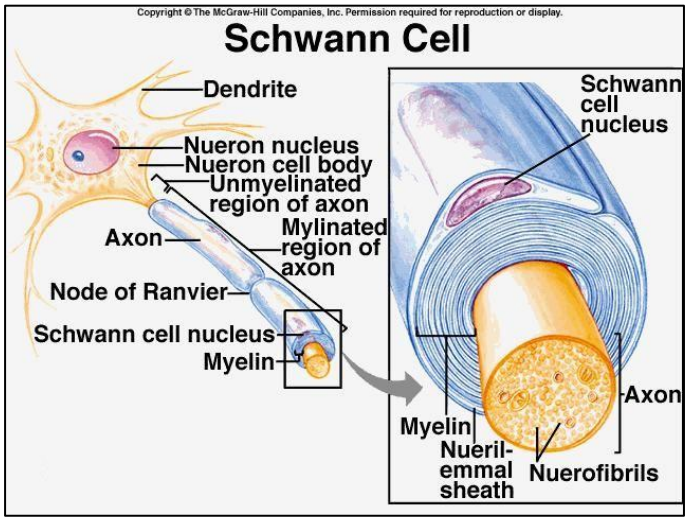


## Supportive Cells: (NEUROGLIA/ Glial Cells)

- There are many types of supportive cells around neurons such as **Microglia** Phagocytic (engulf particles and viruses), **Astrocytes** [star – shaped, have extensions that surround neurons which allow the control of the blood brain barrier preventing the passage of unwanted substances to the CNS (central nervous system)], and **Oligodendrocytes** (formation of myelin sheath on axons in CNS).

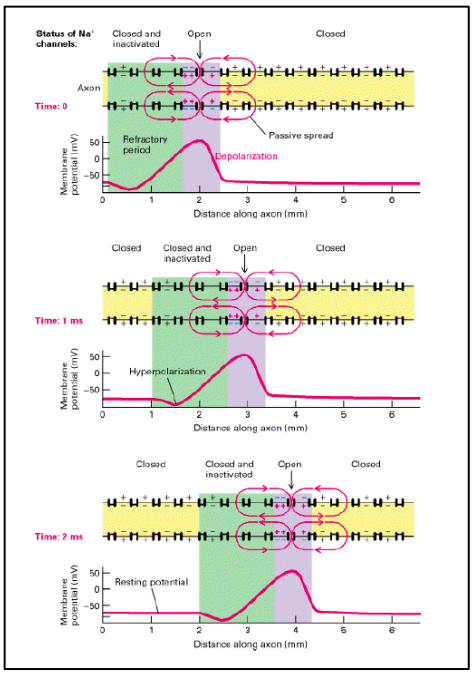



- Other functions of supportive cells include:
  - Maintenance of a clean neural environment, by the removal of K+ from the surrounding area as well as the uptake and recycling of neurotransmitters from the interstitial fluid around the neurons.
  - The synthesis and release of **neurotrophic factors** which are vital for the neural cells survival, support, and protection.
  - **Myelination** of axons, by the help of specialized cells called the oligodendrocytes (forms the myelin sheath for the axons of the CNS) and the **Schwann cells** which are responsible for the myelination of the axons of the PNS (peripheral nervous system). These cells wrap around the axon and secrete a lipid substance called **sphingomyelin** which is a great electrical insulator that decreases ion flow throughout the membrane. The sphingomyelin along with other proteins forms a protein lipid complex that insulates the nerve fiber, called the **myelin sheath**. There are gaps/ uninsulated areas in the myelin sheath where ions can still flow with ease through the axon membrane and the



intracellular fluid inside the axon. These gaps are called **Nodes of Ranvier** and are used for transmission of impulses along a myelinated nerve (generation of action potential).

❖ Many diseases are related to the destruction of the supportive cells rather than the neural cells.

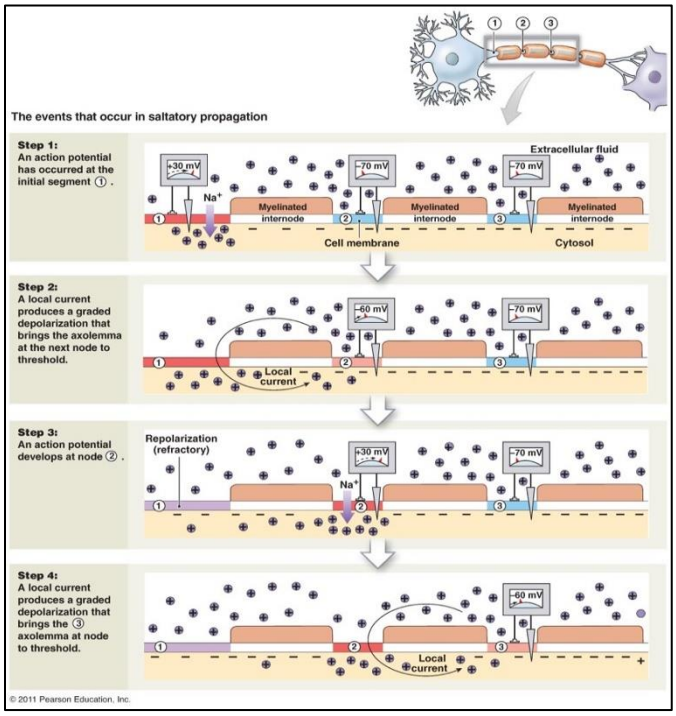



**<u>Conduction of Impulse: (Methods of Propagation)</u>**

- **Continuous Conduction** (conduction due to local current flow), this occurs in unmyelinated fibers and muscle cells. Internal local currents flow between the active area and inactive area. This flow will allow an action potential to become generated as Na+ flows inward across the membrane at one location (inactive area now reaches threshold potential becoming active). The depolarization then spreads to the neighboring region of the membrane (inactive), initiating a new action potential there (making it active). To the left of this region, the membrane is now repolarizing as K+ flows outward. In this situation, the wave of de- and repolarization simply travels from one patch of the membrane to the adjacent patch.

  [Ionic currents are generated since they involve the movement of ions, (Na+ and K+ ions are moving), electrical currents are not generated since there is no movement of electrons.]

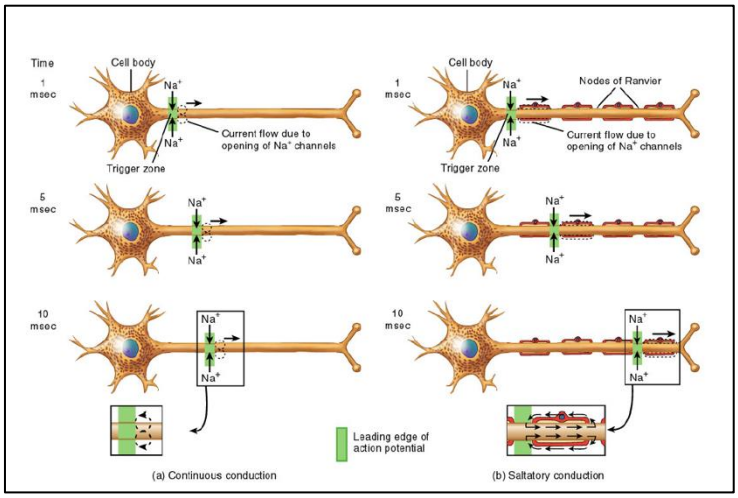
- **Saltatory Conduction**, this occurs in myelinated fibers, where the nerve impulse jumps along the fiber as the action potential is conducted from one node of Ranvier to the next (no ions can travel via the thick myelin sheaths of the myelinated nerves). Thus, ensuring faster propagation of action potential. This is almost 50 times faster than in unmyelinated sheaths of the same size.



Note: In both types of conduction:

1- the current is a flow of positively charged to negatively charged regions on both sides of the membranes.

2-The inner current of + ions plays a bigger role in propagation than the outer current.

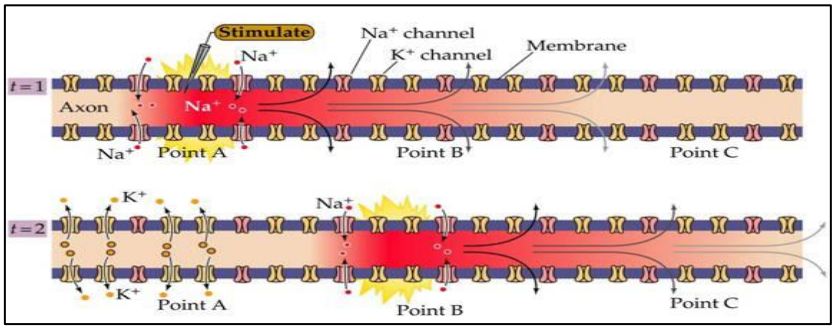



## Factors influencing the rate of conductance:

1- **Myelination** (If present, this increases the rate of conductance.)
2- **Diameter of nerve fibers** (Larger diameter, less resistance, faster depolarization, higher velocity of conductance.)

## Importance of Refractory Period:

- Ensures that the propagation of action potential happens in one direction [Unidirectional, one-way]. For example, after action potential is propagated from point A to point B in the picture below, point A starts repolarizing, preventing any new action potential (relative refractory period). This assures the movement of the action potential in one direction, allows the neuron to adjust briefly for the propagation of the next stimulus, and limits the amount of action potentials sent per minute.)

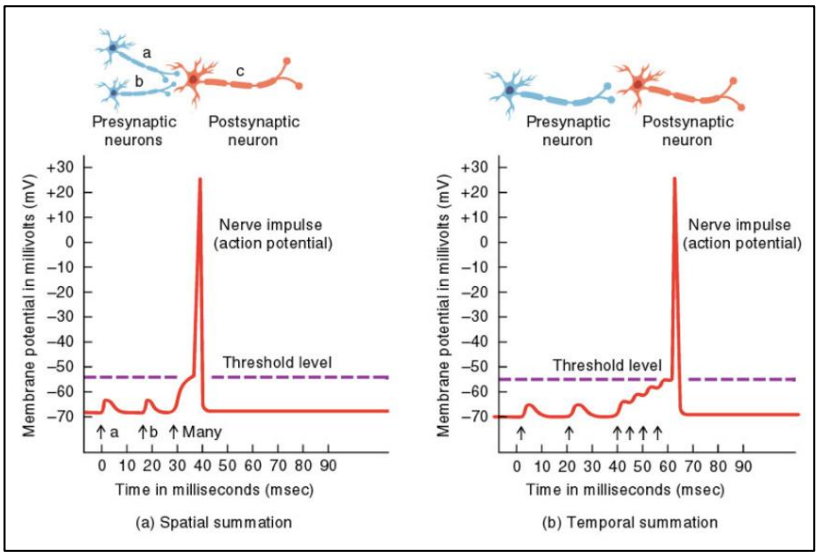



- If an impulse is initiated at the cell body of a neuron as well as at the axon terminal simultaneously, there will be no surpassing of the impulse due to the presence of the refractory period.

For better understanding watch:

- 1.https://www.youtube.com/watch?v=Sa1wM750Rvs
- 2.https://www.youtube.com/watch?v=3SV1DpO7XvY

**Summation:** Is the addition of post-synaptic potentials, meaning for example, two depolarizations can sum to elicit a higher depolarization.



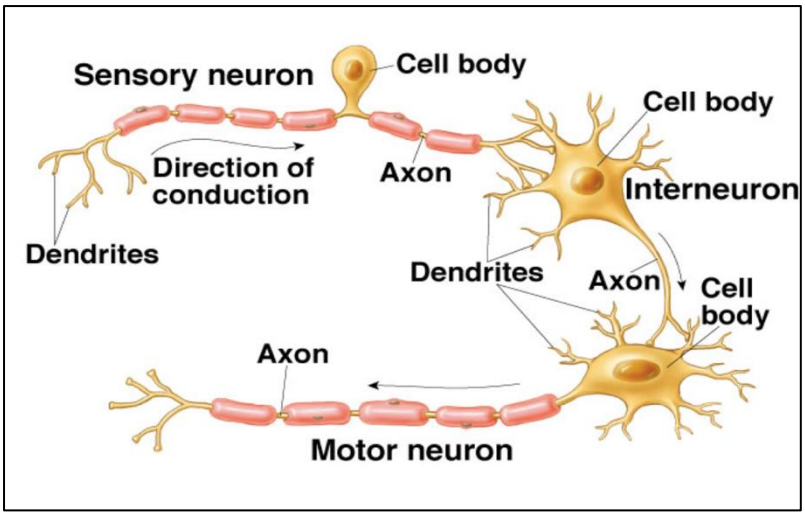

The two types of summation are:

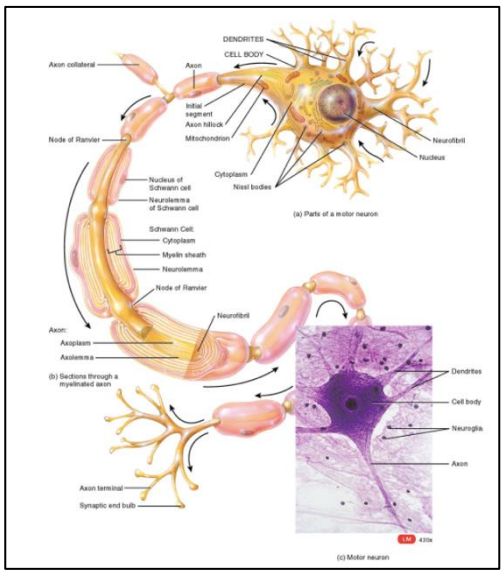
- **Spatial summation**: Which appears when 2 or more potentials (IPSP/EPSP) are generated from 2 or more different presynaptic neurons simultaneously at the same postsynaptic membrane. As a result, these two responses will be summed into a final response. May take a place between 2 EPSPs inducing more depolarization, or between 2 IPSPs triggering more hyperpolarization.
- **Temporal Summation**: Which appears when 2 or more potentials are generated from one presynaptic at different times. These potentials are then summed together to induce more depolarization (frequency dependent).

-Additional Useful Information-

**Motor, Sensory, Relay Neurons:**

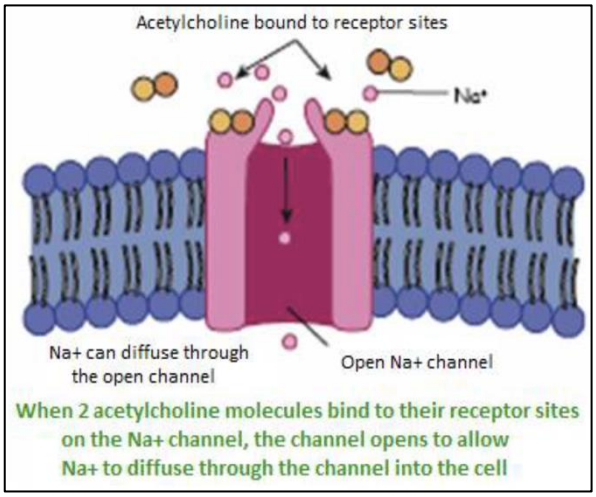
| Motor: | Sensory: | Relay: |
|---|---|---|
| -Short dendrites (synapse with effectors) | -Long dendrites (synapse with receptors) | -Short dendrites |
| -Long axon (found outside CNS) | -Short axon (found inside CNS) | -Short Axon |
| -Cell body found in CNS | -Cell body not in CNS | -Cell body in CNS |
| -Transmit impulses from CNS to effector | -Transmit impulses from receptors to CNS | -Connects sensory and motor neurons to form nerve circuits |



**Acetylcholine neurotransmitter:**

- First neurotransmitter discovered. Its function is to transmit signals across a chemical synapse.
- It's broken down by **acetylcholine esterase** into **acetyl** and **choline** molecules which are transported back to the synaptic knob to form new acetylcholine molecules.




Useful Animated Videos:

https://www.youtube.com/watch?v=3_yAK-nTOjA (excitatory and inhibitory potentials)

**Quiz**

(The Answers are marked with a full stop[.])

1- Action potential cannot be created at the postsynaptic terminals, this is due to:
a -small number of $Na^+$ voltage gated channels, which means high threshold.
b-high number of $Na^+$ voltage gated channels, which means high threshold
c- small number of $Na^+$ voltage gated channels, which means small threshold
d- high number of $Na^+$ voltage gated channels, which means small threshold

2- What's the type of $Ca^{2+}$ channels that are found in the presynaptic area:
a-ligand gated channels
b-mechanical gated channels
c-voltage gated channels.
d- symporters

3- Acetylcholine is an excitatory transmitter, what happens if we increase its concentration in the synaptic cleft?

a-more probability of binding with postsynaptic receptors causing an inhibitory potential

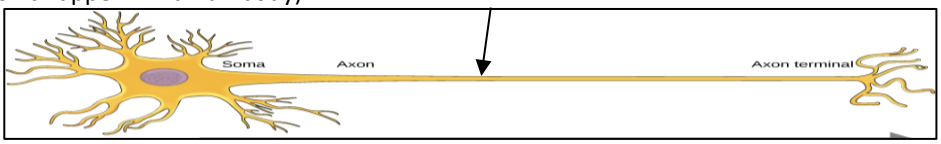
b-more probability of binding with postsynaptic receptors causing an excitatory potential

c- more probability of causing an action potential on the second neuron (postsynaptic neuron)

d- both b and c.

4- If we stimulate a neuron in the middle as shown in the picture, what happens?

(note: this doesn't happen in human body)



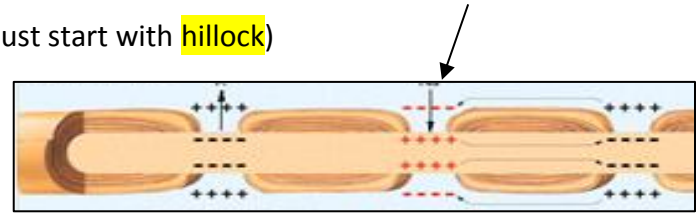

a- Propagation will occur in the right side ( toward the axon terminals)

b- Propagation will occur in the left side (toward cell's body)

c- Propagation will occur in both directions.

d- No action potential would be generated (must start with hillock)

5- What's the direction of propagation?



a-to the right.

b-to the left

6- Which of the following can be found in dendrodendritic synapses but not normal synapses?

a-$Na^+$ voltage gated channels

b- Gap Junctions.

c- $Na^+$ leakage channels

d- all are present

7- Which of the following is true about myelinated neurons?

a-action potential can be formed through myelinated sheaths

b-ions can move through the neuron in myelinated sheaths area of the axon (but not through the myelin sheath itself).

c-myelin sheaths slow down the propagation of an impulse

d-ions can move through the myelin sheath

8- We have one presynaptic terminal with one postsynaptic cell body in a synapse, what do we have to do to increase the probability of generating an action potential in the second neuron (Postsynaptic one)?

a-increase frequency of sub potentials

b-decrease number of receptors on postsynaptic region

c-increase concentration of neurotransmitters released in synaptic cleft

d-both a and c.

e-all above