University of Al-Mustaqbal
College of Science
Department of Medical Physics

BIOPHYSICS

first stage

(Electricity In The Nervous System)

Lecture Four

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Electricity within the Body

The Nervous System

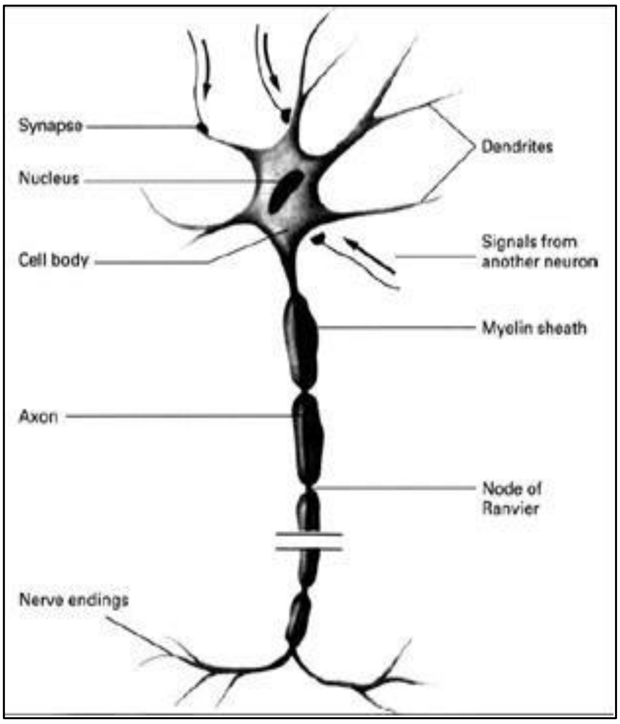
The nervous system can be divided into two parts:

1) The central nervous system consists of brain, the spinal cord and the peripheral nerves. The nerve fibers are of two types:
   a. ***Afferent nerves*** transmit sensory information to the brain or spinal cord.
   b. ***Efferent nerves*** transmit information from the brain or spinal cord to the appropriate muscles and glands.
2) The autonomic nervous system controls various internal organs (heart, intestine, glands etc). The control of autonomic nervous system is essentially involuntary.

The Neuron

Neuron is the basic structural unit of nervous system. It is specialised for reception, interpretation and transmission of electrical messages. Neuron is basically composed of:

1. Cell body receives the signal from other neurons through contacts called ***"synapses"*** which are located on the dendrites or on cell body.
2. Dendrites are part of neuron specialised for receiving information from stimuli or from other cells.
3. Axon or nerve fiber which carries the electrical signal to muscle, gland, or other neurons.

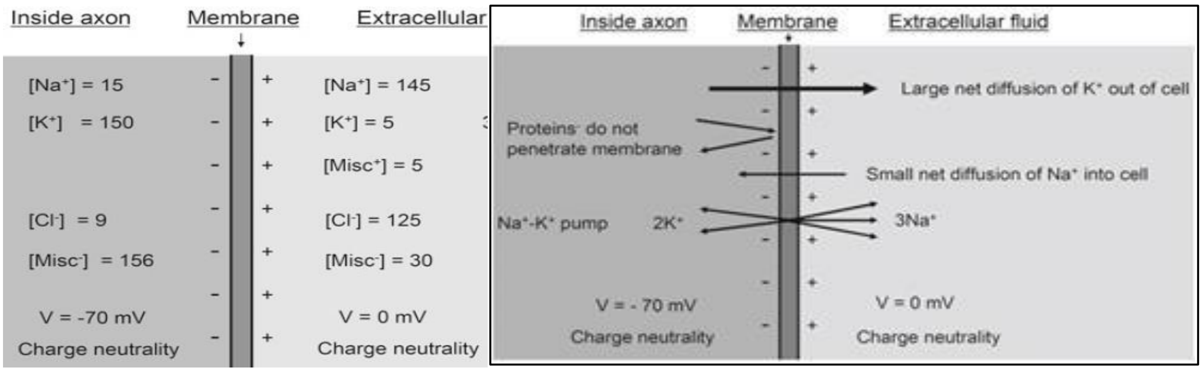


Electrical Potentials of Nerves

Resting Potential of the Neuron

The cell membrane divides the intracellular and extracellular regions, in neurons and other cells. There are Na^+, K^+, Cl^-, negatively-charged proteins, and other charged species both in the neurons (intracellular) and in the extracellular medium.

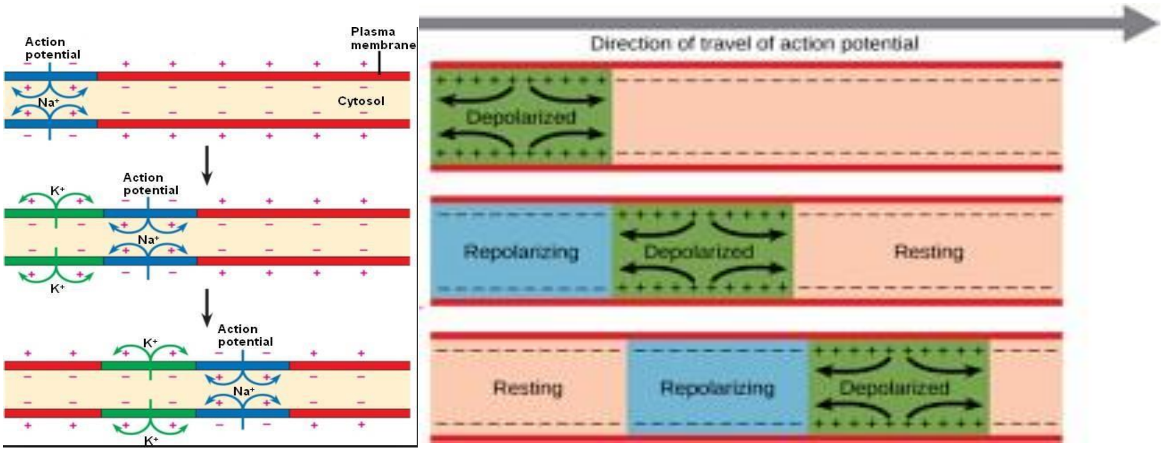
Across the surface or membrane of every neuron, there is an electrical potential (voltage) difference due to the presence of more negative ions inside the membrane than in extracellular fluid. The neuron is said to be ***polarized***. The inside of the cell is typically 60 to 90 mV more negative than the outside. This potential difference is called ***the resting potential*** of the neuron.



The Action Potential **(electrical signal transmission)**

When the neuron is stimulated, a large momentary change in the resting potential occurs at the point of stimulation. This potential change called the ***action potential*** propagates along the axon. The action potential is the major method of signals transmission within the body.

Suppose an axon has a resting potential of about -80 mV. If the left end of the axon is stimulated, the membrane walls become porous to Na^+ ions and these ions pass through the membrane, causing it to ***depolarize***. The inside momentarily goes positive to about 50mV. The reversed potential in the stimulated region cases ions movement which in turn depolarizes the region to the right. Meanwhile the point of original stimulation has recovered (***repolarized***) because K^+ ions have moved out to restore the resting potential.



Types of Nerve Fibers

There are two different types of nerve fibers:

1. ***Myelinated nerves***: the membranes of their axons are covered with a fatty insulating layer called myelin and have small uninsulated gaps called ***nodes of Ranvier*** every few millimeters. Myelinated nerves conduct action potentials much faster than unmyelinated nerves. The myelinated segments of their axons have very low electrical capacitance. Myelinated fibers have outer radii of 0.5–10 μm and a conduction speed of u (in m/s) ≈ 12(a + b) ≈ 17a, where (a) is the radius of

the axon (in μm) and (b) is the myelin sheath thickness (in μm). The spacing between the nodes of Ranvier is ≈280a.

2. ***Unmyelinated nerves***: Approximately 2/3 of the axon fibers in the body are unmyelinated. They have radii of 0.05–0.6 μm and a conduction speed of u (in m/s) ≈ 1.8 $\sqrt{a}$, where (a) is the radius of the axon (in μm). The axons of unmyelinated nerves have no myelin sheath.

Factors Affecting the Propagation Speed of Action Potential

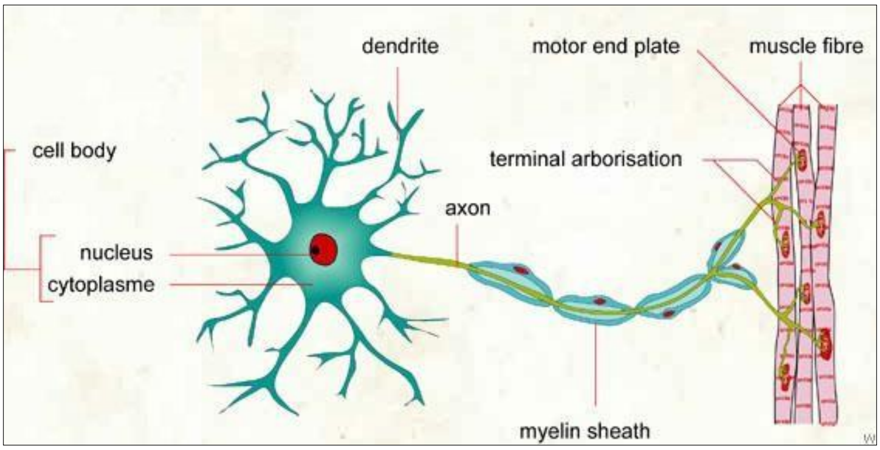
Two primary factors affect the speed of propagation of the action potential:

1. The resistance within the core of the membrane
2. The capacitance (or the charge stored) across the membrane.

- A decrease in either (resistance or capacitance) will increase the propagation velocity.
- The internal resistance of an axon decreases as the diameter increases, so an axon with a large diameter will have a higher velocity of propagation than an axon with a small diameter.
- The greater the stored charge (the capacitance) the longer it takes to depolarize it and thus the slower the propagation speed.

Electrical Signals from Muscles

- One means of obtaining diagnostic information about muscles is to measure their electrical activity. The record of the potentials from muscles during movement is called the ***electromyogram or EMG***.
- Motor unit consists of a single branching neuron (from brain stem or spinal cord) and 25 to 2000 muscle fibers which are connected together by ***motor end plates***.



- EMG can be obtained from single or many motor units that are stimulated electrically.
- Single muscle cells are usually not monitored in an EMG examination because it is difficult to isolate a single fiber.

- In EMG of a motor unit, an electrical stimulation is applied and the response will appear after a latency period. The velocity of the action potential in motor nerve can also be determined. Stimuli are applied at two locations, and the difference in latency period between the two responses is the time for action potential to travel. The velocity of action potential is the distance divided by time.
- EMG can also be obtained for sensory nerve. The conduction velocity for sensory nerves can be measured by stimulating at one site and recording at several locations that are known distances from the point of stimulation.
- Typical velocities are 40 to 60m/sec , below 10 m/sec indicate a problem.

<u>Electrical Signals from the Heart (the electrocardiogram)</u>

The rhythmical action of the heart is controlled by an electrical signal initiated by spontaneous stimulation of special muscle cells located in the right atrium called the ***sinoatrial (SA) node***. The SA node fires at regular intervals about 72 times per minute. The SA node initiates the depolarization of the nerves and muscles of both atria, causing the atria to contract and pump blood into the ventricles. Repolarization of the atria follows. The electrical signal then passes into the ***atrioventricular (AV) node*** which initiates the depolarization of the ventricles causing them to contract. The ventricle nerves and muscles then repolarize and the sequence begins again.

<u>1)</u> The ***surface electrodes*** for obtaining the ECG are most commonly located on the left arm (LR), right arm (RA), and left leg (LL). The measurement of the potential between ***RA and LA is called Lead I***, that between ***RA and LL is called Lead II***, and that between ***LA and LL is called Lead III***. All these leads give the relative amplitude and direction of the electric dipole vector in the frontal plane.

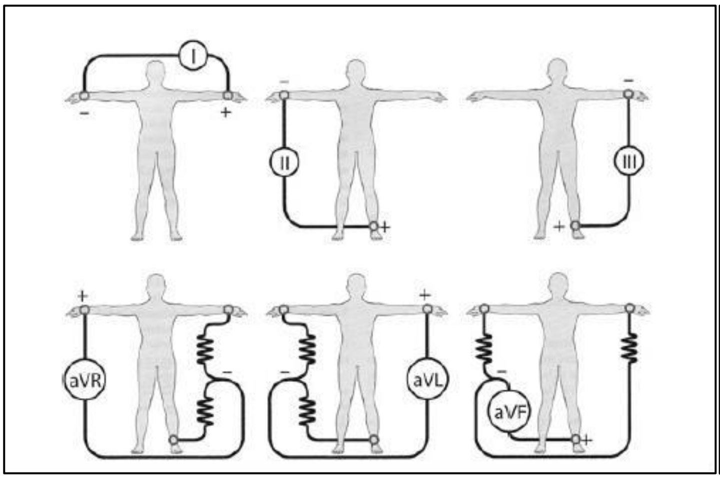
<u>2)</u> Three augmented lead configurations are:

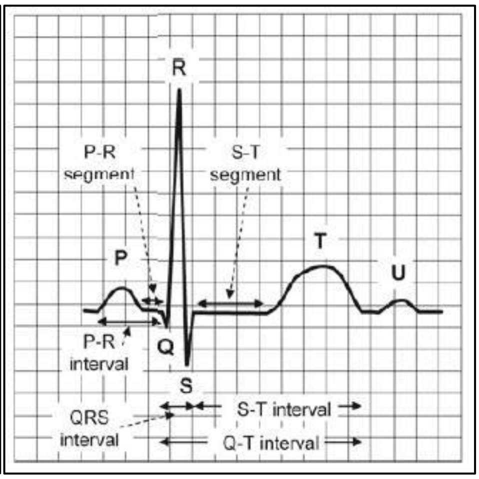
1. aV_R lead :one side of the recorder is connected to RA and the other side is connected to the centre of two resistors connected to LL and LA.
2. aV_L lead :the recorder is attached to the LA electrode and the resistors are connected to RA and LL.
3. aV_F lead: the recorder is attached to the LL electrode and the resistors are connected to RA and LA.

The major electrical events of the normal heart cycle are:

a) The ***atrial depolarization*** which produces the ***P wave***.
b) The ***atrial repolarization*** which is rarely seen and ***is unlabeled***.
c) The ***ventricular depolarization*** which produces the ***QRS complex***.
d) The ***ventricular repolarization*** which produces the ***T wave***.

<u>3)</u> In clinical examination, six ***transverse*** plane ECG leads are usually made which are called V1, V2, V3, V4, V5, and V6



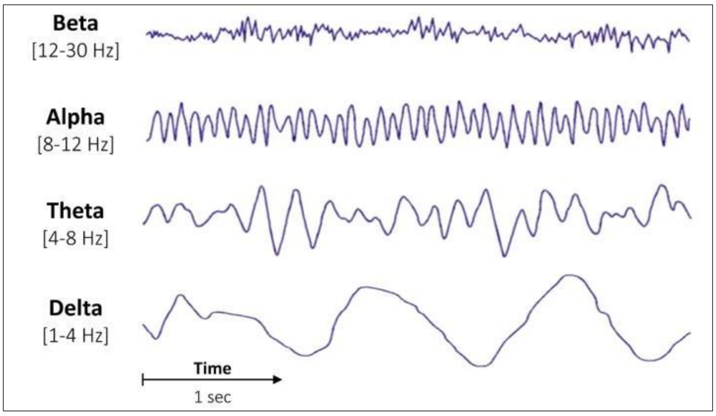


<u>Electrical Signals from the Brain</u>

The recording of the signals from the brain is called the ***electroencephalogram (EEG)***. In routine exams 8to16 channels are recorded simultaneously. Since asymmetrical activity is often an indication of brain disease, the right side signals are often compared to the left side signals.

In general, the EEG signal is irregular but it has identifiable rhythmic patterns:

1. alpha waves (frequency of 8–13 Hz; awake, restful state)
2. beta waves (14–25 Hz; alert wakefulness, extra activation, tension)
3. theta waves (4–7 Hz, mostly in children, also adults with emotional stress and with many brain disorders)
4. delta waves (<3.5Hz; deep sleep)



<u>Electrical Signals from the Eye</u>

The recording of potential changes produced by the eye when the retina is exposed to a flash of light is called the ***electroretinogram (ERG)***. One electrode is located in a contact lens that fits over the cornea and the other electrode is attached to the ear or forehead.

The ***electrooculogram (EOG)*** is the recording of potential changes due to eye movement. For this measurement, a pair of electrodes is attached near the eye. It is provide information on the orientation of the eye, its angular velocity, and its angular acceleration.