Bio-Medical Engineering (UNIT-I)

Introduction:

Biomedical Engineering: It is the application of Engineering principles (electronics, electrical, computer, mechanical and others) to medicine and biology for the health care complications (Diagnostic, monitoring, supporting and therapeutic).

It is multidisplinary branch of Engineering, which contains many areas as follows

1. Medical Instrumentation

2. Signal and Image processing

3. Biomaterials

4. Biotelemetry

5. Medical Informatics

Age of biomedical Engineering:

Age refers to long and distinct period of history (era) of biomedical engineering, similarly age of automobile and radio communication. After the World War II (1939-45) nuclear, aerospace engineering reached its peak activity and settled down but at this era computer science has been rapidly growing and biomedical engineering started its origin or significance.

In 1970 will be well known decade in which most of the rapid progress was made in this highly important filed. There is one vital advantage that biomedical engineering has over many of other fields that preceded it. Bioengineering subdivides into different areas for example, bioelectronics and mechanics. These are categories usually indicate the use of that area of engineering applied to living committees have been formed to define these terms , IEEE engineering in medicine and biology group, the ASME biomechanical and human factor division and the instrument society of America.

One of the societies that emerged in the interface area is the association for advancement of medical instrumentation (AAMI). It consists of both engineers and physicians. Engineers are divided into clinical engineers and medical engineers. Clinical engineer who brings to health care facilities a level of education, experience and effectively and safely manage the medical devices. Medical engineer, who theory of operation, underlying physiological principles and practical, safe clinical application of biomedical equipment. His capabilities include installation, calibration, inspection, preventive maintenance and repair of general biomedical devices.

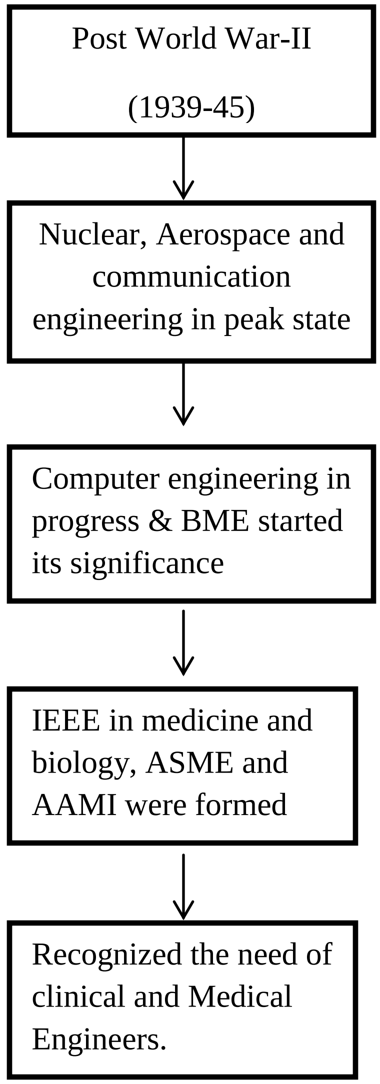


Figure 1: Pictorial representation of age of Biomedical engineering

Development of Biomedical Instrumentation:

Many instruments ware developed as early as the nineteenth century- for example electrocardiograph, first used by Einthoven a Dutch doctor and physiologist. He invented the first practical electrocardiogram (ECG or EKG) in 1903 and received the Nobel Prize in Medicine in 1924 for it ("for the discovery of the mechanism of the electrocardiogram.

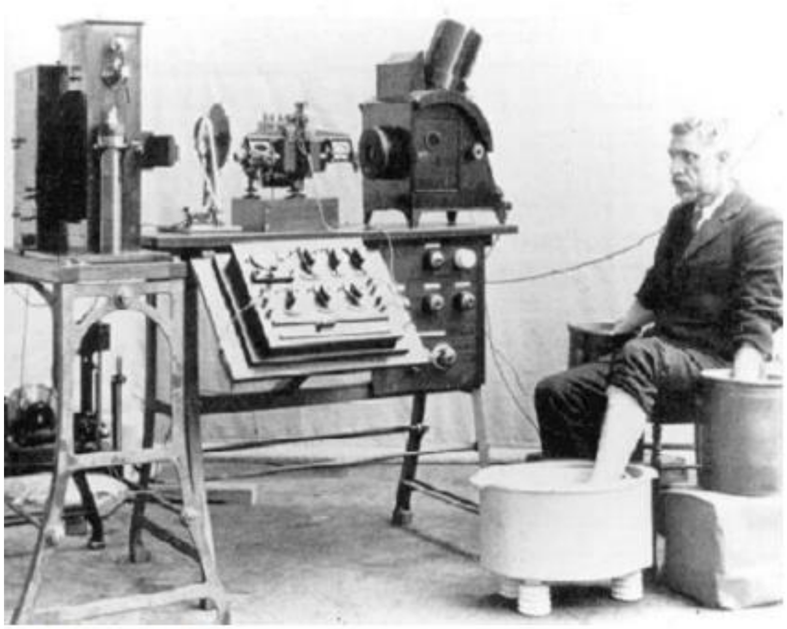


Figure 1.3 Photograph depicting an early electrocardiograph machine.

Progress was rather slow until after World War II, when a surplus of electronic equipment, such as amplifiers and recorders, became available. At that time they started to experiment for medical use, but the results were disappointing.

In 1960 many instrument manufactures entered the field of medical instrumentation, they designed instrumentation for medical use. A large measure help was provided by the US government, in particular By NASA.The mercury, Gemini and Apollo programs need accurate physiological parameters for astronauts. Consequently, much research and development money went to this area.

Both US government and other organization spent money through grants to universities and hospitals research units.Awarness of need for engineers and technicians work with medical profession developed.

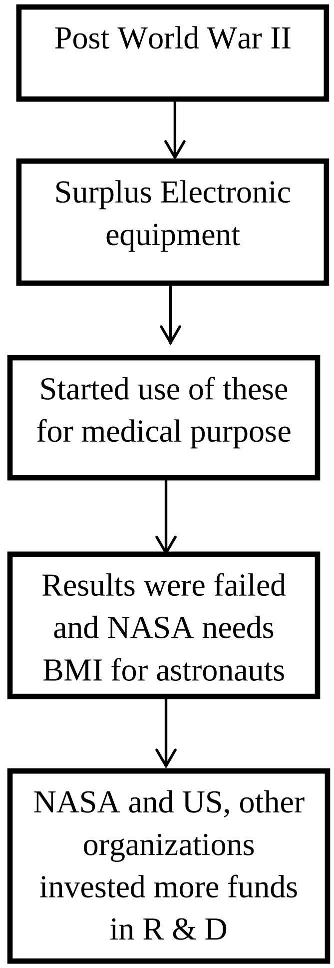


Figure 2: Pictorial representation of age of Biomedical Instrumentation

Components of man-instrument system: It consists of following components.

1. Subject

2. Stimulus

3. Transducer

4. Signal condition circuit

5. Display device

6. Recording, data processing and transmission equipment

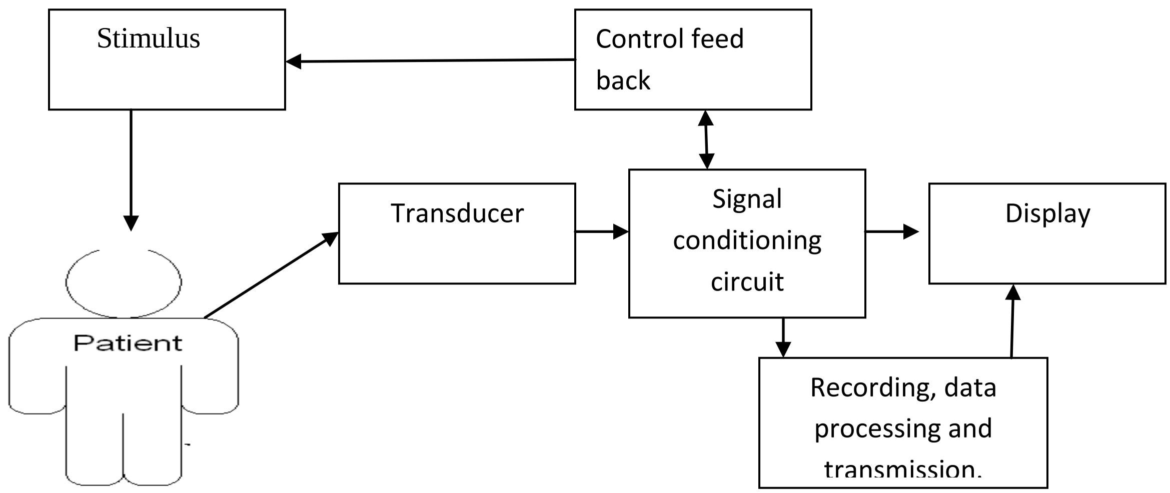


Figure 3: Block diagram of man Instrument system

Subject: subject is the human being on whom the measurements are made. It constitutes a many biopotentials and living organisms. Some of the biopotentials are electrocardiogram, electromyogram, electroencephalogram and electroretinogram.

Stimulus: In many measurements, the response to some of external stimulus is required. The stimulus may ne visual (flash of light), auditory (tone), tactile or direct electrical stimulation of some of the nervous system.

Transducer: it is defined as capable of converting one of energy to another. It sense the biopotential converts to electrical signal. For example thermistor converts temperature to electrical signal, strain gauge produces electrical signal by sensing the pressure.

Signal conditioning circuit: biomedical signal comes from transducer transferred to signal conditioning circuit. It amplify the given signal some extent then process the signal by removing the noise and measure signal parameters. Finally transfer measured parameters to either display or memory for future purpose.

Display device: output of signal conditioning circuit must be converted into form that can be perceived by one of man's senses and that can be convey the information obtained by the measurements in a meaningful way. It can be visual, audible or tactile information.

Recording, data processing and transmission: It is often necessary to record the measured information for possible later use or to transmit it from one location to another. It used, where computer control is employed so that automatic storage or processing is required.

Control feedback device: it is necessary or desirable to have automatic control of stimulus, transducer or ant part of man-instrument system, a control system is incorporated. This system usually consists of a feedback loop in which part of the output from the signal conditioning or display equipment is used to control the operation of the system in some way.

Physiological Systems of Human Body:

Physiology means functional activities of living organs and every organ responsible for one activity in turn these are work together to achieve systematic activity of human body.

Human Body Organ Systems:

These systems include the Biochemical system, skeletal system, muscular system, lymphatic system, respiratory system, digestive system, nervous system, endocrine system, cardiovascular system, urinary system, and reproductive systems. We will briefly discuss the major functions of each organ system below.Biological chemistry is the study of chemical processes within and relating to living organisms. By controlling information flow through biochemical signaling and the flow of chemical energy through metabolism, biochemical processes give rise to the complexity of life. Much of biochemistry deals with the structures, functions and interactions of biological macromolecules, such as proteins, nucleic acids, carbohydrates and lipids, which provide the structure of cells and perform many of the functions associated with life. The chemistry of the cell also depends on the reactions of smaller molecules and ions

Nervous system– (brain, spinal cord, nerves) Control system of the body, responds to internal and external changes, activates muscles and glands.

Endocrine system– (pineal gland, pituitary gland, thyroid gland, thymus, adrenal gland, pancreas, ovary, testis) Glands from the endocrine system secrete hormones that regulate many processes like growth, metabolism, and reproduction.

Cardiovascular system– (heart, blood vessels) The heart pumps blood and blood vessels transport it. Blood carries oxygen, carbon dioxide, nutrients, waste and more throughout the body.

Skeletal system– (bones, joints) Supports and protects the body's organs. Provides a framework muscles use (movement). Bones also store minerals and create blood cells.

Muscular system– (skeletal muscles) Maintains posture and produces movement (locomotion). Produces heat.

Respiratory system– (nasal cavity, pharynx, larynx, trachea, bronchus, lung) Removes carbon dioxide and continually supplies blood with oxygen. Gaseous exchanges occur in the respiratory system (lungs).

Digestive system– (oral cavity, esophagus, liver, stomach, small intestine, large intestine, rectum) Breaks down food to be absorbed and eliminates indigestible waste.

Urinary system– (kidney, ureter, urinary bladder, urethra) Eliminates nitrogenous wastes from the body. Regulates acid-base, electrolyte and WATER balance of blood.

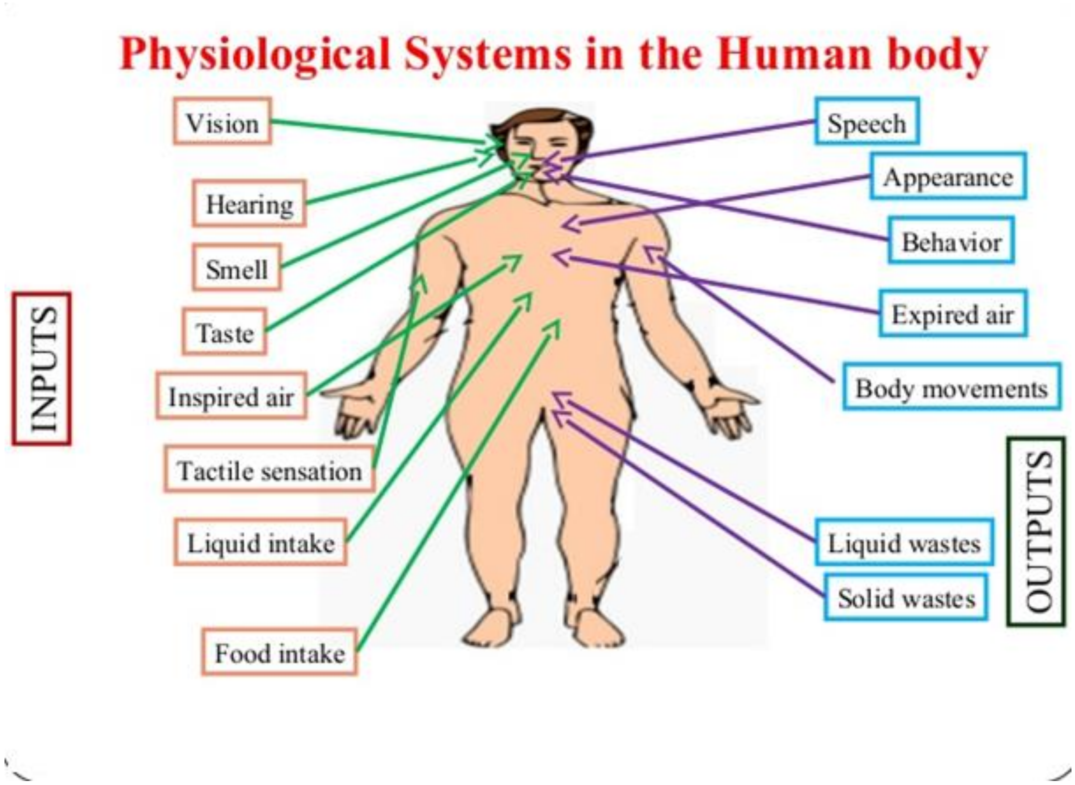
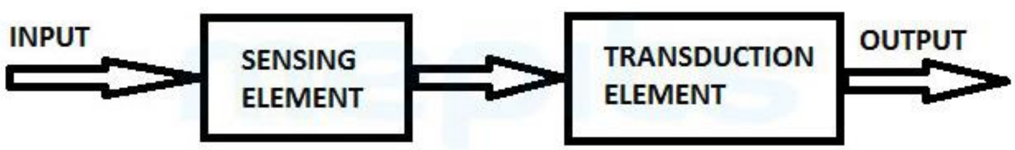


Figure 4: Communication system of human body

Problems encountered in measuring a living system:

1. Inaccebility of variable to measurement: it is greatest difficulty in attempting from a living system is the problem in gaining to the variable being measured. For example neuro chemical activity of brain ,it is impossible to place transducer so we need to do the indirect measurement.in using indirect measurement, however one must be aware of the limitations.
2. Variability of data: majority of physiological variables are nondeterministic, means varies with respect to time.so these must be represented by some statistical or probability distribution.

3. Lack of knowledge of interrelationship: physiological measurements with large tolerance are often accepted by the physician because of lack of this knowledge and the resultant in ability to control variations. Better understanding of physiological relationship would also permit more effective use of indirect measurements as substitutes for inaccessible measure.
4. Interaction among physiological systems: large number of feedback loops involved in the major physiological systems, a severe degree of interaction exists both within a given system and among the major systems. The result is that stimulation of one part of a given system generally affects all other parts of the system in some way and often affects other systems as well.
5. Effect of transducer: Transducer can be considered as a device converting one form of energy to another form. Electrical transducers can be considered as a device meant to convert a form of energy to equivalent electrical signals. The physical quantity to be measured can be position, displacement, flow, temperature, strain, velocity etc. and the output is in the form of electrical parameters like current, capacitance, voltage, inductance, change in resistance etc. Transducer block diagram is given below.



Transducer consists of two main parts, that is,

Sensor or Sensing Element: This part is responsible for generating measurable response with respect to the change in physical quantity to be measured.

Transduction Element: Sensor output is carried on to the transduction element which converts the non-electrical signal to electrical signal in proportion to the input.

Parameters of a Transducer

Ruggedness: Transducers have overload withstanding ability and comes with safety stops for protecting from overloads.

Linearity**:** Transducer is meant to measure a physical quantity and output the electrical signal relative to the measured quantity. This input/output conversion is usually linear in nature and symmetrical too.

Repeatability: Transducer has the ability to reproduce the same output signal for the same input physical quantity measured repeatedly that is being measured under same environmental situations.

Dynamic Response**:** Transducer exhibits good dynamic response with output changing with the input as a function of time.

High stability and reliability**:** Transducer measurements shows minimum error and the output is unaffected by environmental vibrations, temperature etc.

6. Artifacts: it is component or variable is observed while doing experiment, which is not naturally present. Thus random noise generated within the measuring instrument, electrical interference (50/60 Hz),cross talk and all other unwanted variations in a signal are considered artifacts.
7. Energy limitations: many physiological measurement techniques that a certain amount of energy be applied to the living system in order to obtain a measurement. For example, resistance measurements require the flow of electric current through the tissue or blood being measured. Some transducers generate small amount of heat due to the current flow.

8. Safety considerations: methods employed in measuring variables in a living human subject must in no way endanger the life or normal functioning of the subject. Recent emphasis on hospital safety requires that extra caution must be taken in the design of any measurement system to protect the patient.

Sources of Bioelectric Potentials:

Cell: The fundamental unit of every animal or plant is cells. Combination of cells is called tissues. Every organ in the body is made up of combination of many tissues.

Generation of the resting potential:

Cell membranes are typically permeable to only a subset of ions. These usually include potassium ions, chloride ions, bicarbonate ions, and others. To simplify the description of the ionic basis of the resting membrane potential, it is most useful to consider only one ionic species at first, and consider the others later. Since trans-plasma-membrane potentials are almost always determined primarily by potassium permeability, that is where to start. In a more formal notation, the membrane potential is the weighted average of each contributing ion's equilibrium potential. The size of each weight is the relative conductance of each ion. In the normal case, where three ions contribute to the membrane potential:

Equilibrium potentials:

For most animal cells potassium ions (K^+) are the most important for the resting potential. Due to the active transport of potassium ions, the concentration of potassium is higher inside cells than outside. Most cells have potassium-selective ion channel proteins that remain open all the time. There will be net movement of positively charged potassium ions through these potassium channels with a resulting accumulation of excess negative charge inside of the cell. The outward movement of positively charged potassium ions is due to random molecular motion (diffusion) and continues until enough excess negative charge accumulates inside the cell to form a membrane potential which can balance the difference in concentration of potassium between inside and outside the cell. "Balance" means that the electrical force (potential) that results from the build-up of ionic charge, and which impedes outward diffusion, increases until it is equal in magnitude but opposite in direction to the tendency for outward diffusive movement of potassium. This balance point is an equilibrium potential as the net transmembrane flux (or current) of K^+ is zero. A good approximation for the equilibrium potential of a given ion only needs the concentrations on either side of the membrane and the temperature. It can be calculated using the Nernst equation:

$$E_{eq,K^+} = \frac{RT}{zF} \ln \frac{[K^+]_o}{[K^+]_i},$$

where

E_{eq,K^+} is the equilibrium potential for potassium, measured in volts

R is the universal gas constant, equal to 8.314 joules·K^{-1}·mol^{-1}

T is the absolute temperature, measured in kelvins (= K = degrees Celsius + 273.15)

z is the number of elementary charges of the ion in question involved in the reaction

F is the Faraday constant, equal to 96,485 coulombs·mol^{-1} or $J·V^{-1}·mol^{-1}$

$[K^+]_o$ is the extracellular concentration of potassium, measured in mol·m^{-3} or mmol·l^{-1}

$[K^+]_i$ is likewise the intracellular concentration of potassium

Resting potential:

The resting membrane potential is not an equilibrium potential as it relies on the constant expenditure of energy (for ionic pumps as mentioned above) for its maintenance. It is a dynamic diffusion potential that takes this mechanism into account—wholly unlike the equilibrium potential, which is true no matter the nature of the system under consideration. The resting membrane potential is dominated by the ionic species in the system that has the greatest conductance across the membrane. For most cells this is potassium. As potassium is also the ion with the most negative equilibrium potential, usually the resting potential can be no more negative than the potassium equilibrium potential. The resting potential can be calculated with the Goldman-Hodgkin-Katz voltage equation using the concentrations of ions as for the equilibrium potential while also including the relative permeability's of each ionic species. Under normal conditions, it is safe to assume that only potassium, sodium (Na^+) and chloride (Cl^-) ions play large roles for the resting potential:

$$E_m = \frac{g_{K^+}}{g_{tot}} E_{eq,K^+} + \frac{g_{Na^+}}{g_{tot}} E_{eq,Na^+} + \frac{g_{Cl^-}}{g_{tot}} E_{eq,Cl^-}$$

Action potential:

An action potential (also known as a nerve impulse or a spike) is a self-regenerating wave of electrochemical activity that allows excitable cells (such as muscle and nerve cells) to carry a signal over a distance. It is the primary electrical signal generated by nerve cells, and arises from changes in the permeability of the nerve cell's axonal membranes to specific ions. Action potentials are pulse-like waves of voltage that travel along several types of cell membranes

Relatively static membrane potential of quiescent cells is called resting membrane potential (or resting voltage), as opposed to the specific dynamic electrochemical phenomenon called action potential and graded membrane potential.

Action potentials are generated by special types of voltage-gated ion channels embedded in a cell's plasma membrane. These channels are shut when the membrane potential is near the (negative) resting potential of the cell, but they rapidly begin to open if the membrane increases to a precisely defined threshold voltage, depolarizing the transmembrane potential. When the channels open they allow an inward flow of sodium ions, which changes the electrochemical gradient, which in turn produces a further rise in the membrane potential. This then causes more channels to open, producing a greater electric current across the cell membrane, and so on. The process proceeds explosively until all of the available ion channels are open, resulting in a large upswing in the membrane potential. The rapid influx of sodium ions causes the polarity of the plasma membrane to reverse, and the ion channels then rapidly inactivate. As the sodium channels close, sodium ions can no longer enter the neuron, and then they are actively transported back out of the plasma membrane. Potassium channels are then activated, and there is an outward current of potassium ions, returning the electrochemical gradient to the resting state. After an action potential has occurred, there is a transient negative shift, called the after hyperpolarization.

Propagation of action potential:

All cells in animal body tissues are electrically polarized – in other words, they maintain a voltage difference across the cell's plasma membrane, known as the membrane potential. This electrical polarization results from a complex interplay between protein structures embedded in the membrane called ion pumps and ion channels. In neurons, the types of ion channels in the membrane usually vary across different parts of the cell, giving the dendrites, axon, and cell body different electrical properties. As a result, some parts of the membrane of a neuron may be excitable (capable of generating action potentials), whereas others are not. Each excitable patch of membrane has two important levels of membrane potential: the resting potential, which is the value the membrane potential maintains as long as nothing perturbs the cell, and a higher value called the threshold potential. At the axon hillock of a typical neuron, the resting potential is around –70 millivolts (mV) and the threshold potential is around –55 mV. Synaptic inputs to a neuron cause the membrane to depolarize or hyperpolarize

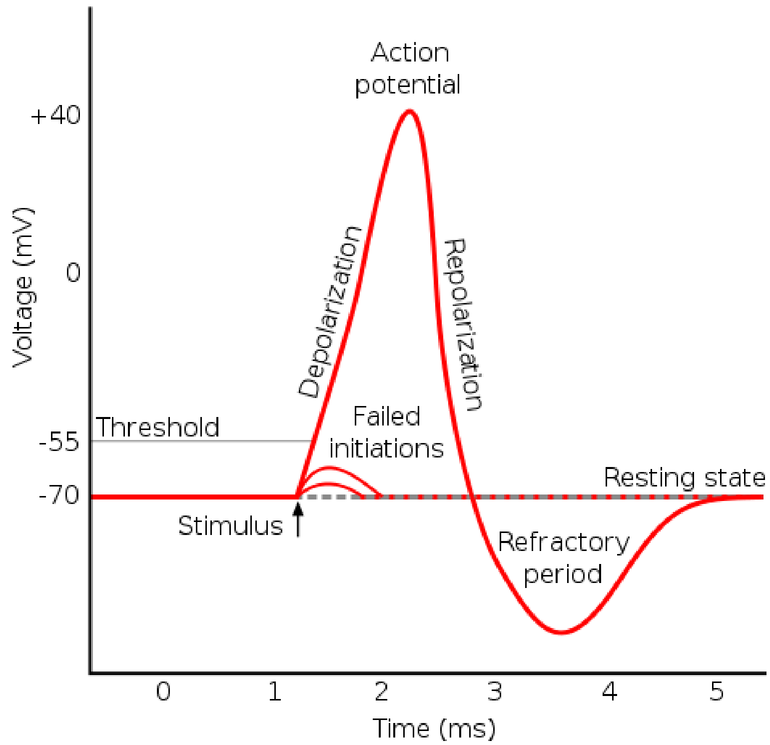


Figure 5: Action potential

Sodium pump:

The process of active transport differs from diffusion in that molecules are transported away from thermodynamic equilibrium; hence, energy is required. This energy can come from the hydrolysis of ATP, from electron movement, or from light. The maintenance of electrochemical gradients in biologic systems is so important that it consumes perhaps 30–40% of the total energy expenditure in a cell. In general, cells maintain a low intracellular Na+ concentration and a high intracellular K+ concentration, along with a net negative electrical potential inside. The pump that maintains these gradients is an ATPase that is activated by Na+ and K+ (Na+-K+ATPase).

Bioelectric potentials ECG, EEG, EMG, ERG and Evoked Potential:

The electrocardiogram (ECG) is a electrical activity of heart in written or printed form. Clinicians can evaluate the conditions of a patient's heart from the ECG and perform further diagnosis. ECG records are obtained by sampling the bioelectric currents sensed by several electrodes, known as leads.

Electrocardiography (ECG or EKG) is the recording of the electrical activity of the heart over time via skin electrodes. It is a noninvasive recording produced by an electrocardiographic device. The etymology of the word is derived from electro, because it is related to electrical activity, cardio, Greek for heart, graph, a Greek root meaning "to write".

Electrical impulses in the heart originate in the sinoatrial node and travel through the intrinsic conducting system to the heart muscle.The impulses stimulate the myocardial muscle fibres to contract and thus induce systole. The electrical waves can be measured at selectively placed electrodes (electrical contacts) on the skin. Electrodes on different sides of the heart measure the activity of different parts of the heart muscle. An ECG displays the voltage between pairs of these electrodes, and the muscle activity that they measure, from different directions, also understood as vectors. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle.

Leads:

Graphic showing the relationship between positive electrodes, depolarization wavefronts (or mean electrical vectors), and complexes displayed on the ECG.

In electrocardiography, the word, "lead" (rhymes with 'speed') refers to the signal that goes between two electrodes. These electrodes are attached to the patient's body, usually with very sticky circles of thick tape-like material (the electrode is embedded in the center of this circle).

Unipolar vs. bipolar leads:

There are two types of leads—unipolar and bipolar. Bipolar leads have one positive and one negative pole. In a 12-lead ECG, the limb leads (I, II and III) are bipolar leads. Unipolar leads have only one true pole (the positive pole). The negative pole is a "composite" pole made up of signals from lots of other electrodes. In a 12-lead ECG, all leads besides the limb leads are unipolar (aVR, aVL, aVF, V1, V2, V3, V4, V5, and V6).

In both the 5- and 12-lead configuration, leads I, II and III are called limb leads. The electrodes that form these signals are located on the limbs—one on each arm and one on the left leg. The limb leads form the points of what is known as Einthoven's triangle.

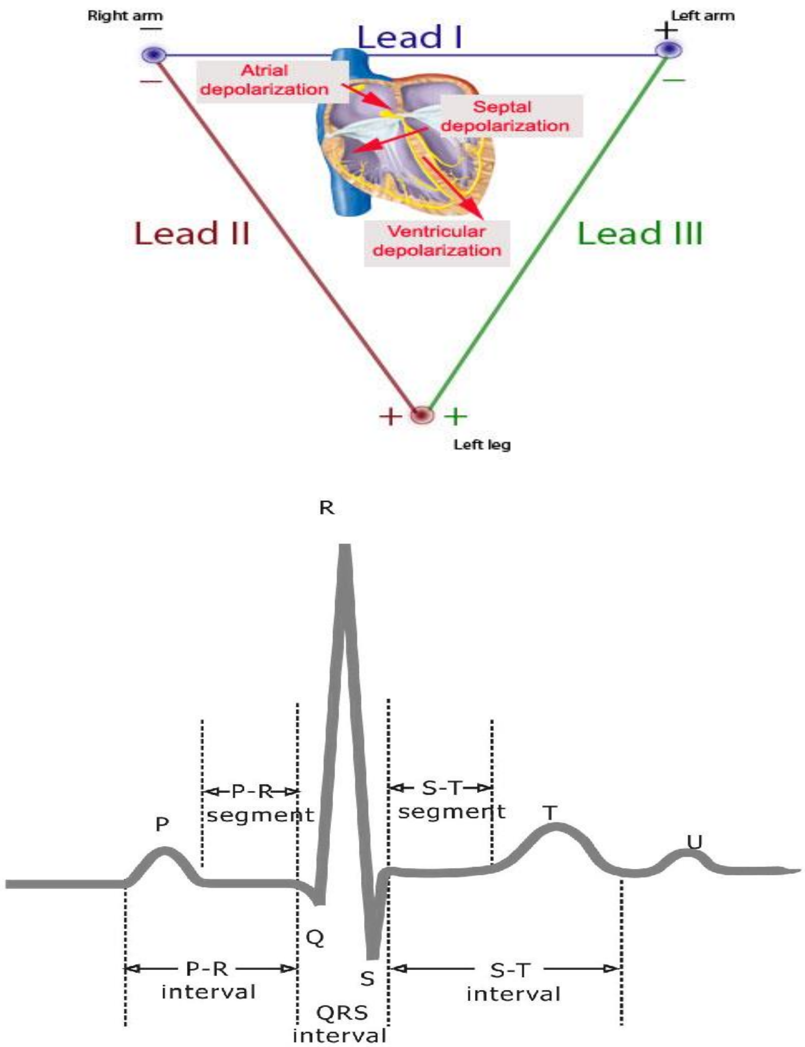


Figure 6: Electrocardiogram

P-Wave:

During normal atrial depolarization, the main electrical vector is directed from the SA node towards the AV node, and spreads from the right atrium to the left atrium.

QRS- Wave:

The QRS complex is a structure on the ECG that corresponds to the depolarization of the ventricles. Because the ventricles contain more muscle mass than the atria, the QRS complex is larger than the P wave.

PR-Interval:The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. It is usually 120 to 200 ms long.

ST segment:The ST segment connects the QRS complex and the T wave and has a duration of 0.08 to 0.12 sec (80 to 120 ms).

T-Wave:The T wave represents the repolarization (or recovery) of the ventricles.

U-Wave:The U wave is not always seen. It is typically small, and, by definition, follows the T wave. U waves are thought to represent repolarization of the papillary muscles or Purkinje fibers.

Electroencephalogram (EEG) is electrical activity along the scalp produced by the firing of neurons within the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp. In neurology, the main diagnostic application of EEG is in the case of epilepsy, as epileptic activity can create clear abnormalities on a standard EEG study. A secondary clinical use of EEG is in the diagnosis of coma and encephalopathy's. EEG used to be a first-line method for the diagnosis of tumors, stroke and other focal brain disorders, but this use has decreased with the advent of anatomical imaging techniques such as MRI and CT.

In this system 21 electrodes are located on the surface of the scalp, as shown . The positions are determined as follows: Reference points are nasion, which is the delve at the top of the nose, level with the eyes; and inion, which is the bony lump at the base of the skull on the midline at the back of the head. From these points, the skull perimeters are measured in the transverse and median planes. Electrode locations are determined by dividing these perimeters into 10% and 20% intervals. Three other electrodes are placed on each side equidistant from the neighboring points,

The EEG is typically described in terms of (1) rhythmic activity and (2) transients. The rhythmic activity is divided into bands by frequency. To some degree, these frequency bands are a matter of nomenclature (i.e., any rhythmic activity between 8–12 Hz can be described as "alpha"), but these designations arose because rhythmic activity within a certain frequency range was noted to have a certain distribution over the scalp or a certain biological significance.

Most of the cerebral signal observed in the scalp EEG falls in the range of 1–20 Hz (activity below or above this range is likely to be artifactual, under standard clinical recording techniques).

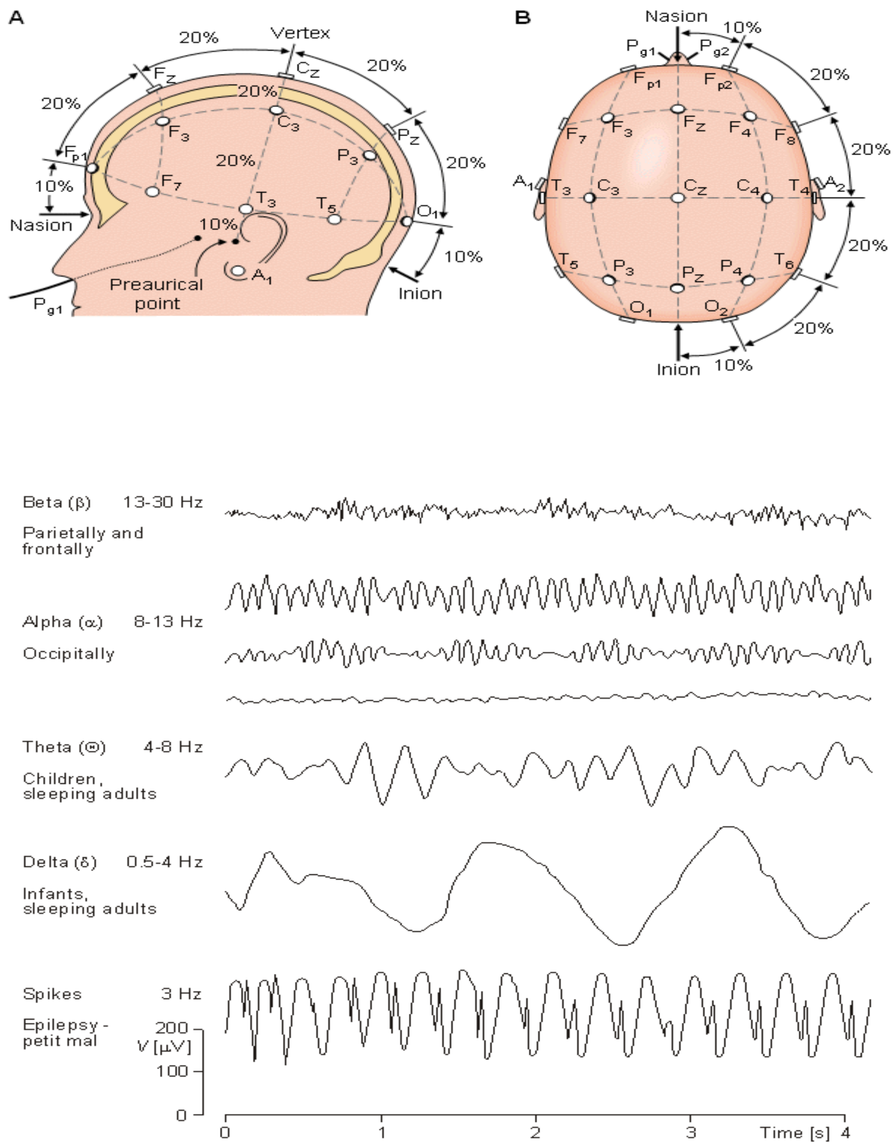


Figure 5: Electroencephalogram

Electromyogram (EMG) is a special test used to determine if there are problems with any of the nerves going to the upper limbs. EMGs are usually done to see if one or more nerve roots have been pinched by a herniated disc. During the test, small needles are placed into certain muscles that are supplied by each nerve root. If there has been a change in the function of the nerve, the muscle will send off different types of electrical signals. The EMG test reads these signals and can help determine which nerve root is involved.

A needle electrode is inserted through the skin into the muscle. The electrical activity detected by this electrode is displayed on an oscilloscope.

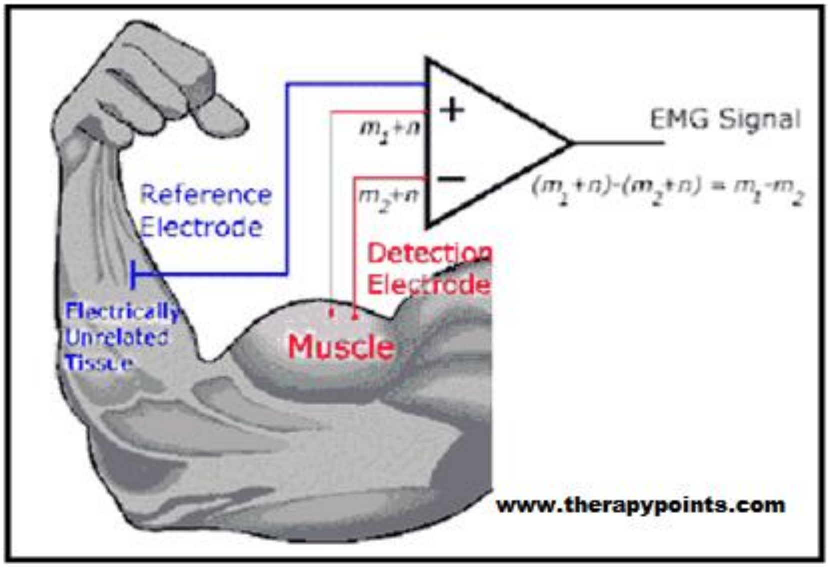


Figure 7: EMG Acquisition

Electroretinogram:

ERG responses are recorded with an active extracellular electrode positioned either on the cornea, in the vitreous or at different levels inside the retina. Extracellular recording of electrical activity of living tissue is rendered possible when electrical currents spread along an extracellular matrix with electrical resistance. An example of extracellular electrical current in the vertebrate retina is the 'dark' current spreading from the inner segments to the outer segments of the photoreceptors

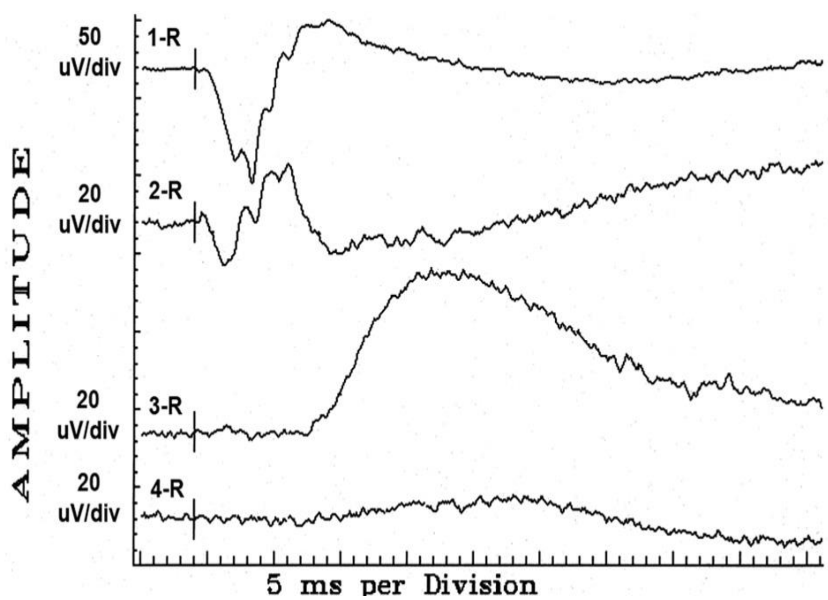


Figure 8 : Electroretinogram(ERG)

Evoked Potential:

An evoked potential or evoked response is an electrical potential recorded from the nervous system of a human or other animal following presentation of a stimulus, as distinct from spontaneous potentials as detected by electroencephalography (EEG), electromyography (EMG), or other electrophysiologic recording method. Such potentials are useful for electrodiagnosis and monitoring.

Evoked potential amplitudes tend to be low, ranging from less than a microvolt to several microvolts, compared to tens of microvolts for EEG, millivolts for EMG, and often close to a volt for ECG. To resolve these low-amplitude potentials against the background of ongoing EEG, ECG, EMG, and other biological signals and ambient noise, signal averaging is usually required. The signal is time-locked to the stimulus and most of the noise occurs randomly, allowing the noise to be averaged out with averaging of repeated responses.

Types of visual evoked potential:

Visual evoked potential: noticed potential changes of the occipital EEG can be observed under stimulation of light

Auditory evoked potential auditory evoked potential can be used to trace the signal generated by a sound through the ascending auditory pathway. auditory evoked potentials can be used to diagnose learning disabilities in children, aiding in the development of tailored educational programs for those with hearing and or cognition problems.[

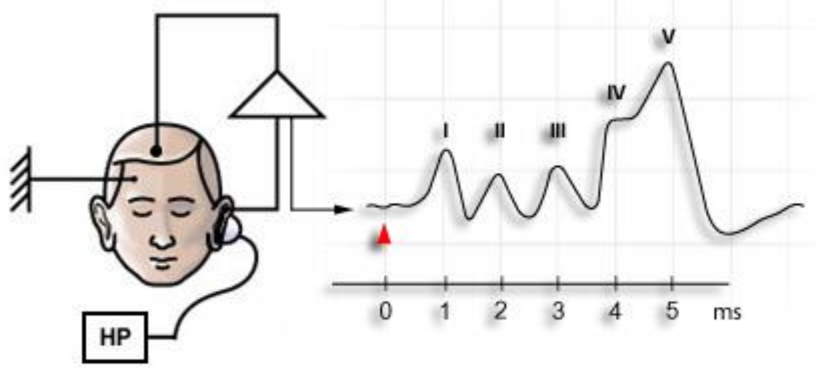


Figure 9: Auditory Evoked potential