Electricity within the body

Electricity plays an important role in medicine, there are two aspects of electricity and magnetism in medicine: electrical and magnetic effects generated inside the body.
Electricity is the flow of electrons (current) through a conductor.
Luigi Galvani made the first contribution in this field in 1786 when he discovered animal electricity in *frog's leg*, since then many years of research have been expanded on a wide variety of experiments dealing with electrical effects in and on the body ,basic research in this area is called *neurophysiology*.
The electricity generated inside the body serves for the control and operation of nerves ,muscle and organs.
Essentially all functions and activities of the body involve electricity in some way, the forces of muscles are caused by the attraction and repulsion of electrical charges.
The action of the *brain* is basically electrical, all nerve signals to and from the brain involve the flow of electrical currents.
The electrical potentials of nerve transmission and the electrical signals seen in the *electromyogram*(EMG) of the muscle, the *electrocardiogram*(ECG) of the heart and the *electroencephalogram* (EEG) of the brain are the best known.
We also discuss some of the less familiar electrical signals of the body ,such as those seen in the *electroretinogram* (ERG) and electrooculogram (EOG) of the eye ,the magnetic signals of the body as shown on the *magneto cardiogram* (MCG) of the heart and the *magneto encephalogram* (MEG) of the brain and those signals associated with bone growth and *biofeedback.*
Various medical specialists are involved in the diagnosis and treatment of malfunctions of this internal electrical system.
If the problem involves any part of the nervous system it is diagnosed and treated by a *neurologist* ,an M.D who has had three or more years of special training in the study of the nervous system, if the problem requires surgery ,it is usually handled by a *neurosurgeon* ,an M.D ,who specializes in surgery of the nervous system and has had three or more years of training in this area of surgery ,since much of neurosurgery involves the brain ,these specialists are sometimes called brain surgeons .
Neuroradiologists are M.D.s who have taken a three-year residency in diagnostic radiology followed by another year in neuroradiological specialization ,pediatric neurology ,a subspecialty of pediatrics ,deals with nerve problems in infants and children .Electromyogram tests are usually performed and interpreted by *physiatrists* ,M.D.s who have taken residencies in physical medicine .Cardiologists ,specialists in the study and treatment of heart disease ,deal with the electrical activity of the heart . *Psychiatrists* are M.D.s

who specialize in the diagnosis ,prevention and treatment of emotional illness and neural disorders ,they may use shock therapy and medication .*Clinical psychologists* are Ph.D.s who have studied behavior and also specialize in the diagnosis and treatment of mental illness ,however ,they cannot use shock therapy or treat with drugs.

<u>(H.W)</u> Q//1. List five electrical signals from the body that are sometimes recorded? 2. What is physiatrist?

THE NERVOUS SYSTEM AND THE NEURON:

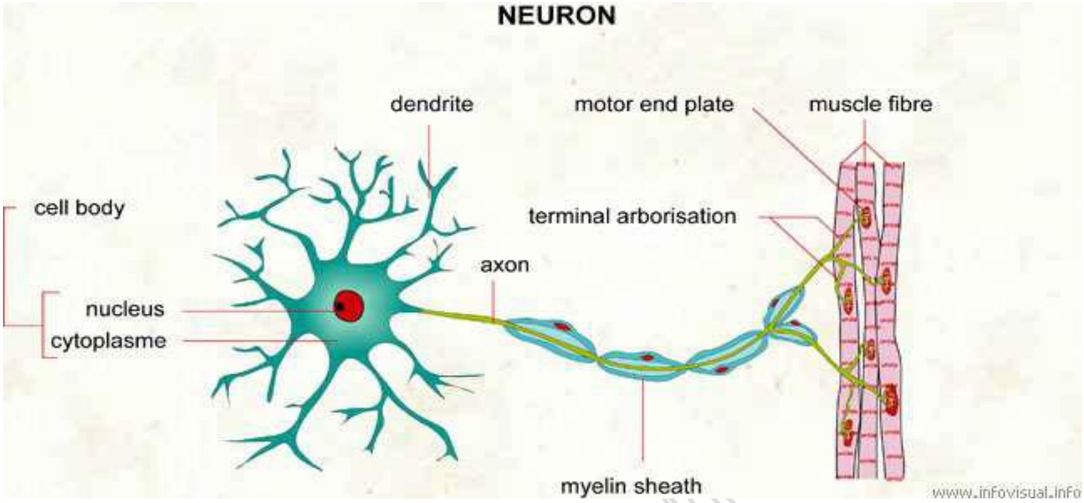
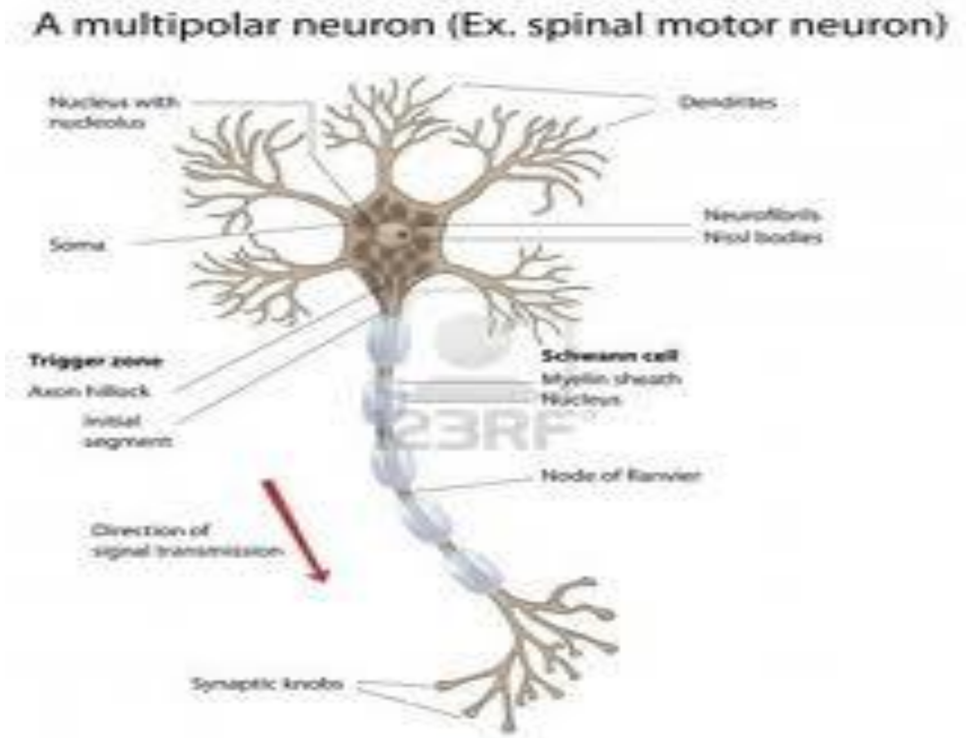


Fig (1) Basic structural unit of the nervous system

The nervous system can be divided in two parts.
1-Central nervous system consists of the
-brain
-spinal cord
-nerve fibers (neurons)
That transmits sensory information to brain or spinal cord and from brain or spinal cord to appropriate muscles and glands.
2-The autonomic nervous system
Controls various internal organs such as the heart, intestines, and glands.
The basic structural unit of the nervous system is a neuron (Fig 1).
A nerve cell specialized for the
-reception
-interpretation
-transmission of the electrical messages
Neuron consists of a cell body that receives electrical messages from other neurons through contacts called synapses located on the dendrites. The neuron transmits an electrical signal out word along axon. The axon carries the electrical signal to muscle, gland, or other neurons.

Electrical potentials of nerves:

The basic structural unit of the nervous system is the *neuron (*Look fig. for schematic of a motor neuron) a nerve cell specialized for the reception, interpretation and transmission of electrical messages.



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 the specialist 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.

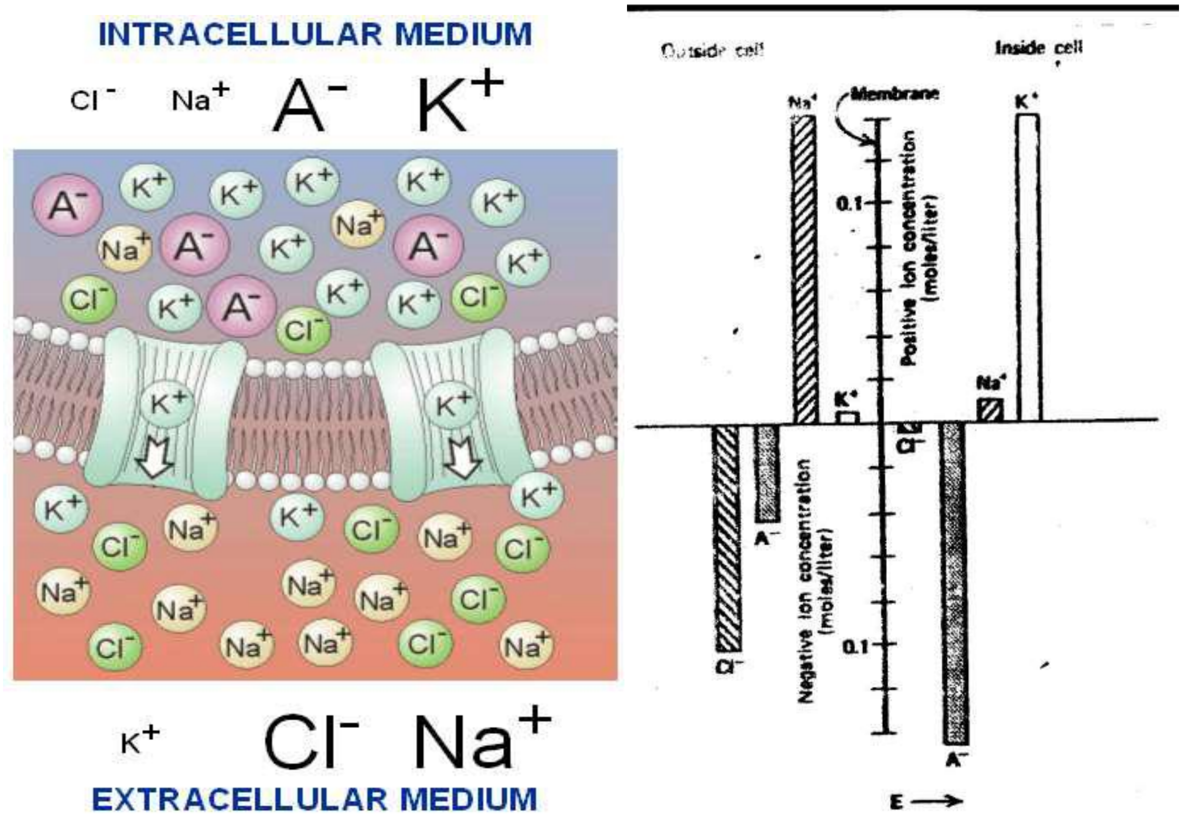
The axon ,or nerve fiber, which be as long as 1 m ,caries the electrical signal to muscles ,glands ,or other neurons .

In this section we discuss the electrical behavior of neuron ,much of the early research on the electrical behavior of nerves was done on the giant nerve fibers of squid .

The conveniently large diameter (1mm) of these nerve fibers allows electrodes to be readily inserted or attached for measurements.

A cross 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 90mv more negative than the outside , this potential difference is called the *resting potential* of the neuron.[Look fig.2]…shows schematically the typical concentrations of various ions inside and outside the membrane of an axon.



(Fig 2) The typical concentrations of various ions inside and outside the membrane of an axon.

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.

The stimulation may be caused various physical and chemical stimuli such as heat, light, sound, and others

We can explain the resting potential by using a model in which a membrane separates a concentrated neutral solution of KCl from one that is less concentrated (Fig.3 A).The KCl in solution forms K^+ ions and Cl^- ions ,we assume that the membrane permits K^+ ions to pass through it but does not permit the passage of the Cl^- ions.

The K^+ ions diffuse back and forth across the membrane , however a net transfer takes place from the high concentration region H to the low concentration region L, eventually this movement results an excess of positive charge in L and an excess of negative charge in H.

These charges form layers on the membrane to produce an electrical force that retards the flow of K^+ ions from H to L, ultimately a condition of equilibrium exists (Fig3.B).

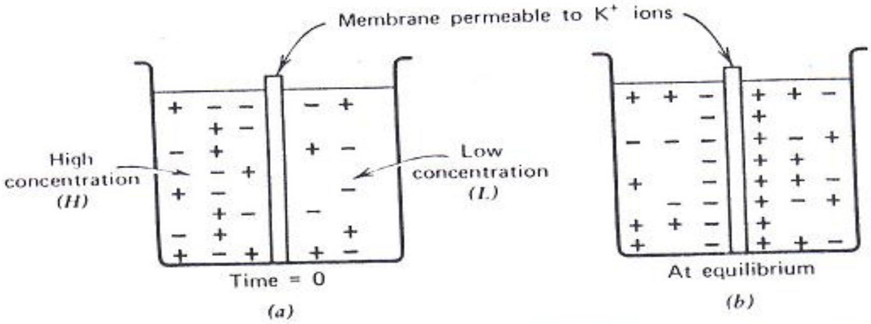


Figure 3 A model of the resting potential. (*a*) A membrane selectively permeable to K^+ ions initially separates two KCl solutions of different concentrations; + and − represent the K^+ and Cl^- ions, respectively. The K^+ ions diffuse from side *H* to side *L*, producing a charge difference (dipole layer) across the membrane and hence a potential. (*b*) The dipole layer provides an electrical force that tends to keep K^+ ions on side *H*. An equilibrium condition is produced when the K^+ ion movement due to diffusion is balanced by the ion movement due to the electrical force from the dipole layer. The dipole layer is equivalent to a resting potential across the membrane.

[fig. 4] shows schematically how the axon propagates an action potential ,graphs of the potential measured between point P and the outside of the axon are also shown .

This axon has a resting potential of about (-80mv) "Fig 4.a",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 causes ion movement as shown by the arrows in "fig 3.b",which in turn depolarizes the region to the right "fig.4 c, d, and e" ,mean while the point of original stimulation has recovered (*repolarized*) because K^+ ions have moved out to restore the resting potential "fig 4c,d and e".

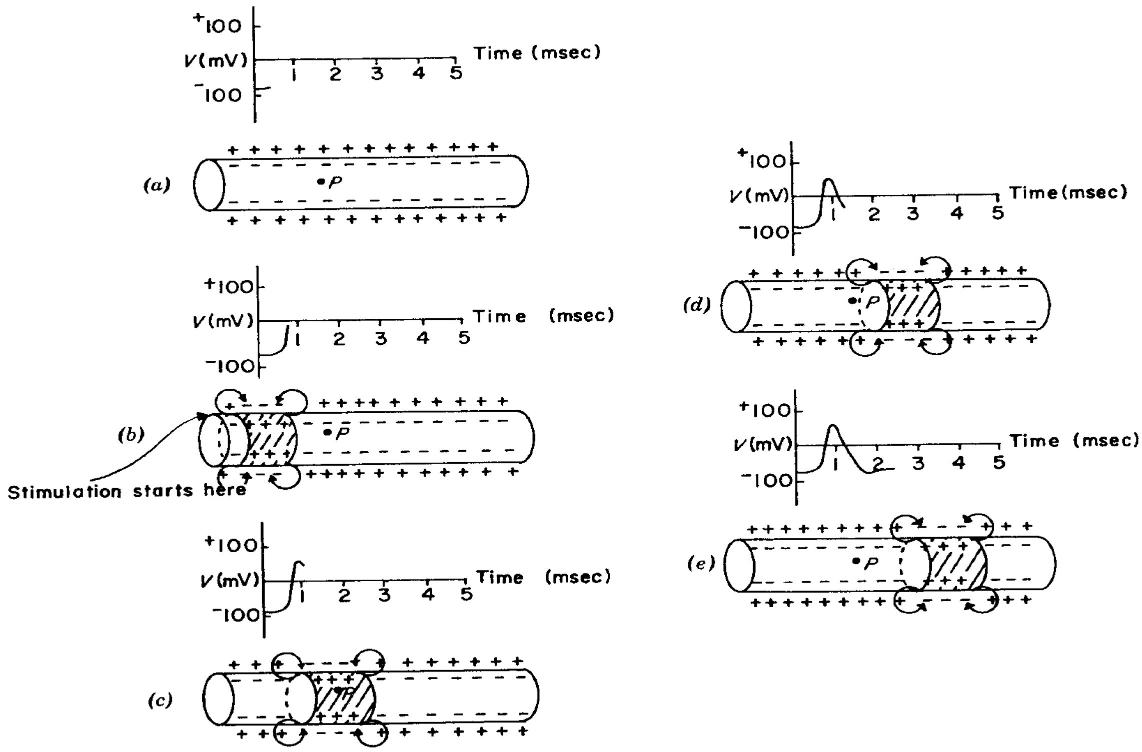
Examination of the axons of various neurons with an electron microscope indicates that there are two different types of nerve fibers, the membranes of some axons are covered with a fatty insulating layer called myelin that has small un insulated gaps called nodes of *Ranvier* every few millimeters, these nerves are referred to as *myelinated nerves*.

The axons of other nerves have no myelin sleeve (sheath) and these nerves are called *un myelinated nerves*, this is a some what artificial classification ,most human nerves have both types of fibers ,much of the early research on the electrical behavior of nerves was done on the un myelinated giant nerve fiber of the squid [fig 4],myelinated nerves ,the most common type in humans ,conduct action potentials much faster than un myelinated nerves.

Fig .3; the transmission of a nerve impulse a long an axon, the graphs show the potential at point P

(a)The axon has a resting potential of about (-80mv)

(b)Stimulation on the left causes Na^+ ions to move into the cell and depolarize the membrane.
(c) The positive current flow on the leading edge ,indicated by the arrows ,stimulates the regions to the right so that depolarization takes place and the potential change propagates .(d and e).mean while K^+ ions move out of the core of the axon and restore the resting potential(*repolarize* the membrane).the voltage pulse moving along the nerve is the action potential.



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. The conduction in the gap is the same as shown in fig.(4).This process repeats along the axon ;the action potential seems to jump from one node to the next ,that is ,it travels by salutatory conduction.
Two primary factors affect the speed of propagation of the action potential: the resistance within the core of the membrane and 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 depolarized 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 a 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 .The unmyelinated squid axons (~ 1mm in diameter) have propagation velocities of 20 to 50 m/sec ,whereas the myelinated fibers in man (~ 10μ m in diameter)have propagation velocities of around 100 m/sec .The advantage of myelinated nerves as found in man is that they produce high propagation velocities in axons of small diameter .A large number of nerve fibers can thus be packed into a small bundle to provide for many signal channels.

(H.W).Q. //What is the advantage of myelinated nerves over unmyelinated nerves?

Electrical signals from Muscle (EMG):-

In this section we briefly trace the transmission of the action potential from the axon into the muscle, where it causes muscle contraction. the record of the potentials from muscles during movement is called the *electromyogram*(EMG). A muscle is made up of many motor units. motor unit consists of a single branching neuron from the brain stem or spinal cord and (25 – 2000) muscle fibers(cells)it connects to via motor end plates (Fig 5-a).

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. The record of the action potential in signal muscle cell is shown schematically in fig (5-b)

EMG electrodes usually record the electrical activity from several fibers, either a surface electrode or a concentric needle electrode is used. Surface electrode attached to the skin measures the electrical signal from many motor units. A concentric needle electrode inserted under the skin measures signal motor unit activity by means of insulated wires connected to its point, In addition to electrically stimulating the motor units, it is possible to excite the sensory nerves that carry information to the central nervous system. The reflex system can be studied by observing the reflex response at the muscle.

A patient with the relatively rare disease *myasthenia gravis* shows muscular weakness when carrying out a repetitive muscular task; the EMG of such a patient shows that in repetitive stimulation the motor nerve to muscle transmission fails.

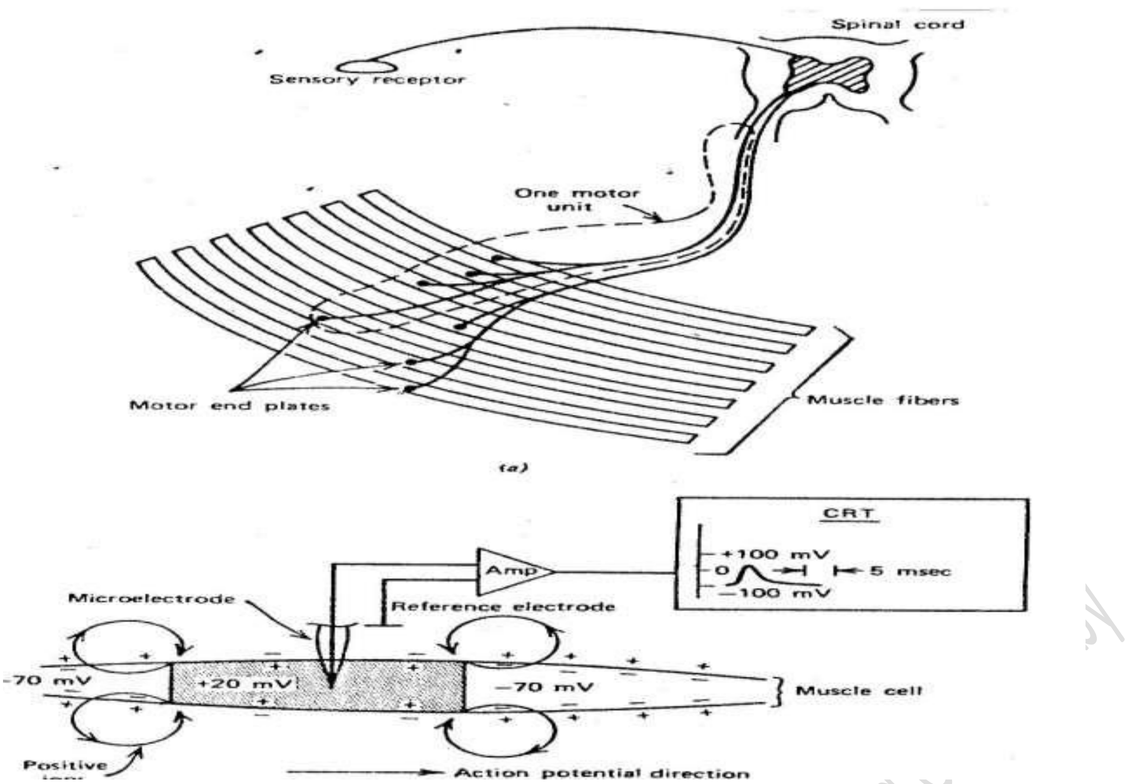


Fig 5: The record of the action potential in a single muscle cell

Electrical potential in the Heart (ECG):

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 *senatorial* (**SA**) node or the *pacemaker*.

The SA node fires at regular intervals about (72) times per minutes ,the rate of firing can be increased or decreased by nerves external to the heart that respond to the blood demands of the body as well as to other stimuli.

The electrical signal from 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 right and left ventricles , causing them to contract and force blood into the pulmonary and general circulation. The ventricle nerves and muscles then repolarize and the sequence begins again.

The record of the hearts potentials on the skin is called the *electrocardiogram* (ECG).

The relationship between the pumping action of the heart and the electrical potentials on the skin can be understood by considering the propagation of an action potential in the wall of the heart as shown in (fig.6). The resulting current flow in the torso leads to a potential drop as shown schematically on the resister.

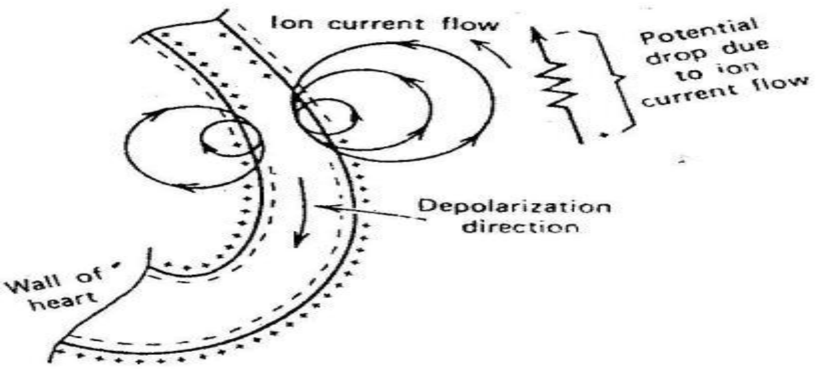


Fig 6: Schematic of an action potential moving down the wall of the heart

Action potential moving down the wall of the heart some of ion current indicated by circles, passes through torso, indicated by the resistor. The potential on the chest wall is due to current flow through the resistance of torso.

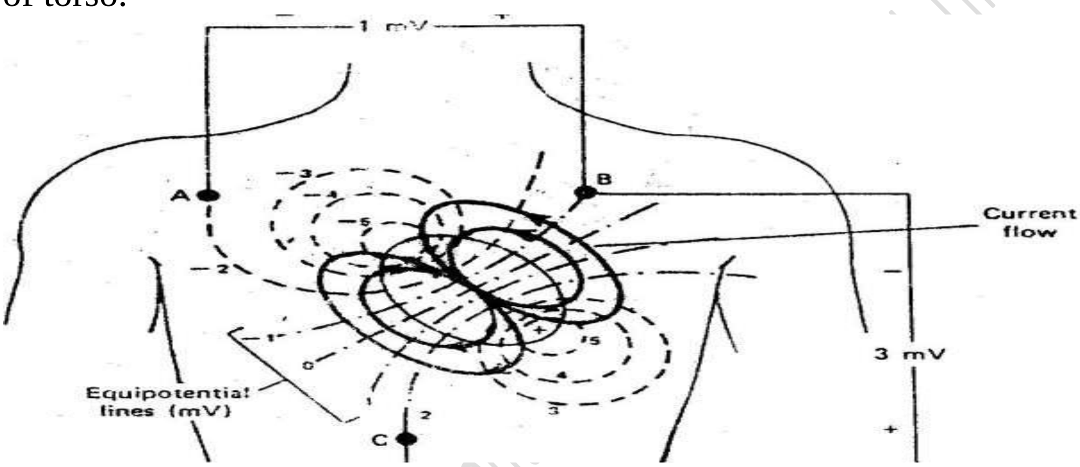


Fig 7. The potential distribution on the chest at the moment when the ventricles are one –half depolarization.

The potential distribution on the chest when the ventricles are one-half depolarized by equipotential measured on the surface of the body depend upon the location of the electrodes for obtaining the ECG located on the left arm(LA), right arm (RA), and left leg (LL).

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

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

The measurement of the potential between LA and LL is called Lead III

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. 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, (fig.8); this configuration was pioneered at the turn of the century by *willem Einthoven*, a Dutch *physiologist*, and these three leads. Usually all three standard limb leads are used in a clinical examination.

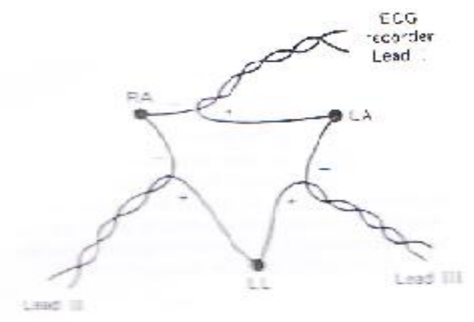


Figure 8 The electrical connections for Leads, I, II, and III. The usual polarities of the recording instrument are indicated for each lead.

The potential between any two gives the relative amplitude and direction of the electric dipole vector in the frontal plane.
Three augmented lead configurations, a V_R ,a V_L , and a V_F, are also obtained in the frontal plane, for the a V_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(fig.9.).
The other two augmented leads are obtained in a similar manner :for the a V_L lead, the recorder is attached to the LA electrode and the resistors are connected to RA and LL; for the a V_F lead, the recorder is attached to the LL electrode and the resistors are connected to RA and LA.

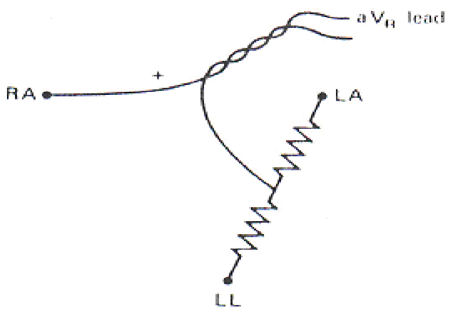


Figure 9 An augmented lead is obtained by placing a pair of resistors between two of the electrodes. The center of the resistor pair is used as one of the connections and the remaining electrode is used as the second connection. The arrangement for the aV_R augmented lead is shown.

Each ECG tracing maps out a projection of the electric vector, or the electrical activity of the heart, through each part of its cycle.(fig.10),shows schematically the lead II output with the standard symbols for the parts of the pattern.
The major electrical events of the normal heart cycle are:-
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 [fig.10].

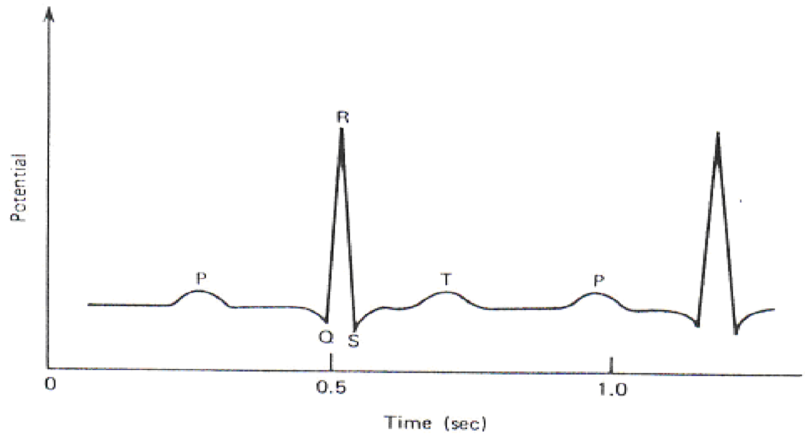


Figure 10 Typical ECG from Lead II position. P represents the atrial depolarization and contraction, the QRS complex indicates the ventricular depolarization, the ventricular contraction occurs between S and T, and T represents the ventricular repolarization.

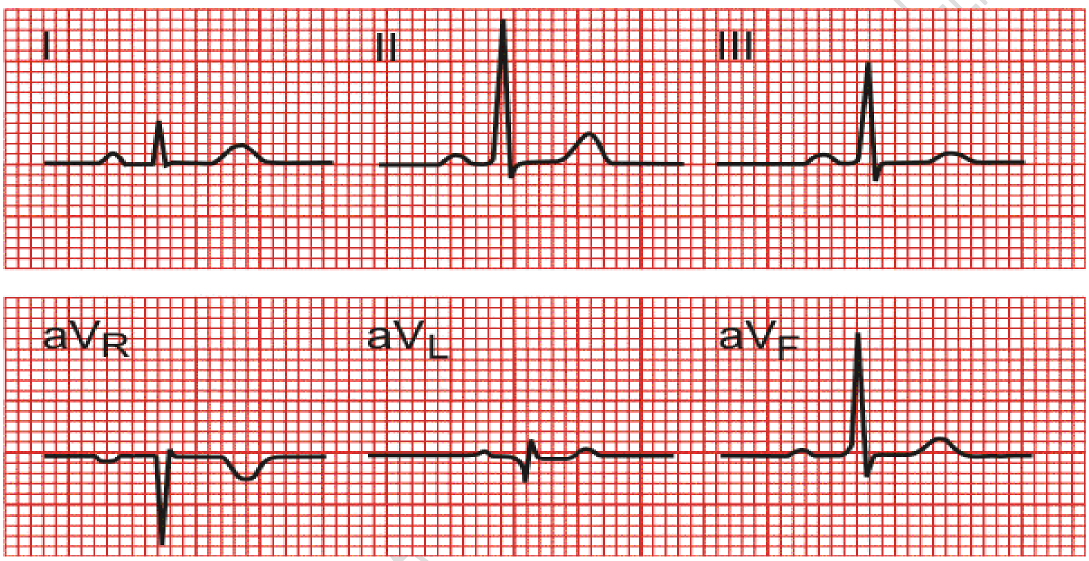


Fig.11.Six frontal plane ECG, some cases the waveform is positive and in other cases it is negative. The sign of the waveform depends upon the direction of electric dipole vector and polarity and position of the electrodes of the measuring instrument. For transverse plane measurement the negative terminal of ECG recorder is attached an indifferent electrode at the center point of three resistors connected RA, LL, LA, and other electrode is moved across the chest wall to the six different positions.

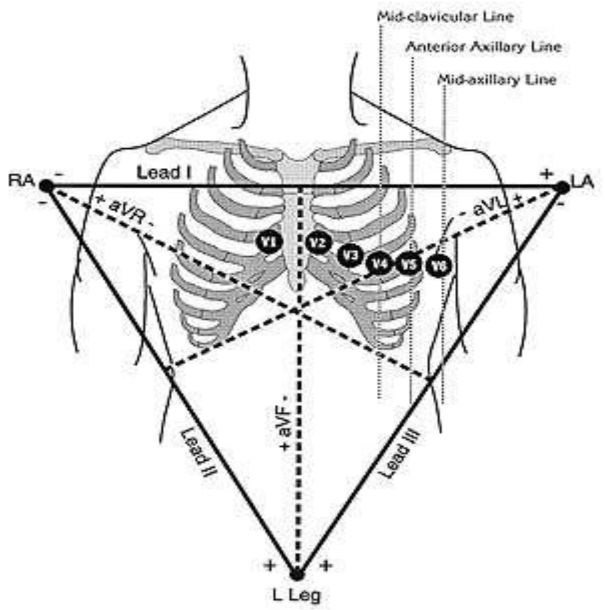
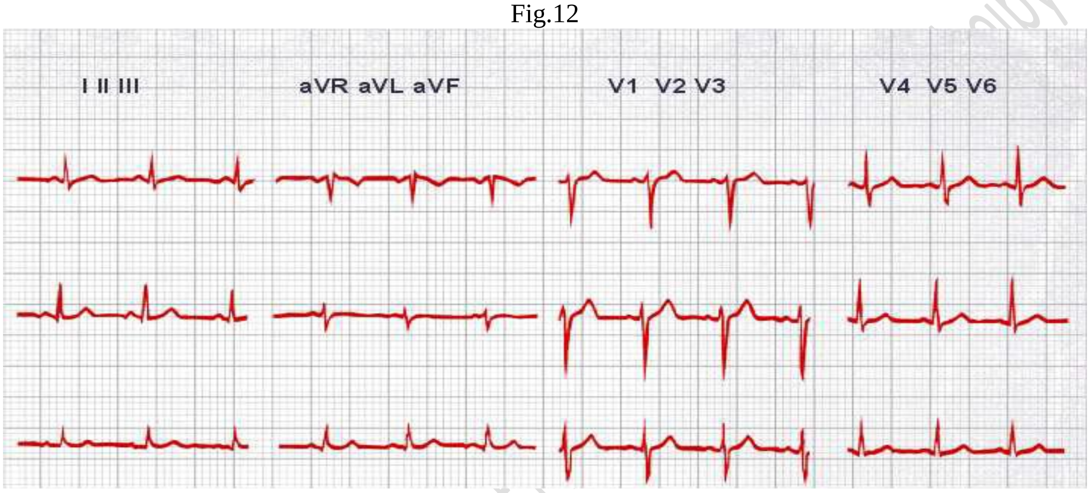


Fig.12



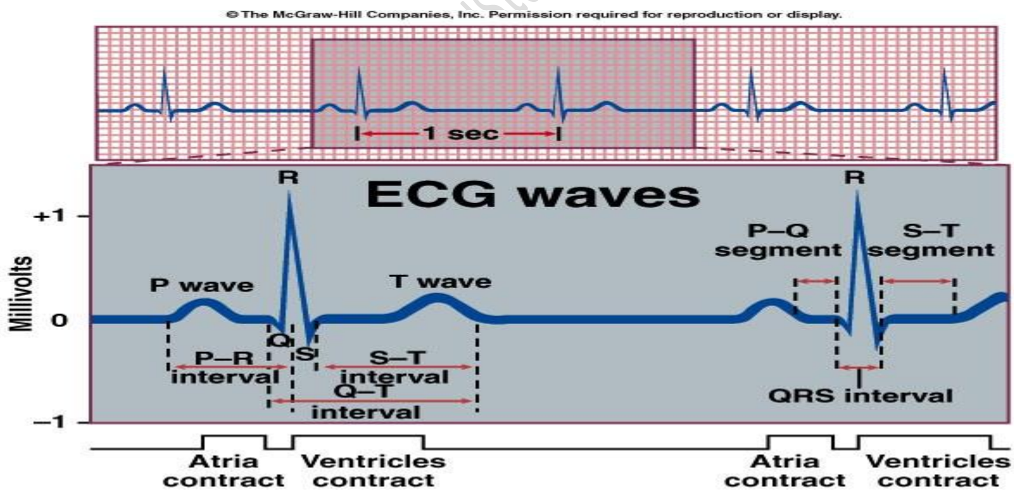


Fig.13a,b

Table (1) intervals.

Intervals	Normal duration(sec) (standard intervals)	Event in the heart during interval
PR	0.12-0.21	A trial depolarization and conduction through AV node
QRS	0.08-0.11	Ventricular depolarization and a trial repolarization
QT	0.35-0.42	Ventricular depolarization puls a trial repolarization
ST	0.27-0.33	Ventricular repolarization

LIMB LEADS		PRECORDIAL LEADS	
I Lateral left ventricle	aVR square root of squat	V1 Septal	V4 Anterior
II Inferior portion of the left ventricle	aVL Lateral left ventricle	V2 Antero-Septal	V5 Lateral left ventricle
III Inferior portion of the left ventricle	aVF Inferior portion of the left ventricle	V3 Antero-Septal	V6 Lateral left ventricle

The sign of the wave form is depends upon the direction of the electric dipole vector , the polarity and position of the electrodes of the measuring instrument.
In a clinical examination, six transverse plane ECG_S are usually made in addition to the six ,frontal plane ECG_S ,for the transverse plane measurements the negative terminal of the ECG recorder is attached to an indifferent electrode at the center point of three resistors connected to RA,LL and LA [Fig14-a] and the other electrode is moved across the chest wall to the six different positions shown in [fig.14-b].

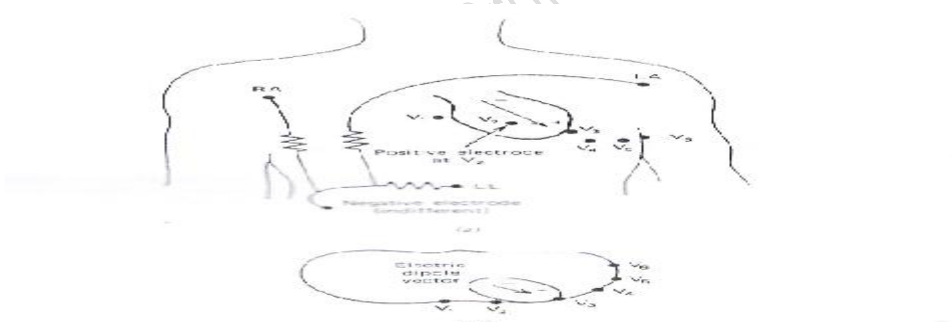


Figure-11 Transverse plane ECG positions. (a) Frontal view. (b) Top view.

ECG_s are usually interpreted by cardiologists who can quickly determine if the patterns are normal and if arrhythmias (rhythm disturbances) exist.
An ECG shows disturbances in the normal electrical activity of an abnormal condition known as heart block.
If the normal SA node signal is not conducted into the ventricle then a pulse from the AV node will control the heartbeat at frequency of (30 to 50 beats/min.),which is much lower than normal (70 to 80 beats/min.),while a heart block like this could make a patient a *semi-invalid* ,an implanted pacemaker could enable him to live a reasonably normal life.

Electrode name	Electrode placement
RA	On the right arm, avoiding thick muscle.
LA	In the same location where RA was placed, but on the left arm.
RL	On the right leg, lateral calf muscle.
LL	In the same location where RL was placed, but on the left leg.
V_1	In the fourth intercostal space (between ribs 4 and 5) just to the right of the sternum (breastbone).
V_2	In the fourth intercostal space (between ribs 4 and 5) just to the left of the sternum.
V_3	Between leads V_2 and V_4.
V_4	In the fifth intercostal space (between ribs 5 and 6) in the mid-clavicular line.
V_5	Horizontally even with V_4, in the left anterior axillary line.
V_6	Horizontally even with V_4 and V_5 in the midaxillary line.

Category	Leads	Activity
Inferior leads'	Leads II, III and aV_F	Look at electrical activity from the vantage point of the inferior surface (diaphragmatic surface of heart)
Lateral leads	I, aV_L, V_5 and V_6	Look at the electrical activity from the vantage point of the lateral wall of left ventricle
Septal leads	V_1 and V_2	Look at electrical activity from the vantage point of the septal surface of the

		heart (interventricular septum)
Anterior leads	V_3 and V_4	Look at electrical activity from the vantage point of the anterior wall of the right and left ventricles (Sternocostal surface of heart)

In addition, any two precordial leads next to one another are considered to be contiguous. For example, though V_4 is an anterior lead and V_5 is a lateral lead, they are contiguous because they are next to one another.

(H.W) Q//1.Give the locations of the electrodes for the standard ECG limb leads? 2. What electrical phenomenon in the heart produces the QRS complex of the ECG?

Electrical signals from Brain (EEG)
The recording of the signals from the brain is called the *electroencephalogram* (EEG) ,the EEG is used as an aid in the diagnosis of disease involving the brain Electrodes for recording the signals are often small discs of chloride silver. They are attached to the head at locations that depend upon the part of the brain to be studied. The international standard 10 -20 system of electrode location. Since asymmetrical activity is often an indication of brain disease, the right side signals are often compared to the left side signals.

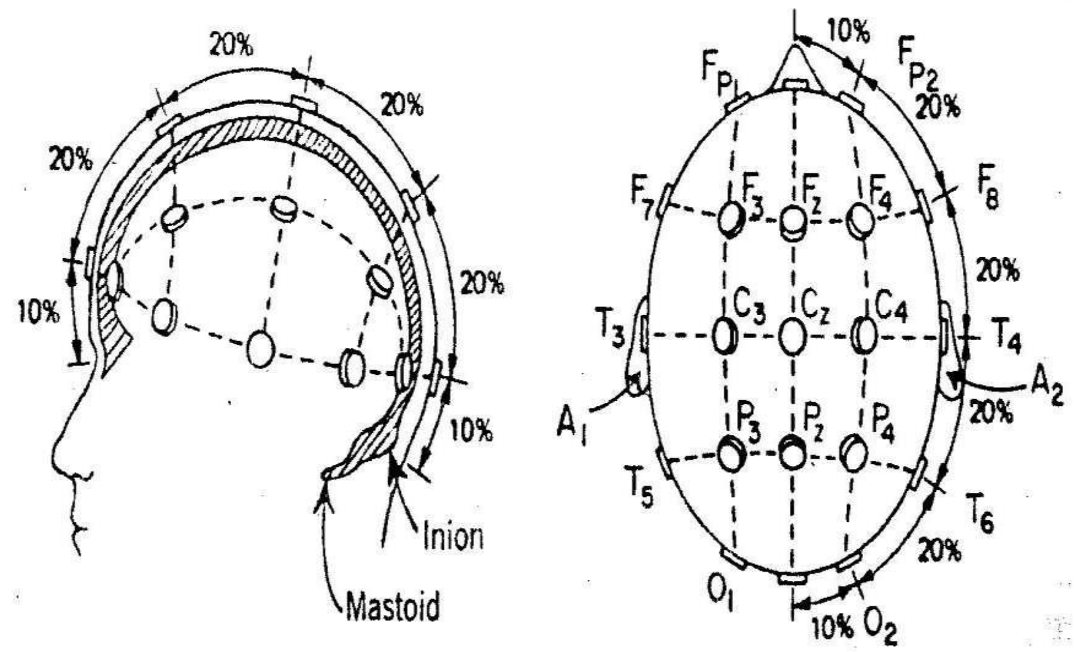
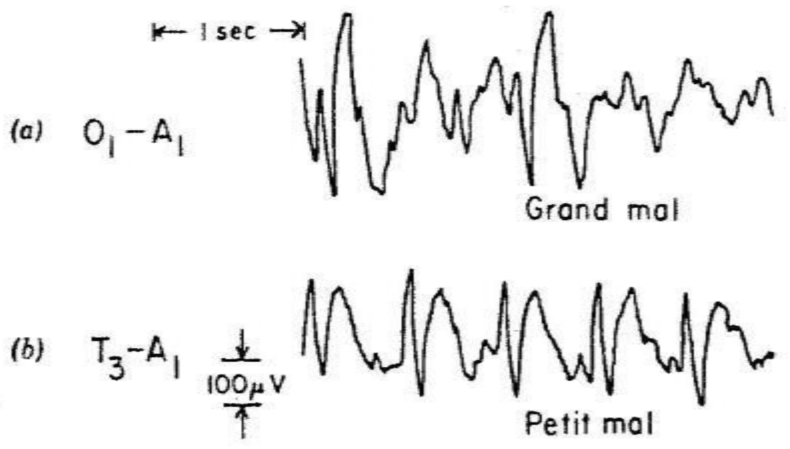


Fig 15: International standard 10 -20 system of electrode location for EEG

The frequencies of the EEG signals seem to be dependent upon the mental activity of the subject ,for example , a relaxed person usually has an EEG signal composed primarily of frequencies from 8 to 13 Hz ,or *alpha waves* .
When a person is more alert higher frequency range , the beta wave range (above 13Hz) ,dominates the EEG signal ,the various frequency bands are as follows:
*Delta (δ) ,or slow [0.5 to 3.5 Hz]
*Theta (θ) ,or intermediate slow [4 to 7 Hz]
*Alpha (α) [8 to 13 Hz]
*Beta (β) ,or fast [greater than 13Hz
As a person becomes drowsy , particularly with his eyes closed ,the frequencies from 8 to 13Hz (alpha waves) dominate the EEG .The amplitude increases and the frequency decreases as a person moves from light sleep to deeper sleep.
Occasionally an EEG taken during sleep shows a high frequency pattern called *paradoxical sleep or rapid eye movement* (REM) sleep because the eyes move during this period.
Paradoxical sleep appears to be associated with dreaming , besides recording the spontaneous activity of the brain ,we can measure the_signals that result when the brain receives external stimuli such as flashing lights or pulses of sound ,signals of this type are called *evoked responses* .
The EEG is used as an aid in the diagnosis of diseases involving the brain.
It is most useful in the diagnosis of epilepsy and allows classification of epileptic seizures.
1-The EEG for a sever epileptic attack with loss of consciousness, called a grand mal seizure, shows fast high voltage spikes in all leads from the skull (Fig. 16- a).
2-The EEG for a less severe attack, called a petit mal seizure, shows up to 3 rounded wave per second followed or preceded by fast spikes (Fig.16- b).
The EEG aids in confirming brain tumors since electrical activity is reduced in the region of a tumor.
_The EEG is used as a monitor in surgery when the ECG cannot be used.
_It is useful in surgery for indicating the anesthesia level of the patient.
_Much research on sleep involves observing the EEG patterns for various stages of sleep.



Electroencephalograms for two types of epilepsy: (a) grand mal and (b)

a-As a person becomes drowsy, particularly with eyes closed, the frequencies from 8 to 13 Hz (α waves) dominate the EEG. The amplitude increases and the frequency decreases as a person moves from light sleep to deeper sleep.

b-EEG taken during sleep shows a high frequency pattern called paradoxical sleep or rapid eye movement (REM) sleep because the eyes move during this period. Paradoxical sleep appears to be associated with dreaming.

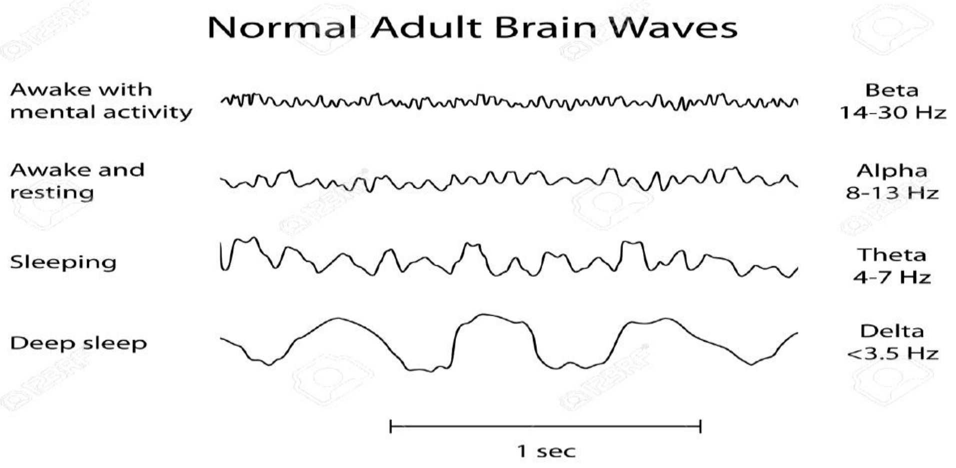


Fig. 17

(H.W)….. Q//What is REM sleep?

Electrical signals from the Eye (ERG &EOG):

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 to approximate the potential at the back of the eye.

An ERG signal is more complicated than a nerve axon signal because it is the sum of many effects taking place within the eye .The general form of an ERG is shown in fig.(18).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 that results in pigment changes or *retinitis pigmentosa*.

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(fig.13-a).The EOG potential is defined as zero with the eye in the position shown in (fig.19-a) fixed on the reference spot labeled 0^0. Fig.(19-b) shows the EOG potential change for horizontal movement of the eyeball

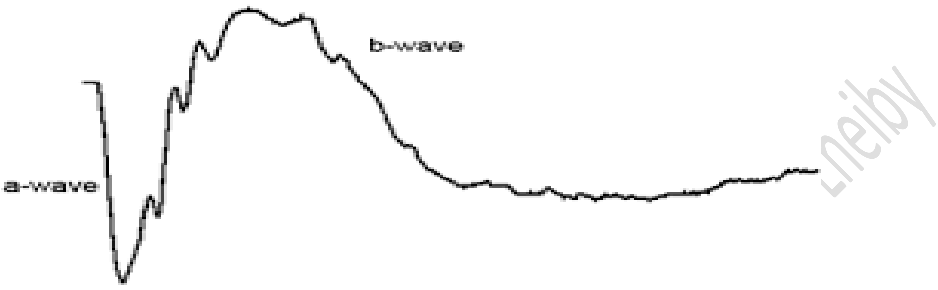


fig.(18). The B wave is the most interesting clinically since it arises in the retina

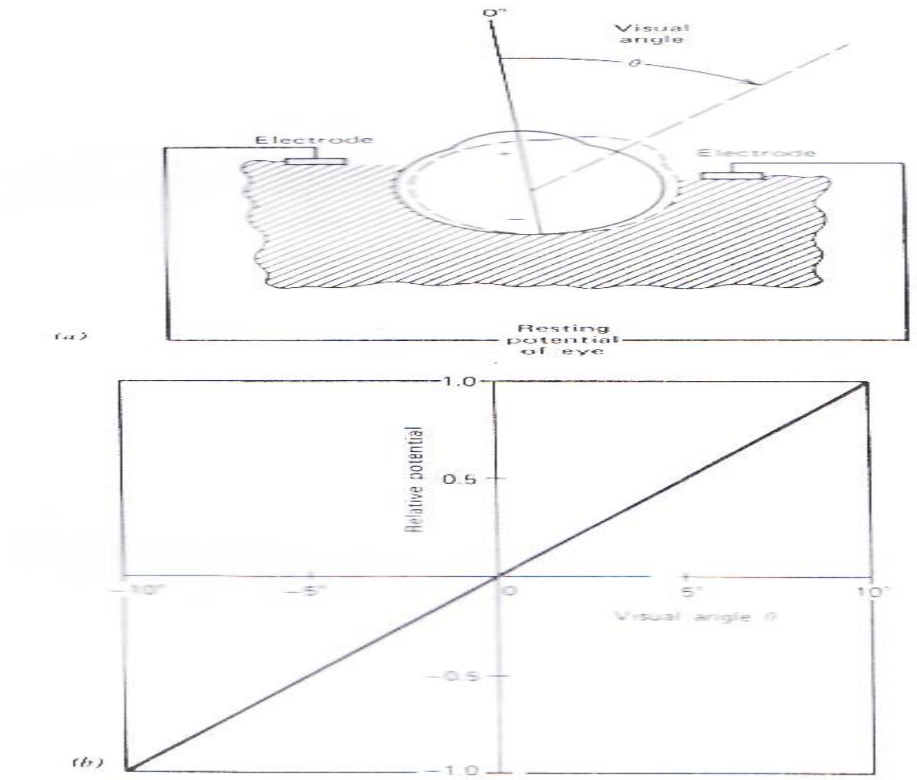


Figure 19 (*a*) For obtaining the EOG an electrode is mounted on each side of the eye. The visual angle is indicated. (*b*) The change of potential is plotted as a function of visual angle.

EOG_s provide information on the orientation of the eye , its angular velocity and its angular acceleration .Some studies have been done to determine the effects of drugs on eye movement and the eye movement involved in sleep and in visual search.

(H.W)..Q. // what is the difference between an ERG & EOG?

Magnetic signals from the Heart & Brain (MCG & MEG):

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.

Magnetocardiography measured these very weak magnetic fields around the heart, the recording of the heart's magnetic field is the magnetocardiogram (MCG).

The magnetic field around the heart is about (5×10^{-11}tesla"T") or about one-millionth of the earth's magnetic field "the cgs unit for magnetic fields is the gauss,($T=10^4$gauss)" ,to measure fields of this size it is necessary to use magnetically shielded rooms and very sensitive magnetic field detectors (*magnetometers*).

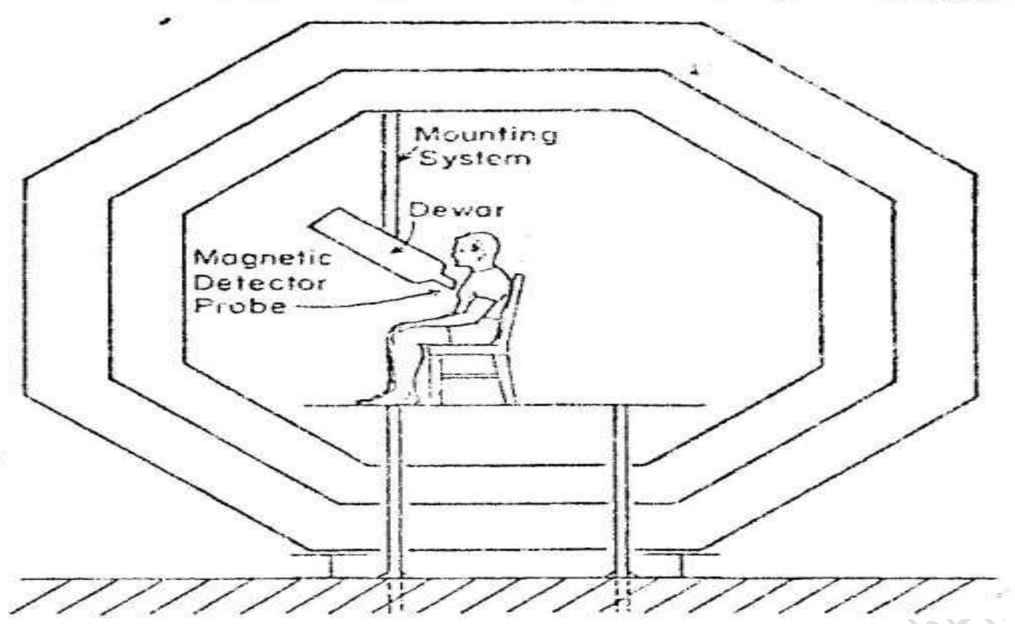
One such detector called a *SQUID* (Superconducting Quantum Interference Device) ,operates at about 5^0K and can detect both steady (dc) and alternating magnetic fields as small as 10^{-14} T. The SQUID is so sensitive that it can detect the changing magnetic field caused by someone walking past a horseshoe magnet 400 m (0.25 mile) away from it!

The magnetic detector probe in the low-temperature Dewar almost touches the subject and various points on the chest are measured by moving the Dewar. The output of the magnetic detector is recorded at a station outside the shielded room; the total time involved for each MCG is usually less than 1 minute.

The MCG gives information about the heart without the use of electrodes touching the body; since the MCG and the ECG arise from the same charge movement they have similar features and can MCG compared.

The MCG provides information not available in an ECG because it measures magnetic fields due to direct currents, which occur in injured muscle and nerve tissue.

The SQUID magnetometer has also been used to record the magnetic field surrounding the brain .The recording of the this field is called the *magnetencephalogram* (MEG).During the alpha rhythm ,the magnetic field from the brain is about (1×10^{-11}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.

(H.W)Q.//What is the difference between an MCG & MEG?

Current research involving Electricity in the body .

- Piezoelectric effect , forces on bone produce currents that induce and control bone growth.
- Injury current , small direct current arises in an injured zone
- Biofeedback
- Negative feedback

Although the autonomic nervous system is not generally under voluntary control, it can, as previously mentioned, be influenced by external stimuli.

One means of influencing the system that has been known for some time is called *biofeedback.* Recently there has been renewed interest in biofeedback, while early research on biofeedback has been promising, many aspects are still not understood, as we learn more about it we may be able to utilize it more in medicine.

Cardiovascular Instrumentation

1.Biopotentials of the heart:

Ion movements in heart muscle cells constitute a current flow ,which results in potential differences in the tissue outside the fibers and the surface of the body (fig.20),this current only flows while the action potential is propagating(mainly during the QRS wave of the(ECG)or during the recovery period (the T wave).

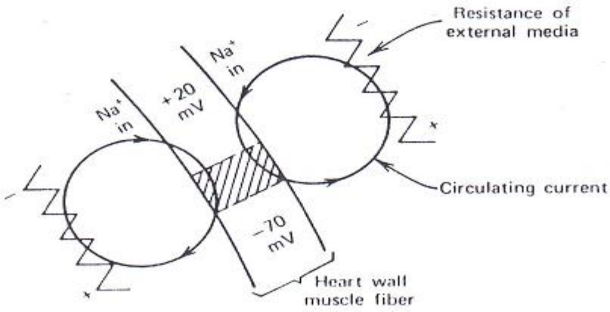


Figure 20 An action potential propagates downward in a heart muscle fiber. Na^+ ions move into the shaded region and cause the −70 mV resting potential to change to +20 mV. Their movement constitutes a current, which flows in a circulating path through the resistance of the external media, thus causing a voltage drop with the polarity shown. The region ahead of a propagating action potential is positive with respect to the region behind it.

At the peak of the R wave, the potentials on the surface of the body are as shown in (fig.21),we measure these potential differences on the surface of the body by placing electrodes on the skin, amplifying the potentials, and then displaying the result as an ECG. moving the electrodes to different positions on the body may result in amplitude changes or even inversion of the signal, as(fig.21)shows.

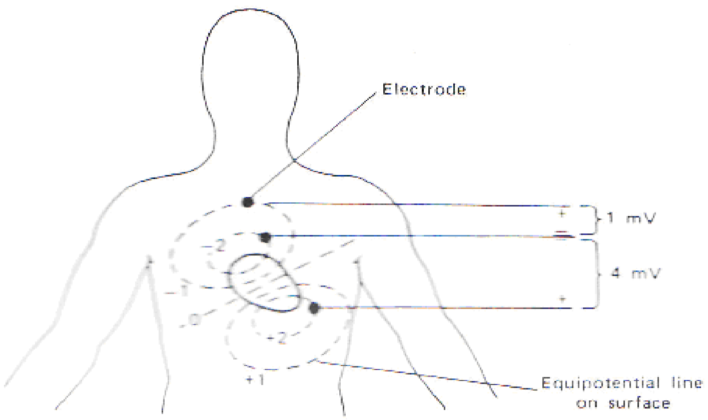


Figure 21 At the peak of the R wave of the ECG, most heart wall muscle fiber action potentials are propagating downward. The dashed lines show the resulting surface potentials. Note the difference in the measured potentials caused by using different electrode locations. Both voltage and polarity may change with electrode position.

2.Electrodes:-

At the interface between the body and a metal electrode ion flow must be converted to electron flow through a chemical reaction.

If ordinary metal are used for electrodes polarization results from this chemical reaction as shown in (fig.22-a).at one or both electrodes, gas bubbles from due to electrolysis, and the resulting electrodes-to-solution interface is electrically unstable. This instability produces electrical noise and drift which may be much large than the ECG signal. These problems may be avoided by using silver-silver chloride electrodes, as shown in (fig.22-b) these electrodes are easily made by electrodepositing a silver chloride coating on pure silver electrodes, current passes very readily through silver-silver chloride electrodes. The coating merely depletes on one electrode and builds up on the other. There is no formation pf gas, and there is no electrical noise from the electrode –to-solution interface.

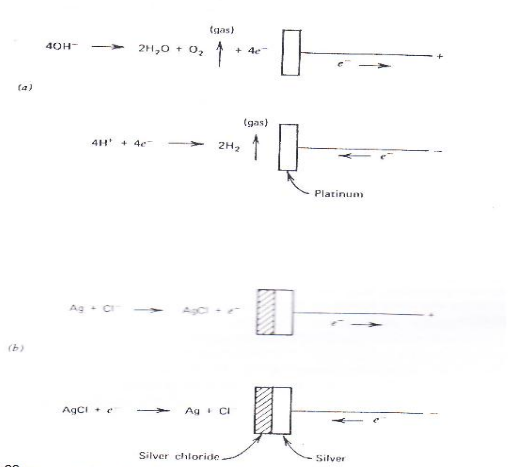


Figure 22 The chemical reactions at a skin-electrode interface are determined by the electrode composition. (a) Electrodes of platinum, an inert metal, cause gas bubbles to form (O_2 at the + electrode and H_2 at the − electrode), producing a high resistance and polarization at the interface. (b) Electrodes of silver-silver chloride enter into the chemical reaction. Thus no gas bubbles are formed, the resistance at the interface remains low, and the interface does not become polarized.

For these reasons the silver-silver chloride electrode is the natural choice for the typical patient monitoring electrode shown in (fig.23), at the electrode-to-solution interface, complex layers of positive and negative charge form. This electrical double layer should not be disturbed by patient movement, which might cause artifacts (undesirable voltage changes).hence the metal electrode is recessed from the skin, and the space between the electrode and the skin is filled with a conductive paste. The plastic electrode case is attached to the skin by a pressure-sensitive adhesive.

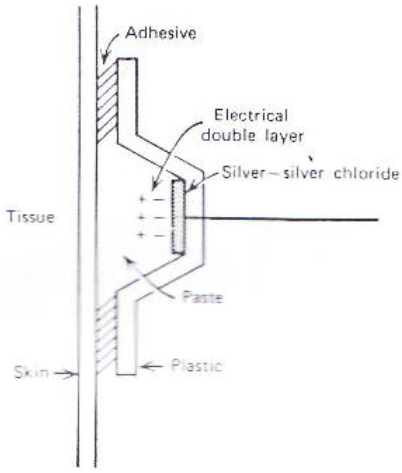
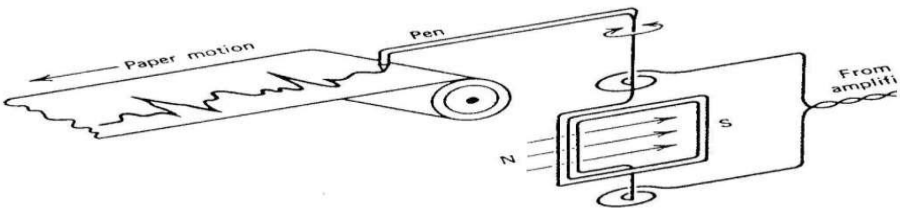


Figure 23 Silver-silver chloride electrodes are used for patient monitoring to prevent polarization. The electrode is recessed from the skin to prevent skin motion from disturbing the electrical double layer. A conductive paste fills the space between the electrode and the skin.

3.Amplifiers:-
The amplitude of the typical ECG signal is only about 1MV.however, in atypical building the current competitively coupled into the body from the 120Vpower lines can produce a much larger potential. The amplifier used to record the ECG must be able to eliminate interference from voltages induced in the body from such external sources.

4. Patient Monitoring:
After amplification, the ECG signal must be displayed. When a routine diagnostic ECG is taken, a permanent record is required for analysis and a pen recorder is usually used (Fig.24).
In a pen recorder, the amplifier output passes through a coil of wire suspended in a magnetic field. In the same way that a galvanometer twists when current passes through it, the pen twists to write on a moving strip of paper.



(Fig.24)

5.Defibrillators:-
Prompt therapeutic action can be taken to save the patient's life. Many heart attack patient's undergo sudden changes in rhythm. The orderly heart muscle contractions associated with normal heart pumping change to the uncoordinated twitching of ventricular fibrillation, which halts the heart pumping action. Death follows within minutes unless the heart can be

defibrillated. Defibrillated is accomplished as shown in (fig.25).the paddle handles are made of plastic and electrically insulated to prevent accidental shock.
When the switch is thrown, a current of about 20A flows through the heart for about 5Msec.this current contracts every muscle fiber in the heart at the same time and the heart can initiate normal rhythm again.
The line voltage is stepped up to several thousand volts by a transformer. a diode rectifies the alternating current in to direct current to charge up the capacitor when the switch is thrown the capacitor discharges through the peddles and the heart.

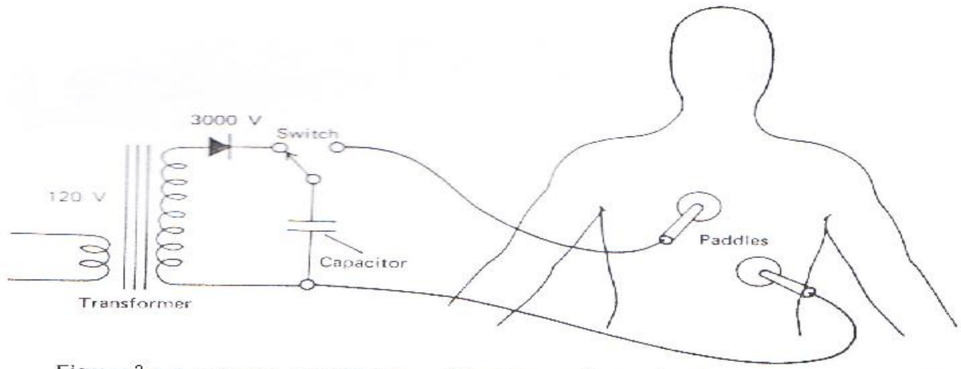


Figure 25 A simple defibrillator. The line voltage is stepped up to several ɪousand volts by a transformer. A diode rectifies the alternating current into direct ɪrrent to charge up the capacitor. When the switch is thrown, the capacitor disɪarges through the paddles and the heart.

6.Pacemakers:-

The pacemaker is usually implanted in a pocket on the right side of the chest. The pacing wire is fed through a vein in the shoulder and advance through the right atrium and through the valve, until its tip is at the bottom of the right ventricle. The atria of the heart are separated from the ventricles by a fatty layer that does not conduct electricity or propagate nerve impulses. At a single location, the atrioventricular node, impulses from the atria are conducted to the ventricles, which perform the heart's pumping action.
If AV node is damaged, the ventricles receive no signals from the atria, the ventricles do not stop pumping, there are natural pacing centers in the ventricles a pulse if none has been received from the atria for 2 seconds. The resulting heart rate, 30 beats/min, will sustain life, but the patient may have to live a life of semi-invalidism.
To improve the quality of life with faulty AV nodes, artificial pacemakers have been developed. The pacemaker contains pulse generator that puts out 72 pulses /min.
The pacemaker is put in place, the patient is given local anesthetic and flap of skin just below the right collar is lifted.

The pacing wire is fed through a slit in the shoulder vein and advanced under fluoroscopic control until the tip is imbedded in the wall of the right ventricle, then the pacemaker is placed in the pocket under the skin and the flap is replaced.
The pacemaker runs on batteries that last about 2 years, it is made of materials that are impervious to body fluids and not cause tissue reaction.
About 150,000 patients were wearing pacemakers and living near-normal lives.

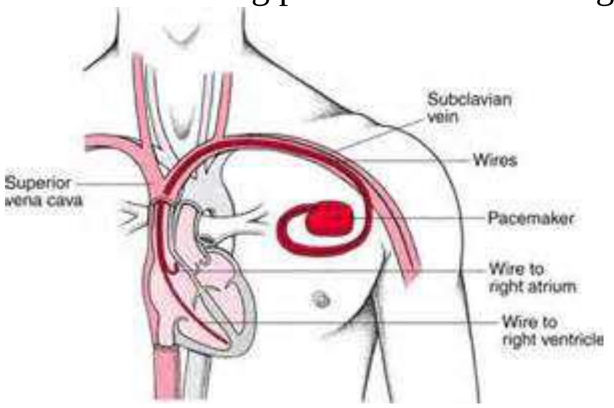


Fig.26.Pacemakers provide electrical pulses to the heart in order to produce a normal heart rate.

Applications of electricity and magnetism in medicine:-

1. **Electrical shock.**

When an electrode is connected to each hand and 60 Hz currents of different levels are passed through the body various reactions are produced. The amount of current depends on the resistance of body between two points due to *Ohm's law*:

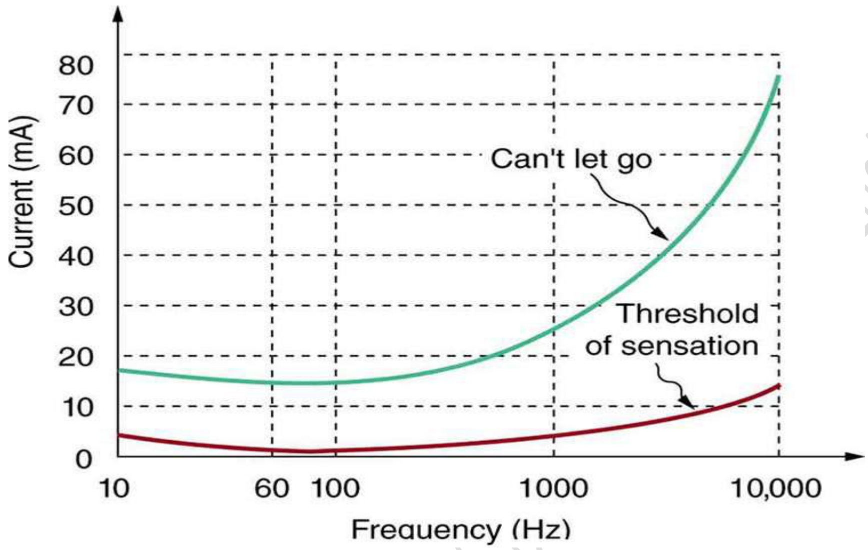
$$v = I \times R$$

As the current is increased from zero, the level at which we can just feel the current –the perception level-is reached.
About 50% of adult men feel a 60Hz current of about 1.0mA.Women perceive lower levels-about one-third lower than those felt by Men.
The perception level is frequency dependent; it rises as the frequency increases above 100Hz.
As the current is increased still further, pain and some cases fainting occur; near the 100 mA level the portion of the 60Hz current passing through the heart is sufficient to cause *ventricular fibrillation* (rapid irregular and ineffectual contraction of the ventricles).
As a 60 Hz current is increased above the perception level it causes a *tingling sensation* in the hands or body, at currents of 10 to 20m A, a sustained muscular contraction takes place in the hands and many subjects cannot let go of the electrodes.
For a 60 Hz shock, the estimated maximum current that will not induce fibrillation in man is given by:

$$(116/t^{1/2})\ \text{mA}$$

Where t is the time (in seconds) the shock lasts …For example, if t=1sec, the safe current is 116 mA, if t=4sec, the safe current is 58 mA.

Current levels of 6 A and above cause *sustained muscular contraction* of the heart similar to the (cannot let go) behavior of the hands. Defibrillators make use of such current levels. If a potential has ventricular defibrillation, a brief shock from a defibrillator usually restores normal coordinated pumping in the heart. The defibrillator uses a brief pulse of up to 10 kV. A defibrillator can also be used to synchronize the heart to its normal rhythm when a patient has atrial fibrillation, in this case the electrical pulse is applied after R wave but before T wave .



Continuous currents above **6 A** can cause *temporary respiratory paralysis* and *serious burns*. The damage depends upon the *individual*, the *dampness* of the skin, and the *contact* of the skin with the conductor.

Macroshock

Which occurs when electrical contact is made on the surface of the body.

Microshock

When the current is applied inside the body, microshock results. In microshock, the current does not have to pass through the high resistance of the skin; it instead often follows the arteries and passes directly through the heart. Ventricular fibrillation can be induced with microshock current levels that are much smaller than the current levels needed to induce it under macroshock conditions. It has been estimated that about 30 μA cause ventricle fibrillation.

It is possible for microshock to occur in a medical situation, hazards of this sort are correct by modern power cords have three wires-two that supply the ac power and one that serves as ground wire. If either of power wires breaks the equipment will not operate, and if these wires touch (short) a fuse will blow and the failure will be obvious. A break in the ground wire may go undetected and present a serious electrical hazard to patient internal electrodes, some current flow from the ac power parts to the metal case of the instrument is called *Leakage current*, usually flows to ground through ground wire in the power cord. The main source of the Leakage current is capacitance between the power wires and ground or between power transformer and its case.

The impedance $\mathbf{X_c}$ of a capacitance **C** for applied voltage frequency **f** is

$$\mathbf{X_c = 1/\ 2\ \pi\ f\ c}$$

A typical Leakage capacitance is: $\mathbf{2 \times 10^{-2} \mu f}$.

If the ac potential **V** is **110 v** at a frequency of **60 Hz,** then the capacitive reactance is $\mathbf{1.3 \times 10^5 \Omega}$ and Leakage current;

$$\mathbf{I = V / X_c = 110 / 1.3 \times 10^5 = 8.5 \times 10^{-4}\ A = 850\ \mu A}$$

Let us consider what would happen if this Leakage current were in a ECG instrument with broken ground wire and the unit were connected to a patient in an intensive care units who also had a pacemaker connected. Since the Leakage current could not flow to ground through the broken ground wire it would flow through the *implanted cardiac pacemaker* to ground, microshock current could result in ventricular fibrillation and death.

There are a number of ways that shock hazards could be reduced.

(1) The body is less sensitive to direct current than to 60 Hz current.

Since $\mathbf{X_c = \infty}$ **if** $\mathbf{f = 0}$

There would be no Leakage current due to stray capacitance if we operated our electrical equipment with direct current.

(2) Hazards could also reduce at frequencies much higher than 60 Hz where the sensitivity of the heart to ventricular fibrillation is much less.

2. High-frequency electricity in medicine.

The heating effects produced by electrical diathermy.

(1) In short wave (30 MHz) diathermy two methods are used to get electromagnetic energy into the body: the capacitance methods and inductance method. In both methods the body part to be heated becomes a part of resonant electrical circuit.

(2) In microwave (2450 MHz) diathermy.

It is used to control hemorrhage during surgery.

3. Low- frequency electricity and magnetism in medicine.

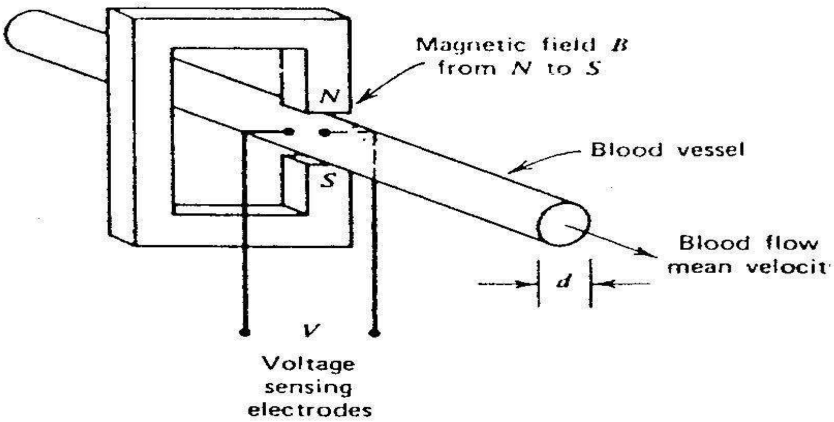
When an electrical conductor is moved perpendicular to a magnetic field, a voltage is induced in the conductor proportional to the product of the magnetic field and the voltage of the conductor (*Faradays Low*). This law, which also holds for a conducting fluid moving perpendicular to a magnetic field, is the basis of magnetic blood flow meters.

It is used in the treatment of *bursitis*, *arthritis*, *traumatic injuries*, *strains* and *sprains*.

-Blood acts as a conducting fluid ,if it passes with mean velocity *v* through a magnetic field **B** ,a voltage **V** is induced between the electrodes such that :

$$V = B\,d\,v$$

Where **d** is the diameter of the blood vessel, since **V**, **B** and **d** can all be measured.



The mean velocity can be obtained ,the volume flow of blood **Q** through the vessel can then be calculated ,since **Q** is the product of the mean velocity times the area of the vessel ($\pi d^2/4$) ,or

$$Q = \frac{\pi d^2}{4}\frac{V}{Bd}$$

3. **Current research involving electricity applied to the body**.

At lower current levels than those used for *electroanesthesia*, electro-sleep can be induced, a 100 Hz signal of 1mA average current used with electrodes placed over each *eye* and *mastoid* (the bony protuberance behind the ear) is effective.

Electrosleep has been discussed in the foreign literature for a number of years, but there has been limited interest in the some world countries, recent research on this phenomenon in the U.S.A has dealt with its basis and its usefulness in psychiatry.

The Eastern art of *acupuncture* and its medical applications have aroused considerable interest in the U.S.A as communication channels with China have been renewed ,the origin of acupuncture dates back several thousand years in China's history.

Acupuncture is used today to reduce or prevent pain associated with surgery and dental work.

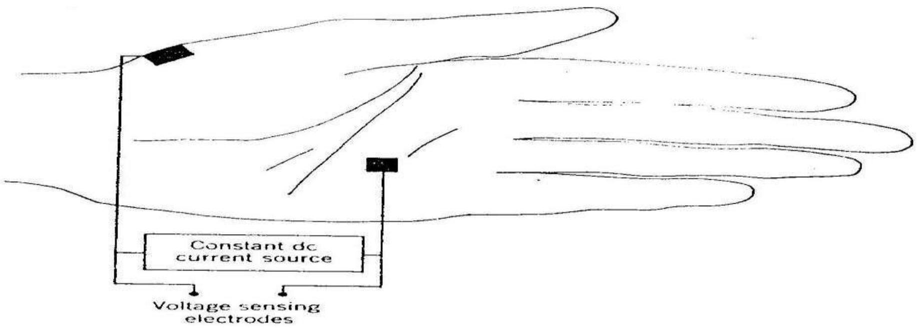
Stainless steel needles are inserted in one or more different acupuncture sites (there are about 1000) depending upon the area to be anesthetized.

The needles are then either twisted, moved up and down or connected to small electrical currents, the effectiveness of acupuncture varies with its intended use and it is more effective on some subjects than on others.

The reason that acupuncture appears to control pain is not understood.
Theories range from *hypnosis* and autosuggestion to physiological block-age of pain, this last theory is in conflict with our present understanding of the nervous system.
More studies will have to be done before the mechanisms of acupuncture are understood.

Electro surgery:
-What makes electrosurgery work?
Current flows when a high frequency probe is immersed in tissue and under certain conditions a high power density will exist around the probe.
For example, if 15W is dissipated by a 0.25mm diameter, straight wire probe used at 5MHz, a direct application of electrical principles would show that the power density at the probe is 3.3×10^3 W/cm^{3}and the power density 1.25cm from it is 0.3 W/cm^3 ,these power densities would cause rapid temperature rises of about 800^{0}C at the probe and about 0.1^{0}C at 1.25cm from the probe .
The "cutting" of electrosurgery is thought to be the physical rupturing of tissue due to rapid boiling of the fluids from the intense local heat.
Since the cutting of tissue takes place rapidly, the probe must be moved rapidly (5 to 10 cm/sec) to reduce the destruction of surrounding tissues.
With proper control ,the destruction can be limited to a depth of about 1mm from the probe .Electrosurgery is often used in operations on the *brain ,spleen ,bladder ,prostate* and *cervix*.

Galvanic skin response (GSR):
Changes in perspiration (sweat gland activity) are related to skin resistance: the variation from the basal or normal, skin resistance (BSR) due to psychological changes or external stimuli is called the *galvanic skin response* (GSR).
A decrease in skin resistance indicates increased sweat gland activity, while an increase in skin resistance indicates reduced sweat gland activity.
The GSR can be easily measured where there is a concentration of sweat glands such as the palm of the hand or sole of the foot ,the GSR depends upon the activity of the sweat glands only and not upon the amount of visible perspiration .
Galvanic skin response (or GSR), also known as electrodermal response (EDR) or psychogalvanic reflex (PGR), is a method of measuring the electrical resistance of the skin and interpreting it as an image of activity in certain parts of the body.
A constant direct current (~ 10 μA/cm^2) is passed: resulting voltage indicates the GSR proportional to resistance.
The details of this response are still not completely understood.



EX: A magnetic blood flow meter is positioned across a blood vessel (0.005m) in diameter, with a magnetic field (300gauss), an induced voltage of (15×10^{-6}V) is measured.

1. Find the mean velocity in the vessel?
2. Assuming all the blood travels at the mean velocity, what is the volume flow rate?

Solution./

1. 300gauss=3×10^{-2}T

$$v = \frac{V}{Bd} = \frac{1.5\times10^{-5}}{3\times10^{-2}\times5\times10^{-3}} = 0.1m/\sec$$

2.

$$Q = \frac{\pi d^2}{4}\frac{V}{Bd} = \frac{\pi(5\times10^{-3})^2}{4}(0.1) = 1.9\times10^{-6}m^3/\sec$$