SRI CHANDRASEKHARENDRA SARASWATHI

VISWA MAHAVIDYALAYA

DEPARTMENT OF ELECTRONICS & COMMUNICATION

ENGINEERING

COURSE MATERIAL PREPARATION

BIO-MEDICAL ELECTRONICS

Dr.R.JAYALAKHSMI

PEC5 BIO-MEDICAL ELECTRONICS VII SEMESTER

Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya

Department of Electronics and Communication Engineering

Syllabus for Full Time BE, Regulations 2018

(Applicable for students admitted from 2018-19 onwards)

PRE-REQUISTIE:

Basic Knowledge in Electronic Devices and Circuits

OBJECTIVES:

- To learn the electrical and non-electrical physiological measurements
- To understand the function of bio amplifiers.
- To know the configuration of various electrodes

UNIT I BIO POTENTIAL ELECTRODES (9 Hrs)

Origin of bio potential and its propagation, Electrode-electrolyte interface, electrode–skin interface, half-cell potential, impedance, polarization effects of electrode – non polarisable electrodes. Types of electrodes - surface, needle and micro electrodes and their equivalent circuits, Recording problems - measurement with two electrodes

UNIT II ELECTRODE CONFIGURATIONS (9 Hrs)

Bio signals characteristics – frequency and amplitude ranges. ECG – Einthoven's triangle, standard 12 lead system. EEG – 10-20 electrode system, unipolar, bipolar and average mode, EMG– unipolar and bipolar mode

UNIT III BIO AMPLIFIER (9 Hrs)

Need for bio-amplifier - single ended bio-amplifier, differential bio-amplifier – right leg driven ECG amplifier. Band pass filtering, isolation amplifiers – transformer and optical isolation - isolated DC amplifier and AC carrier amplifier. Chopper amplifier, Power line interference

UNIT IV MEASUREMENT OF NON-ELECTRICAL PARAMETERS (9 Hrs)

Temperature, respiration rate and pulse rate measurements. Blood Pressure: indirect methods - auscultatory method, oscillometric method, direct methods: electronic manometer, Pressure amplifiers - systolic, diastolic, mean detector circuit. Blood flow and cardiac output measurement: Indicator dilution, thermal dilution and dye dilution method, Electromagnetic and ultrasound blood flow measurement.

UNIT V BIO-CHEMICAL MEASUREMENT (9 Hrs)

Biochemical sensors - pH, pO2 and pCO2, Ion selective Field effect Transistor (ISFET), immunologically sensitive FET (IMFET), Blood glucose sensors - Blood gas analyzers, colorimeter, flame photometer, spectrophotometer, blood cell counter, auto analyzer (simplified schematic description).

OUTCOMES: Total: 45 Hrs

At the end of the course, the student should be able to:

- Perform electrical and non-electrical physiological measurements
- Explain the function of bio amplifiers

TEXT BOOKS:

1. John G. Webster, “Medical Instrumentation Application and Design”, John Wiley and sons, 2004.

2. Khandpur R.S, “Handbook of Biomedical Instrumentation”, Tata McGraw-Hill, 2003.

REFERENCES:

1. Leslie Cromwell, “Biomedical Instrumentation and measurement”, PHI, 2007.

2. Myer Kutz, “Standard Handbook of Biomedical Engineering and Design”, McGrawHill, 2003.

3. Joseph J. Carr & John M. Brown, “Introduction to Biomedical Equipment Technology”, Pearson Education, 2004.

UNIT I BIO POTENTIAL ELECTRODES

THE ORIGIN OF BIO-POTENTIALS:

- Bioelectric phenomenon is of immense importance to biomedical engineers because these potentials are routinely recorded in modern clinical practice.

- ECG (Electrocardiogram), EMG (Electromyogram), EEG (Electroencephalogram), ENG (Electroneurogram), EOG (Electro-oculogram), ERG (Electroretinogram), etc. are some examples of biopotentials.

ELECTRICAL ACTIVITY OF EXCITABLE CELLS

- Biopotentials are produced as a result of electrochemical activity of excitable cells: i.e., nervous, muscular (cardiac and smooth) and glandular cells.

Factors influencing the flow of ions across the cell membrane

- Diffusion gradients

- Inwardly directed electric field (inside negative, outside positive)

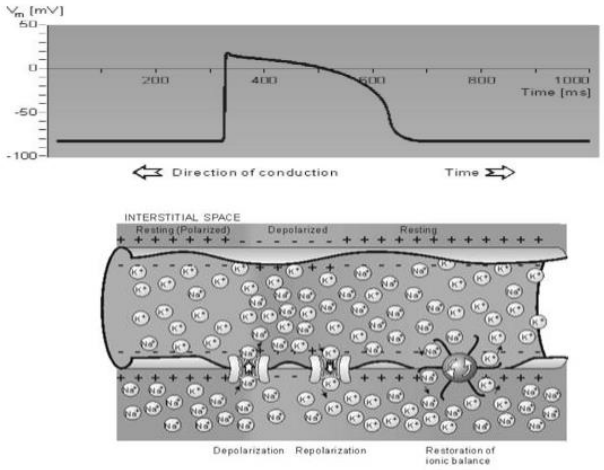
- Membrane structure (availability of pores; K+, Na+ and permeability of membrane to different ions)

- Active transport of ions across membrane against established electrochemical gradients

- When appropriately stimulated, they generate an action potential (flow of ions across the cell membrane and generation of a propagating wave of depolarization along the membrane)

BIOELECTRIC PHENOMENA AT THE CELLULAR LEVEL

A very important topic in electrophysiology is the relationship between intracellular and extracellular potentials, especially in nerve or muscle fibres.



Action Potential

BIOPOTENTIAL ELECTRODES

- If electrode has same material as cation, then this material gets oxidized and enters the electrolyte as a cation and electrons remain at the electrode and flow in the external circuit.

- If anion can be oxidized at the electrode to form a neutral atom, one or two electrons are given to the electrode The dominating reaction can be inferred from the following:

- Current flow from electrode to electrolyte: Oxidation (Loss of e-)

- Current flow from electrolyte to electrode: Reduction (Gain of e-)

Half Cell Potential

A Characteristic Potential difference established by the electrode and its surrounding electrolyte which depends on the metal, concentration of ions in solution and temperature.

Resting Potential:

Fluids surrounding the cells of the body are conducting. These conductive solutions contain atoms known as ions.

Principal ions present are: Sodium-Na+, Potassium-K+ and Chloride-Cl−.

The membrane of excitable cells readily permits entry of K+ and Cl-, but effectively blocks Na+ Ions. According to concentration and electric charge, various Ions seek a balance between inside and outside of cell.

Action Potential:

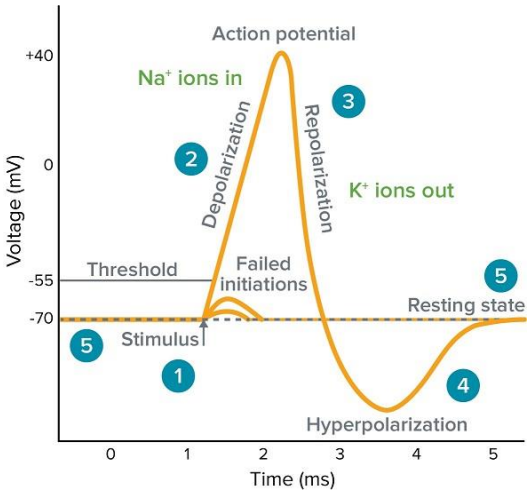
Due to some external energy or by the flow of ionic current, a section of cell membrane changes its characteristics and begins to allow some of sodium ions to enter. This movement of sodium ions into cell constitutes an ionic current flow that further reduces the balance of membrane to sodium ions. The net result is avalanche effect and tries to balance with ions outside. At the same time, K+ ions, in higher concentration inside the cell during resting state, try to leave cell, but are unable to move as fast as Na+ ions. The result is cell attains small +ve potential on the inside due to imbalance of K+ ions, known as action potential. The action potential is nearly +20 mV.

When a cell is excited and displays an action potential, it is said to be "depolarized" and the process of changing from resting state to action potential is called as depolarization. Once the rush of sodium ions through the cell membrane has stopped (a new state of equilibrium is reached), the ionic currents that lowered the barrier to sodium ions are no longer present and the membrane reverts back to its original, selectively permeable condition. Now passage of sodium ions from the outside to inside of the cell is again blocked. However, it would take a long time for a resting potential to develop again.

By an active process, called a sodium pump, the sodium ions are quickly transported to the outside of the cell, and the cell again becomes polarized and assumes its resting potential. This

process is called Repolarization. The rate of pumping is directly proportional to the sodium concentration in the cell. It is also believed that the operation of this pump is linked with the influx of potassium into the cell, as if a cyclic process involving an exchange of sodium for potassium existed.

The Figure below shows a typical action-potential waveform, beginning at the resting potential, depolarization, and returning to the resting potential after repolarization. The time scale for the action potential depends on the type of cell producing the potential. In nerve and muscle cells, repolarization occurs so rapidly following depolarization that the action potential appears as a spike of as little as 1 msec total duration.



Polarizable versus Non-Polarizable Electrodes

All electrodes fall into the range defined by two idealized types of electrodes, namely perfectly polarizable and perfectly non-polarizable. These electrode types are characterized by observing the consequence when current is passed through the electrode/electrolyte junction. Perfectly polarizable electrodes behave like capacitors, because only displacement (transient) current

flows through the junction. A direct (non-transient) current does not flow through perfectly polarizable electrodes. In the case of perfectly non-polarizable electrodes, direct current easily flows through the electrode / electrolyte junction and requires no specific excitation voltage to permit the flow of electrons. Perfectly non-polarizable electrodes behave like resistors.

All electrodes have a half-cell potential that is measured in reference to the half-cell potential of the Standard Hydrogen Electrode (SHE). The half-cell potential of the hydrogen electrode is arbitrarily defined as 0 volts. The half-cell potential, assuming no current is passing through the electrode, is known as the equilibrium potential (Ve). With a non-polarizable electrode, the potential of the electrode will not materially change from its potential at equilibrium (zero current state) even with relatively large currents passing through the electrode /electrolyte junction. This is because the electrode/electrolyte reactions occur quickly. With a polarizable electrode, the potential of the electrode will significantly change from its potential at equilibrium even with relatively small currents passing through the electrode /electrolyte junction. This is because the electrode /electrolyte reactions occur slowly.

Over-potential is the difference in the electrode /electrolyte potential of an electrode between its equilibrium and and operating states. An electrode is in operating state when a current is flowing. The over-potential consists of three elements:

Resistive Over-potential (Vr)

The additional potential that results from current flowing through the electrode / electrolyte junction due to resistance of that junction.

Activation Over-potential (Va)

The additional potential that results because of the difference in activation potential between two circumstances:

1. Activation energy barrier (voltage) required for a metal atom to oxidize and enter the electrolyte as a cation.
2. Activation energy barrier (voltage) required for a cation to be reduced and deposit a metal atom on the electrode.

Concentration Over-potential (Vc)

The additional potential that results because the concentration of ions at the electrode-electrolyte interface changes when current passes across through the electrode/electrolyte junction.

The total over-potential (Vp), where Vp = Vr + Va + Vc, represents the additional voltage needed to force the electrode reaction to proceed at the required rate. The operating potential of an anode is always more positive, with respect to cathode, than the equilibrium potential.

The total potential (Vt) associated with an operating electrode is its Equilibrium potential (Ve) summed with its Over-potential (Vp), where:

Vt = Ve + Vp

No electrode is perfectly polarizable or non-polarizable, however certain classes of electrodes can approximate these characteristics. Platinum electrodes are a reasonable approximation of perfectly polarizable electrodes and they exhibit Vp that primarily results from Vc and Va. Ag/AgCl electrodes behave reasonably closely to perfectly non-polarizable electrodes and they exhibit Vp that primarily results from Vr only. Generally considered, electrodes that are non-

polarizable are used for recording biopotentials and electrodes that are polarizable are better suited for transient electrical stimulation. Polarizable electrodes can be used to record biopotentials, but because they behave capacitively, these electrodes are better suited for higher frequency biopotential measurements. Because non-polarizable electrodes behave resistively, they are better suited for biopotential recordings that range from high frequency to very low frequency.

Electrode Size and Class

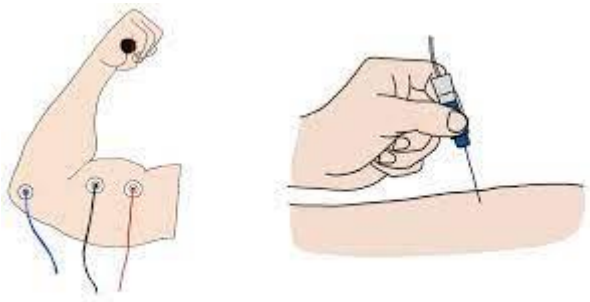
Depending on the biopotential measurement of interest, differently-sized electrodes and classes may be required. Electrode size and class types are:

1. Micro-electrodes
2. Fine Wire Electrodes
3. Needle Electrodes
4. Surface Electrodes
5. Electrode Arrays

Micro-electrodes are typically saline-filled glass electrodes. These are pulled glass tubes that, when filled with saline, connect a very tiny exposed portion of saline to a conducting element. The glass tube is pulled, when held to a heat source, to craft a tapered tube. The conducting element, such as platinum wire or Ag/AgCl pellet, is held in the large portion of the tube. When the tube is filled with saline, the saline establishes a conductive pathway between the conductive element and the exposed saline at the electrode tip. The tip can be made so tiny as to be able, when placed against the surface of a cell, to connect to a small patch of the cellular membrane. This configuration permits measurement of cellular ionic channel activity in the patch area. Micro-electrodes can be used for intercellular or extracellular measurements.

Intercellular measurements are recordings from a single cell and extracellular measurements will typically record signals from multiple cells.

Fine wire electrodes are single strands of metal wire – typically platinum or silver, that are partially insulated with a coating – typically epoxy. The insulating coat usually is applied to expose only an area at the tip of the wire. When a fine wire electrode is inserted into tissue, the metal conducting wire will be fully insulated from surrounding tissue except at the tip. Fine wire electrodes are too large to be used as intercellular electrodes. Fine wire electrodes are used as extracellular electrodes to collect, or introduce, signals from or to groups of cells or in specific tissue volumes. Fine wire electrodes can be made in a range of lengths and diameters, suitable for precision microscopic clamping systems to hand-insertion into tissue.



(a) Surface EMG (b) Needle EMG

Needle electrodes are metal electrodes similar to fine wire electrodes. However, needle electrodes are usually much bigger and more robust than fine wire wires. Needle electrodes are usually made out of stainless steel; however, a variety of metal alloys can be employed. Needle electrodes are usually partially insulated, like fine wire electrodes, however uninsulated needle electrodes are also used. When insulated, with an epoxy coat, the coating is applied to expose only an area at the tip of the needle. Needle electrodes are used as extracellular electrodes. Needle electrodes are typically hand-inserted into tissue.

Surface electrodes are typically the largest types of electrodes. These electrodes typically attach to the surface of the body via an adhesive tape ring or adhesive electrode gel. Surface electrodes come in a wide range of conductive materials, including metals, metal alloys, metal compounds and conductive rubber or fabric. The best performing surface electrodes for very low to high frequency biopotential recordings are Ag/AgCl electrodes that have an electrolyte-mediated connection to the body surface. Conductive rubber and other polarizable electrodes are better suited for electrical stimulation at the skin surface, versus biopotential measurements. However, for higher frequency biopotential measurements, all electrode material types can be used with varying degrees of success. A relatively new class of surface electrodes are active, non-contact, electrodes that employ electronics at the point of the electrode to establish a fully-capacitive connection to the body surface. These electrodes can have very good performance over a range of biopotential frequencies, however, they do not operate to zero frequency. Other new electrode types include stretchable, conductive, fabric electrodes that can be employed to collect biopotential data from ambulatory subjects.

Electrode arrays can range in size from microscopic to many square centimeters in area. Arrays can be arranged linearly, circularly or in a rectangular grid. Very tiny arrays can have imbedded electrode points of differing heights, able to be placed against the surface of a nerve fiber bundle where the different electrode point heights may intercept different fibers in the bundle.

Larger surface arrays can be placed against the skin to collect biopotentials over a selected area. A classical surface electrode array is the 10-20 EEG System. The “10-20” nomenclature refers to the inter-electrode spacing of 10% and 20%, depending on electrode location on the scalp. The electrodes are spaced either 10% or 20% of the full, front-to-back or right-to-left, circumferential distance of the skull. This system employs 19 active electrodes, each of which is normally referenced to the right ear, left ear or summed ears.

Electrode-Electrolyte-Skin Junction

Electrode-electrolyte-skin junction can be modeled as a cascaded series of resistance/capacitance networks and potential sources. The characteristics of these junctions are important to consider when measuring biopotential signals generated by the body, because these small signal currents must pass through the junctions to be measured. The resistances, capacitances and potentials associated with these junctions can change with the type of electrode and electrolyte or time, temperature and physical displacement.

The electrode-electrolyte junction fundamentally consists of a metal element in contact with an electrolyte. In this situation, an electron/metal ion /electrolyte ion interaction occurs. Metal ions enter the electrolyte and orient with respect to electrons in the metal and electrolyte ions in the electrolyte. This orientation layering results in a charge distribution (half-potential) at the metal-electrolyte junction. A simple circuit model for the electrode-electrolyte junction can be described as a resistance in parallel with a series resistance and capacitance, and the combined network is in series with a voltage source (half-potential). At low frequency, this impedance is mostly resistive and high-valued. At intermediate frequencies, this impedance is becoming more capacitively dominated and drops rapidly with increasing frequency. At high frequencies, this impedance becomes resistive and low-valued.

The electrolyte-skin junction is characterized by the the interaction of the electrolyte with the top layer of skin (epidermis). The epidermis, itself, is composed of layers. The top layer, the stratum corneum, consists of dead skin cells. These dead cells establish an impedance and behave as a semi-permeable barrier when in contact with an electrolyte. Ions underneath this barrier orient with respect to ions in the electrolyte, so a potential is developed. A simple circuit model for electrolyte-electrode skin junction can be described as two resistances (electrolyte resistance and dermis resistance) in series with a parallel resistance and capacitance (from

epidermis), and the combined network is in series with a voltage source (skin potential). At low frequency, this impedance is largely resistive and high-valued. At intermediate frequencies, this impedance is capacitively dominated and drops rapidly with increasing frequency. At high frequencies, this impedance becomes resistively dominated at low values.

The electrode-electrolyte-skin junction decreases in impedance with increasing electrode surface area. Conversely, very small skin electrodes will have high electrode-skin junction impedance. As electrode contact areas shrink, increasing demands are placed on the recording amplifier. This is because the recording amplifier input impedance should be much greater (100 times greater) than the electrode source impedance to minimize loading. As the source and load impedances increase, then the associated conductors running from the electrode-skin junction to the amplifier input become receptive targets for ambient displacement currents in the local environment. According, protective shielding is needed in these cases to control and redirect interfering displacement currents away from the sensitive input conductors.

Impedance Checking

Impedance checking between a pair of electrodes, attached to the skin surface, is a simple method to verify the conductive quality of electrode-skin junctions. For high-quality biopotential recordings it's best to have low electrode-to-skin junction impedances. Generally, a good electrode-skin junction impedance measurement, consisting of the series combination of two, 1cm diameter, Ag/AgCl, surface electrodes and the tissue volume between, will be 10 Kohms or less. Nearly all the measured impedance is comprised by the two electrode-to-skin junctions (e.g., about 5 Kohms each) and the tissue volume typically has much lower impedance (e.g. less than 100 ohms). These two terminal impedance measurements is best performed at a frequency which is mid-band in the spectra for the signal of interest. Surface biopotentials have most signal energy in the 1-300 Hz region. Consequently, anywhere from

10 to 30 Hz is a reasonable test frequency because a number in this range is roughly mid-logarithmic to the overall signal spectra amplified. Two terminal, electrode-to-skin, impedance checking using a DC current is unreliable because of the influences of the electrode /electrolyte equilibrium half-potentials, over-potentials, and skin potentials.

Unipolar and Bipolar

When electrodes are placed on a subject's body, two electrodes are needed for any signal measurement. This is because a signal must have a reference against which the signal is measured. For many types of biopotential recordings, such as ECG, EEG and EMG, one reference might be used with many "active" signals. This type of biopotential measurement is called unipolar recording. When no global reference lead is used, the biopotential measurement is called bipolar recording

All biopotential measurements are intrinsically differential voltage measurements. This means that the amplifier is simply reporting the voltage sensed between two electrodes. A reference electrode is just one of these two electrodes considered as "reference". And, automatically, the other electrode (in the differential pair) is considered as "active" or "input".

Noise

All electrodes exhibit noise when attached to the skin surface. This noise has several components; a thermal component associated with the resistance of the electrode-skin junction, a "spiky" erratic component associated with sporadic ion transfer, a slow-moving "drift" associated with the offset potential between skin and electrode and "movement artifact" which may have "spiky" or "drift" aspects resulting from any electrode physical displacement on the skin surface.

Silver / Silver Chloride Electrodes

Silver / Silver Chloride (Ag/AgCl) electrodes are the best performing of all electrode types. The largest concern when using these electrodes is typically noise associated with movement artifact. Ag/AgCl electrodes are considered essentially non-polarizable. Non-polarizable means that the electrode / electrolyte junction will not develop an activation or concentration over-potential resulting from the flow of current through the electrode. This behavior creates a very stable electrode for the use in biopotential recordings. The AgCl layer, between the Ag layer and the electrolyte, has a stabilizing effect on the electrode / electrolyte junction, acting to reduce the noise in the junction, assuming that the Ag/AgCl electrode is in contact with an electrolyte that contains a sufficiently high concentration of Cl,Äì ions. Sintered Ag/AgCl electrodes have the highest stability and plated Ag/AgCl electrodes perform nearly as well.

The half-cell potential of the Ag/AgCl electrode is usually estimated to be about 0.22 volts higher than the half cell potential of the hydrogen electrode, which has arbitrarily been defined as 0 volts. This half-cell potential will vary on the basis of the conducting electrolyte. If the electrolyte's ionic concentration is saturated, the half-cell potential reduces to about 0.20 volts. When the ionic concentration is lower, as with seawater, the half-cell potential increases about 0.27 volts. When two Ag/AgCl electrodes are used to record biopotentials, the half-cell potentials cancel in the measurement loop, so the amplifier only records the biopotential signal evident in the tissue volume.

Gold, Tin, Stainless Steel, Carbon Composition Electrodes

Any metal, such as gold, silver, tin or stainless steel, can be used as a skin electrode. Gold and tin are often used for some kinds of biopotential recordings, typically EEG. Historically, Collodian (an adhesive and conductive electrode gel) has been used with tin or gold cup electrodes for high density EEG recordings. These electrode-gel configurations provide very

low contact impedance to the scalp, for a small adhesive contact area, and are rugged for continual use.

Metal electrodes are polarizable. Polarizable means that the metal electrode – gel – skin junction will develop an offset potential over time, as current passes through the junction. This characteristic makes the electrode less useful for low frequency biopotential recordings (less than 0.1 Hz), because varying offset potentials can mask underlying slow biopotential signals.

Carbon Composition electrodes are flexible conductive electrodes consisting of carbon-impregnated rubber. These electrodes are used as stimulating electrodes, typically in transcutaneous nerve stimulation applications. These electrodes are very noisy and are not useful for general purpose biopotential recordings.

Skin Preparation for Biopotential Measurements

For highest electrode to skin conductivity, the skin should be lightly abraded with a gentle abrasive wipe, such as BIOPAC's ELPAD. An alcohol wipe is not recommended, to improve conductivity, as this will only serve to dry out the skin surface. Lightly abrading the top layer of the epidermis will effectively remove dead skin cells and prepare the skin site to establish a high conductivity path, once the gelled electrode is applied.

After application, the electrode can be verified for robust galvanic connection to the skin via impedance checking. BIOPAC's EL-CHECK can be used to measure the impedance between any two applied surface electrodes. Because each electrode/electrolyte junction forms a half-cell, impedance measurements are more accurately measured at some frequency resident in the band of biopotentials. EL-CHECK operates by injecting a 3.5uA rms constant current of 25Hz through the electrodes undergoing impedance check. The complete series impedance loop,

including both electrodes/skin junction and coupling body impedance, is reported. Ideally, the reading should be 10,000 ohms or less (approximately 5000 ohms per electrode). In practice, BIOPAC biopotential amplifiers are very tolerant of electrode/skin impedances, even higher than 50,000 ohms. However, the highest quality recordings will always be accompanied by electrode/skin impedance junctions of 10,000 ohms or less.

Wet, Dry and Capacitively-coupled Surface Electrodes

Wet electrodes incorporate an electrolyte layer between the subject's skin and the conductive electrode substrate (typically Ag/AgCl). These types of electrodes provide the lowest noise and highest signal transmission bandwidth. These electrodes are also optimal for measuring bioelectric potentials with very low frequency because they establish a direct current path to the signal source. Dry electrodes do not employ any electrolyte between conductive electrode and skin surfaces, other than skin sweat. Dry electrodes, if touching the skin directly, may provide both galvanic (direct-coupled) and capacitive (displacement current-coupled) electrical current pathways between the skin surface and electrode. A dry electrode that provides no direct-coupled current path, is considered capacitively-coupled only. A conductive material coated with an electrically insulating layer could be employed as a dry electrode, with no direct-coupled current path, and could function as a capacitively-coupled electrode even when placed directly on the skin surface. Capacitively-coupled electrodes can sense biopotentials some distance from the recording site. These electrodes operate via displacement currents only and so they have increasing inability to transfer signals of decreasing frequency. Because dry electrodes do not incorporate an electrolyte layer, they are easier to apply than wet electrodes.

Motion Artifact

Motion artifact includes the range of signals can can be produced during any motion, which act to mask signals of interest. Motion artifact has many sources, the following list indicates some commonly encountered artifacts:

1. Electrode-Electrolyte-Skin Surface Junctions

The multiple junctions in the electrode-electrolyte-skin interface all cause potentials. These potentials are sensitive to motion artifact. When an electrode is pushed against the skin, the potential changes can easily approach 1mV in magnitude. With electrode side to side motion against the skin, potentials of around 500uV are easily obtained. In addition, the electrode-electrolyte junction can produces artifacts when mechanically disturbed. An Ag/AgCl electrode will produce up to a 1.5mV signal when moved in an electrolyte. This potential can be reduced by eliminating motion of the electrolyte with respect to the Ag/AgCl electrode by placing the electrolyte /electrode junction at one end of a small cavity. An inert mesh is used to hold the gel still in this small cavity, next to the electrode.

2. Skin Potential Changes Related to Stretching

The top surface layer of the skin is slightly more negative (approximately 5mV) then the underlying layers. This potential is thought to be a junction potential between the electrolyte and underlying layers if the skin. Stretching the skin causes a reduction in the magnitude of this potential. If a surface electrode is placed on top of skin subject to stretching, the electrode will transmit this change of voltage. By slightly abrading the skin surface, this skin potential can be substantially reduced.

3. Triboelectric Effect

The triboelectric effect is the generation of an electrical charge as a consequence of friction between certain types of materials. Static electricity largely results from the triboelectric effect. In the context of motion artifact, triboelectric noise is the internal noise generated by the flexing or vibrating of a cable, which may be carrying a very small signal prior to being amplified. Cable movements can result in friction between the cable's various conductors and insulators. In turn, this friction can generate triboelectric noise. This friction-induced electrical noise can easily surpass the magnitude of the signal of interest.

To reduce triboelectric noise in cabling systems, special low noise cable can be used. This cable will minimize the possibility of friction between the cable layers, employ materials that generate low triboelectric noise when in contact and incorporate conductive layers to drain away any triboelectric developed charges.

4. Faraday's law, Hall effect and Lenz's law

Faraday's law:

Any change in the magnetic field environment of an electrical circuit will cause a electromotive force (voltage) to be generated in the circuit.

E (volts) = B (tesla) xL (meters) xV (meters/sec)

Hall effect:

When moving charges (current) travel in a conductor, perpendicular to a magnetic field, a voltage differential (Hall voltage) will develop across (transverse) to the current in the conductor.

Lenz's law:

The induced emf in an electrical circuit, because of a change in a magnetic field, generates a current to oppose the change in the magnetic field. Accordingly, that current will result in a mechanical force opposing the motion of the magnetic field relative to the circuit.

In particular, in the context of motion artifact, any conductive circuit moving in a magnetic field will generate a voltage. The Earth's magnetic field is approximately 50 uTesla. A 1 meter long conductor moving through this field at 1 meter/sec, in the orientation to maximally cut the lines of force, will result in a generated emf of 50 uV between the ends of the conductor.

5. Displacement Current Shifts

When a varying voltage difference is applied to two isolated conductors, a displacement current flows between the conductors. This principle is manifested clearly in the operation of a capacitor or transmission line. Given motion between conductors, displacement current magnitudes will change as the distance between conductors changes. The distance between conductors is inversely proportional to the effective capacitance between conductors.

In a typical laboratory environment, an isolated subject's charge will be subject to the displacement current magnitudes and associated paths in the environment. Primarily, the

displacement current magnitudes will be driven by local, high-level, varying voltage sources in the environment. Typically, the largest source is be the mains power network supplying electricity. Voltages would range from 120 VAC to 240 VAC and alternating frequencies from 50 Hz to 60 Hz.

As a subject moves around the environment, which such described alternating voltage (emf), this emf will induce an alternating charge on the subject. The alternating charge on the subject will vary in magnitude depending upon the flow of displacement currents surrounding the subject. As the subject moves closer to the source emf, all else being held the same, the charge on the subject will rise closer to the level of the source emf.

6. Magnetohydrodynamics

Magnetohydrodynamics is the branch of physics that is concerned with the behavior of electrically conductive fluids in magnetic fields. Observed behavior is largely subject to Faraday's law and Lenz's law. Magnetohydrodynamic (MHD) phenomena is very pronounced, and easily observed, when performing ECG measurements on a subject during magnetic resonance imaging procedures.

The influence of a static magnetic field on the blood flow inside the human vessel system leads to the MHD effect. This effect results in an additional voltage signal (Hall effect) that superimposes with the ECG signal. This superposition makes it impossible to perform a conventional diagnostic analysis of the ECG signal unless specific math is applied to the signal to compensate for the MHD effect.

The blood flow in the aorta is highest during systole, which corresponds to the ST segment in the ECG. Because of the Hall effect, the maximum MHD effect will result during the ST

segment, thus elevating the T wave. In addition, absolute blood flow (stroke volume) will reduce in the presence of a magnetic field as per Lenz's law.

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

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 senses 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 amplifies 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.

Problems encountered in measuring a living system:

1. Inaccessibility 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 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.

UNIT II ELECTRODE CONFIGURATIONS

Bio signals characteristics – frequency and amplitude ranges.

ECG – Einthoven's triangle, standard 12 lead system.

EEG – 10-20 electrode system, unipolar, bipolar and average mode,

EMG– unipolar and bipolar mode

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

The electrocardiogram (ECG) is an 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.

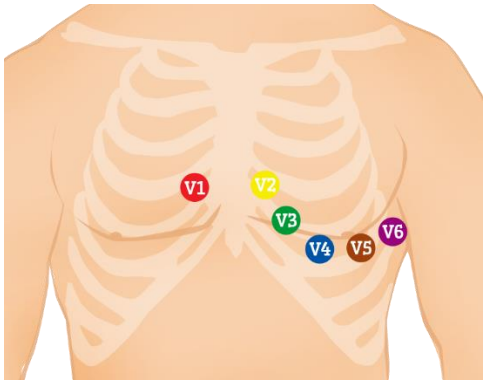
Electrocardiography (ECG or EKG) is the recording of the electrical activity of the heart over time via skin electrodes. It is a non-invasive recording produced by an electrocardiographic device. The etymology of the word is derived from electro, because it is related to electrical activity, cardio, 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.

A 12-lead ECG paints a complete picture of the heart's electrical activity by recording information through 12 different perspectives. Think of it as 12 different points of view of an object woven together to create a cohesive story - the ECG interpretation. These 12 views are collected by placing electrodes or small, sticky patches on the chest (precordial), wrists, and ankles. These electrodes are connected to a machine that registers the heart's electrical activity. The main purpose of the 12-lead ECG is to screen patients for possible cardiac ischemia. It helps EMS and hospital staff to quickly identify patients who have STEMI (ST elevation myocardial infarction or in other words, heart attack) and perform appropriate medical intervention based on initial readings.

To measure the heart's electrical activity accurately, proper electrode placement is crucial. In a 12-lead ECG, there are 12 leads calculated using 10 electrodes.

Chest (Precordial) Electrodes and Placement



V1 - Fourth intercostal space on the right sternum

V2 - Fourth intercostal space at the left sternum

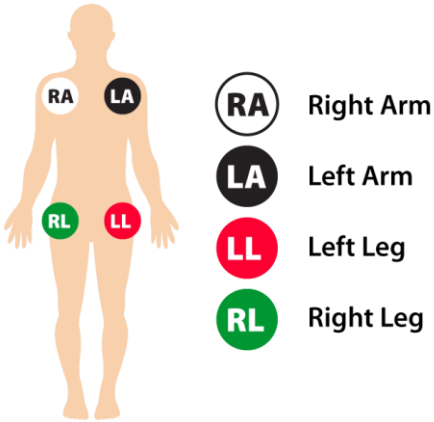
V3 - Midway between placement of V2 and V4

V4 - Fifth intercostal space at the midclavicular line

V5 - Anterior axillary line on the same horizontal level as V4

V6 - Mid-axillary line on the same horizontal level as V4 and V5

Limb (Extremity) Electrodes and Placement



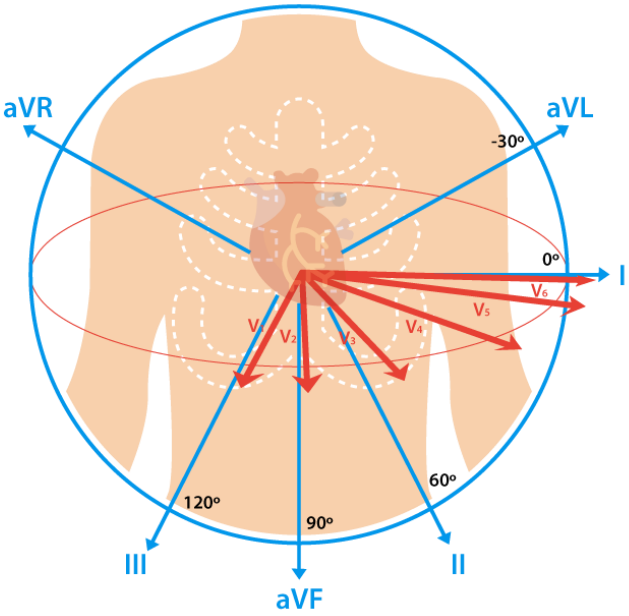
RA (Right Arm) - Anywhere between the right shoulder and right elbow

RL (Right Leg) - Anywhere below the right torso and above the right ankle

LA (Left Arm) - Anywhere between the left shoulder and the left elbow

LL (Left Leg) - Anywhere below the left torso and above the left ankle

12 LEAD SYSTEM



A lead is a glimpse of the electrical activity of the heart from a particular angle. Put simply, a lead is like a perspective. In 12-lead ECG, there are 10 electrodes providing 12 perspectives of the heart's activity using different angles through two electrical planes - vertical and horizontal planes.

Vertical plane (Frontal Leads):

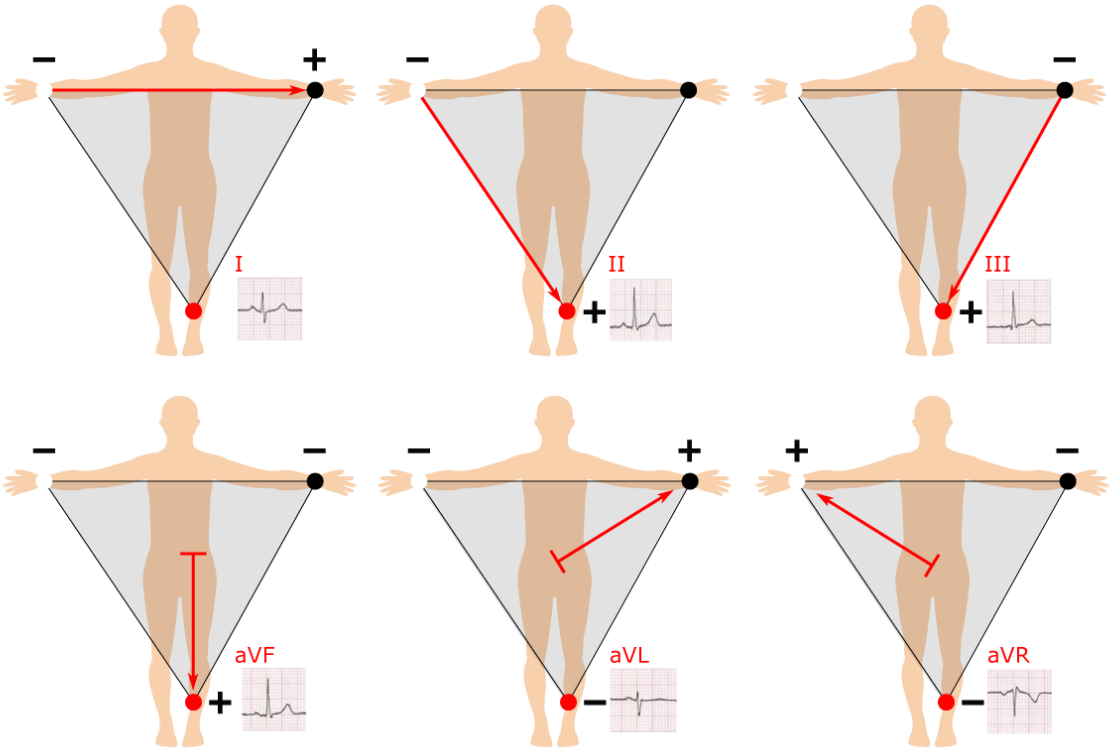
By using 4 limb electrodes, you get 6 frontal leads that provide information about the heart's vertical plane:

- Lead I

- Lead II
- Lead III
- Augmented Vector Right (aVR)
- Augmented Vector Left (aVL)
- Augmented vector foot (aVF)

Leads I, II, and III require a negative and positive electrode (bipolarity) for monitoring. On the other hand, the augmented leads-aVR, aVL, and aVF-are unipolar and requires only a positive electrode for monitoring.

Einthoven's Triangle



The Einthoven's triangle explains why there are 6 frontal leads when there are just 4 limb electrodes.

The principle behind Einthoven's triangle describes how electrodes RA, LA and LL do not only record the electrical activity of the heart in relation to themselves through the aVR, aVL and aVF leads. They also correspond with each other to form leads I (RA to LA), II (RA to LL) and III (LL to LA).

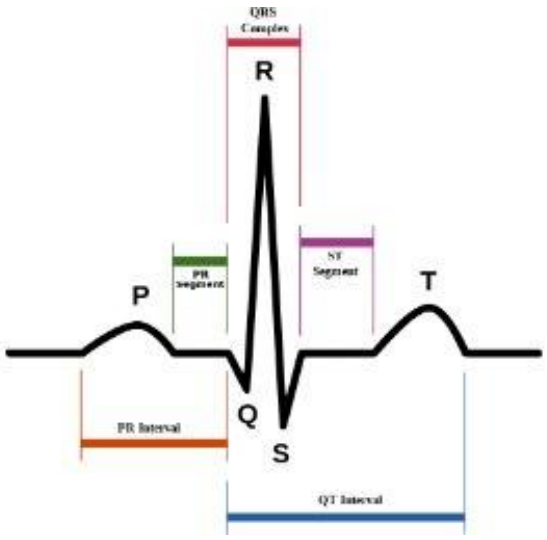
As a result, they form an equilateral triangle. Hence, it's called the Einthoven's triangle, named after Willem Einthoven who invented the first practical ECG.

Keep in mind that RL is neutral (also known as point zero where the electrical current is measured). RL doesn't come up in ECG readings, and is considered as a grounding lead that helps minimize ECG artifact.

Horizontal Plane (Transverse Leads)

By using 6 chest electrodes, you get 6 transverse leads that provide information about the heart's horizontal plane: V1, V2, V3, V4, V5, and V6. Like the augmented leads, the transverse leads are unipolar and requires only a positive electrode. The negative pole of all 6 leads is found at the center of the heart. This is calculated with the ECG.

ECG Interpretation



1. P waves

The P wave represents the depolarization of the atria, the two upper chambers of the heart, which receive blood from the vena cava and pulmonary veins.

2. Measure the PR interval

The PR interval is the time interval between the P wave (atrial depolarization) to the beginning of the QRS segment (ventricular depolarization). The normal PR interval is 0.12-0.20 seconds, or 3-5 small boxes on the ECG graph paper. A prolonged PR interval suggests a delay in getting through the atrioventricular (AV) node, the electrical relay system between the upper and lower chambers of the heart.

3. Measure the QRS segment

The normal QRS segment has three graphical deflections — the first negative wave (Q wave); the positive wave above the isoelectic line (R wave) and the negative wave after the positive wave (S wave) — and the normal time duration is 0.04-0.10 seconds. If you notice a prolonged QRS segment, it might be due to a bundle branch block which could be relatively benign or a sign of underlying heart disease.

4. Observe the T wave

The T wave represents repolarization (recovery) of the ventricles and should be upright in Lead II and appear after the QRS segment. Any variations in the T waves are important to note. Inverted T waves could be due to a lack of oxygen to the heart; too much potassium (hyperkalemia) could cause peaked T waves; flat T waves may be due to too little potassium and a raised ST segment — the end of the QRS segment to the beginning of the T wave — might be due to a heart attack.

5. Note any ectopic beats

An ectopic beat is a change in a heart rhythm caused by beats arising from fibers outside the SA node, the normal impulse-generating system of the heart. If you notice ectopic beats, determine if they are premature atrial contractions (PACs); premature junctional contractions (PJCs) or premature ventricular contractions (PVCs). Also, note how many ectopic beats are present in the ECG, the interval at which they are appearing, their shape, and if they arise singularly or in groups.

6. Determine the origin

The last step before correctly indentify your ECG is to determine where the rhythm is originating. Here are some key elements to look for:

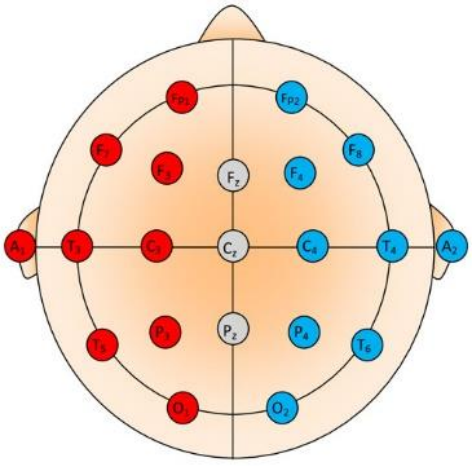
- Sinus: 60-100 bpm; regular rhythm; P waves upright, round and present before each QRS segment; normal PR interval; normal QRS duration.
- Atrial: Rhythm may be regular or irregular; normal QRS segment, but P waves premature and different shapes — flattened notched, peaked, inverted or hidden.
- Junctional: Look for a junctional type P wave — inverted before, during or after the QRS segment that is normal in duration.
- Ventricular: Wide and bizarre QRS segment and no P waves since the impulse is originating below the SA node.
- Paced rhythm: Observe low voltage pacer spikes before the QRS.

7. Correctly identify the rhythm

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 neighbouring points.



Small metal discs called electrodes are placed on the scalp in special positions. These positions are identified by the recordist who measures the head using the International 10/20

System. This relies on taking measurements between certain fixed points on the head. The electrodes are then placed at points that are 10% and 20% of these distances.

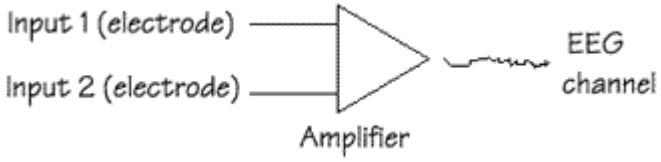
Each electrode site is labelled with a letter and a number. The letter refers to the area of brain underlying the electrode.

- F - Frontal lobe
- T - Temporal lobe
- C - Central lobe
- P - Parietal lobe
- O - Occipital lobe
- Even numbers denote the right side of the head
- Odd numbers denote the left side of the head.

There are a great variety of electrodes that can be used. The majority are small discs of stainless steel, tin, gold or silver covered with a silver chloride coating. These normally have a lead attached. Alternative methods consist of a cap in which the electrodes are already imbedded.

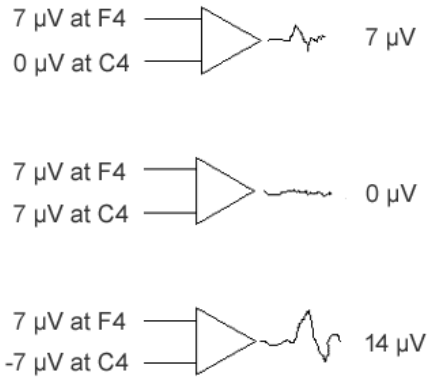
Montages

EEG machines use a differential amplifier to produce each channel or trace of activity. Each amplifier has two inputs. An electrode is connected to each of the inputs.



Differential amplifier

Differential amplifiers measure the voltage difference between the two signals at each of its inputs. The resulting signal is amplified and then displayed as a channel of EEG activity.

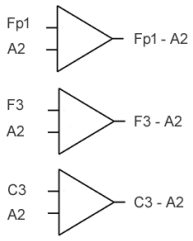


The manner in which pairs of electrodes are connected to each amplifier of the EEG machine is called a montage.

Each montage will use one of three standard recording derivations, average reference and common reference.

Common reference derivation

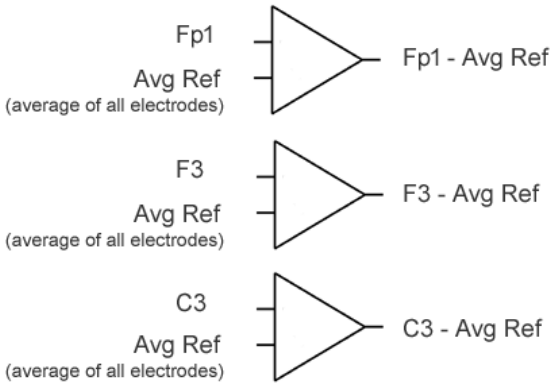
Each amplifier records the difference between a scalp electrode and a reference electrode. The same reference electrode is used for all channels. Electrodes frequently used as the reference electrode are A1, A2, the ear electrodes, or A1 and A2 linked together.



Common reference derivation

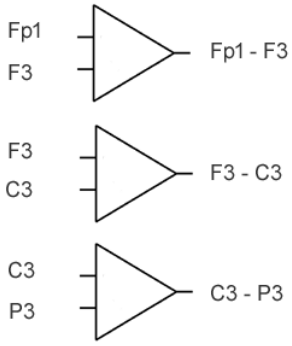
Average reference derivation

Activity from all the electrodes is measured, summed together and averaged before being passed through a high value resistor. The resulting signal is then used as a reference electrode and connected to input 2 of each amplifier and is essentially inactive. All EEG systems will allow the user to choose which electrodes are to be included in this calculation.



Bipolar derivation

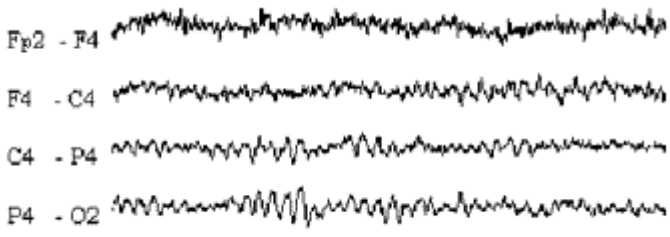
These sequentially link electrodes together usually in straight lines from the front to the back of the head or transversely across the head. For example, the first amplifier may have electrodes FP1 and F3 connected to it and the second amplifier F3 and C3 connected to it.



EEG Activity

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).

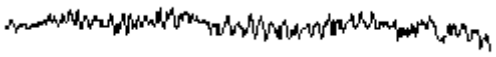


EEG TRACES

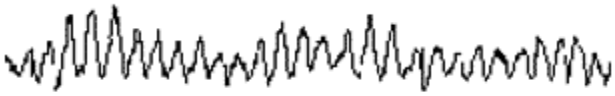
EEG activity can be broken down into 4 distinct frequency bands:

- Beta activity > 13 Hz
- Alpha activity 8 Hz-13 Hz
- Theta activity 4 Hz-7 Hz
- Delta activity < 4 Hz

Beta activity is a normal activity present when the eyes are open or closed. It tends to be seen in the channels recorded from the centre or front of the head. Some drugs will increase the amount of beta activity in the EEG.



Alpha activity is also a normal activity when present in waking adults. It is mainly seen in the channels recorded from the back of the head. It is fairly symmetrical and has an amplitude of 40 µV to 100 µV. It is only seen when the eyes are closed and should disappear or reduce in amplitude when the eyes are open.



Theta activity can be classed as both a normal and abnormal activity depending on the age and state of the patient. In adults it is normal if the patient is drowsy. However, it can also indicate brain dysfunction if it is seen in a patient who is alert and awake. In younger patients, theta activity may be the main activity seen in channels recorded from the back and central areas of the head.

Delta activity is only normal in an adult patient if they are in a moderate to deep sleep. If it is seen at any other time, it would indicate brain dysfunction. Abnormal activity may be seen in all or some channels depending on the underlying brain problem.

There are a number of other waveforms which tend to be a little more specific to certain conditions. For example, **spike and wave activity** indicates a seizure disorder and may be seen in the EEG even if the patient is not having an epileptic seizure. Other epileptic conditions may be diagnosed if spikes or sharp waves are seen.

EMG Introduction

Small electrical currents are generated by muscle fibres prior to the production of muscle force. These currents are generated by the exchange of ions across muscle fibre membranes, a part of the signalling process for the muscle fibres to contract. The signal called the electromyogram

(EMG) can be measured by applying conductive elements or electrodes to the skin surface, or invasively within the muscle.

Surface EMG is the more common method of measurement, since it is non-invasive and can be conducted by personnel other than Medical Doctors, with minimal risk to the subject. Measurement of surface EMG is dependent on a number of factors and the amplitude of the surface EMG signal (sEMG) varies from the uV to the low mV range (Basmajian & DeLuca, 1985). The amplitude and time and frequency domain properties of the sEMG signal are dependent on factors such as (Gerdle et al., 1999): • the timing and intensity of muscle contraction • the distance of the electrode from the active muscle area • the properties of the overlying tissue (e.g. thickness of overlying skin and adipose tissue) • the electrode and amplifier properties • the quality of contact between the electrode and the skin

In most cases, information on the time and intensity of muscle contraction is desired. The remainder of the factors only exacerbates the variability in the EMG records, making interpretation of results more difficult. Nevertheless, there are methods to reduce the impact that non- muscular factors have on the properties of the EMG signal.

For example, much of this variability in the sEMG signal can be minimized through:

• using the same electrodes and amplifier (i.e. same signal conditioning parameters)

• ensuring consistency in the quality of contact between the electrodes and the skin.

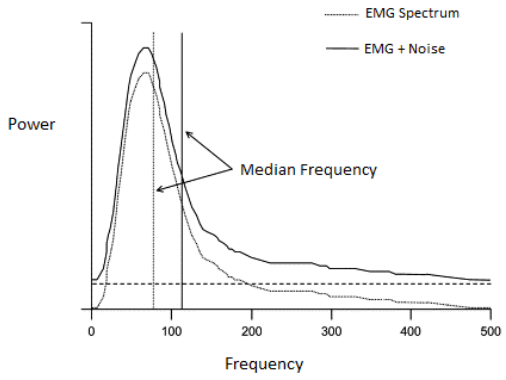
Types of Electrodes

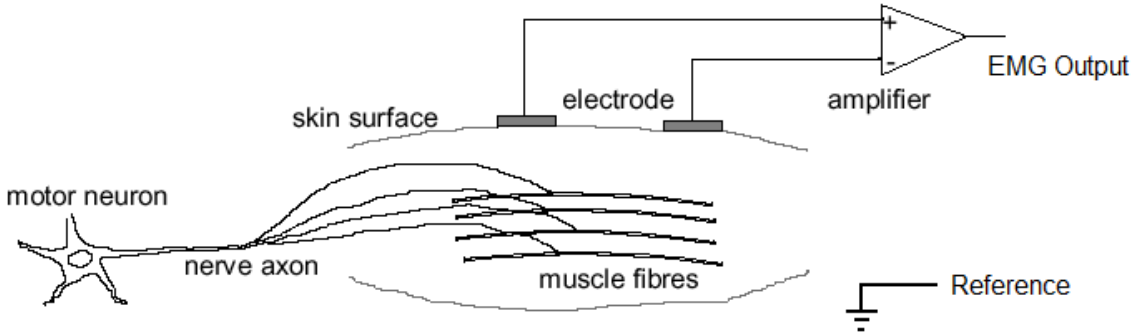
Two types of surface electrodes are commonly in use:

• Dry electrodes in direct contact with the skin

• Gelled electrodes using an electrolytic gel as a chemical interface between the skin and the metallic part of the electrode.

Before we move on to the signal acquisition phase, it is very important to get acquainted with the EMG signal and the various concerns and factors affecting the qualitative properties of the signal. The EMG signal's amplitude lies in between 1-10 mV, making it a considerably weak signal. The signal lies in the frequency range from 0-500 Hz and most dominant in between 50-150 Hz.





Bipolar configuration is used to acquire EMG signal using two EMG detecting surfaces with the help of a reference electrode. The signals from the two EMG surfaces are connected to a differential amplifier. The two detecting surfaces are placed only 1-2 cm from each other. The differential amplifier suppresses the common noise signals to both inputs and then amplifies

the difference. The limitations of the monopolar configuration are catered for by this configuration. This is the most commonly used electrode configuration. The bipolar EMG electrode configuration is shown is in above Figure.

UNIT III BIO AMPLIFIER

Need for bio-amplifier

single ended bio-amplifier

differential bio-amplifier – right leg driven ECG amplifier.

Band pass filtering

isolation amplifiers – transformer and optical isolation - isolated DC amplifier and AC carrier amplifier.

Chopper amplifier, Power line interference

Bio signals are recorded as potentials, voltages, and electrical field strengths generated by nerves and muscles. The measurements involve voltages at very low levels, typically ranging between 1 μV and 100 mV, with high source impedances and superimposed high level interference signals and noise. The signals need to be amplified to make them compatible with devices such as displays, recorders, or A/D converters for computerized equipment. Amplifiers adequate to measure these signals have to satisfy very specific requirements. They have to provide amplification selective to the physiological signal, reject superimposed noise and interference signals, and guarantee protection from damages through voltage and current surges for both patient and electronic equipment. Amplifiers featuring these specifications are known as biopotential amplifiers.

The basic requirements that a biopotential amplifier has to satisfy are:

• the physiological process to be monitored should not be influenced in any way by the amplifier

• the measured signal should not be distorted • the amplifier should provide the best possible separation of signal and interferences

• the amplifier has to offer protection of the patient from any hazard of electrical shock

• the amplifier itself has to be protected against damages that might result from high input voltages as they occur during the application of defibrillators or electrosurgical instrumentation.

A typical configuration for the measurement of biopotentials is shown. Three electrodes, two of them picking up the biological signal and the third providing the reference potential, connect the subject to the amplifier.

The input signal to the amplifier consists of five components:

(1) the desired biopotential,

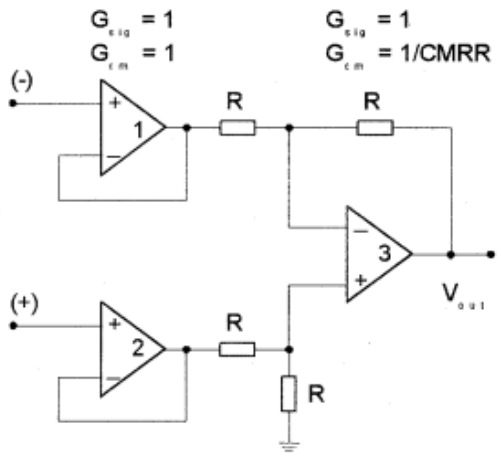
(2) undesired biopotentials,

(3) a power line interference signal of 60 Hz (50 Hz in some countries) and its harmonics,

(4) interference signals generated by the tissue/electrode interface, and

(5) noise.

Proper design of the amplifier provides rejection of a large portion of the signal interferences. The main task of the differential amplifier is to reject the line frequency interference that is electrostatically or magnetically coupled into the subject. The desired biopotential appears as a voltage between the two input terminals of the differential amplifier and is referred to as the differential signal. The line frequency interference signal shows only very small differences in amplitude and phase between the two measuring electrodes, causing approximately the same potential at both inputs, and thus appears only between the inputs and ground and is called the common mode signal. Strong rejection of the common mode signal is one of the most important characteristics of a good biopotential amplifier.



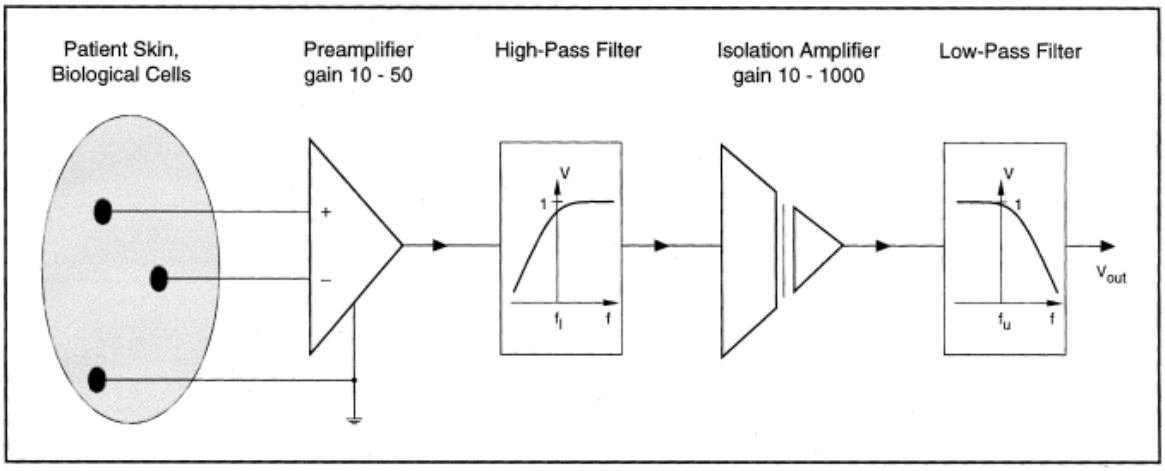
Typical configuration for the measurement of biopotentials.

The common mode rejection ratio (or CMRR) of an amplifier is defined as the ratio of the differential mode gain over the common mode gain. As shown in the figure., the rejection of the common mode signal in a biopotential amplifier is both a function of the amplifier CMRR and the source impedances Z_1 and Z_2. For the ideal biopotential amplifier with $Z_1 = Z_2$ and infinite CMRR of the differential amplifier, the output voltage is the pure biological signal amplified by G_D, the differential mode gain: $V_{out} = G_D \cdot V_{biol}$. With finite CMRR, the common mode signal is not completely rejected, adding the interference term $G_D \cdot V_c$ /CMRR to the output signal. Even in the case of an ideal differential amplifier with infinite CMRR, the common mode signal will not completely disappear unless the source impedances are equal. The common mode signal V_c causes currents to flow through Z_1 and Z_2. The related voltage drops show a difference if the source impedances are unequal, thus generating a differential signal at the amplifier input which, of course, is not rejected by the differential amplifier. With amplifier gain G_D and input impedance Z_{in}, the output voltage of the amplifier is:

$$V_{out} = G_D V_{biol} + \frac{G_D V_c}{CMRR} + G_D V_c \left(1 - \frac{Z_{in}}{Z_{in} + Z_1 - Z_2} \right)$$

The output of a real biopotential amplifier will always consist of the desired output component due to a differential bio signal, an undesired component due to incomplete rejection of common mode interference signals as a function of CMRR, and an undesired component due to source impedance unbalance allowing a small proportion of a common mode signal to appear as a differential signal to the amplifier. Since source impedance unbalances of 5,000 to 10,000 Ω, mainly caused by electrodes, are not uncommon, and sufficient rejection of line frequency interferences requires a minimum CMRR of 100 dB, the input impedance of the amplifier should be at least 109 Ω at 60 Hz to prevent source impedance unbalances from deteriorating

the overall CMRR of the amplifier. State-of-the-art biopotential amplifiers provide a CMRR of 120 to 140 dB.



A typical design of the various stages of a biopotential amplifier is shown. The electrodes which provide the transition between the ionic flow of currents in biological tissue and the electronic flow of current in the amplifier, represent a complex electrochemical system that is described elsewhere in this handbook. The electrodes determine to a large extent the composition of the measured signal. The preamplifier represents the most critical part of the amplifier itself since it sets the stage for the quality of the biosignal.

With proper design, the preamplifier can eliminate, or at least minimize, most of the signals interfering with the measurement of biopotentials. In addition to electrode potentials and electromagnetic interferences, noise—generated by the amplifier and the connection between biological source and amplifier—has to be taken into account when designing the preamplifier. The total source resistance Rs, including the resistance of the biological source and all transition resistances between signal source and amplifier input, causes thermal voltage noise with a root mean square (rms) value of:

$$E_{rms} = \sqrt{4kTR_s B} \quad (Volt)$$

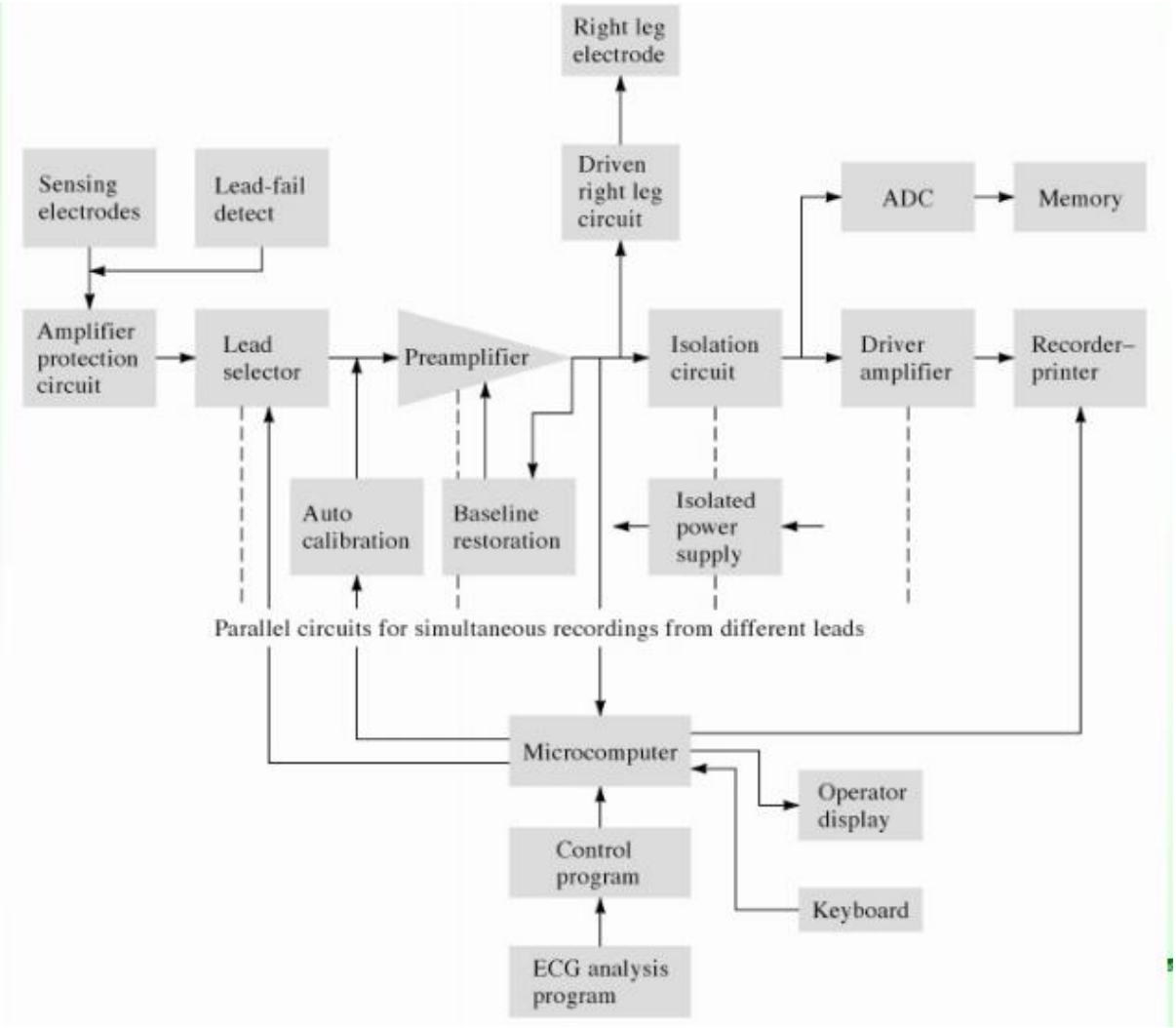
where k = Boltzmann constant,

T = absolute temperature, Rs = resistance in Ω and.,

B = bandwidth in Hz

Interferences

The most critical point in the measurement of biopotentials is the contact between electrodes and biological tissue. Both the electrode offset potential and the electrode/tissue impedance are subject to changes due to relative movements of electrode and tissue. Thus, two interference signals are generated as motion artifacts: the changes of the electrode potential and motion-induced changes of the voltage drop caused by the input current of the preamplifier. These motion artifacts can be minimized by providing high input impedances for the preamplifier, usage of non-polarized electrodes with low half-cell potentials such as Ag/AgCl electrodes, and by reducing the source impedance by use of electrode gel. Motion artifacts, interferences from external electromagnetic fields, and noise can also be generated in the wires connecting electrodes and amplifier. Reduction of these interferences is achieved by using twisted pair cables, shielded wires, and input guarding.



In clinical electrocardiography

• more than one lead must be recorded to describe the heart's electric activity fully

• several leads are taken in the frontal plane several leads are taken in the frontal plane and the transverse plane

• frontal plane: parallel to the back when lying

• transverse plane: parallel to the ground when standing

• Frontal plane lead placement - called Eindhoven’s triangle

• Additional leads Additional leads

• unipolar measurements

• potential measured at electrodes with respect to a reference; average of the 2 electrodes

• Wilson central terminal

• three limb electrodes connected through equal-valued resistors to a common node

• augmented leads

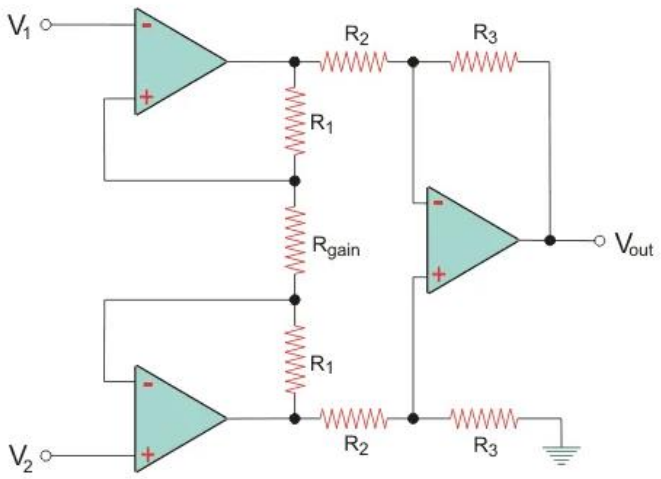
• some nodes disconnected increase the amplitude of measurement using amplifiers.

Types of Bio Amplifiers

1. Differential Amplifier
2. Operational Amplifier
3. Instrumentation Amplifier
4. Chopper Amplifier
5. Isolation Amplifier

Instrumentation Amplifier

In biomedical applications, high gain and the high input impedance are attained with an instrumentation amplifier. Usually, a 3-amplifier setup forms the instrumentation amplifier circuit. The output from the transducer is given as input to the instrumentation amplifier. Before the signal goes to the next stage, a special amplifier is required with high CMRR, high input impedance and to avoid loading effects. Such a special amplifier is an instrumentation amplifier, which does all the required process.



To each input of the differential amplifier, the non-inverting amplifier is connected. From the figure, the amplifier on the left side acts as non-inverting amplifiers.

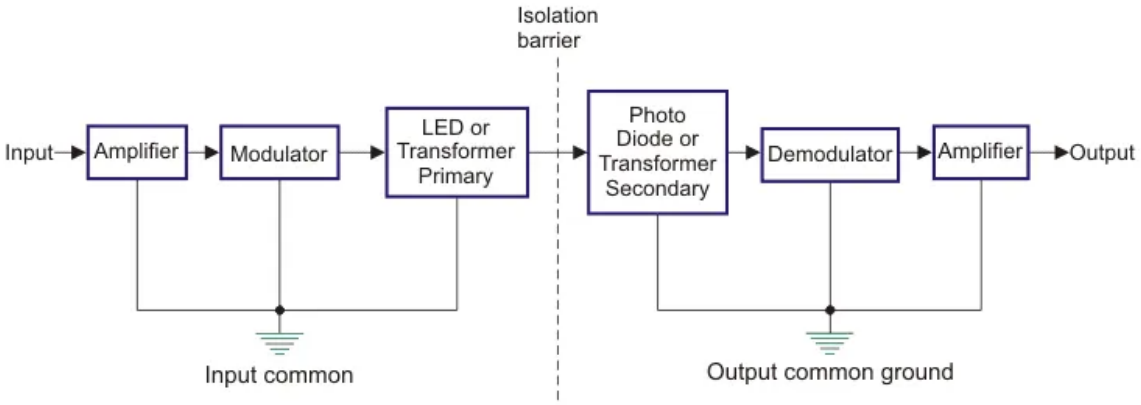
They are combined together to form the input stage of the instrumentation amplifier. The third op-amp is the difference amplifier, and it is the output of the instrumentation amplifier.

The output from the difference amplifier V_{out} is the difference between two input signals given at the input points. V_{O1} is the output from op-amp 1 and V_{O2} is the output from op-amp 2.

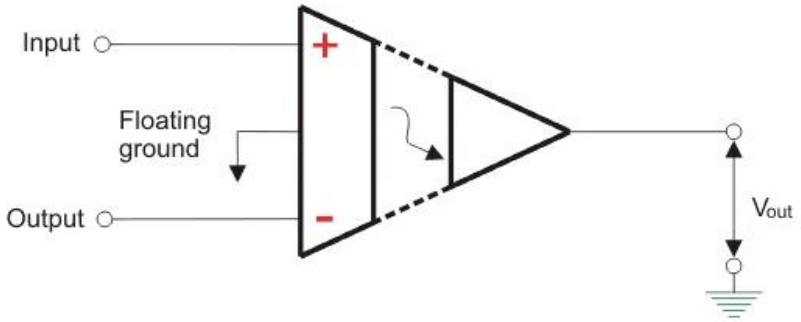
$$V_{out} = \frac{R_3}{R_2}(V_{O1} - V_{O2})$$

Isolation Amplifier

Isolation amplifiers are known as Pre-amplifier isolation circuits. An isolation amplifier increases the input impedance of a patient monitoring system. It also helps to isolate the patient from the device. Using the isolation amplifier prevents accidental internal cardiac shock. It provides up to 1012 Ω insulation between the patient and the power line in the hospital.



Block Diagram of Isolation Amplifier



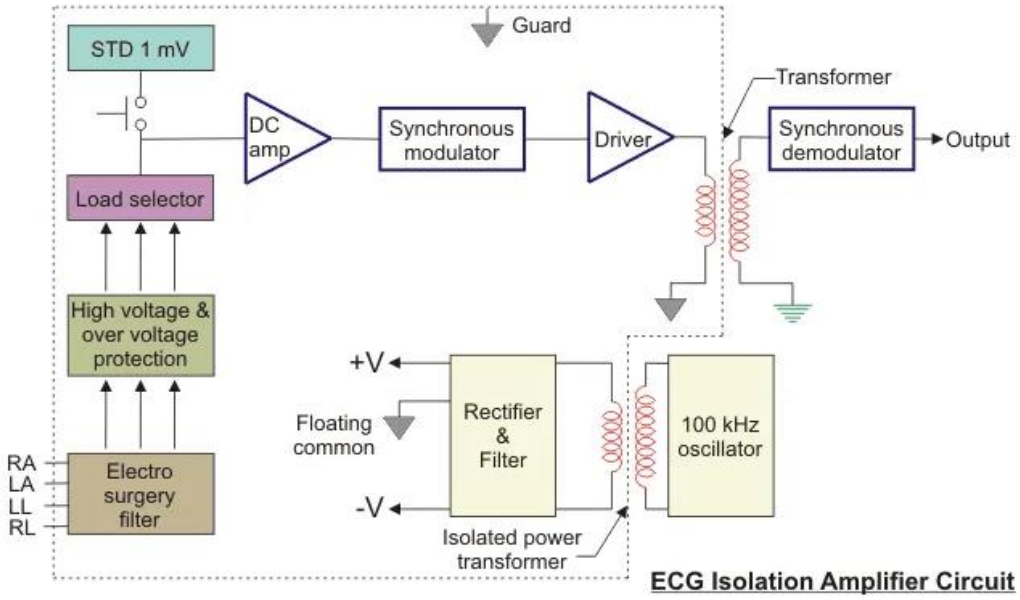
Symbol of Isolation Amplifier

The electrical signals are obtained with electrodes. The signals received goes to the amplifier block, where signals amplification occurs. After amplification, the signal enters the modulation block. When either it goes to the isolation barrier, optical cable or transformer can be used. If in case of optical cable, modulator output travels to LED. The LED converts electrical signals into light energy. If the transformer acts an isolation barrier, modulator output connects the primary winding of the transformer. Energy from primary transfers to the secondary winding

based on the mutual induction principle. At the next stage, secondary output enters the demodulation block. Finally, the amplified demodulated signal is obtained.

ECG Isolation Amplifier

During ECG measurement, signals generated from all leads are sent to the low pass filter. This filter is named as Electro surgery filters because it decreases the interference between electrosurgery and radio frequency. Next block is the high voltage and overvoltage protection that can withstand large voltage during defibrillation. Proceeding further, it goes to Lead Selector Switch block, which selects the required configuration.



ECG Isolation Amplifier Circuit

Lead selection output goes to the DC amplifier. We have a transformer, whose primary winding is connected to the oscillator and secondary to rectifier and filter. ECG signal is modulated with the Synchronous modulator. The second transformer delivers the output from the synchronous modulator to the synchronous demodulator. The output from the demodulator is fed as input to the power amplifier.

UNIT IV MEASUREMENT OF NON-ELECTRICAL PARAMETERS

Temperature, respiration rate and pulse rate measurements.

Blood Pressure: indirect methods - auscultatory method, oscillometric method,

direct methods: electronic manometer, Pressure amplifiers - systolic, diastolic, mean detector circuit.

Blood flow and cardiac output measurement: Indicator dilution, thermal dilution and dye dilution method, Electromagnetic and ultrasound blood flow measurement.

Vital signs are measurements of the body's most basic functions. The four main vital signs routinely monitored by medical professionals and health care providers include the following:

- Body temperature
- Pulse rate
- Respiration rate (rate of breathing)
- Blood pressure (Blood pressure is not considered a vital sign, but is often measured along with the vital signs.)

Vital signs are useful in detecting or monitoring medical problems.

Body temperature

The normal body temperature of a person varies depending on gender, recent activity, food and fluid consumption, time of day.

Normal body temperature can range from 97.8 degrees F (or Fahrenheit, equivalent to 36.5 degrees C, or Celsius) to 99 degrees F (37.2 degrees C) for a healthy adult.

A person's body temperature can be taken in any of the following ways:

- **Orally.** Temperature can be taken by mouth using either the classic glass thermometer, or the more modern digital thermometers that use an electronic probe to measure body temperature.
- **Rectally.** Temperatures taken rectally (using a glass or digital thermometer) tend to be 0.5 to 0.7 degrees F higher than when taken by mouth.
- **Axillary.** Temperatures can be taken under the arm using a glass or digital thermometer. Temperatures taken by this route tend to be 0.3 to 0.4 degrees F lower than those temperatures taken by mouth.

- **By ear.** A special thermometer can quickly measure the temperature of the ear drum, which reflects the body's core temperature (the temperature of the internal organs).
- **By skin.** A special thermometer can quickly measure the temperature of the skin on the forehead.

Digital Thermometer

Body temperature may be abnormal due to fever (high temperature) or hypothermia (low temperature). A fever is indicated when body temperature rises about one degree or more over the normal temperature of 98.6 degrees Fahrenheit. Hypothermia is defined as a drop in body temperature below 95 degrees Fahrenheit.

Pulse rate

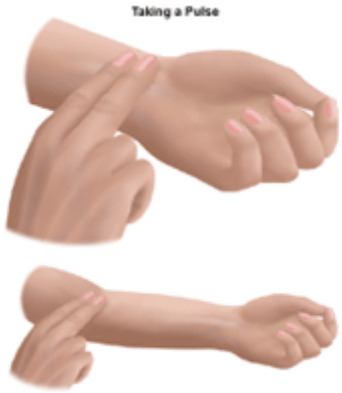
The pulse rate is a measurement of the heart rate, or the number of times the heart beats per minute. As the heart pushes blood through the arteries, the arteries expand and contract with the flow of the blood. Taking a pulse not only measures the heart rate, but also can indicate the following:

- Heart rhythm
- Strength of the pulse

The normal pulse for healthy adults ranges from 60 to 100 beats per minute. The pulse rate may fluctuate and increase with exercise, illness, injury, and emotions. Females ages 12 and older, in general, tend to have faster heart rates than do males. Athletes, such as runners, who do a lot of cardiovascular conditioning, may have heart rates near 40 beats per minute and experience no problems.

Measuring the Pulse Rate:

As the heart forces blood through the arteries, you feel the beats by firmly pressing on the arteries, which are located close to the surface of the skin at certain points of the body. The pulse can be found on the side of the neck, on the inside of the elbow, or at the wrist.



When taking your pulse:

- Using the first and second fingertips, press firmly but gently on the arteries until the pulse is felt.
- Begin counting the pulse when the clock's second hand is on the 12.
- Count the pulse for 60 seconds (or for 15 seconds and then multiply by four to calculate beats per minute).
- When counting, do not watch the clock continuously, but concentrate on the beats of the pulse.

Respiration rate

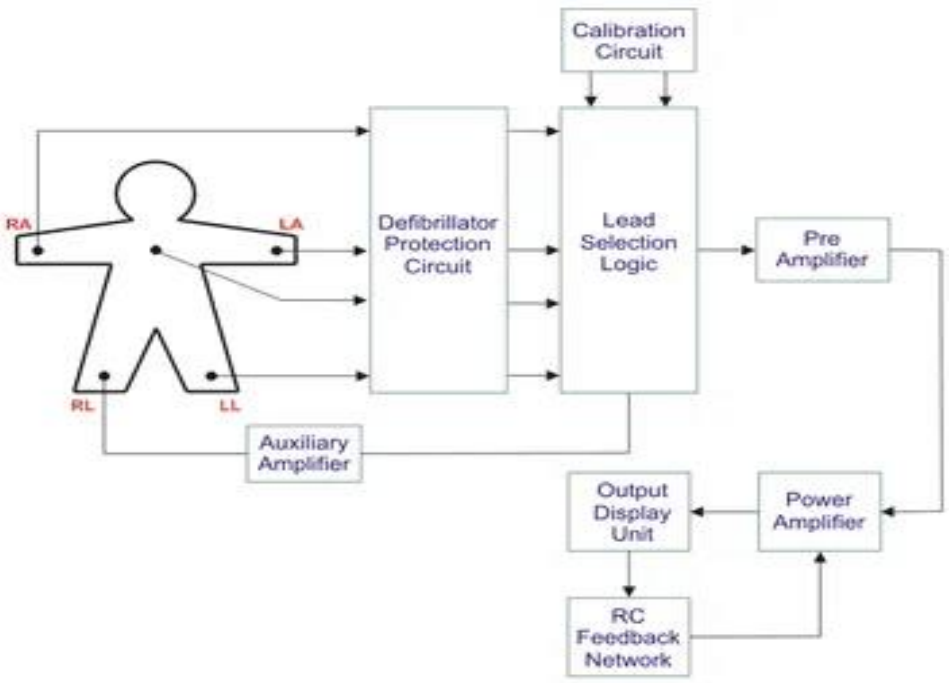
The respiration rate is the number of breaths a person takes per minute. The rate is usually measured when a person is at rest and simply involves counting the number of breaths for one minute by counting how many times the chest rises. Respiration rates may increase with fever, illness, and other medical conditions. When checking respiration, it is important to also note whether a person has any difficulty breathing. Normal respiration rates for an adult person at rest range from 12 to 16 breaths per minute.

Pulse Oximeter

Pulse oximetry is a noninvasive method for monitoring a person's oxygen saturation. Peripheral oxygen saturation (SpO_2) readings are typically within 2% accuracy (within 4% accuracy in the worst 5% of cases) of the more desirable (and invasive) reading of arterial oxygen saturation (SaO_2) from arterial blood gas analysis. But the two are correlated well enough that the safe, convenient, noninvasive, inexpensive pulse oximetry method is valuable for measuring oxygen saturation in clinical use. The Pulse oximeter also provides Pulse rate.

ECG RECORDER:

The ECG recorder is used for measuring the ECG waveforms from the Human body. The block diagram is shown below.,



The potentials picked up by the patient electrodes are taken to the lead selector switch. In the lead selector the electrodes are selected two by two by use of lead programs. By means of capacitive coupling the signals are connected symmetrically to the differential preamplifier which has high CMRR. It is ac coupled to avoid problems with small dc voltages that may originate from polarization of the electrodes. The amplified output is given to power amplifier which is of push pull type.

The output of power amplifier is fed to the pen motor, which deflects the writing arm on the paper. The input of the pen amplifier is usually accessible separately, with a special auxillary input jack at the rear or side of the ECG. Frequency selective network is usually a R-C network which provides necessary damping to the pen motor and is preset by the manufacturer.

The auxillary circuits provide a 1 mv calibration signal and automatic blocking of the amplifier during a change in position of the lead switch.

It also includes a speed control circuit for the chart drive motor.

Types of ECG recorders:

1. Single channel recorders:

2. Three channel recorders

3. Vector Electrocardiographs

4. ECG systems for stress testing

5. ECG for computer processing

6. Continuous ECG recording

Measurement of blood pressure:

Accurate Blood Pressure Measurement is the first step in treating hypertension or high blood pressure.

Primary factor in 68% of heart attacks and 75% of strokes. Hypertension is one of the major modifiable risk factors for many cardiovascular diseases. Blood Pressure- measurement of the force exerted by blood against the walls of the arteries. Maximum blood pressure is exerted on the walls of arteries when the left ventricle of the heart pushes blood through the aortic valve into the aorta at the beginning of systole. Pressure rises as the ventricle contracts and falls as the heart relaxes. This continuous contraction and relaxation of the left ventricle creates a pressure wave that is transmitted through the arterial system. Blood pressure is recorded as two numbers—the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats).

The measurement is written one above or before the other, with the systolic number on top and the diastolic number on the bottom.

Systolic pressure (numerator) – the highest pressure reached during cardiac ejection

Diastolic pressure (denominator) – the lowest pressure occurring at the end of a ventricular relaxation.

Pulse pressure – the difference between Systolic and Diastolic pressure.

Mean blood pressure: diastolic + 1/3 of pulse pressure.

Measured in millimeters of mercury (mm Hg) and recorded as a fraction. (Example 120/80 – systolic 120, diastolic 80, pulse pressure 40). Most frequently measured pressures are arterial and venous pressure.

Pressure Value of arterial system - 30 to 300 mmHg

Pressure Value of the venous system – 5-15 mmHg

Methods For Obtaining a BP:

All blood pressure measurements are made with reference to the atmospheric pressure.

1. DIRECT – Direct intra-arterial measurement with a catheter

(i)arterial (ICU, surgery)

(ii)venous (ICU)

2. INDIRECT – Compression of the brachial artery using a sphygmomanometer (blood pressure cuff) or using automatic equipment.

- Differential Auscultatory technique

- Oscillometric measurement method

- Ultrasonic doppler shift method

1.Direct Method: This method is used when high degree of accuracy, dynamic response and continuous monitoring is required. Also used to measure pressure in deep regions not

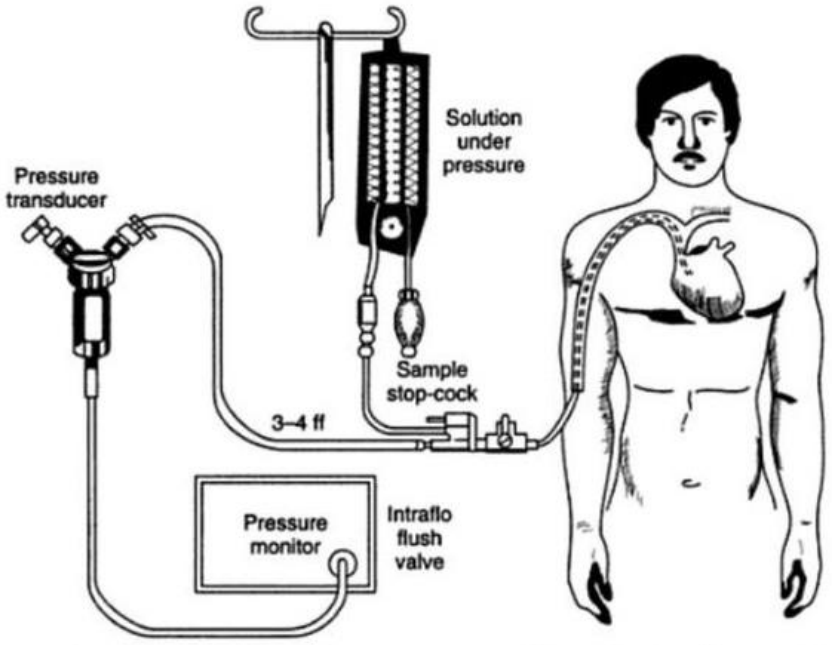
accessible by indirect method. In this method a catheter or a needle type probe is inserted through the vein or artery to area of interest.

2 types of probes:

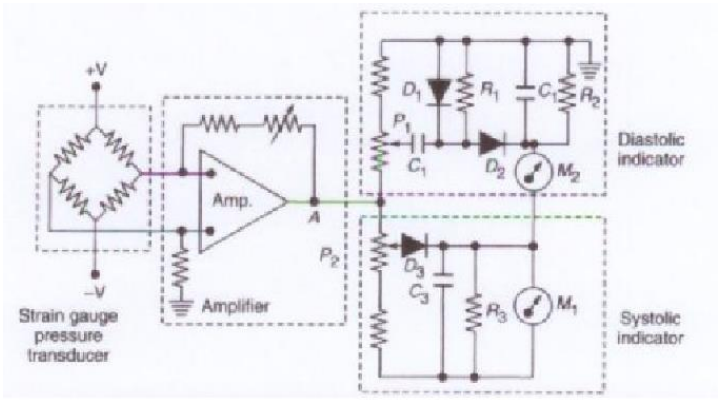
1. Extravascular pressure sensor in which catheter tip probe which has sensor at the tip and pressure exerted on it are converted to proportional electrical signals.

2. Intravascular pressure sensor in which Fluid filled catheter type which transmits the pressure exerted on the fluid to an external transducer and the transducer converts pressure to electrical signals.

This method gives details of systolic pressure, diastolic pressure and means pressures. This also gives visualization of pulse contour, stroke volume, duration of systole, ejection time and other variables. A typical set-up of a fluid filled system for measuring BP is shown below. Before insertion of the catheter, the fluid filled system should be thoroughly flushed. A steady flow of sterile saline is passed through the catheter to avoid clotting of blood. The system should be free from air bubbles as the frequency response of the system may be dampened.



Typical set up of a pressure measuring system by direct method



Circuit for Measuring Systolic and Diastolic Pressure

The block diagram represents the measurement of arterial pressure. The transducer is excited with a 5v dc excitation. The excitation for the transducer comes from an amplitude-controlled bridge oscillator through an isolating transformer. The electrical signals corresponding to the arterial pressure are amplified in a carrier amplifier. For measurement of systolic pressure, a conventional peak reading type voltmeter is used. When a positive going pressure pulse appears at A, D3 conducts and charges C3 to peak value of input signal which corresponds to systolic

value. Time constant R3C3 is chosen such that it gives steady output to the indicating meter. The value of the diastolic is derived in the following way.

A clamping circuit consisting of C1 and D1 is used to develop a voltage equal to the peak-to-peak value of the pulse pressure. This voltage appears across R1. 2 will conduct and charge C2 to the peak value of the pulse signal. The diastolic pressure is indicated by the second meter M2 which shows the peak systolic minus the peak-to-peak pressure signal. Central venous pressure (CVP) measurements made with needle cannulation technique prove extremely useful in management of acute circulatory failure and in the maintenance of blood volume in difficult fluid balance problems. Simple water manometers are still the most common measuring device in use. The transducers cannot be conveniently mounted at the catheter tip and small positional changes cause lager errors in venous pressure.

CVP is usually measured from a catheter located in the superior vena cava. CVP reflects the pressure of the right atrium and is also referred to as the right atrial pressure. Catheters used for CVP monitoring are usually 25 to 30 cm long. Regardless of the electrical or physical principles involved, direct measurement of BP is got by one of three methods.

1. Percutaneous insertion

2. Catheterization (vessel cut down)

3. Implantation of a transducer in a vessel or in the heart

For percutaneous insertion, a local anaesthetic is injected near the site of invasion. The vessel is occluded and a hollow needle is inserted at a slight angle toward the vessel. When needle is in place, a catheter is fed through the hollow needle and when catheter is in place in the vessel the needle and the guide are withdrawn.

Catheterization helps in getting BP as well as to get blood samples from the heart for oxygen content analysis and also for location of abnormal blood flow pathways.

Implantation techniques involve major surgery. This method helps in keeping the transducers in the appropriate vessel for long periods of time. The transducers used may be capacitive, inductive and resistive. The most commonly used type is the resistive type. Intra vascular sensors.

Advantages:

1. Enable the physician to obtain a high frequency response

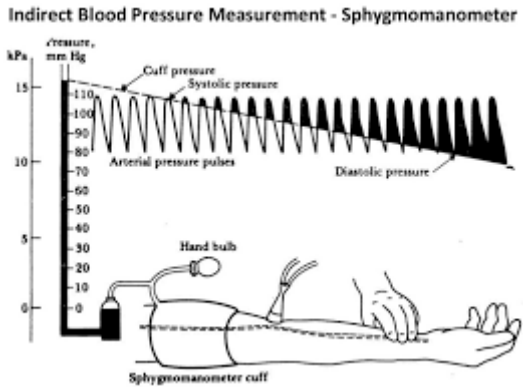
2. No time delay encountered when the pressure pulse is transmitted in a catheter–sensor system

Disadvantages:

1. more expensive

2. may break after only a few uses

2. Indirect BP measurement:



1.KOROTOKOFF SOUNDS METHOD

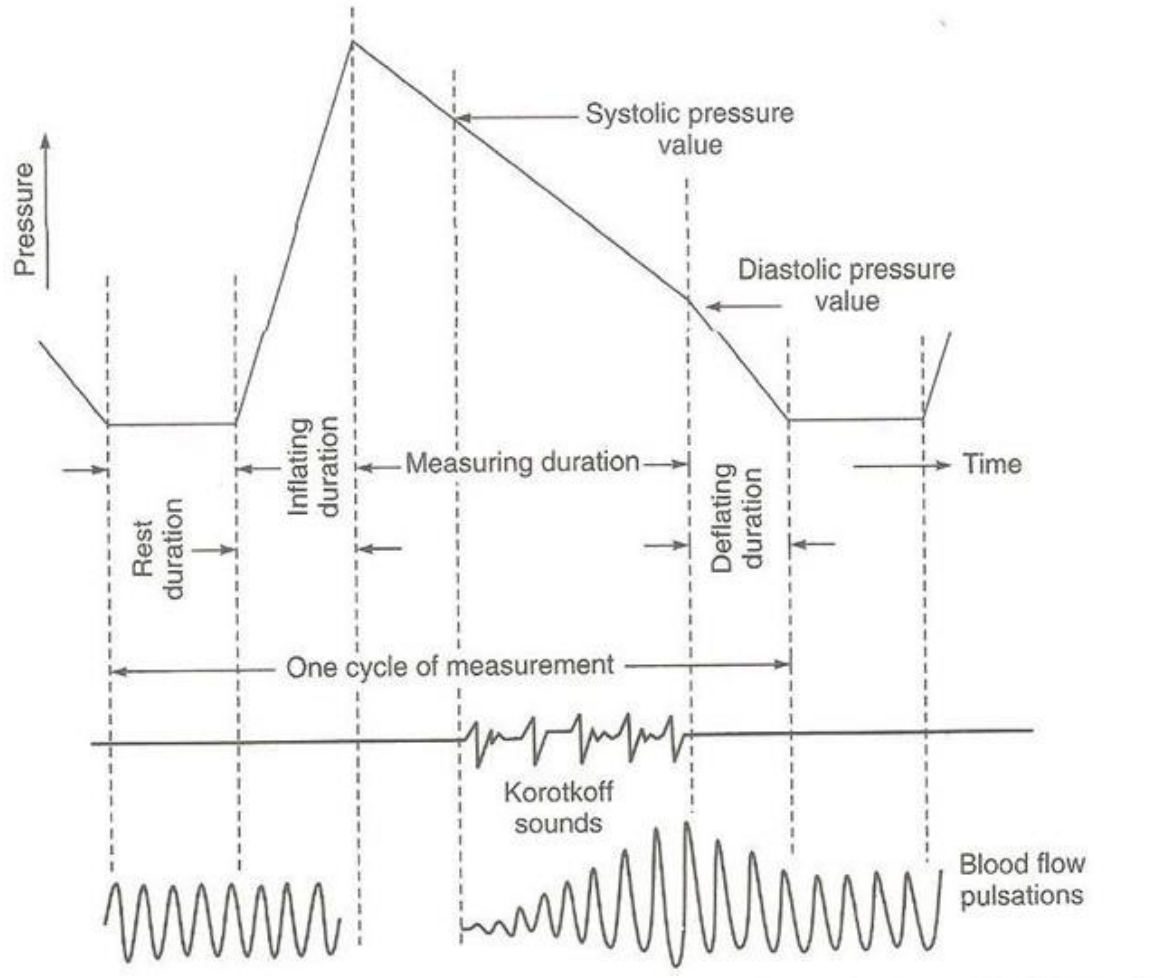
2. AUSCULTATORY METHOD

3. OSCILLOMETRIC METHOD

4. RHEOGRAPHIC METHOD

1. KOROTOKOFF SOUNDS METHOD:

Korotkoff are the sounds that medical personnel listen for when they are taking blood pressure using a non-invasive procedure. If the pressure is dropped to a level equal to that of the patient's systolic blood pressure, the first Korotkoff sound will be heard. As the pressure in the cuff is the same as the pressure produced by the heart, some blood will be able to pass through the upper arm when the pressure in the artery rises during systole.



Principle of blood pressure measurement based on Korotkoff sounds

The sounds heard during measurement of blood pressure are not the same as the heart sounds 'lub' and 'dub' that are due to the closing of the heart's valves. If a stethoscope is placed over the brachial artery in the antecubital fossa in a normal person (without arterial disease), no sound should be audible. As the heart beats, these pulses are transmitted smoothly via laminar (non-turbulent) blood flow throughout the arteries and no sound is produced. Also, if the cuff of a sphygmomanometer is placed around a patient's upper arm and inflated to a pressure above the patient's systolic blood pressure, there will be no sound audible. This is because the pressure in the cuff is high enough such that it completely occludes the blood flow. It is similar to a flexible tube or pipe with fluid in it that is being pinched shut.

The Five Korotokoff Sounds: Korotkoff actually described five types of Korotkoff sounds:

1. The first Korotkoff sound is the snapping sound first heard at the systolic pressure.

2. The second sounds are the murmurs heard for most of the area between the systolic and diastolic pressures.

3. The third = A loud, crisp tapping sound.

4. The fourth sound, at pressures within 10 mmHg above the diastolic blood pressure, were described as "thumping" and "muting".

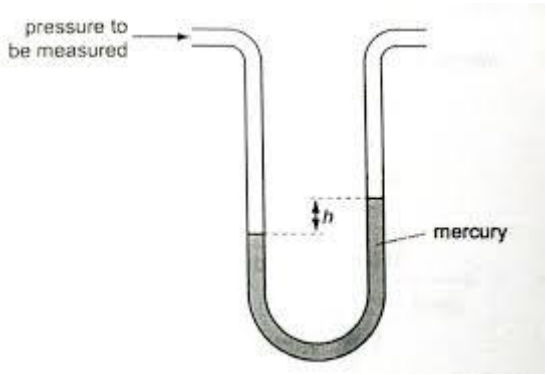
5. The fifth Korotkoff sound is silence as the cuff pressure drops below the diastolic blood pressure.

6. The second and third Korotkoff sounds haven't had clinical significance.

2. AUSCULTATORY METHOD: The auscultatory method (from the Latin word for listening) uses a stethoscope and a sphygmomanometer. This comprises an inflatable cuff placed around the upper arm at roughly the same vertical height as the heart, attached to mercury or aneroid manometer. The mercury manometer measures the height of a column of mercury, giving an

absolute result without need for calibration, and consequently not subject to the errors and drift of calibration which affect other methods. The use of mercury manometers is often required in clinical trials and for the clinical measurement of hypertension in high-risk patients, such as pregnant women. A cuff of appropriate size is fitted smoothly, then inflated manually by repeatedly squeezing a rubber bulb until the artery is completely occluded. Listening with the stethoscope to the brachial artery at the elbow, the examiner slowly releases the pressure in the cuff.

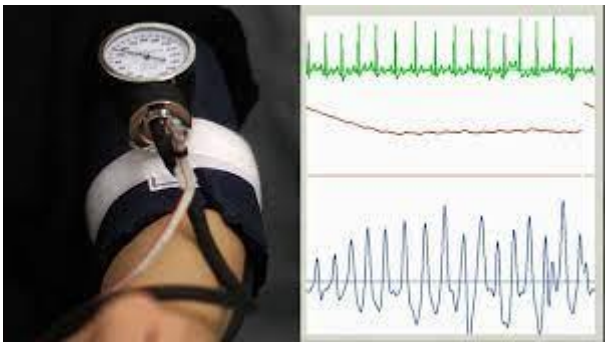
When blood just starts to flow in the artery, the turbulent flow creates a "whooshing" or pounding (first Korotkoff sound). The pressure at which this sound is first heard is the systolic BP. The cuff pressure is further released until no sound can be heard (fifth Korotkoff sound), at the diastolic arterial pressure. The auscultatory method has been predominant since the beginning of BP measurements but in other cases it's being replaced by other non-invasive techniques.



Mercury Manometer

Auscultatory method aneroid sphygmomanometer with stethoscope

3.OSCILLOMETRIC METHOD: Automated method of non-invasive BP measurement. It has some distinct advantages over the auscultatory method. Automated method of non-invasive BP measurement. It has some distinct advantages over the auscultatory method. Sound is not used during measurement. This technique does not require a microphone or transducer in the cuff. This is based on oscillometric pulses generated in the cuff during inflation or deflation.

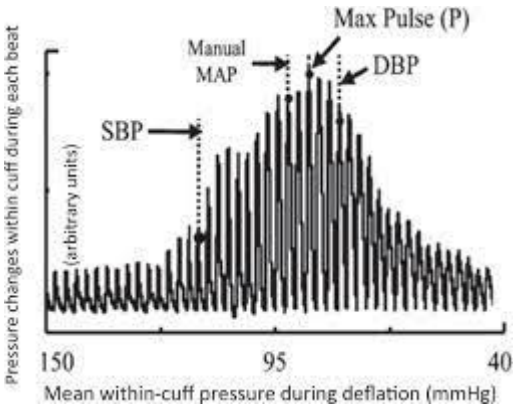


Oscillometric Method

Disadvantage of oscillometric method as well as auscultatory method is that the excessive movement or vibration can cause inaccurate readings.

PRINCIPLE: —occluding cuff deflates from a level above the systolic pressure, the artery walls begin to vibrate as the blood flows through the partially occluded artery and these

vibrations will be sensed in the transducer system monitoring cuff pressure‖. As pressure decreases in the cuff, the oscillations increase to a maximum amplitude and then decrease until the cuff fully deflates and blood flow returns.



The cuff pressure at the point of maximum oscillations usually corresponds to the mean arterial pressure. The point above the mean pressure at which the oscillations begin to rapidly decease in amplitude correlates with the diastolic pressure. Advantages: In this method of measuring BP, the cuff need not be precisely positioned as in the case with the Korotkoff microphone which is to be fixed exactly above an artery. Also, the readings are not affected by ambient sound.

Disadvantages: Many devices use fixed algorithms leading large variance in blood pressures.

Ultrasonic Doppler shift method:

Automatic BP monitors have been designed based on the ultrasonic detection of arterial wall motion. The control logic incorporated in the instrument analyzes the wall motion signals to detect the systolic and diastolic pressures and displays the corresponding values. The observed doppler frequency can be expressed as

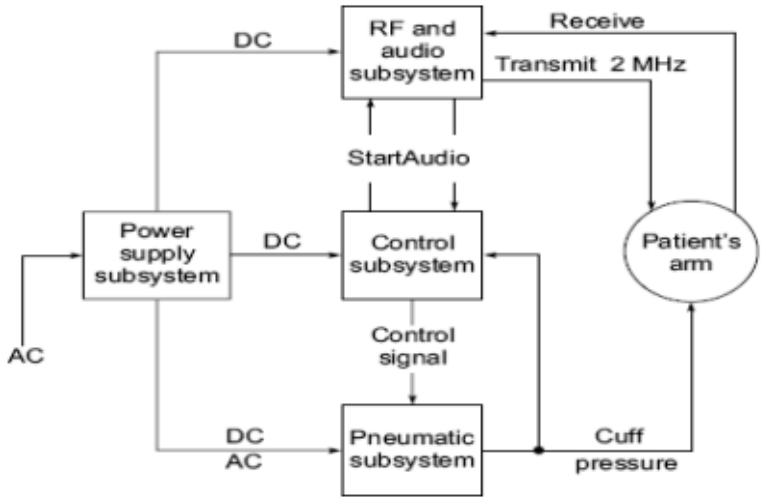
$$\Delta f = \frac{2V_t}{\lambda_t}$$

Δf = Doppler frequency (Hz)

V_t = velocity of the object(m/s)

λ_C= carrier wavelength (m)

Instruments making use of ultrasonic doppler shift principle is based on the detection of the frequency shift that may be due to back scattering from moving blood particles. The blood pressure instrument filters out these higher frequency reflections and senses the lower frequency refractions from the movement of the relatively slow-moving arterial wall.

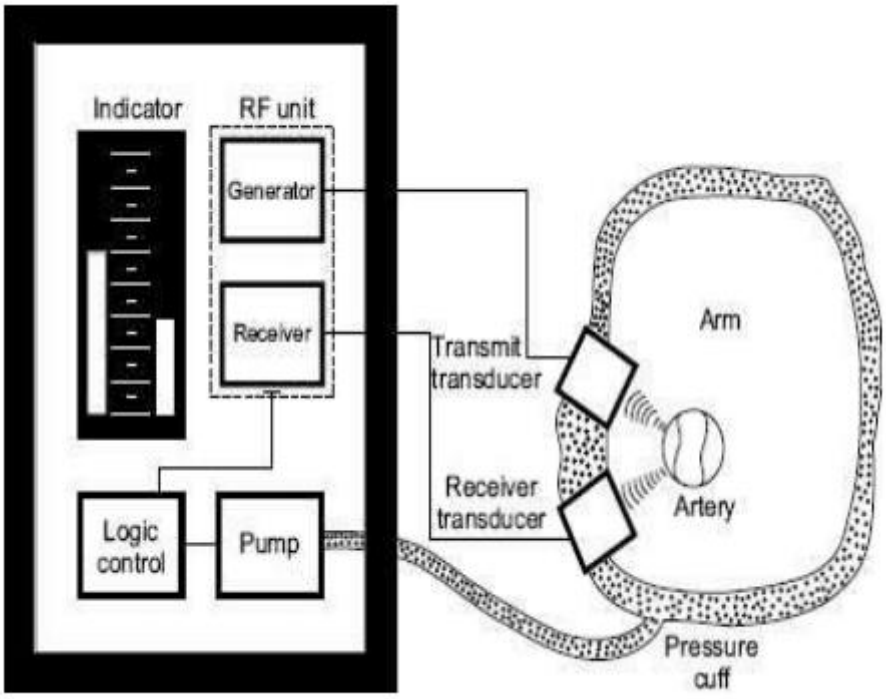


In principle, the instrument consists of four major subsystems as shown in figure. The power supply block converts incoming ac line voltage to several filtered and regulated dc voltages required for the pneumatic subsystem in order to inflate the occlusive cuff around the patient's arm.

At the same time, control subsystem signals gate-on the transmitter in the RF and audio subsystem, thereby generating a 2 MHz carrier, which is given to the transducer located in the cuff. The transducer converts the RF energy into ultrasonic vibrations, which pass into the patient's arm. The cuff pressure is monitored by the control subsystem and when the pressure reaches the preset level, further cuff inflation stops. At this time, audio circuits in the RF and

audio subsystems are enabled by control subsystem signals, and the audio signals representative of any Doppler frequency shift are thus able to enter the control subsystem logic. The control subsystem signals the pneumatic subsystem to bleed off the cuff pressure at a rate determined by the preset bleed rate. As air bleeds from the cuff, the frequency of the returned RF is not appreciably different from the transmitted frequency as long as the brachial artery remains occluded. Till then, there are no audio signals entering the control subsystem.

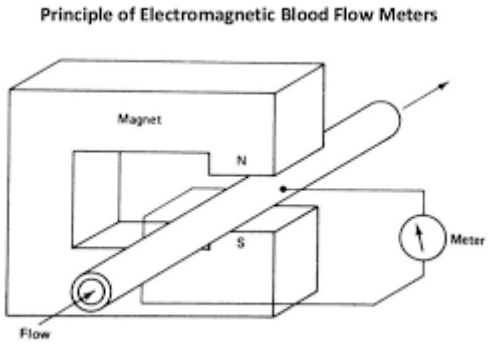
At the systolic pressure, the occluded artery snaps open and the arterial blood flow starts. This artery motion results in a Doppler shift in the returning ultrasonic vibrations. The converted audio frequency signal is recognized as tentative systolic by the control subsystem logic. Four valid artery returns must be recognized in order to register the tentative systole and for it to become fixed as true systole. This reduces the possibility of artefacts from recording a false systole reading. As a further check, the audio returns are examined for width and rate of occurrence to prevent artefacts from being accepted as true artery returns.



An occlusive cuff is placed on the arm shown in figure in the usual manner, with an ultrasonic transducer on the arm over the brachial artery. The cuff is inflated first to above systolic pressure and then deflated at a specified rate. A low energy ultrasonic beam (less than 50 mw/cm2) at a frequency of 2 MHz is transmitted into the arm. The portion of the ultrasound that is reflected by the arterial wall shifts in frequency when the wall of the artery moves. Above systolic, the vessel remains closed due to the pressure of the occluding cuff, and the monitor signals are not received. As the cuff pressure falls to the point where it is just overcome by the brachial artery pressure, the artery wall snaps open. This opening wall movement, corresponding to the occurrence of the first Korotkoff sound, produces a Doppler-shift which is interpreted by logic in the instrument as systolic and displayed accordingly. With each subsequent pulse wave, a similar frequency shift is produced until at the diastolic pressure the artery is no longer occluded. Its rapid motion suddenly disappears and the Doppler-shift becomes relatively small. The instrument notes the sudden diminution in the amplitude of the Doppler shift and cuff pressure at this point is displayed as diastolic pressure.

Special electronic circuits used in the instrument help to discriminate against extraneous motion artefacts. A coupling medium is essential between the transducer and the patients' skin for the efficient transmission of ultrasonic energy. Unlike the Korotkoff method, the instruments based on the ultrasonic Doppler-shift principle often provide reliable blood pressure measurements in severe hypotensive states, at unfavourable sites such as the popliteal artery, in neonates where no other indirect method of measurement is feasible, in patients too obese for successful auscultation, under unfavourable conditions such as high ambient noise, and in many species of laboratory research animals.

Electromagnetic flowmeter: The electromagnetic flowmeter measures instantaneous pulsatile flow of blood and thus has a greater capability than indicator-dilution methods, which measure only average flow. It operates with any conductive liquid, such as saline or blood. It uses a magnetic field applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines. The potential difference is sensed by electrodes aligned perpendicular to the flow and the applied magnetic field. The physical principle at work is Faraday's law of electromagnetic induction.

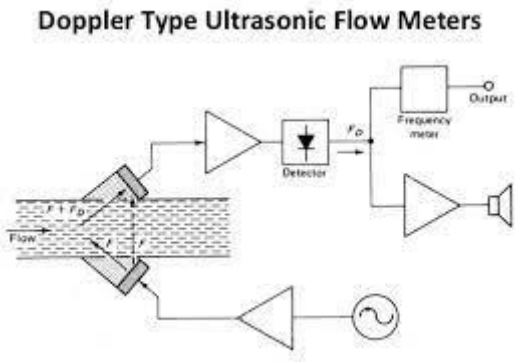


2. Ultrasonic Flow meter: It measures the velocity of a liquid or gas (fluid) by using the principle of ultrasound. It can measure instantaneous flow of blood. The ultrasound can be beamed through the skin. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow.

Ultrasonic flow meters are affected by the temperature, density and viscosity of the flowing medium. They are inexpensive to use and maintain because they do not use moving parts. They measure the difference of the transit time of ultrasonic pulses propagating in and against flow direction. This time difference is a measure for the average velocity of the fluid along the path of the ultrasonic beam. Ultrasonic flow meters are also used for the measurement of natural gas flow. One can also calculate the expected speed of sound for a given sample of gas; this can be

compared to the speed of sound empirically measured by an ultrasonic flow meter and for the purposes of monitoring the quality of the flow meter's measurements.

By passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of blood flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow.



Continuous-wave Doppler flowmeter: When a target recedes from a fixed source that transmits sound, the frequency of the received sound is lowered because of the Doppler effect. For small changes, the fractional change in frequency equals the fractional change in velocity. The Doppler flowmeter is capable of recording very rapid pulsatile changes in flow as well as steady flow.

UNIT V BIO-CHEMICAL MEASUREMENT

Biochemical sensors - pH, pO2 and pCO2,

Ion selective Field effect Transistor (ISFET),

immunologically sensitive FET (IMFET),

Blood glucose sensors - Blood gas analyzers,

colorimeter,

flame photometer,

spectrophotometer,

blood cell counter,

auto analyzer (simplified schematic description).

PH MEASUREMENT

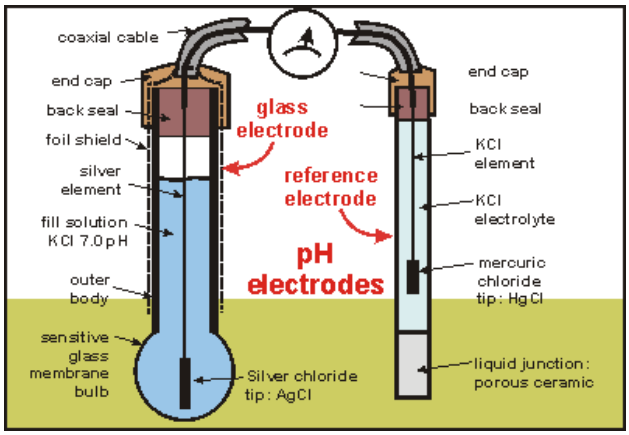
The chemical balance in the body can be determined by the ph value of blood and other body fluids.ph is defined as the hydrogen ion concentration of a fluid. It is the logarithm of the reciprocal value of h+ concentration. The ph equation is given as,

$$Ph= - \log_{10} [H^+] = \log_{10} 1/[H^+]$$

pH is the measure of acid- base balance in a fluid, A neutral solution has the ph value as 7. Solutions with pH value less than 7 are acidic and above 7 are basic. Most of the body fluids are slightly basic in nature.

Construction and working

The ph meter is made up of a thin glass membrane and it allows only the hydrogen ions to pass through it. The glass electrode provides a membrane interface for H^+ ions. The glass bulb at the lower end of the ph meter contains a highly acidic buffer solution. The glass tube consists of a sliver-sliver chloride (Ag/Agcl) electrode and the reference electrode which is made up of calomel sliver-sliver chloride (Ag/Agcl) is tan placed in the solution in which ph is being measured.



The potential is measured across the two electrodes. The electrochemical measurement, which should be obtained by each of the electrodes called half- cell. The electrode potential is called as half-cell potential. Here the glass electrode inside the tube constitutes one half –cell and the calomel or reference electrode is considered as the other half-cell.

pO2 MEASUREMENT

The term po2 is defined as the partial pressure of oxygen respectively. The determination of po2 is one the most important physiological chemical measurement. The effective functioning of both respiratory and cardiovascular system can be by po2 measurement. The partial pressure of a gas is proportional to the quantity of that gas present in the blood. The platinum wire, which is an active electrode, is embedded in glass for insulation and only its tip is exposed. It is kept in the electrolyte solution in which the oxygen is allowed to diffuse. The reference electrode is made up of silver-silver chloride (Ab/AgCl). A voltage of 0.7 is applied between the platinum wire and the reference electrode. The negative terminal is connected to the active electrode through a micro ammeter and the positive terminal is given to the reference electrode.

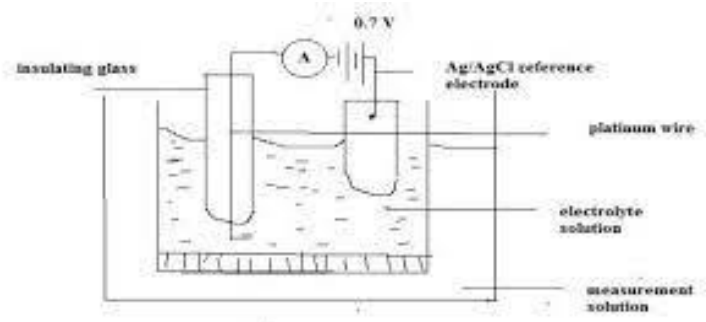


Figure 2.2 pO_2 Electrode

Due to the negative terminal, the oxygen reduction takes place at the platinum cathode. Finally, the oxidation reduction current proportional to the partial pressure of oxygen diffused into the electrolyte can be measured in the micro ammeter. The electrolyte is generally scaled in the electrode chamber by means of a membrane through which the oxygen can diffuse from the blood or sample solution. There are two types of pO2 measurement.

They are I) Vitro measurement II) Vivo measurement.

In case of dark electrode, the platinum cathode and the reference electrode are present in a single unit. This electrode is used for vitro and vivo measurements. In Vitro Measurements In this method the blood sample is taken and the measurement for oxygen saturation is made in the laboratory. The electrode is placed in the sample blood solution and the pO2 value is determined.

In Vivo Measurements In this method the oxygen saturation is determined while the blood is flowing in the circulatory system. A micro version of the pO2 electrode is placed at the tip of the catheter so that it can be inserted into various parts of the heart or circulatory system. The pO2 measurement also has some disadvantages in it. The reduction process in the platinum cathode removes a finite amount of the oxygen from the cathode. And there is a gradual reduction of current with respect to time. However careful design and proper procedures in modern pO2 electrodes reduce the errors.

pCO2 MEASUREMENT

The term pco2 is defined as the partial pressure of carbon dioxide respectively. The determination of pco2 is one the most important physiological chemical measurement. The effective functioning of both respiratory and cardiovascular system can be by pco2 measurement. The partial pressure of a gas is proportional to the quantity of that gas present in the blood. The partial pressure of carbon dioxide can be measured with the help of pCO2 electrodes. Since there is a linear relationship between the logarithm of pCO2 and pH of a solution.

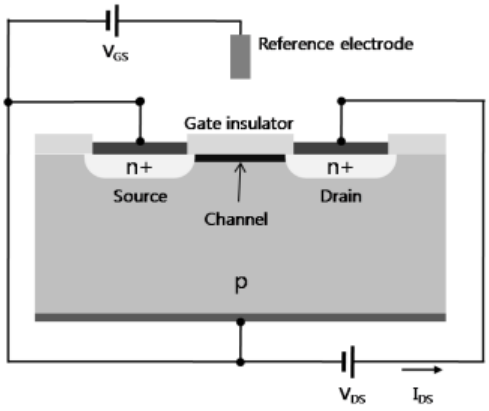
The pCO2 measurement is made by surrounding a pH electrode with a membrane selectively permeable to CO2. The modern improved pCO2 electrode is called as severinghous electrode. In this electrode the membrane permeable to CO2 is made up of Teflon which is not permeable

to other ions which affects the pH value. The space between the Teflon and glass contains a matrix layer which allows only the CO2 gas molecules to diffuse through it. One of the demerits in older CO2 electrode is, it requires a length of time for the CO2 molecules to diffuse through the membrane. The modern CO2 electrode is designed in such a way to overcome this demerit. Here the CO2 molecules diffuse rapidly through the membrane and the measurement can be done easily.

Blood Gas analyser: Blood gas analyzers are used to measure the content of pH, pCO and PO2 from the blood. • Two gases of accurately known O2 and CO2 percentages are required for calibrating the analyzer in pO2 and pCO2 modes. These gases are used with precision regulators for flow and pressure control.

Ion selective Field effect Transistor (ISFET)

In general, a field-effect transistor (FET) consists of three terminals; the source, drain, and gate. The voltage between the source and drain of the FET regulates the current flow in the gate voltage. Specifically, the current-control mechanism is based on an electric field generated by the voltage applied to the gate. The current is also conducted by only one type of carrier (electrons or holes) depending on the type of FET (n-channel or p-channel). A positive voltage applied to the gate causes positive charges (free holes) to be repelled from the region of the substrate under the gate.

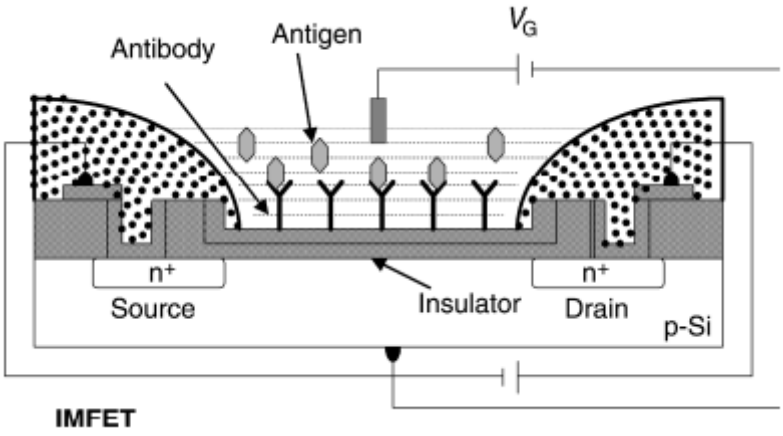


Structure of ISFET. It consists of source, drain, gate insulator, and reference electrode.

These positive charges are pushed downward into the substrate, leaving behind a carrier-depletion region. The depletion region is populated by the bound negative charge associated with the acceptor atoms. These charges are "uncovered" because the neutralizing holes have been pushed downward into the substrate. The positive gate voltage also pulls negative charges (electrons) from the substrate regions into the channel region. When sufficient electrons are induced under the gate, an induced thin n-channel is in effect created, electrically bridging the source and drain regions. The channel is formed by inverting the substrate surface from p-type to n-type (inversion layer). When a voltage is applied between the drain and source with the created channel, a current flow through this n-channel via the mobile electrons (n-type FET). In the case of a p-type semiconductor, applying a positive gate voltage depletes carriers and reduces the conductance, whereas applying a negative gate voltage leads to an accumulation of carriers and an increase in conductance (the opposite effect occurs in n-type semiconductors). The applied gate voltage generates an electric field which develops in the vertical direction. This field controls the amount of charge in the channel, and thus it determines the conductivity of the channel. The gate voltage applied to accumulate a sufficient number of electrons in the channel for a conducting channel is called the threshold voltage (V_{TH}).

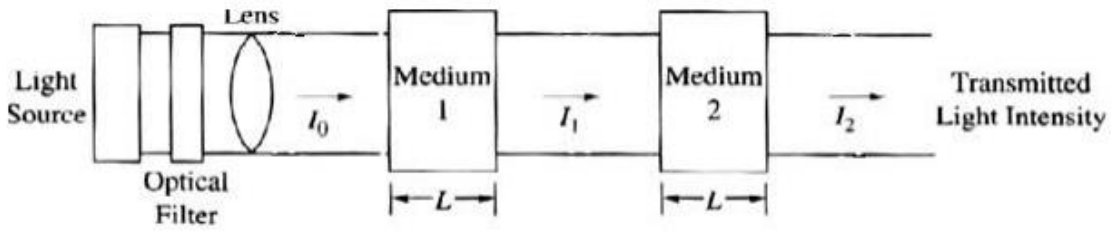
Immunologically sensitive FET (IMFET)

The Immunologically Sensitive Field-Effect Transistors (IMFETs) represent the amalgamation of the technologies of Solid-state electronics and Immunodiagnostics. The immunosensor is fabricated by immobilizing immunoagent, preferably, antibody on the gate region of an Ion-Sensitive Field Effect Transistor (ISFET). Consequently, IMFETs embodying a range of monoclonal antibodies and the unique ISFET transduction mechanism could, in principle, be made possible for detection of a wide array of analytes, ranging from small biomolecules to bacteria. This design for the measurement of the adsorption of charged molecules is practicable only if charge cannot cross the interface, which, thus, acts as an ideal capacitor. As will be seen, failure to achieve a perfectly polarizable interface has a detrimental effect on the specificity of the IMFET.



COLORIMETER

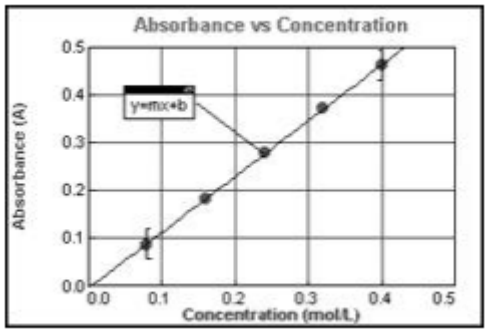
• Measures the colour concentration of a substance in a solution by detecting the colour light intensity passing through a sample containing the substance and a reagent



Colorimeter

• Optical colour filters are used to detect the colour wavelength of interest. E.g., urine passes yellow light and absorbs blue and green

• Laser LEDs are preferred if their wavelength is suitable due to purity of the monochromatic colour.



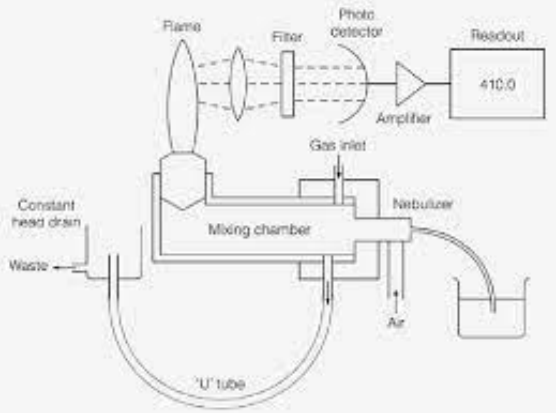
Concentration vs Absorbance

PHOTOMETER

FLAME PHOTOMETER

Measures the colour intensity of a flame supported by O2 and a specific substance. Sample's emission of light is measured (rather than the absorbance of light). Typically used to determine the concentration of pure metals and/or Na+, K+, Li+ and Ca++. In this method, fine droplets

of the sample is aspirated into gas flame that burns in a chimney. A known amount of lithium salt is added to the sample, as a reference.



As a result, red light is emitted by the lithium and yellow and violet beam are emitted due to sodium and potassium respectively. These diffracted colours are made to incident on photodiodes. The photo detector circuits consist of a reverse biased diode in which the current flow increases as intensity of incident light increases. A calibration potentiometer is used in every channel. Since the lithium is used as a standard reference, the output of sodium and potassium channel are calibrated in terms of differences with the known lithium. The output can be compared with the spectral illustration.

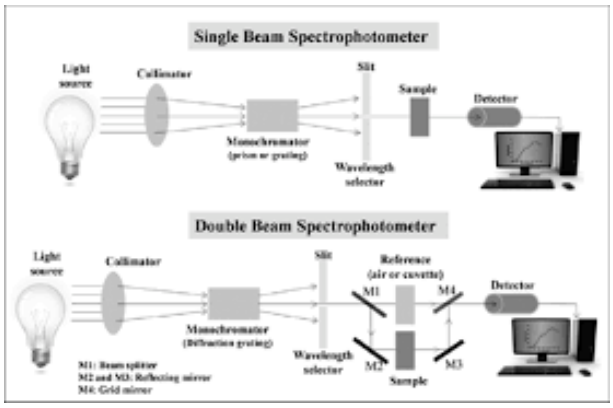
SPECTROPHOTOMETER

- The general name given to the group of instruments whose principle of operation is based on the fact that substances of clinical interest selectively absorb or emit EM energy (light) at different wavelengths.

Depending on the substance being measured, the wavelength used is typically in the ultraviolet (200-400 nm), visible (400-700nm) or infrared (700 to 800 nm) range.

- Spectrophotometer can be used to determine the entity of an unknown substance, or the concentration of a number of known substances.

• The type of source / filters used typically determines the type of the spectrophotometer.



• Rays of light bend around sharp corners, where the amount of bending depends on the wavelength. This results in separation of light into a spectrum at each line.

• In spectrophotometer, selection filter of colorimeter is replaced by a monochromator. Monochromatic uses a diffraction grating G to disperse light from the lamp. Light falls through the slit S0 into its spectral components.

• Slit S1 is used for selecting a narrow band of the spectrum which is used to measure the absorption of a sample in the cuvette.

• The light from the cuvette is given to photo detector. It converts light into a electrical signal. This electrical signal is amplified by using an amplifier. The output from the amplifier is given to meter which shows absorbance.

• Light absorption is varied when the wavelength is varied. Mirror M is used to reduce the size of the instruments.

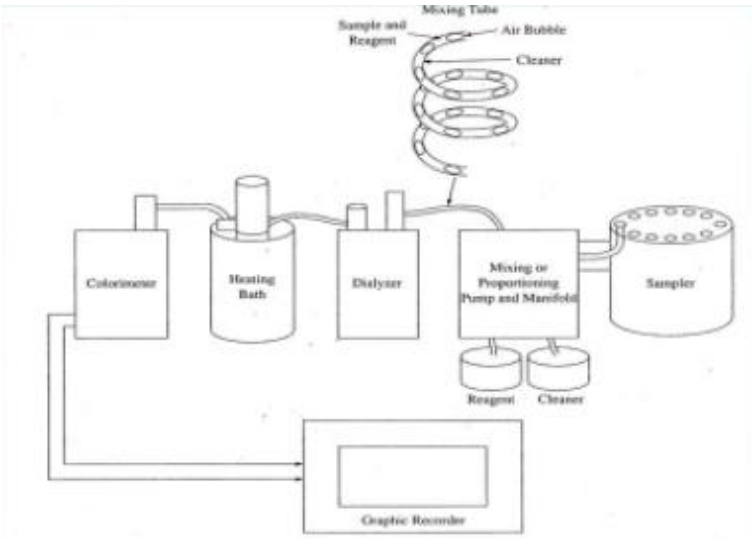
AUTOANALYZER

An auto analyzer sequentially measures blood chemistry through a series of steps of mixing, reagent reaction and colorimetric measurements.

It consists of

• Sampler: Aspirates samples, standards, wash solutions into the system

• Proportioning pump: Mixes samples with the reagents so that proper chemical colour reactions can take place, which are then read by the colorimeter



Autoanalyzer

• Dialyzer: separates interfacing substances from the sample by permitting selective passage of sample components through a semi permeable membrane

• Heating bath: Controls temperature (typically at 37 °C), as temp is critical in colour development

• Colorimeter: monitors the changes in optical density of the fluid stream flowing through a tubular flow cell. Colour intensities proportional to the substance concentrations are converted to equivalent electrical voltages.

• Recorder: Displays the output information in a graphical form.

BLOOD CELL COUNTER

The blood cell counter counts the number of RBC or WBC per unit of volume of blood using either of two methods:

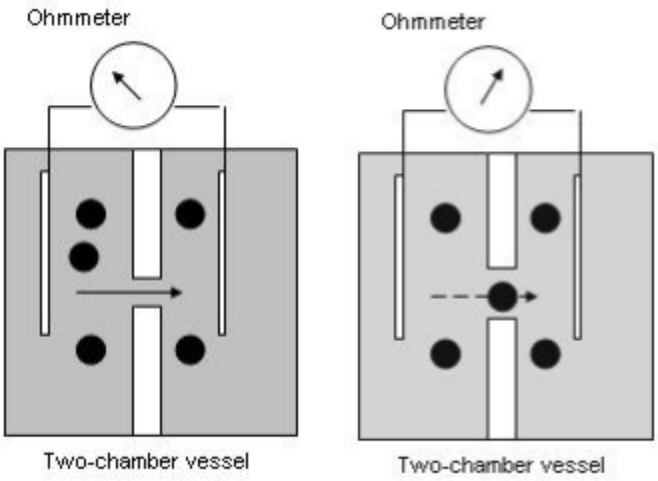
Electrical method called aperture impedance change –

Optical method called flow cytometry

Aperture impedance change

• When blood is diluted in the proper type of solution, the electrical resistivity of blood cells (ρ_c) is higher than the resistivity of the surrounding fluid (ρ_f)

• By contriving a situation in which these resistivities can be differentiated from each other, we can count cells



Blood Cell Sensing

Blood cell sensing

The sensor consists of a two-chamber vessel in which the dilute incoming blood is on one side of barrier, and the waste blood to be discarded is on the other.

A hole with a small diameter (50μm) is placed in the partition between the two halves of the cell. Ohmmeter measure the change on the resistance when the blood cell passes the aperture.