The Action Potential

And a Case Study on Epilepsy

Taking into consideration that the **brain** executes **so many functions**; flexing one muscle or a group of muscles, walk, talk, to see, to memorize, to solve the most difficult problems and even to CREATE and do new things that change the life of generations and millions of people….

Every second, our **brain receives** hundreds of thousands of pieces of **information** in the forms of vision, hearing, equilibrium, somatic sensation (Touch, Pressure, pain…), tasting, smelling…etc.

However, the brain can execute that much of functions and understand that much of information by **two** types or languages (bilingual) of **electrical activities**:

1- The Action Potential
2- The Graded Potential (Electrotonic Potential)

The Action Potential:

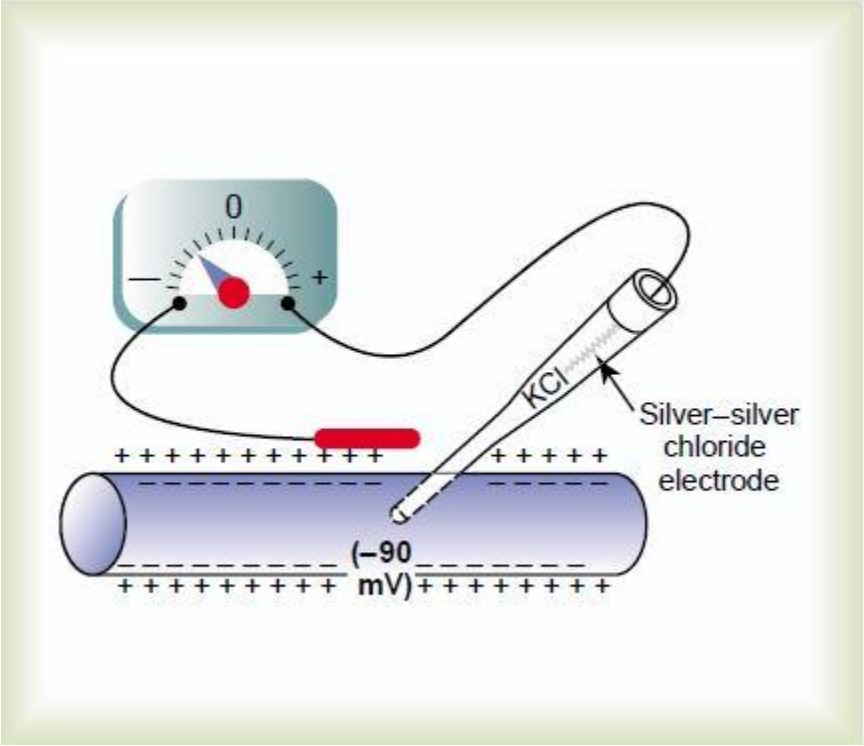
Its **importance** towards physicians and patients (Actually many scientists have won the noble prize in works related to it):

1- Many **drugs** have been invented after understanding the physiology of the action potential such as:
   - **Local anesthesia**: any drug with a name ending with the suffix **–caine** (e.g. Lidocaine) is a local anesthesia drug.
   - Its major **function** is to **stop feeling pain**, by interrupting action potential (**stopping the Na+** voltage-gated channels) and stopping it from reaching the brain and the patient will not feel the pain.
   - It is sometimes **used** in emergency cases to save life such as **tachycardia** and **arrhythmia** (irregular heart rate, a **very high heart rate** that may lead to death) in such cases (arrhythmia), Lidocaine is **injected directly to the heart** to slow heart rate, or in other cases it is given **by IV** (intravenous) fluid. And according to the **dose**, we can inhibit or reduce the action potential frequency.
2- For neurologist and neurophysiologist, many disorders are **diagnosed** by the understanding of the action potential. Actually, the action potential is the principle of EEG (for the brain), EMG (for muscles) and ENG (for the nerves).

One of the major **criteria** for the action potential is that it **propagates** (moves), that's why it is usually recorded from the **axons**, not the soma (neurons).

The **recordin**g of action potential is done by a **microelectrode**, a very simple glass pipette with a much tapered ending that is placed on the axon for recording, you will find out that the action potential, once stimulated, will propagate until the end (to the brain) **without the need of any further stimulation**.

A very good analogy to propagation is the **dominos falling**, only the first one has to be hit (stimulation) so that the rest of the pieces fall without the need of any other hit (propagation).



Since the brain receives so many pieces of **information,** it has to **categorize** them according to **importance**, as a result, some of the action potentials have to be propagated **very quickly**, while others can be propagated in a **slower rate**.

In order to increase the **conduction velocity** for a given nerve, it has to be either **myelinated** or by **increasing the diameter** so that resistance to action potential decreases. However, increasing the diameter is impossible for human beings due to the limited size of our brain, so to compensate for that, **myelination (insulation) is the method**.

Myelination in the **central** nervous system is done by **Oligodendrocytes**, while myelination in the **peripheral** nervous system is down by **Schwann cells**.

In the **peripheral** nervous system, the **difference** between meylinated and unmyelinated nerve fibers is that in the meylinated cells, the Schwann cell during growth and development starts **revolving** around the axon more and more for 10-15 times. This will make it a heavily-meylinated and fast-conducting

nerve fiber. On the other hand, in the “unmyelinated” cell or - better - in the **partially meylinated** cell, a single Schwann cell is **surrounded** by those partially meylinated nerve fibers.

Just like electrical cables, they are either much insulated or slightly insulated but **never not insulated at all**.

This will create a difference in conductions, **continuous** in the **unmyelinated** and **saltatory** conduction in the **meylinated** nerve fibers (the action potential will be jumping from one **node of Ranvier** to the other).

Saltatory conduction is **faster**, and more **energy-conserving** than the continuous conduction. Energy conservation comes from the fact that when action potential starts in an unmyelinated fiber it starts walking step by step turning on **Na+ channels** to allow for the leakage of Na+ to the inside of the axon, and to return to the normal condition, **so much ATP is required**. While in meylinated fibers, the **jumping** of the action potential allowing it to bypass regions in the axon leading to much less leakage of Na+, as well as the leaving of K+. Thus, the amount of **ATP required** to return the nerve fiber to its normal situation **is much less**.

In our body, we have the very **large** (heavily) meylinated nerve fibers to the **small** (partially meylinated) or unmyelinated nerve fibers. And each one of which has a specific **function.**

The **large, heavily-meylinated** nerve fibers convey and at a **very high rate (120 m/s)** the most important information to the brain, that is: **equilibrium** and keeping the position of parts of the body and whole body in a stable, balanced and appropriate way “Proprioception” (if you, for example, lean to one side and have a slow reaction you will fall and get injured).

The **small, partially-meylinated (unmyelinated)** nerve fibers convey at **a slower rate (.5 m/s)** the less important information to the brain that doesn’t make a difference if transported quickly or not, such as **pain**.

Pain, can wait, but it only has to be persistent to keep alerting the brain, so it is transported by C and A-delta fibers. Sharp pain is transported by the A-delta fibers. Visceral (abdominal) pain is transported by the C fibers (the lowest).

Susceptibility of Different Types of Fibers to conduction block by various agents:

Effect	Most susceptible	Intermediate	Least susceptible
Block by hypoxia	B	A	C
Block by pressure	A	B	C
Block by local anesthetics	C	B	A

- By **Hypoxia** (**Lack of Oxygen**, which causes pain): The **least effect is on the C fibers**, the pain is important so that the patient would call for help.
- By **Pressure** (intense pressure that causes pain): **The least effect is on the C fibers**, pain is also important for the same reason in hypoxia.
- By **Local Anesthesia** (to stop pain in a much safer way than general anesthesia): **Mainly C fibers are anesthetized** (the ones responsible for pain) to relieve his pain, **while other fibers** (such as those responsible for touch sensation and pressure, and the ones responsible for location and position) **are not affected**.

The Refractory Period:

- **Absolute Refractory Period**: Starts from the **beginning of the action potential** until the end of the **first one-third of repolarization**. Here, the **Na+ channels** are **not ready to receive another action potential**, they are inactivated. It doesn't matter whether the stimulation is 1 volts or 10 volts during this period, it will not be able to create another action potential. Because, they are no Na+ voltage-gated channels available to open and start a new action potential.
- **Relative Refractory Period**: Starts from **the end of the absolute period** until the **end of the action potential**. Here, by increasing the stimulation to say, 10 volts, this will create another action potential. Because the **Na+ are now capable to be reopened**, but with **only a stronger stimulus**.

The Features of the Action Potential (Nerve Impulse):

- Regenerative;
- It has a threshold;
- It moves along the axon;
- It is usually created by voltage-gated channels (Fast Na+ and Slow, delayed K+);
- It propagates;
- It is all or none (Once there is a stimulation and the nerve reaches threshold it will make an action potential (all), if the stimulus was sub-threshold, an action potential is never generated (none));
- It has an amplitude above 100 mV (from -70 to +35mV);
- It has a very short duration;
- It usually starts with depolarization and ends with repolarization;
- It has a refractory period;
- It never summates (No larger action potential is created of an action potential is put on top of another).

The Function (physiology) of Action Potential: To convey a piece of information faithfully, unchanged with a fixed amplitude form a faraway area to the brain.

For example, if you step on sharp object, you need this pain to be conveyed to your brain in a fixed magnitude without fading, so that your brain responds correctly – it is action potential.

Case Study: Epilepsy, Seizure, Fit or Convulsion.

The Patient starts with **feeling something wrong** that is about to happen, if he were experienced he would lie, but if it was the first time, the patient would drop. The he would **go spastic** (all muscles become very tense) and his back would take **the shape of a bridge**, **respiratory muscles stop**, so is breathing and the patient would **turn blue**. If he were lucky enough, the seizure will **only last no more than two minutes (the tonic phase)**, followed by the **clonic phase**, which includes **contraction and relaxation** of muscles, the patient would **urinate, defecate** and have a **froth** and then followed by the **resumption of breathing**.

In such cases, one should stand away from the patient and wait for the end of the seizure.

During the seizure, one mustn't put their fingers in the mouth of the patient to clear the airways, a clench in the jaw of the patient would **easily break his fingers**. The most valuable tool for a physician is his mind then his hands.

Epilepsy is an **excessive excitability** to all nerves in the body

One of the **causes** of epilepsy, is **hypocalcaemia** (a **drop** in the concentration of **Ca++** in blood), **parathyroid** glands are responsible for the regulation of Ca++ in the body, their removal or death may cause epilepsy. A **severe fever** harming the brain would also cause epilepsy.

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Our Mind is the Greatest Machine

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