ELECTRICITY WITHIN THE BODY

Electricity plays an important role in medicine. There are **two** aspects of **electricity** and **magnetism** in medicine: -

1. **Electrical** and **magnetic** effects generated inside the body.
2. Applications of **electricity** and **magnetism** to the surface of the body.

The electricity generated inside the body serves for the control and operation of **nerves**, **muscles**, and **organs**.

The **nervous system** plays a fundamental role in nearly every body function. Basically, a central computer (**the brain**) receives internal and external signals and (**usually**) makes the proper response.

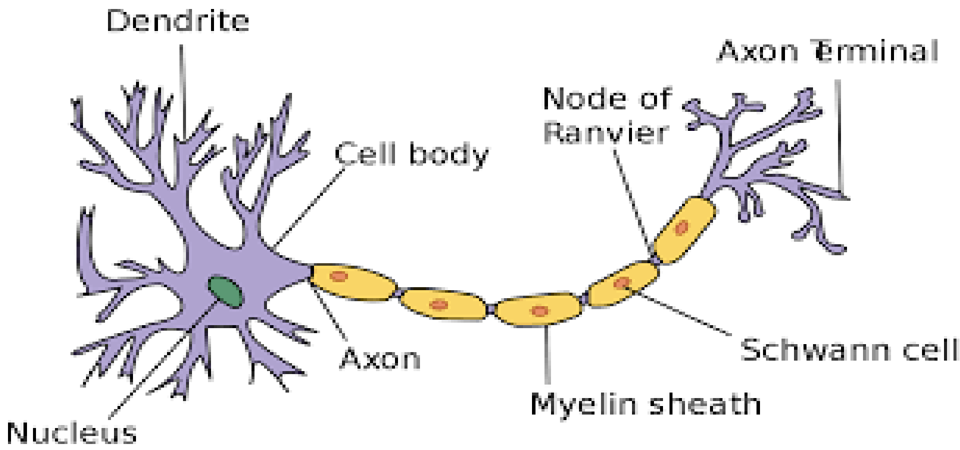
The nervous system and the neuron

The nervous system can be divided into **two** parts: -

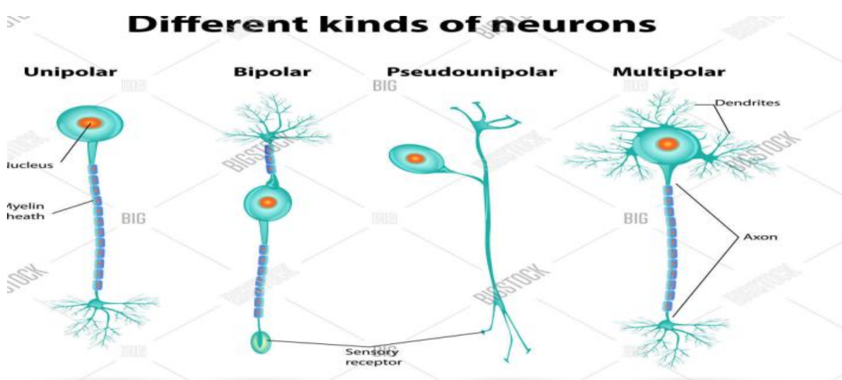
1. The **central** nervous system.
2. The **autonomic** nervous system.

The **central nervous system** consists of the brain, the spinal cord, and the peripheral nerves-nerve fibers (**neurons**) that transmit sensory information to the brain or spinal cord (**afferent nerves**) and nerve fibers (**neurons**) that transmit information from the brain or spinal cord to the appropriate muscles and glands (**efferent nerves**).

The **autonomic nervous system** controls varies internal organs such as the heart, intestines, and glands. The control of the autonomic nervous system is essentially involuntary.



The basic structural unit of the nervous system is the **neuron**; a nerve cell specialized for reception, interpretation, and transmission of electrical massages. There are many types of neurons.



Basically, a neuron consists of a cell body that receives electrical messages from other neurons through contacts called **synapses** located on the **dendrites** or on the **cell body**.

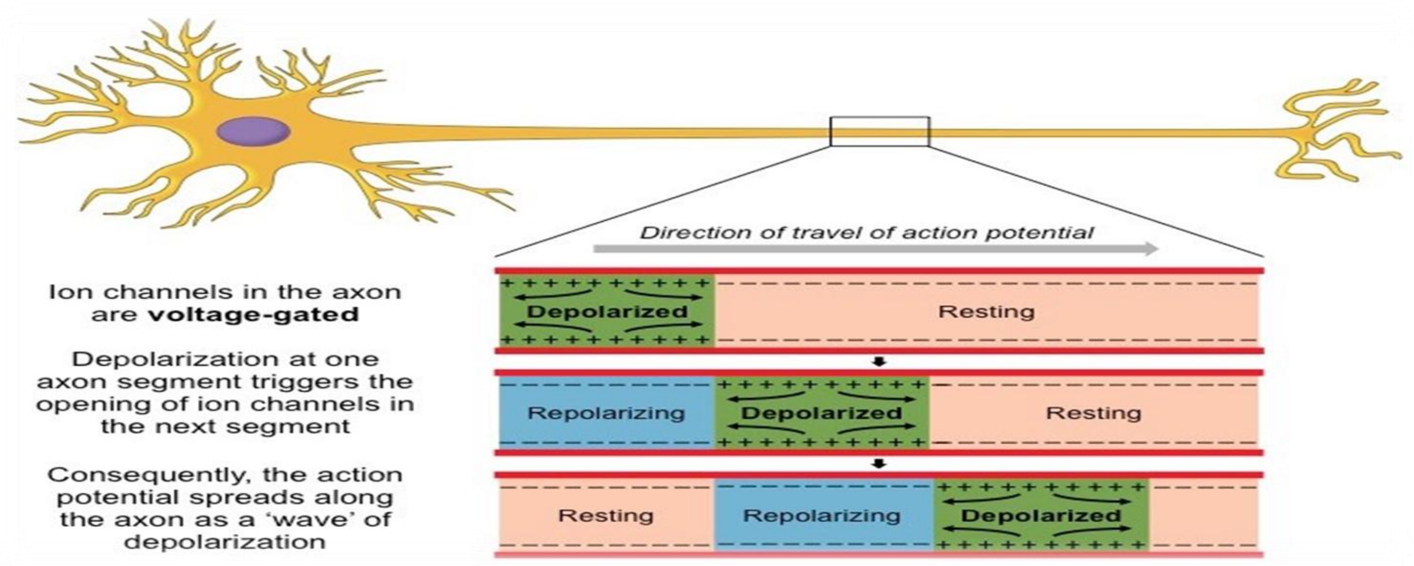
The **dendrites** are the parts of the neuron specialized for receiving information from stimuli or from other cells. If the stimulus is strong enough, the neuron transmits an electrical signal outward along a fiber called an **axon**. The **axon**, or **nerve fiber**, which may be as long as **1m**, carries the electrical signal to muscles, glands, or other neurons.

Electrical potentials of nerves

Across the surface or membrane of every neuron is an electrical potential (**voltage**) difference due to the presence of more negative ions on the inside of the membrane than on the outside.

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. 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 transmission of signals within the body.

An axon can transmit in either direction. However, the synapse that connects it to another neuron only permits the **action potential** to move along the axon away from its own cell body.

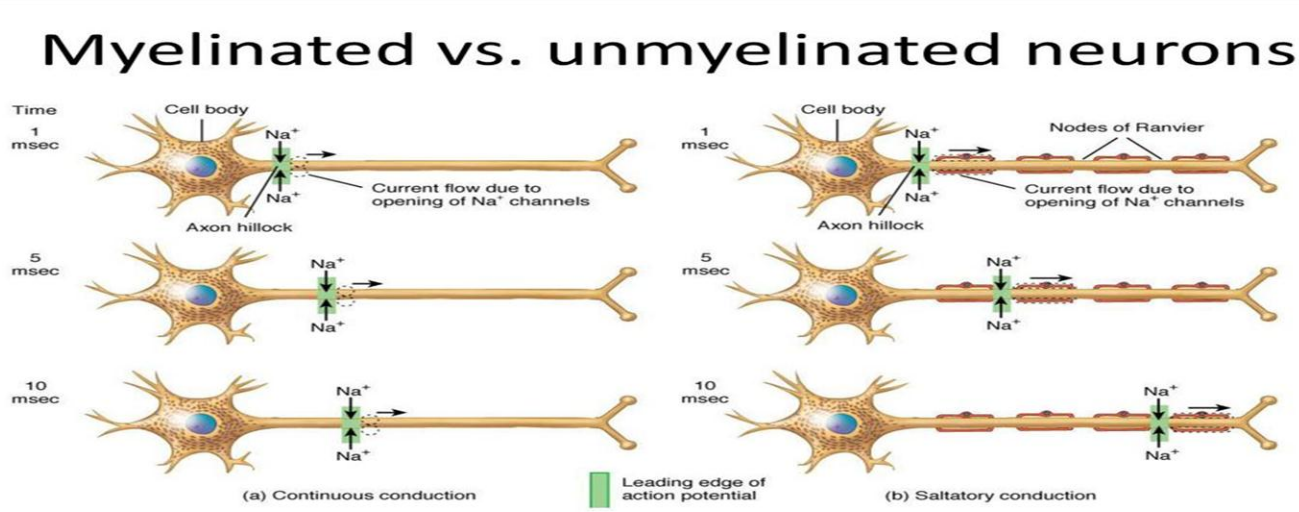


Examination of the axons of various neurons with an electron microscope indicates that there are ***two*** *different types of* ***nerve fibers****: -*

1. The membranes of some axons are covered with a fatty insulating layer called **myelin** that has small uninsulated gaps called **nodes of Ranvier** every few millimeters; these nerves are referred to as **myelinated nerves**.

2. The axons of other nerves have no myelin sleeve (**sheath**), and these nerves are called **unmyelinated nerves**.

Myelinated axons conduct differently than the unmyelinated axon. The myelin sleeve is a very good insulator, and the myelinated segment of an axon has very low electrical capacitance. The action potential decreases in amplitude as it travels through the myelinated segment just as an electrical signal is attenuated when it passes through a length of cable. The reduced signal then acts like a stimulus at the next **node of Ranvier** (**gap**) to restore the action potential to its original **size** and **shape**. This process repeats along the axon; the action potential seems to jump from one node to the next, that is, it travels by ***saltatory conduction***.



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

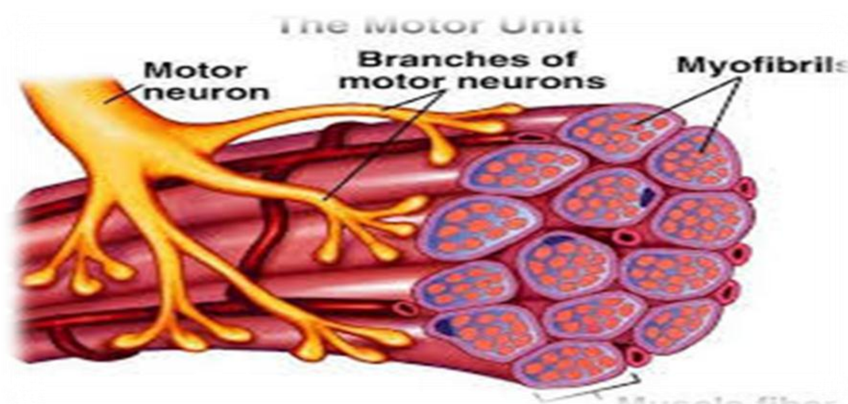
1. The **resistance** within the core of the membrane.
2. The **capacitance** (or the charge stored) across the membrane.

A decrease in either 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 on a membrane, the longer it takes to depolarize it, and thus the slower the propagation speed. Because of the low capacitance, the charge stored in a **myelinated** section of a nerve fiber is very small compared to that on an **unmyelinated** fiber of the same diameter and length. Hence the conduction speed in the **myelinated** fiber is many times faster.

Electrical signals from muscles

The record of the potentials from muscles during movement is called the **electromyogram**, or **EMG**.

A muscle is made up of many motor units. A motor unit consists of a single branching neuron from the brain stem or spinal cord and the **25** to **2000** muscle fibers (**cells**) it connects to via motor end plates.

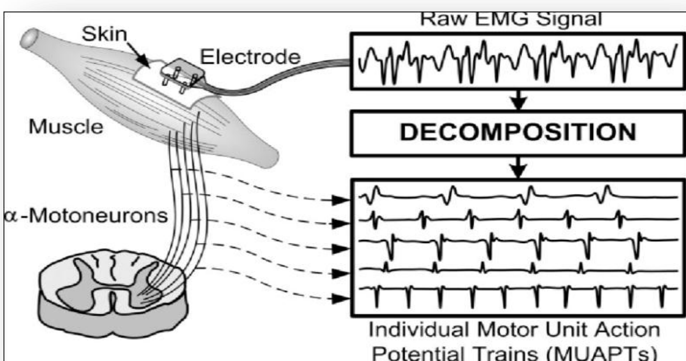


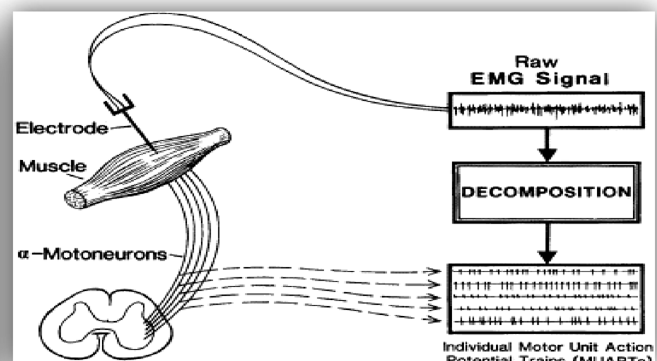
The **resting potential** across the membrane of a muscle fiber is similar to the **resting potential** across a nerve fiber. **Muscle action** is initiated by an **action potential** that travels along an axon and is transmitted across the motor end plates into the muscle fibers, causing them to contract.

Single muscle cells are usually not monitored in an EMG examination **because** it is difficult to isolate a single fiber. Instead, EMG electrodes usually record the electrical activity from several fibers.

1. Either a **surface electrode** attached to the skin measures the electrical signals from many motor units.

2. Or a **concentric needle electrode** inserted under the skin measures single motor unit activity by means of insulated wires connected to its point.

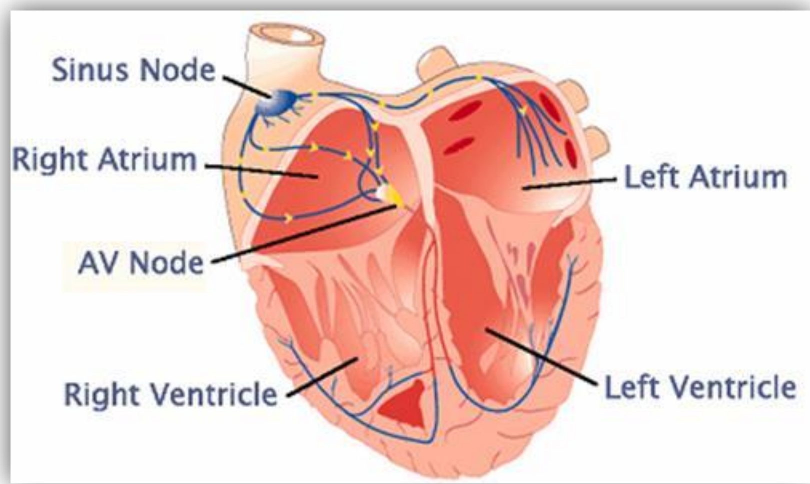




The **action potential** appears in the EMG after a **latency period** (the time between stimulation and the beginning of the response). Sometimes the EMGs from symmetrical muscles of the body are compared to each other or to those of normal individuals to determine whether the action potentials and latency periods are similar.

Electrical signals from the heart

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. These cells make up the **sinoatrial (SA) node**, or the **pacemaker.**



The **SA** node fires at regular intervals about **72** times per minute. The electrical signal from the **SA** node initiates the depolarization of the nerves and muscles of atria, causing the atria to contract and pump blood into the ventricles. Repolarization of the atria follows. The electrical signals then passes into the **atrioventricular** (AV) **node**, which initiates the depolarization of the right and left ventricles, causing them to contract and force blood into the pulmonary and general circulations. The ventricle nerves and muscles then repolarize and the sequence begins again.

Obviously it is not practical to make direct electrical measurements on the heart; diagnostic information is obtained by measuring at various places on the surface of the body the electrical potentials generated by the heart. The record of the heart's potentials on the skin is called the **electrocardiogram** or **ECG**.

The surface electrodes for obtaining the ECG are most commonly located on the left arm (**LA**), right arm (**RA**), and left leg (**LL**), although the location of the electrodes can vary in different clinical situations; sometimes the hands or positions closer to the heart are used.

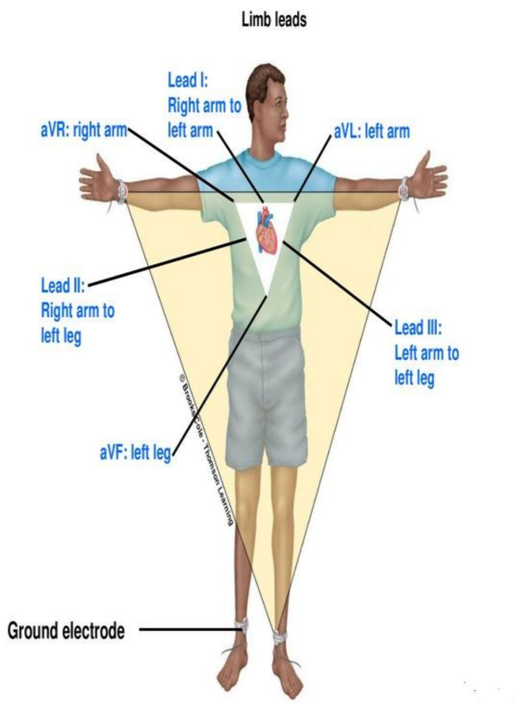
<u>The standard limb leads: -</u>

These leads are obtained in the frontal plane.

1-The measurement of the potential between **RA** and **LA** is called **Lead I**.

2- The measurement of the potential between **RA** and **LL** is called **Lead II**.

3- The measurement of the potential between **LA** and **LL** is called **Lead III.**



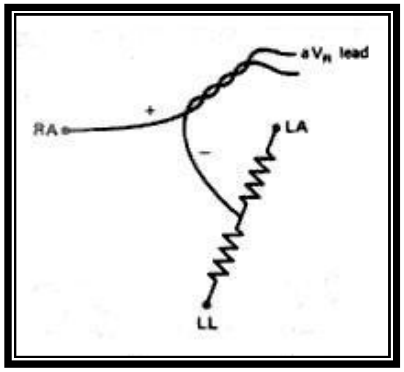
<u>The augmented lead configurations: -</u>

These leads are also obtained in the frontal plane.

1. aV_R lead, one side of the recorder is connected to **RA** and the other side is connected to the center of two resistors connected to **LL** and **LA**.

2. aV_L lead, one side of the recorder is connected to **LA** and the other side is connected to the center of two resistors connected to **LL** and **RA**.

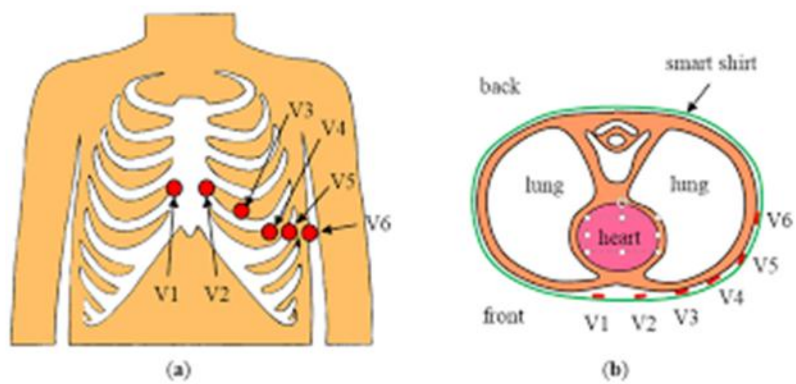
3. aV_F lead, one side of the recorder is connected to **LL** and the other side is connected to the center of two resistors connected to **LA** and **RA**.



<u>Six precordial, unipolar chest leads</u>.

In a clinical examination, six **transverse plane** ECGs are usually made in addition to the six frontal plane ECGs.

Electrode is moved across the chest wall to the **six** different positions. (V1,V2,V3,V4,V5,V6)



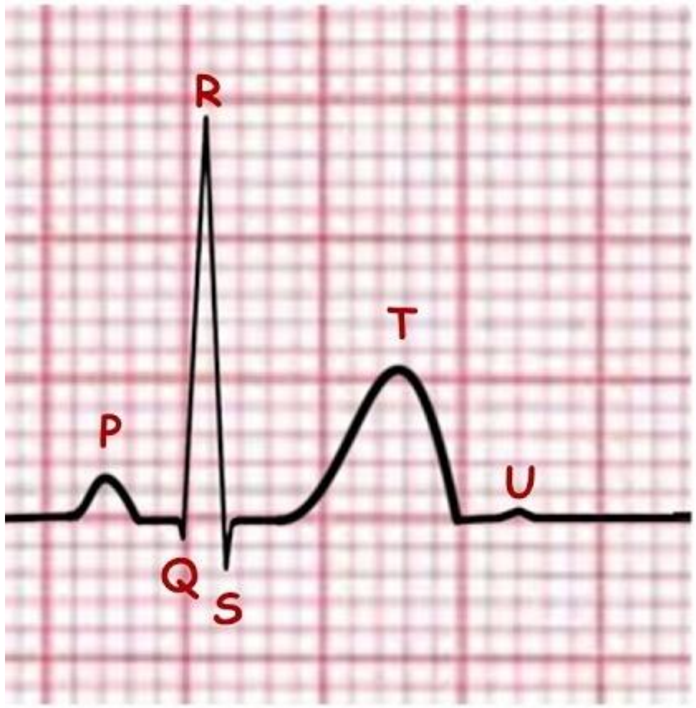
<u>The major electrical events of the normal heart cycle are: -</u>

1-The atrial depolarization, which produces the P wave.

2. The atrial repolarization, which is rarely seen and is unlabeled.

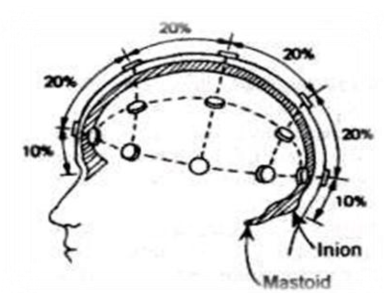
3. The ventricular depolarization, which produces the QRS complex.

4. The ventricular repolarization, which produces the T wave.



Electrical signals from the brain

If you place electrodes on the scalp and measure the electrical activity, you will obtain some very weak complex electrical signals. These signals are due primarily to the electrical activity of the neurons in the **cortex** of the **brain**.



The recording of the signals from the brain is called the **electroencephalogram** or **EEG**. Electrodes for recording the signals are often small discs of **chlorided silver**. They are attached to the head at locations that **depend** upon the part of the brain to be studied. The reference electrode is usually attached to the ear (**A_1 or A_2**).

Since asymmetrical activity is often an indication of brain disease, the right side signals are often compared to the left side signals.

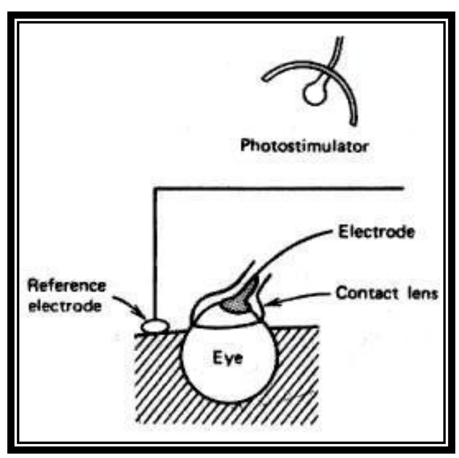
Interference from external electrical signals often causes serious problems in EEG signal processing. Even if the external noise is controlled, the potentials of muscle activity such as eye movement can cause artifacts in the record.

The frequencies of the EEG signals seem to be dependent upon the mental activity of the subject.For Example: -

1. A relaxed person usually has an EEG signal composed primarily of frequencies from 8 to 13 Hz, or alpha waves (**α**).
2. When a person is more alert a higher frequency range, the beta wave (**β**) or fast range (above 13Hz).
3. Delta (**δ**) or slow (0.5 to 3.5 Hz).
4. Theta (**θ**) or intermediate slow (4 to 7 Hz).

Electrical signals from the eye

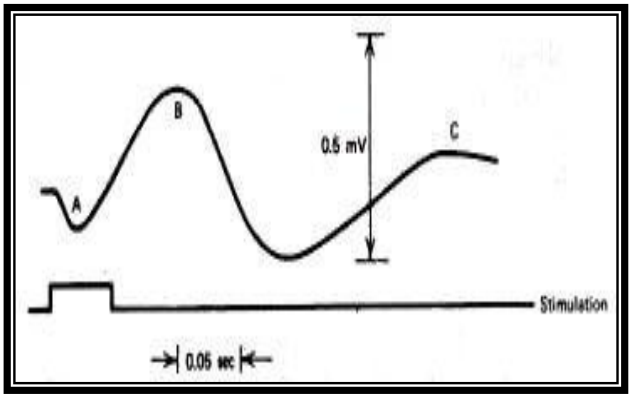
The recording of potential changes produced by the eye when the retina is exposed to a flash of light called the **electroretinogram** or **ERG**.



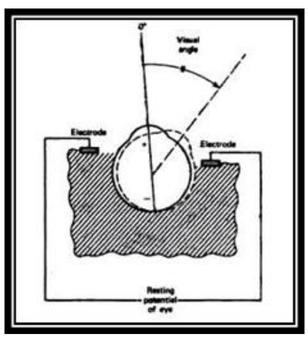
One electrode is located in a contact lens that fits over the cornea and the other electrode is attached to the ear or forehead to approximate the potential at the back of the eye.

An **ERG** signals is more complicated than a nerve axon signal **because** it is the sum of many effects taking place with the eye.

The **B** wave is the most interesting clinically since it arises in the retina. The **B** wave is absent in the **ERG** of a patient with inflammation of the retina.



The **electrooculogram** or **EOG** is the recording of potential changes due to eye movement. For this measurement, a pair of electrodes is attached near the eye



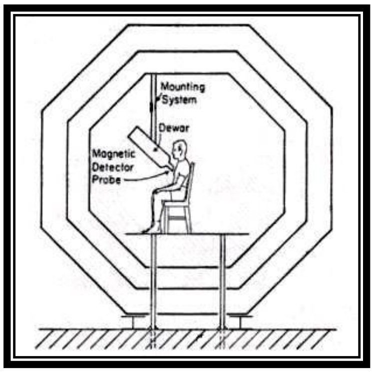
Electrooculograms provide information on the **orientation** of the eye, its **angular velocity**, and its **angular acceleration**.

Magnetic signals from the heart and brain

Since a flow of electrical charge produces a magnetic field, a magnetic field is produced by the current in the heart during depolarization and repolarization. The recording of the heart's magnetic field is the **magnetocardiogram** or **MCG**(**Magnetocardiograhy** measures these very week magnetic fields around the heart).

The magnetic field around the heart is about **5x10^{-11} tesla** (**T**), or about **one-millionth** of the earth's magnetic field.

To measure fields of this size it is necessary to use magnetically shielded rooms and very sensitive magnetic field detectors (**magnetometers**). One such detector, called a SQUID (**Superconducting QUantum Interference Device**).



The **SQUID** magnetometer has also been used to record the magnetic field surrounding the brain. The recording of this field is called the **magnetoencephalogram** or **MEG**. The magnetic field from the brain is about

1x10^{-13} tesla (**T**). This is almost **one-billionth** of the earth's magnetic field.

Not all magnetic fields produced within the body are due to ion currents; the body can be easily contaminated with magnetic materials. ***For Example***, asbestos workers inhale asbestos fibers, which contain **iron oxide** particles. The size of the magnetic field from the **iron oxide** in a worker's lungs can be used to estimate the amount of inhaled asbestos dust. Typical magnetic fields from asbestos workers' chests are about **one-thousandth** of the earth's magnetic field (**5x10^{-8}T**).