Is Your Body Electric? The Amazing World of Bioelectricity

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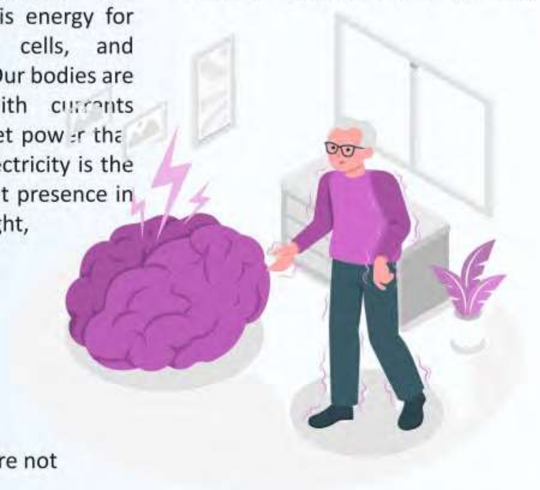
Bioelectricity is the concept that our bodies vibrate with tiny **electric currents**, a **dance of energy** that drives our **lives**. Our **cells** communicate using these **pulses**, like lightning, which are like telegraphs. Nerves send these pulses, which cause hearts to beat, eyes to blink, and muscles to move. Our brains are also electric, powerhouses of thought and emotion. They use this energy for **self-healing,** healing cells, and causing skin to tingle. Our bodies are like hidden [eels](#) with currents flowing inside—a secret power that is silent but strong. Electricity is the spark of life, a constant presence in every [heartbeat](#), thought, and move. Our bodies act as batteries, storing and releasing energy, which powers our lives. Understanding bioelectricity opens a new world where we are not just alive but electric.

Brief History

For ages, people have been aware of electricity in the form of lightning. In the past, humans were able to generate electricity through the use of **saltwater cells.** Volta developed presence of electricity in living systems. This was possible because electronic devices in the form of valves became available. Then it was possible to measure small currents of the order of microamperes. Placing electrodes on the **skull**

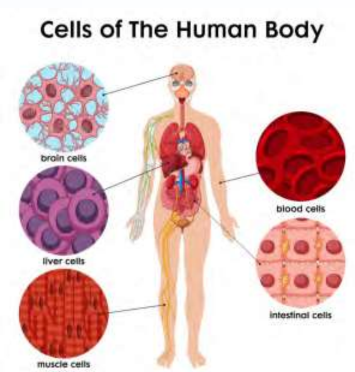


Electric brain signals illustration

allowed for the recording of [electric brain signals.](#) Since then, a lot of advancement has taken place in this field over the last century.

Cells of the Human Body

Now we know that every cell in the living system shows the presence of **electric potential**. However, **nerve** and **muscle** cells exhibit special **electric** characteristic properties. They form the basis of **brain** function. In the human being, the



Scientific medical illustration of cell types

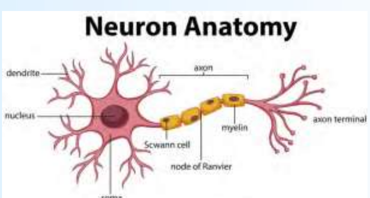
nervous system is the most advanced and possesses many characteristics not found in other animals. We will present a brief account of this extraordinary phenomenon in the present article.

The vertebrate nervous system is made up of the central nervous system (CNS), which includes the brain and spinal cord, and two peripheral nervous systems (PNS) that encompass all sensory nerve cells and local ganglia (clusters of nerve cells). This system facilitates communication between different parts of the body, controlling reactions to stimuli, processing information, regulating behavioral patterns, and enabling adaptation. It primarily communicates by transmitting electrical signals through the fundamental building blocks of the nervous system, called ***neurons.***

Nerve Cell or Neuron

A **nerve cell**, or neuron, serves as the brain's primary unit for processing information, responsible for receiving, sending, and transmitting electrochemical signals throughout the body. Recent research indicates that the human brain contains about 86 billion neurons (Hercul-ano-Houzel, 2009). These cells are different from other cells. After birth, they cannot reproduce. They cannot regenerate either. They do not grow back or multiply, despite being fully grown at birth.

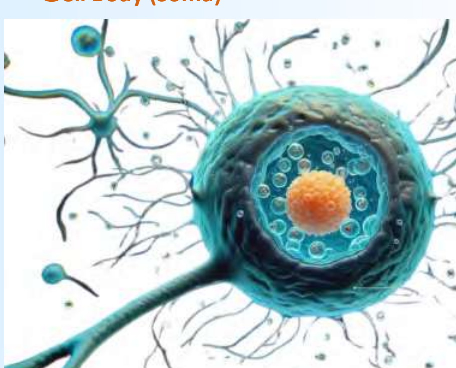
Structure of Neuron



Structure of a neuron or nerve cell illustration

A neuron essentially consists of a cell body (soma), long neuron fiber (axon), and dendrites.

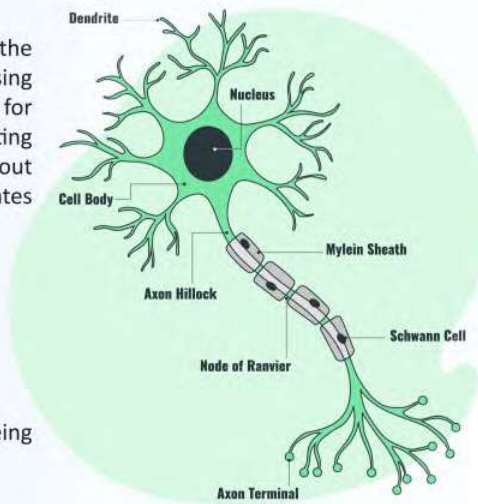
Cell Body (Soma)



The **soma**, or **cell body**, is the central part of the neuron, housing the nucleus and surrounding cytoplasm. Its primary function is to ensure the efficient operation of the neuron (Luengo-Sanchez et al., 2015).

A protective membrane encircling the soma engages with its immediate surroundings. The nucleus within the soma produces genetic information and regulates **protein** synthesis, which is essential for the functioning of other parts of the **neuron**. Additionally, the soma's membrane integrates signals received from other neurons.

Axon



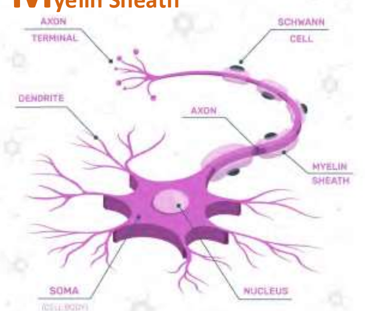
The axon, also known as a **nerve fiber**, is a long, tail-like extension of a neuron that connects to the cell body at a region called the axon hillock. Its primary function is to transmit signals away from the cell body to terminal buttons, enabling communication with other neurons, muscles, or glands. Axons can also receive signals through dendrites and transmit them back toward the cell body. Most neurons have a single axon, which can vary greatly in length, from as short as **0.1 millimeters** to over **91 centimeters. Myelin,** which serves as an insulator and speeds up signal transmission, covers some axons. Within the axon, the axoplasm facilitates the transport of proteins and organelles between the cell body and synaptic terminals, supporting the axon's function. The release of neurotransmitters at synapses at the end of the axon enables communication with target cells.

Dendrites

Dendrites are parts of a neuron. They look like the roots of a tree. Dendrites are usually shorter than axons. Neurons have more dendrites than axons. Neurons are cells in the nervous system that send and receive information. Their main function is to receive information from other neurons and transmit **electrical signals** to the cell body. **Synapses,** which allow for the receiving of signals from nearby neurons, connect dendrites. While some neurons have short dendrites, others feature longer ones.

In the central nervous system, neurons often have long, complex dendrite branches that enable them to gather signals from many sources. For example, **Purkinje** cells in the **cerebellum** possess highly developed dendrites, allowing them to receive signals from thousands of other cells.

Myelin Sheath



The myelin sheath is a fatty layer that encases the axons of neurons, serving to insulate one nerve cell from another and preventing interference between impulses. It also enhances the speed of nerve **impulses** along the axon.

Glial cells, specifically **oligodendrocytes** and **Schwann** cells, wrap around the axon to form the myelin sheath. This insulation allows for much faster signal transmission compared to unmyelinated neurons.
The myelin sheath contains gaps known as nodes of **Ranvier**, where

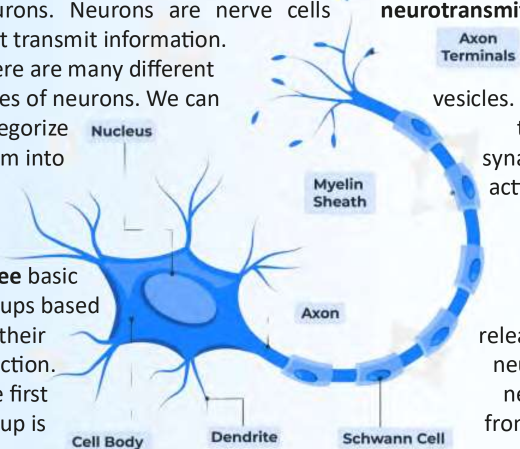
electrical signals can jump between nodes, further accelerating signal transmission.

Axon Terminals

At the end of the neuron, **axon** terminals (or terminal buttons) transmit signals to other neurons. Each terminal button contains vesicles filled with neurotransmitters. When electrical signals arrive at the buttons, they trigger the release of neurotransmitters. The **synapse** is a small gap between nerve cells where they can pass messages. **Neurotransmitters** are chemicals that help send messages across this gap. This process changes the **electrical signals** into chemical ones. Additionally, the terminal buttons reabsorb any extra neurotransmitters that the following neuron doesn't receive.

Types of Neurons

The human brain contains **billions** of neurons. Neurons are nerve cells that transmit information. There are many different types of neurons. We can categorize them into **three** basic groups based on their function. The first group is **sensory neurons.** These have **long dendrites** and **short axons.** Dendrites are branches that receive signals from other cells. Axons are long fibers that send signals to other cells. The second group is **motor neurons.** These have short dendrites and **long axons**. The third group is **relay neurons.** These have **short dendrites** and **either short** or long axons.



Synapse

In neuroscience, a **synapse** is a place where two **neurons** meet. Neurons are nerve cells in the brain. The synapse is the point where one neuron sends information to another. It consists of the **axon** terminal of the transmitting (pre-synaptic) neuron, the synaptic cleft (a small gap), and the dendrite or cell body of the receiving (post-synaptic) neuron. Neurotransmitters help neurons **communicate** with each other. There is a small gap between these neurons. **Neurotransmitters** move across this gap. They carry signals from one neuron to another. Although neurons don't physically touch synapses, they come close enough for a synapse to form, allowing them to communicate. This synaptic connection is essential for signal transmission, as signals traveling through a neuron must pass through a **synapse** to reach the next neuron.

At the **pre-synaptic** terminal, terminal buttons contain **vesicles** filled with neurotransmitters, which are key to passing signals to other neurons. When a neuron generates a signal, such as an action or graded potential, it triggers the release of **neurotransmitters** from these vesicles. The neurotransmitters then diffuse across the synaptic cleft to reach and activate the post-synaptic neuron.

When a nerve impulse reaches the end of a neuron, it causes the release of chemicals called neurotransmitters. These neurotransmitters come from the terminal buttons of the **pre-synaptic** neuron. The **pre-synaptic** neuron is the neuron that sends the message. The neurotransmitters move into a small gap called the **synaptic cleft.** They then attach to special proteins called receptors. These receptors are on the surface of the next neuron. The **post-synaptic** neuron is the neuron that gets the neurotransmitters. Neurons can receive signals from multiple terminal buttons, and similarly, the terminal buttons of a single neuron can form synapses with many other neurons.

A synapse is a combination of the following:

- **Presynaptic axon terminal** – which contains the neurotransmitters (chemical messengers).
- **Synaptic cleft** – which is the gap between the two neurons, typically about 20 to 30 nanometers wide.
- **Postsynaptic dendrite** – which contains the sites for receptors (molecules that receive signals for a cell).

Synapses are critical for overall **neural** activity and are fundamental to many cognitive functions, such as learning and memory formation. Neuroscientists recognize that synapses enable communication between neurons, facilitating the transmission of signals necessary for brain function.

Synapse Transmission

Synaptic transmission can occur through **chemical synapses** or **electrical synapses,** each with distinct characteristics:

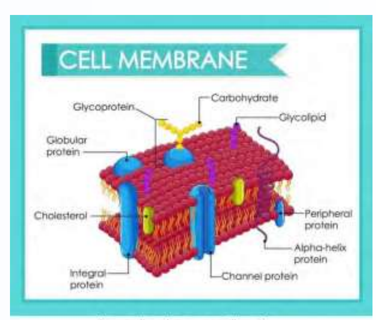
Chemical Synapses

- Gap between cells: approximately 20 nanometers
- Transmission speed: several milliseconds
- Can be either excitatory or inhibitory
- Signal strength remains constant throughout transmission

Electrical Synapses

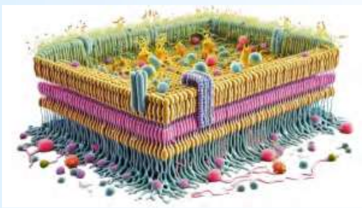
- Gap between cells: approximately 3.5 nanometers
- Transmission speed: nearly instantaneous
- Can be either excitatory or inhibitory
- Signal strength weakens over time and distance

Membrane Potentials



Human cell membrane structure illustration

Cell membranes consist of a **fluid** mosaic of lipid and **protein** molecules. As shown in the figure, the lipid molecules are arranged in a **bilayer of 6 nm thick**, with their polar hydrophilic heads facing outward and their hydrophobic tails extending to the middle of the layer. The **lipid is sparingly permeable** to water and **virtually impermeable to ions.** Embedded in the lipid bilayer are protein molecules—some on the extracellular side, some facing the cytoplasm, and some spanning the membrane. Many of the membrane-spanning proteins form ion channels. Such channels allow ions like potassium, sodium, calcium, or chloride to move passively as a result of concentration gradients and the electrical potential across the membrane.



Conductance of Channel Human Cell for Bioelectricity

The conductance of a channel depends on two factors: The first is the ease with which ions can pass through the open channel; this is an intrinsic property of the channel known as the channel **permeability**. The second is the concentration of the ions in the region of the channel. Thus, if there are no potassium ions in the inside or outside solution, there can be no current flow through an open **potassium channel,** no matter how large its permeability or how great a potential is applied.

One way to think these relations is as follows:

Open channel → **permeability**

Permeability + ions → **conductance**

Potassium current through the channel depends on both the electrical potential across the membrane and the potassium concentration gradient, i.e., on the electrochemical gradient for potassium. The difference in potential that just balances the potassium concentration difference is called the potassium equilibrium potential **Ek.** The equilibrium potential depends only on the ion concentrations on either side of the membrane—not on the properties of the channel or on the mechanism of ion permeation through the channel.

Thus, in living cells, an electrical potential difference across the plasma membrane does exist, arising out of the unequal distribution of ions inside and outside the membranes. This potential difference between the inside and outside the **membrane** is called membrane potential. Several factors contribute to the existence of **membrane potential**, which includes:

1. Donan potential
2. Selective membrane permeability to solute
3. Active transport (chemical potential gradient) to maintain a concentration gradient

Nernst Equation:
If you measure the potential difference (voltage) across a membrane at equilibrium, this equation shows how the concentrations of an ion on each side of the membrane relate to each other. The membrane is perfectly selective for that ion. The Nernst equation is:

$$E_K = \frac{RT}{zF} \ln \frac{[K]_o}{[K]_i}$$

Where,

$[K]_i$ - Inside concentration

$[K]_o$ - Outside concentration

R = Gas constant, 8.135 J K^{-1} mol^{-1}

T = Temperature in K

z = Valency of ion (Na^+ is plus one, Ca^{2+} is plus two and Cl^- is minus one)

F = Faraday's constant, 9.684 x 10^4 C mol^{-1}

This is the Nernst equation for potassium. The factor $\frac{RT}{zF}$ has the dimensions of volts and is equal to about 25 mV at room temperature (20 °C). It is sometimes more convenient to use the logarithm to the base 10 (log) of the concentration ratio, rather than the natural logarithm (ln). Then $\frac{RT}{zF}$ must be multiplied by ln (10) or 2.31, which gives a value of 58 mV.

$$E_K = 25 \ln \frac{[K]_o}{[K]_i} = 58 \log \frac{[K]_o}{[K]_i}$$

At mammalian body temperature (37 oC), 58 mV increases to 61 mV. It is negative with respect to the outside.

Action Potential
A surface membrane that surrounds nerve cells serves as a **barrier** to the diffusion of ion species (and polar solutes). Selective changes in the cell membranes' permeability to solute molecules (Na+, K+, Ca+, and Cl-) are what cause the majority of electrical signals in nerve cells. Electrically excitable cell membranes contain voltage-gated ion channels, which are responsible for the generation of action potentials.

An action potential is a rapid change in voltage, or membrane potential, across a cellular membrane, following a specific pattern. It occurs when sufficient stimulus is applied to the cell membrane, causing a voltage response. If the stimulus is not strong enough to **depolarize** the membrane to a certain threshold, the action potential will not be triggered. Cells that communicate through action potentials include neurons and **muscle cells.**

1. A stimulus initiates the rapid change in voltage, known as the action potential. In patch-clamp experiments, enough current must be applied to exceed the threshold voltage, triggering membrane depolarization.
2. Depolarization occurs when sodium channels in the membrane open, causing a rapid rise in membrane potential due to the influx of sodium ions.
3. Repolarization follows as sodium channels close and potassium channels open, leading to an efflux of potassium ions, which helps restore the membrane potential.
4. Hyperpolarization occurs as the membrane potential temporarily drops below its resting level due to the continued efflux of potassium and the closing of potassium channels.
5. Finally, the resting state is restored when the membrane potential returns to its original resting voltage before the stimulus.

Compound action potentials

Compound action potentials are the name for electrical signals produced by collections of nerve or muscle cells. Keeping electrodes primarily on the body's surface allows for the recording of these. Some of these ignals, such as electrocardiogram (ECG) and electroencephalogram (EEG) are generated without any stimulus. Whereas electroneurogram (ENG), electromyogram (EMG), and evoked potentials need external stimulus. Compound action potentials provide useful information about the system from which they originate. For example, ECG provides information about the structure and function of the heart. EEG provides information about epileptic conditions and also about sleep patterns. EMG and ENG

signals can be used to find out muscle weakness and nerve degeneration. Evoked potentials provide information about visual, auditory and sensory system.

In short, the study of electricity in a living system is a very vast and emerging field. It is used to study brain functions such as memory, speech, hearing, cognitive functions of the brain and many more. The way neurons work has provided clues to develop neural networks, used in machine learning. Maybe we will deal with aspects sometime later.

References

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