SRI CHANDRASEKHARENDRA SARASWATHI VISWA MAHAVIDYALAYA

(University established under section 3of UGC Act 1956)
(Accredited with 'A' Grade by NAAC)
Enathur, Kanchipuram – 631 561

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Course Material

Bio-Medical Electronics

FULL TIME B.E IV YEAR, VIIth SEMESTER

Prepared by:
Dr. V.Jayapradha, Assistant Professor

PEC5 BIO-MEDICAL ELECTRONICS VII SEMESTER

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

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 ofelectrodes - surface, needle and micro electrodes and their equivalent circuits, Recording problems - measurement with two electrodes

UNIT II ELECTRODE CONFIGURATIONS

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

UNIT III BIO AMPLIFIER

Need for bio-amplifier - single ended bio-amplifier, differential bio-amplifier – right leg driven ECGamplifier. 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

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

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:

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.

Joseph J. Carr & John M. Brown, "Introduction to Biomedical Equipment Technology", PearsonEducation, 2004.

UNIT- I

BIO POTENTIAL ELECTRODES

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 ofelectrodes - surface, needle and micro electrodes and their equivalent circuits, Recording problems - measurement with two electrodes

DESIGN OF MEDICAL INSTRUMENT

To design any medical instrument, the factors to be considered are

1. **Accuracy:** ccuracy is the closeness with which an instrument reading approaches the true value of variable being measured.

2. **Frequency Response:** It is the response of the instrument for various frequency components present in a physiological signal.

3. **Hysteresis**: Hysteresis error occurs due to mechanical friction.

4. **Isolation:** Electrical isolation is made for electrical safety and to avoid any interference between different instruments.

5. **Linearity:** It is defined as the degree to which variations in the output of an instrument follow input variations

6. **Sensitivity:** It is the ability of an instrument to detect even a very small change that is taking place in the input.

7. **Signal to Noise (S/N) ratio:** It should be high to get reliable information about input.

8. **Simplicity:** It is an essential one to eliminate the human errors.

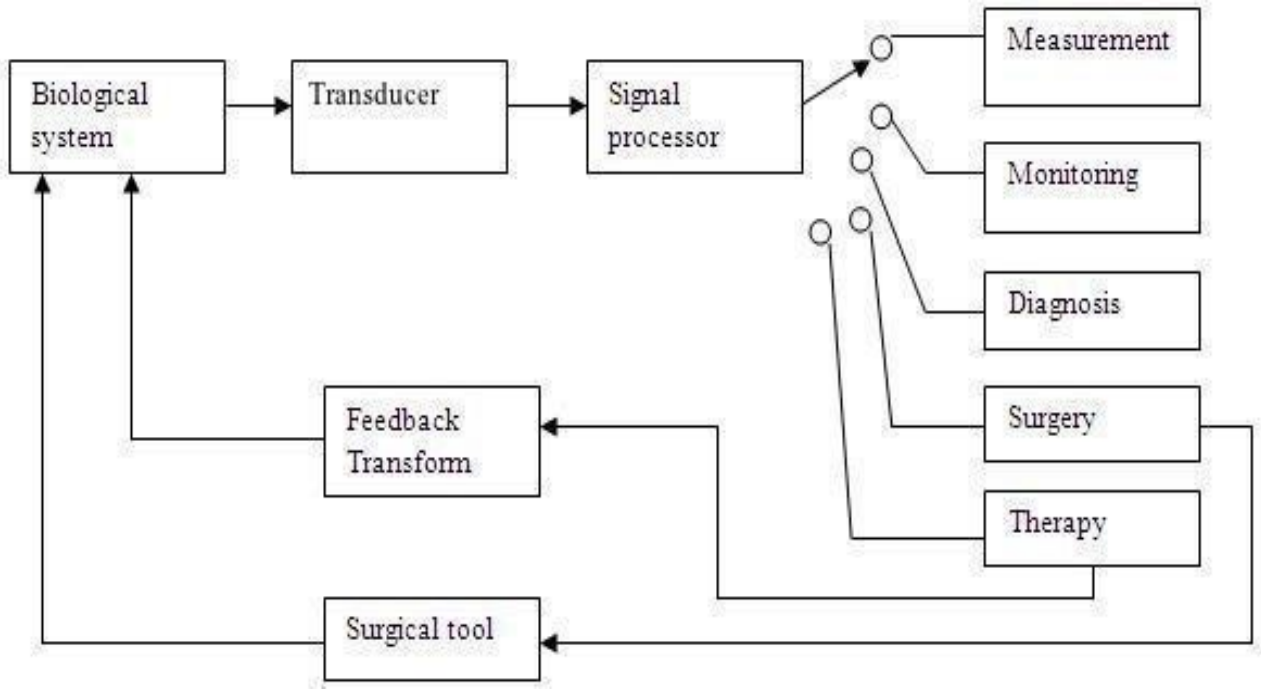
9. **Stability:** It is the ability of the instrument to produce constant output for a given input.

10. **Precision:** It is the measure of the reproducibility of the measurements.

COMPONENTS OF BIO- MEDICAL INSTRUMENT SYSTEM:

The clinical laboratory instrument is used to investigate the pH value and concentration of various radicals present in the body fluids and to count blood cells in the blood sample. Each switch position connects an instrument for measurement, for monitoring, diagnosis, therapy or surgery with signal processor.

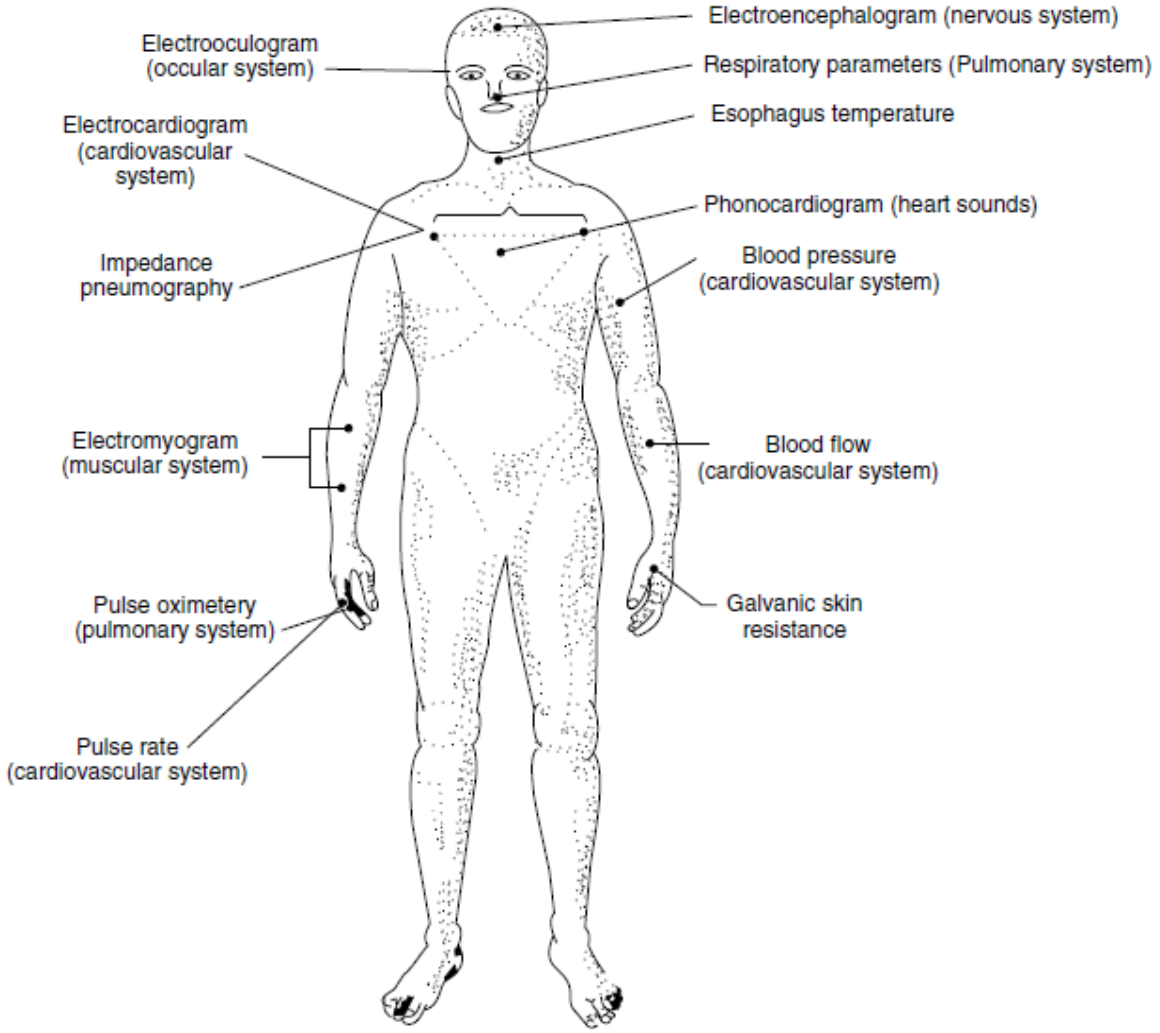
Transducer transforms the physiological signal like temperature, pressure or bio-potential into an electrical form.



Block Diagram of a Generalized Bio-Medical Instrument System

Sources of Biomedical Signals

Biomedical signals are those signals (phenomenon that conveys information) which are used primarily for extracting information on a biological system under investigation.



Sources of biomedical signals

The process of extracting information could be as simple as feeling the pulse of a person on the wrist or as complex as analyzing the structure of internal soft tissues by an ultrasound scanner. Biomedical signals originate from a variety of sources (Fig. 1.8) such as:

Bioelectric Signals: These are unique to the biomedical systems. They are generated by nerve cells and muscle cells. Their basic source is the cell membrane potential which under certain conditions may be excited to generate an action potential. The electric field generated by the action of many cells constitutes the bio-electric signal. The most common examples of bioelectric signals are the ECG (electrocardiographic) and EEG (electroencephalographic) signals.

Bioacoustic Signals: The measurement of acoustic signals created by many biomedical phenomena provides information about the underlying phenomena. The examples of such signals are: flow of blood in the heart, through the heart's valves and flow of air through the upper and lower airways and in the lungs which generate typical acoustic signal.

Biomechanical Signals: These signals originate from some mechanical function of the biological system. They include all types of motion and displacement signals, pressure and flow signals etc. The movement of the chest wall in accordance with the respiratory activity is an example of this type of signal.

Biochemical Signals: The signals which are obtained as a result of chemical measurements from the living tissue or from samples analyzed in the laboratory. The examples are measurement of partial pressure of carbon-dioxide (pCO2), partial pressure of oxygen (pO2) and concentration of various ions in the blood.

Biomagnetic Signals: Extremely weak magnetic fields are produced by various organs such as the brain, heart and lungs. The measurement of these signals provides information which is not available in other types of bio-signals such bio-electric signals. A typical example is that of magneto-encephalograph signal from the brain.

Bio-optical Signals: These signals are generated as result of optical functions of the biological systems, occurring either naturally or induced by the measurement process. For example, blood oxygenation may be estimated by measuring the transmitted/back scattered light from a tissue at different wavelengths.

Bio-impedance Signals: The impedance of the tissue is a source of important information concerning its composition, blood distribution and blood volume etc. The measurement of galvanic skin resistance is a typical example of this type of signal. The bio-impedance signal is also obtained by injecting sinusoidal current in the tissue and measuring the voltage drop generated by the tissue impedance. The measurement of respiration rate based on bio-impedance technique is an example of this type of signals.

Origin of Bioelectric Signals

The association of electricity with medical science dates back to the 18th century when Galvani demonstrated that most of the physiological processes were accompanied with electrical changes. This discovery formed the basis of the explanation of the action of living

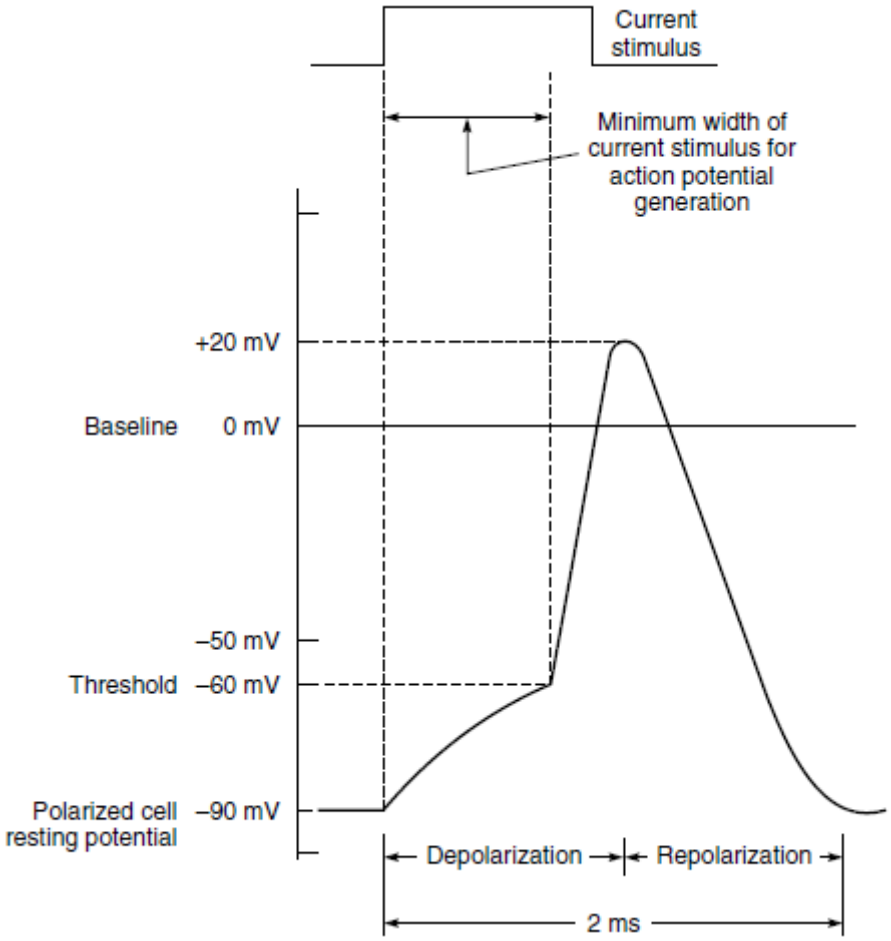
tissues in terms of bioelectric potentials. It is now well established that the human body, which is composed of living tissues, can be considered as a power station generating multiple electrical signals with two internal sources, namely muscles and nerves.

Normal muscular contraction is associated with the migration of ions which generates potential differences measurable with suitably placed electrodes. For example, the heart and the brain produce characteristic patterns of voltage variations which when recorded and analyzed are useful in both clinical practice and research. Potential differences are also generated by the electrochemical changes accompanied with the conduction of signals along the nerves to or from the brain. These signals are of the order of a few microvolts and give rise to a complicated pattern of electrical activity when recorded. The fact that the activity of the living tissues is due to the potential changes in them suggested the use of external electricity for the diagnosis of certain diseases affecting muscles and nerves, for the augmentation or replacement of a deficient natural activity or for the restoration of a palsied muscle.

Bioelectric potentials are generated at a cellular level and the source of these potentials is ionic in nature. A cell consists of an ionic conductor separated from the outside environment by a semipermeable membrane which acts as a selective ionic filter to the ions. This means that some ions can pass through the membrane freely where as others cannot do so. All living matter is composed of cells of different types. Human cells may vary from 1 micron to 100 microns in diameter, from 1 mm to 1 m in length, and have a typical membrane thickness of 0.01 micron (Peter Strong, 1973). Surrounding the cells of the body are body fluids, which are ionic and which provide a conducting medium for electric potentials. The principal ions involved with the phenomena of producing cell potentials are sodium (Na^+), potassium (K^+) and chloride ($Cl^–$). The membrane of excitable cells readily permits the entry of K^+ and $Cl^–$ but impedes the flow of Na^+ even though there may be a very high concentration gradiant of sodium across the cell membrane. This results in the concentration of the sodium ion more on the outside of the cell membrane than on the inside. Since sodium is a positive ion, in its resting state, a cell has a negative charge along the inner surface of its membrane and a positive charge along the outer portion.

The unequal charge distribution is a result of certain electrochemical reactions and processes occurring within the living cell and the potential measured is called the resting potential. The

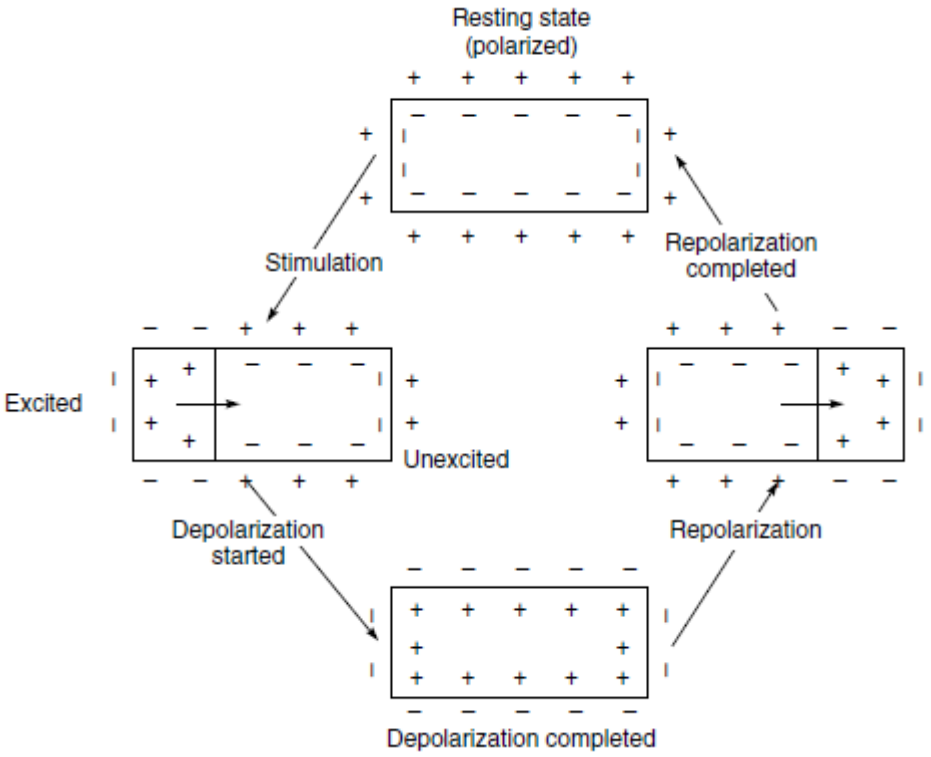
cell in such a condition is said to be polarized. A decrease in this resting membrane potential difference is called depolarization..



A typical cell potential waveform

The distribution of positively charged ions on the outer surface and negatively charged ionsinside the cell membrane results in the difference of potential across it and the cell becomes,in effect, a tiny biological battery. Experiments have shown that the internal resting potentialwithin a cell is approximately –90 mV with reference to the outside of the cell. When the cellis excited or stimulated, the outer side of the cell membrane becomes momentarily negativewith respect to the interior. This process is called depolarization and the cell potential changes to approximately +20 mV. Repolarization then takes place a short time later when the cell regains its normal state in which the inside of the membrane is again negative with respect to the outside. Repolarization is necessary in order to re-establish the resting potential. This discharging and recharging of the cell produces the voltage waveforms

which can be recorded by suitable methods using microelectrodes. A typical cell potential waveform so recorded is shown in Fig.



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Electrical activity associated with one contraction in a muscle

The wave of excitation while propagating in the muscle causes its contraction. The contraction wave always follows the excitation wave because of its lower velocity. This phenomenon is found with the skeletal muscles, the heart muscle and the smooth muscles. In its turn, every contraction (movement) of a muscle results in the production of an electric voltage. This voltage occurs in the muscle in such a way that the moving muscle section is always negative with respect to its surroundings. These voltages are called action potentials because they are generated by the action of the muscles. After complete contraction, repolarization takes place resulting in the relaxation of the muscle and its returning to the original state. Figure shows electrical activity associated with one contraction in a muscle

The currents involved in bioelectricity are unlike the currents involved in electronics. Bioelectric currents are due to positive and negative ion movement within a conductive fluid. The ions possess finite mass and encounter resistance to movement within the fluid for they have limited speeds.

The cell action potential, therefore, shows a finite rise time and fall time. It may be noted that a cell may be caused to depolarize and then repolarize by subjecting the cell membrane to an ionic current. However, unless a stimulus above a certain minimum value is applied, the cell will not be depolarized and no action potential is generated. This value is known as the stimulus threshold. After a cell is stimulated, a finite period of time is required for the cell to return to its pre-stimulus state. This is because the energy associated with the action potential is developed from metabolic processes within the cell which take time for completion. This period is known as refractory period.

• Table *Bioelectric Signals*

Parameter	*Primary signal characteristics*	*Type of Electrode*
Electrocardiography (ECG)	Frequency range: 0.05 to 120 Hz Signal amplitude: 0.1 to 5 μV Typical signal: 1 μV	Skin electrodes
Electroencephalography (EEG)	Frequency range: 0.1 to 100 Hz Signal amplitude: 2 to 200 μV Typical signal: 50 μV	Scalp electrodes
Electromyography (EMG)	Frequency range: 5 to 2000 Hz Signal amplitude: 0.1 to 5 μV	Needle electrodes
Electroretinography (ERG)	Frequency range: dc to 20 Hz Signal amplitude: 0.5 μV to 1 μV Typical signal: 0.5 μV	Contact electrodes
Electro-oculography (EOG)	Frequency range: dc to 100 Hz Signal amplitude: 10 to 3500 μV Typical signal: 0.5 μV	Contact electrodes

The bioelectric signals of clinical interest, which are often recorded, are produced by the coordinated activity of large groups of cells. In this type of synchronized excitation of many cells, the charges tend to migrate through the body fluids towards the still unexcited cell areas. Such charge migration constitutes an electric current and hence sets up potential differences between various portions of the body, including its outer surface. Such potential differences can be conveniently picked up by placing conducting plates (electrodes) at any two points on the surface of the body and measured with the help of a sensitive instrument. These potentials are highly significant for diagnosis and therapy. The primary characteristics of typical bioelectric signals are given in Table .

Polarizable and Non-Polarizable Electrodes

Perfectly Polarizable Electrodes: These are electrodes in which no actual charge crosses the electrode-electrolyte interface when a current is applied. The current across the interface is a displacement current and the electrode behaves like a capacitor. Example : Ag/AgCl Electrode

Perfectly Non-Polarizable Electrode: These are electrodes where current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition.

Example: Ag-AgCl is used in recording while Pt is use in stimulation

Recording Electrodes–Electrode-tissue interface,

Bioelectric events have to be picked up from the surface of the body before they can be put into the amplifier for subsequent record or display. This is done by using electrodes.

Electrodes make a transfer from the ionic conduction in the tissue to the electronic conduction which is necessary for making measurements.

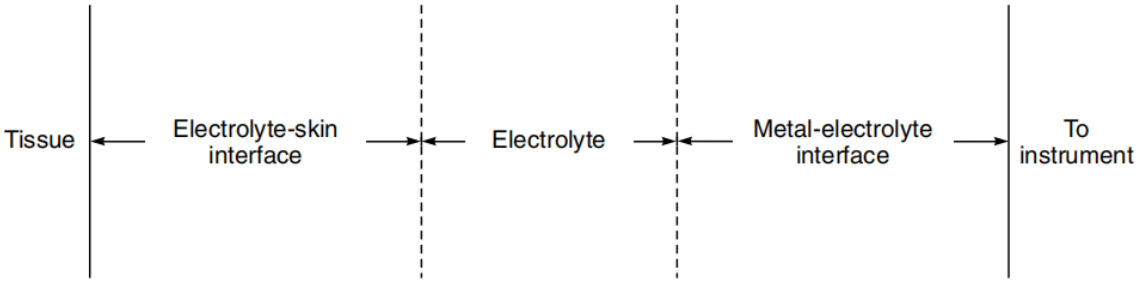
Two types of electrodes are used in practice-surface electrodes and the deep-seated electrodes. The surface electrodes pick up the potential difference from the tissue surface when placed over it without damaging the live tissue.

ELECTRODE TISSUE INTERFACE

The most commonly used electrodes in patient monitoring and related studies are surface electrodes. The notable examples are when they are used for recording ECG, EEG and respiratory activity by impedance pneumography.

In order to avoid movement artefacts and to obtain a clearly established contact (low contact impedance) an electrolyte or electrode paste is usually employed as an interface between the

electrode and the surface of the source of the event. Figure (a, b) represent the electrode-tissue interface.

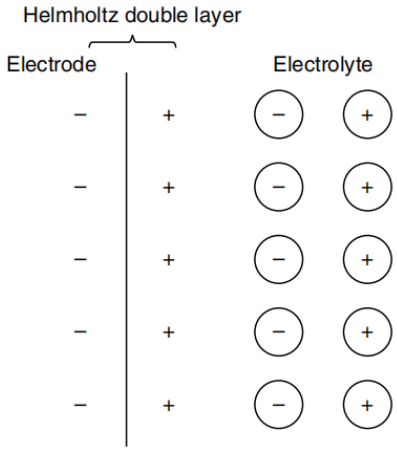


(a) *Electrode-tissue interface for surface electrodes used with electrode jelly*

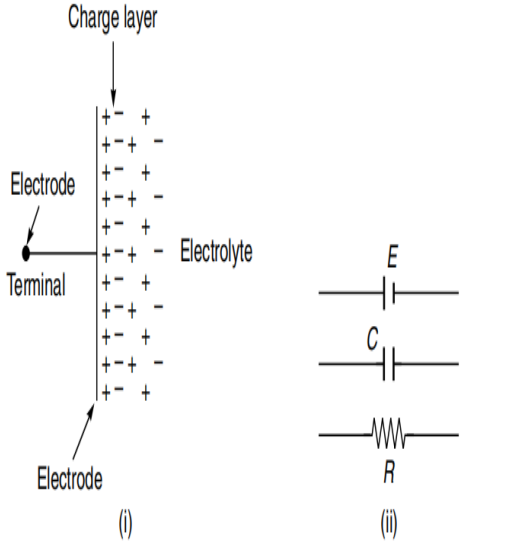
The characteristic of a surface electrode composed of a metal electrode and attached to the surface of the body through an electrolyte (electrode jelly) are dependent upon the conditions at the metal-electrolyte interface, the electrolyte-skin interface and the quality of the electrolyte.

Metal-Electrolyte Interface:

At the metal-electrolyte transition, there is a tendency for each electrode to discharge ions into the solution and for ions in the electrolyte to combine with each electrode. The net result is the creation of a charge gradient (difference of potential) at each electrode, the spatial arrangement of which is called the electrical double layer (Fig.). The double layer is known to be present in the region immediately adjacent to the electrode and can be represented, in its simplest form, as two parallel sheets of charge of opposite sign separated by a thin film of dielectric. Therefore, the metal-electrolyte interface appears to consist of a voltage source in series with a parallel combination of a capacitance and reaction resistance. The voltage developed is called the half-cell potential.



'(b) *Electrode tissue interface circuit involves transfer of electrons from the metal phase to an ionic carrier in the electrolyte, a charge double layer (capacitance) forms at the interface*



'(c) *(i) Charge distribution at electrode-electrolyte interface*
(ii) Three components representing the interface

Electrolyte-Skin Interface:

An approximation of the electrolyte-skin interface can be had by assuming that the skin acts as a diaphragm arranged between two solutions (electrolyte and body fluids) of different concentrations containing the same ions, which is bound to give potential differences.

The simplest equivalent representation could then be described as a voltage source in series with a parallel combination of a capacitance and resistance. The capacitance represents the charge developed at the phase boundary whereas the resistance depends upon the conditions associated with ion-migration along the phase boundaries and inside the diaphragm.

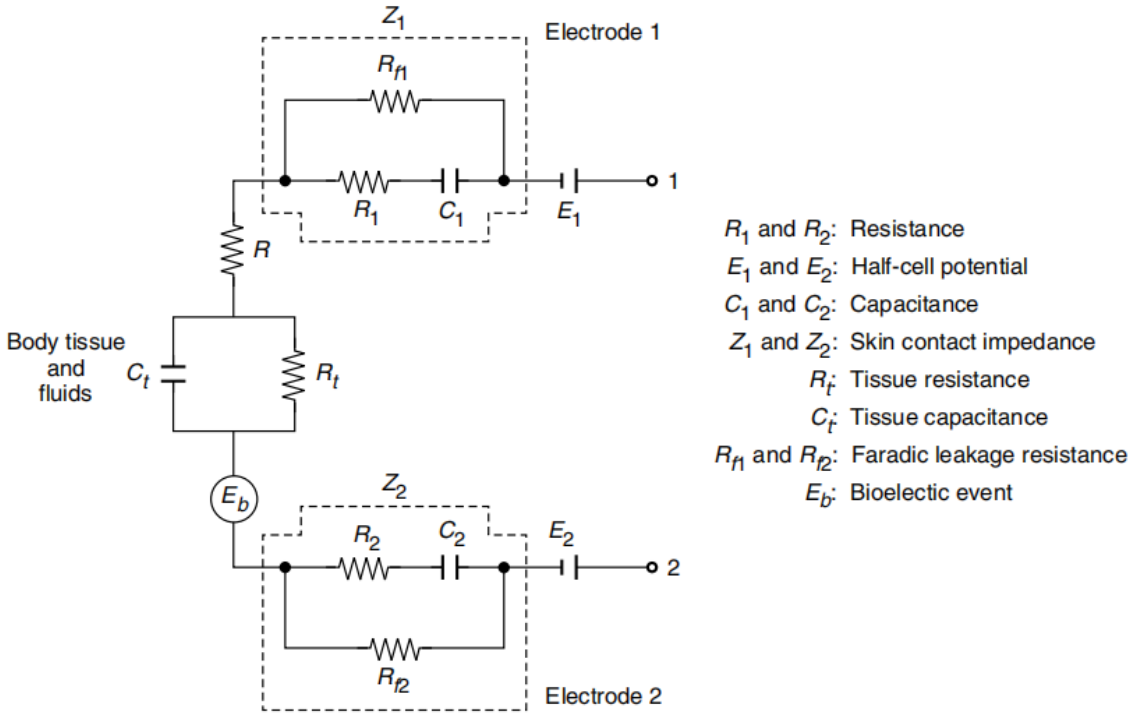
The above discussion shows that there is a possibility of the presence of voltages of Non physiological origin. These voltages are called contact potentials.

The electrical equivalent circuit of the surface electrode suggests that the voltage presented to the measuring instrument from the electrode consists of two main components. One is the contact potential and the other is the biological signal of interest.

The contact potential depends upon several factors and may produce an interference signal which exceeds several times the useful signal. The contact potential is found to be a function of the type of skin, skin preparation and composition of the electrolyte.

The electrodes are used to measure a bioelectric event and are connected to a differential amplifier. Three potentials are found to exist in this circuit , one is due to the bioelectric event (*Eb*) and the other two are non-physiologicand represent the half-cell potentials (*E*1 and *E*2) of the electrodes. *Z*1 and *Z*2 are the skin contact impedances of these electrodes and *R* is the tissue resistance or resistance of the bioelectric generator.

This circuit shows that the impedance of the electrodes would be high in the low frequency region and it would decrease with increasing frequency. It is further clear that in the measurement of a bioelectric signal, it is essential to minimize potential drops across the electrode impedance. This is achieved by making the skin-contact impedance as low as possible and making the input impedance of the measuring device as high as possible.



Equivalent circuit for a pair of electrodes (1,2) on a subject represented by R R_t, C_t. Embedded in the subject is a bioelectric generator E_b (after Tacker and Geddes, 1996)

POLARISATION

If a low voltage is applied to two electrodes placed in a solution, the electrical double layers are disturbed. Depending on the metals constituting the electrodes, a steady flow of current may or may not take place.

In some metal/liquid interfaces, the electrical double layer gets temporarily disturbed by the externally applied voltage, and therefore, a very small current flows after the first surge, thus indicating a high resistance. This type of electrode will not permit the measurement of steady or slowly varying potentials in the tissues.

They are said to, be polarized or nonreversible. Thus, the phenomenon of polarization affects the electro-chemical double layer on the electrode surface and manifests itself in changing the value of the impedance and voltage source representing the transition layer.

Parsons (1964) stated that electrodes in which no net transfer of charge takes place across the metal-electrolyte interface can be termed as perfectly polarized. Those in which unhindered exchange of charge is possible are called non-polarizable or reversible electrodes. The ionic double layer in metals of these electrodes is such that they allow considerable current to flow when a small voltage is applied, thus offering a low resistance.

SKIN CONTACT IMPEDANCE :

Measurement of Skin Contact Impedance: A convenient method to measure the contact impedance at any individual electrode is shown in Fig.

The three electrodes, A, B and C, have contact impedance respectively of Za, Zb andZc. An oscillator provides a constant current in the frequency range of 0.1–100 Hz through the 47 kW series resistor.

By suitably positioning the switch, a sensitive oscilloscope can be used to monitor either the voltage dropped across the 1 kW resistor or the voltage dropped across Zb.

The voltage drop across Zb can be neglected since the input impedance of the oscilloscope used with an input probe is usually high. From the voltage dropped across the 1 kW resistor it is possible to calculate the circuit current and thus to obtain a value for Zc.

Using this technique, the skin contact impedance of the following types of electrodes were measured by Hill and Khandpur (1969).

• Plastic cup self-adhesive electrodes (Boter et al, 1966)

• Metal plate limb electrodes used with conducting jelly

• Metal plate electrodes used with conducting plastic (Jenkner, 1967)

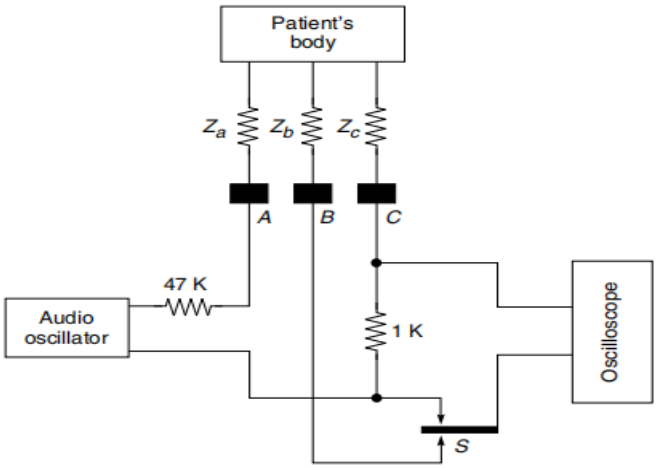
• Dry multi-point limb electrodes (Lewes, 1966)

• Dry multi-point suction chest electrodes

• Self-adhesive multi-point chest electrodes used with conducting jelly

• Self-adhesive gauze electrodes

• Self-adhesive dry multi-point chest electrodes (Lewes and Hill, 1967)



Arrangement for measurement electrode skin-contact impedance for surface electrodes

Motion Artifacts

Motion artefact is a problem in biopotential measurements. The problem is greatest in cardiac stress laboratories where the exercise ECG is recorded. The problem is also serious in coronary care units where patients are monitored for relatively long periods.

Motion of the subject under measurement creates artefacts which may even mask the desired signal or cause an abrupt shift in the baseline. These artefacts may result in a display being

unreadable, a recording instrument exceeding its range, a computer yielding incorrect output or a false alarm being triggered by the monitoring device.

Tam and Webster (1977) concluded that the skin-electrolytic paste interface is the major source of motion artefact. When a metal electrode contacts an electrolytic paste, a half cell potential is generated at the electrode-paste interface. Kahn (1965) demonstrated that when polarizable metal-plate electrodes are used, the electrode-paste interface can be a source of motion artefact.

When the paste is agitated, the half-cell potential varies because of the altered metallic ion gradient at the interface. He recorded a 1 mV offset potential change from a silver-silver chloride electrode exposed to a flowing stream of saline solution, as contrasted to 30 mV change for some silver electrodes.

Motion artefact is reduced to a negligible magnitude by skin abrasion. However, when the skin is abraided, it is more susceptible to irritants. The possible sources for skin irritation include the electrode, the paste and the adhesive. When large currents flow through metallic electrodes, migration of some ions into the skin can cause irritation.

Silver-Silver Chloride electrodes

Production of Silver-Silver Chloride Electrodes: Silver-silver chloride electrodes are normally prepared by electrolysis. Two silver discs are suspended in a saline solution. The positive pole of a dc supply is connected to the disc to be chlorided and the negative pole goes to the other disc. A current at the rate of 1 mA/cm^2 of surface area is passed through the electrode for several minutes. A layer of silver chloride is thus deposited on the surface of the anode. The chemical changes that take place at the anode and cathode respectively are:

$$NaCl = Na^+ + Cl^-$$
$$Cl^- + Ag^+ \rightarrow AgCl$$

The positively charged sodium ions generate hydrogen when they reach the cathode surface.

$$2Na^+ + 2H_2O + 2 \text{ electrons} \rightarrow 2NaOH + H_2$$

To prepare silver-silver chloride electrodes of good quality, only pure silver should be used and the saline solution should be made from analar grade sodium chloride. Before chloriding, silver must be cleaned—preferably by the electrolytic method.

ELECTRODES

Employed to pick up the electrical signals of the body

Pair of electrodes play the role of a transducer

Amplifier has to be designed – to accommodate the characteristics of electrodes

Type of electrode – depends on anatomical location of bioelectric event and dimensions of the bioelectric generator

Electrical characteristics of the electrodes specify the type of preamplifier

For microelectrodes, many restrictions on the input impedance of the amplifier

Amplifier – have large impedances, high resistance and low capacitance input circuits – need to transfer the bioelectric event to the amplifying system

ELECTRODES:

Electrodes are generally used to pick up the electric signals of the body. There are various electrodes that are used in instrumentation system. They are

1. Surface electrode
2. Micro electrode
3. Depth electrode
4. Needle electrode
5. Chemical electrode

TYPES OF ELECTRODES:

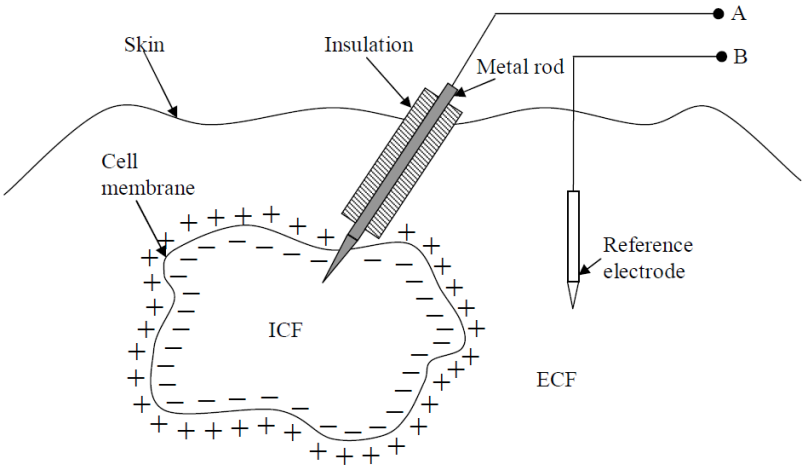
1. Micro-Electrodes:

- They are normally used to measure the potential within a single cell.
- The microelectrodes are very small in diameter and so it will not damage the human cell.
- Microelectrodes are classified into Metallic & Non-Metallic.

Metallic Electrode:

- The metal microelectrodes are formed by electrolytically etching the tip of fine tungsten filament into a minute structure.
- The final potential within the cell is the difference between the microelectrode potential and reference potential.

$$\text{Final potential} = E_A - E_R$$



Micropipet:

- It is used to measure the potential within a single cell, but instead of metal electrolyte non-metallic material is used.

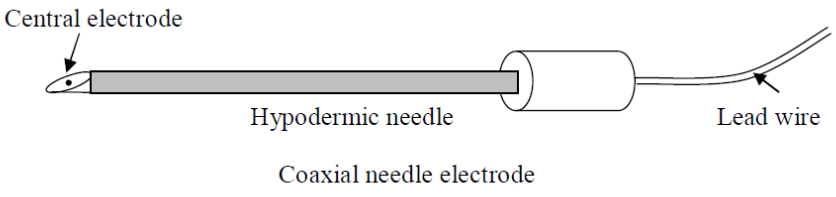
2. Depth Electrode:

- Depth electrodes are used to measure the oxygen tension.
- These are used to study the electrical activity of neuron of superficial layers of brain.
- In some depth electrode, the supporting element is in the form of capillary tube, which is used to inject medicine into the brain.

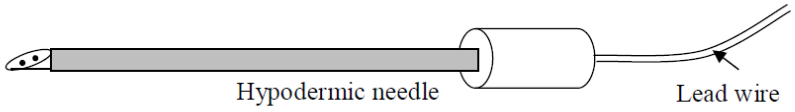
3. Needle Electrode:

- Needle electrodes are used to record the peripheral nerve action potential.
- The needle electrode will resemble a medicine dropper. There are two types:

1. Monopolar needle electrode.
2. Bipolar needle electrode.



Coaxial needle electrode



Bipolar needle electrode

4. Surface Electrode:

- The surface electrodes are used to measure the potential available from the surface of the skin and used to sense the potential from heart, brain and nerves.

- The smaller area surface electrodes are used to measure EEG,EMG potentials and the larger area surface electrodes are used to measure ECG potentials.
- Depends on construction, the surface electrodes are classified into

    1. Metal plate electrode
    2. Suction cup electrode
    3. Adhesive tape electrode
    4. Multipoint electrode
    5. Floating electrode

1. Metal plate electrode:

It is made up of Ag-AgCl (Silver-Silver Chloride). It is used to pick up ECG from the limb lead positions. It is fixed to the skin surface by means of conductive gel & rubber belt.

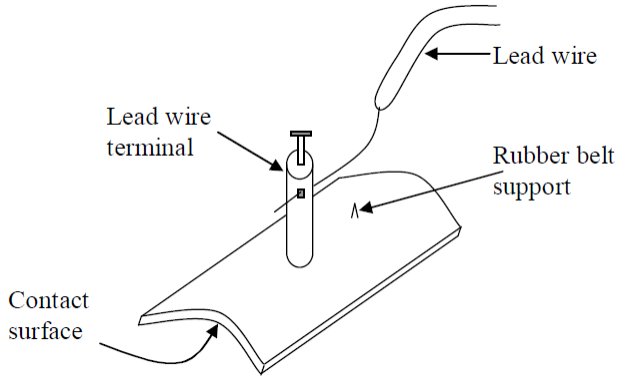


Fig: Metal plate electrode.

2. Metal disc electrode:

It is made up of Ag-AgCl. It is used to pick up EEG from the scalp. It is fixed to the scalp by means of adhesive tape.

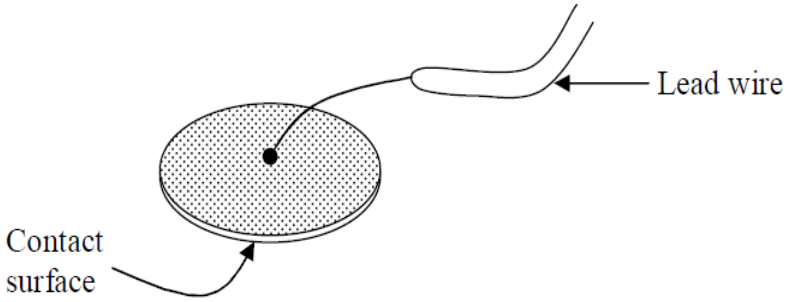


Fig: Metal disc electrode.

3. *Metallic suction electrode:*

It is made up of Ag-AgCl. It is used to pick up ECG from chest lead positions and EMG from muscular areas such as calf, thigh etc. It does not require adhesive tapes or rubber bands. It is fixed to the skin surface by means of air suction.

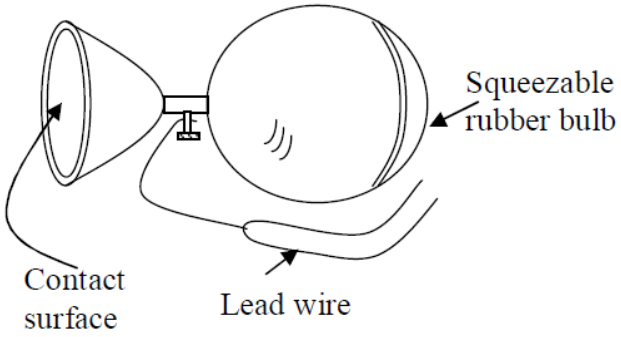


Fig: Metal suction electrode.

4. *Disposable foam-pad electrode:*

It is made up of Ag-AgCl. It is used to pick up ECG or EEG for those patients with contagious skin diseases. It is fixed to the skin surface by means of adhesive tapes attached to the electrode.

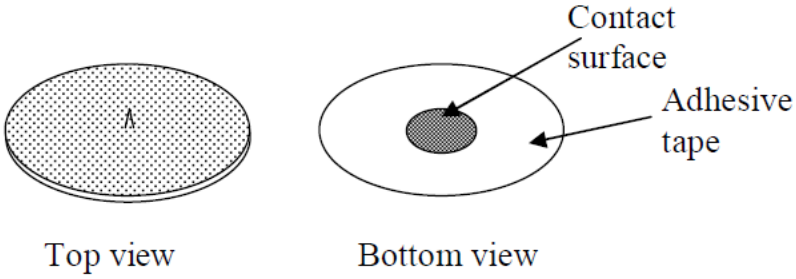


Fig: Disposable foam-pad electrode.

5. *Floating electrode:*

This type of electrode is used to prevent the motion-artifact from being picked up.

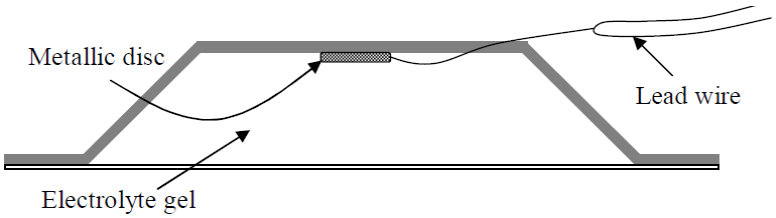


Fig: Floating electrode.

5. Chemical electrodes:

- The chemical electrodes are used to measure the pH content and pO_2 of blood. It is also used to determine the oxygen content & CO_2 content in blood.
- Various types of chemical electrodes are
  1. Hydrogen electrode.
  2. Practical reference electrode.
  3. pH electrode.
  4. pO_2 electrode.
  5. pCO_2 electrode.

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

BIOPOTENTIAL AMPLIFIERS

- These are very important part of modern medical instrumentation. We need to amplify biopotentials which are generated in the body at low levels with high source impedance.
- Biopotentials amplifiers are required to increase signal strength while maintaining fidelity

Basic Requirements of Biopotential Amplifiers

Essential functions of a bioamplifier are:

• To take a weak biopotential and increase its amplitude so that it can be processed, recorded or displayed

• To amplify voltage, but it could be considered as a power amplifier as well.To amplify current since in some cases a biopotential amplifier is used to isolate the load from the source current gain only

Input Impedance (Zin)

• All biopotential amplifiers must have **high input impedance** minimize loading (remember the characteristics of biopotential electrodes resulting into loading and distortion if input impedance of the amplifier is not high enough) – typical values of Zin over the frequency range of the measure and = 10 MΩ (remember the loading rule)

Protection & Isolation

• The input circuit of a biopotential amplifier must provide protection to the live measure **Vbio**

• Any potential or current at amplifier's input terminals can affect **Vbio**

• Electric currents produced by the biopotential amplifier can result in microshock and macro shock

• The bioamplifier must have isolation and protection circuitry so that the current through the electrodes can be kept at safe levels and any artifact generated by such current can be minimized

Output Impedance (Zout)

- The output circuit does not present any critical problems, all it needs to do is to drive the load
- Output impedance must be low with respect to the load impedance and it must be capable of satisfying the power requirements of the load

Bandwidth (BW)

Frequency response

• The biopotential amplifier must be sensitive to important frequency components of the biosignal
• Since biopotentials are low level signals, it is important to limit bandwidth optimize signal-to-noise ratio

Gain (G)

• Biopotential amplifiers have a gain of **1000** or greater

Mode of Operation

• Very frequently biosignals are obtained from bipolar electrodes
• Electrodes symmetrically located with respect to ground need differential amplification
• High CMRR required because:

1. Common mode signals much greater than the biosignal appear on bipolar electrodes
2. Symmetry with respect to ground is not perfect (mismatch between electrode impedances) – more on this later

Calibration Signal

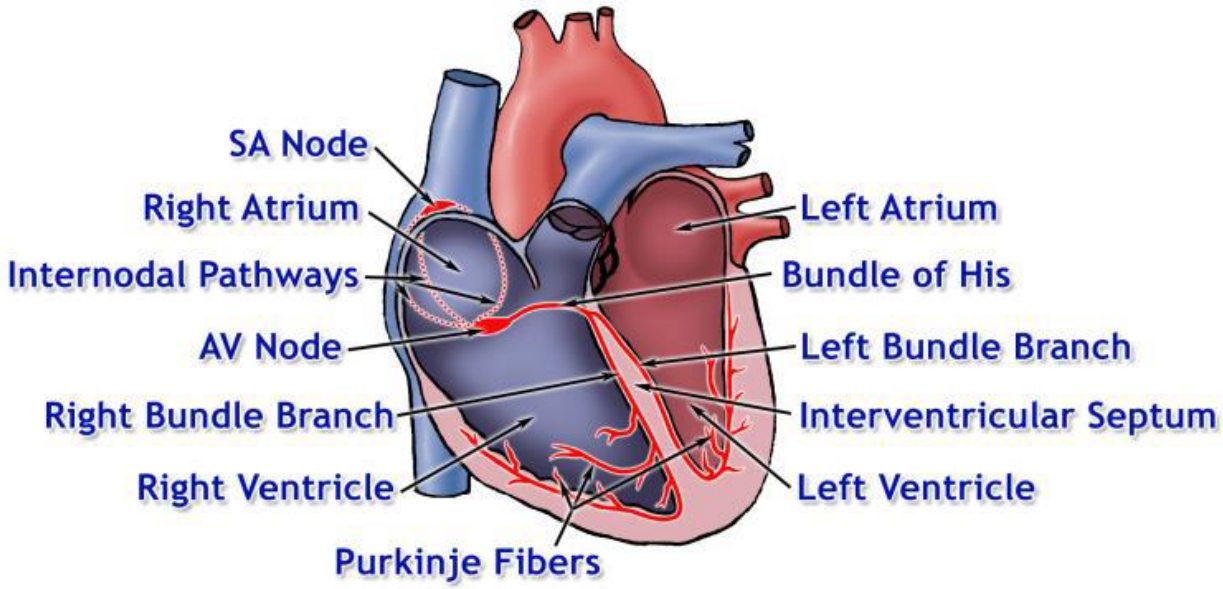
- Medical and clinical equipment require quick calibration. The gain of the biopotential amplifier must be calibrated to provide us with an accurate indication of the signal's amplitude
- Push button to apply standard signal to the input of the biopotential amplifier
- Adjustable gain switch carefully selects calibrated fixed gains.

ELECTROCARDIOGRAPHY (ECG)

- A very widely used medical instrument, which is utilized to diagnose and monitor cardiac beat abnormalities, is the electrocardiograph.
- It measures the electrical activity of the heart (more precisely biopotential differences arising from the electrical activity of myocardium). We've already talked about the genesis of the ECG signal.
- The ECG machine uses surface electrodes and high input impedance
- Differential amplifiers with good common mode rejection ratio to record the electrocardiogram
- Normal ECG amplitude ranges between 0.5-4 mV. Normal frequency content of ECG (for diagnostic purposes) is 0.05-100 Hz. A typical ECG waveform is shown below:

The Electrical and Mechanical Sequence of a Heartbeat

The heart has specialized **pacemaker** cells that start the electrical sequence of **depolarization** and **repolarization**. This property of cardiac tissue is called **inherent rhythmicity** or **automaticity**. The electrical signal is generated by the **sinoatrial node (SA node)** and spreads to the ventricular muscle via particular conducting pathways: **intermodal pathways** and **atrial fibers**, the **atrioventricular node (AV node**,) the **bundle of His**, the right and left **bundle branches**, and **Purkinje fibers**



When the electrical signal of a depolarization reaches the contractile cells, they contract—a mechanical event called **systole**. When the repolarization signal reaches the myocardial cells, they relax—a mechanical event called **diastole**. Thus, the electrical signals cause the mechanical pumping action of the heart; mechanical events always follow the electrical events.

The **SA node** is the normal pacemaker of the heart, initiating each electrical and mechanical cycle. When the SA node depolarizes, the electrical stimulus spreads through atrial muscle causing the muscle to contract. Thus, the SA node depolarization is followed by atrial contraction.

The SA node impulse also spreads to the **atrioventricular node (AV node**) via the **inter nodal fibers**. (The wave of depolarization does not spread to the ventricles right away because there is non conducting tissue separating the atria and ventricles.) The electrical signal is delayed in the AV node for approximately 0.20 seconds when the atria contract, and then the signal is relayed to the **ventricles** via the **bundle of His, right** and **left bundle branches**, and **Purkinje fibers**.

The Purkinje fibers relay the electrical impulse directly to ventricular muscle**,** stimulating the ventricles to **contract** (ventricular **systole**). During ventricular systole, ventricles begin to repolarize and then enter a period of diastole.

Although the heart generates its own beat, the heart rate (beats per minute or BPM) and strength of contraction of the heart are modified by the **sympathetic** and **parasympathetic** divisions of the autonomic nervous system.

- The sympathetic division increases automaticity and excitability of the SA node, thereby increasing heart rate. It also increases conductivity of electrical impulses through the atrioventricular conduction system and increases the force of atrioventricular contraction. Sympathetic influence increases during inhalation.

- The parasympathetic division decreases automaticity and excitability of the SA node, thereby decreasing heart rate. It also decreases conductivity of electrical impulses through the atrioventricular conduction system and decreases the force of atrioventricular contraction. Parasympathetic influence increases during exhalation.

The average resting heart rate for adults is between 60-80 beats/min. (Average 70 bpm for males and 75 bpm for females.) Slower heart rates are typically found in individuals who regularly exercise. Athletes can pump enough blood to meet the demands of the body with resting heart rates as low as 50 beats/min. Athletes tend to develop larger hearts, especially the muscle in the left ventricle—a condition known as "left ventricular hypertrophy." Because athletes (usually) have larger and more efficient hearts, their ECGs may exhibit differences other than average resting heart rate. For instance, low heart rate and hypertrophy exhibited in sedentary individuals can be an indication of heart failure, but these changes are "normal" for well-trained athletes.

ECG Activity

Just as the electrical activity of the pacemaker is communicated to the cardiac muscle, "echoes" of the depolarization and repolarization of the heart are sent through the rest of the body. By placing a pair of very sensitive receivers (**electrodes**) on other parts of the body, the echoes of the heart's electrical activity can be detected. The record of the electrical signal is called an **electrocardiogram (ECG).**

The ECG represents electrical events of the cardiac cycle whereas Ventricular Systole and Ventricular Diastole represent mechanical events (contraction and relaxation of cardiac muscle, passive opening and closing of intracardiac valves, etc.).

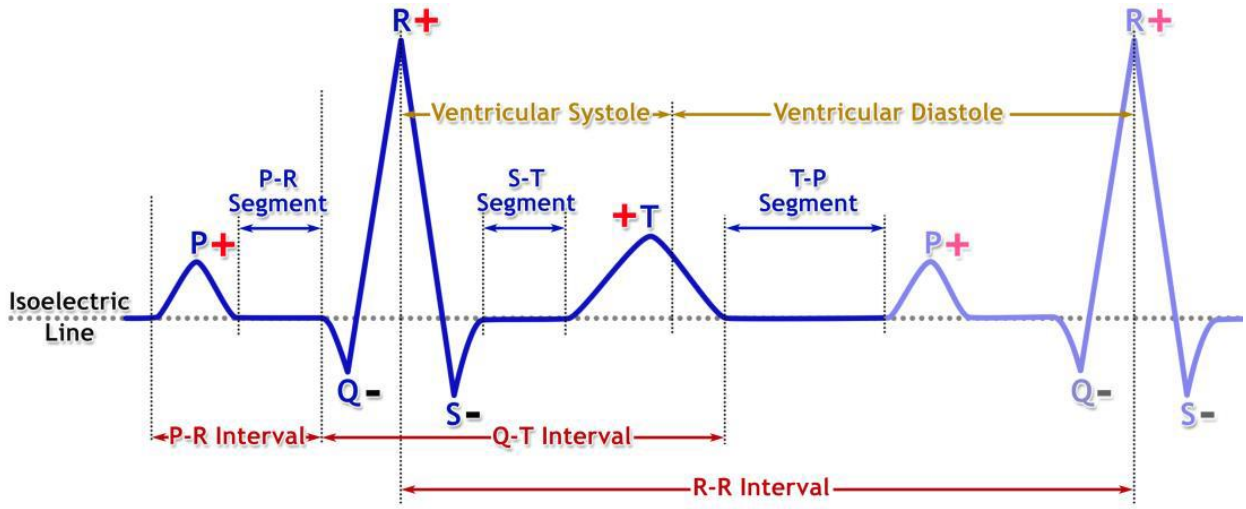
Electrical events occur quickly, mechanical events occur slowly. Generally, mechanical events follow the electrical events that initiate them. Thus, the beginning of ventricular diastole is preceded by the beginning of ventricular depolarization. In fact, in a normal resting Lead II, ventricular repolarization normally begins before the completion of ventricular systole in the same cardiac cycle. That is why the end of ventricular systole/beginning of ventricular diastole is marked in about 1/3 of the way down the T-wave.

Because the ECG reflects the electrical activity, it is a useful "picture" of heart activity. If there are interruptions of the electrical signal generation or transmission, the ECG changes. These changes can be useful in diagnosing changes within the heart.

Components of the ECG

The electrical events of the heart (ECG) are usually recorded as a pattern of a baseline (isoelectric line,) broken by a **P** wave, a **QRS** complex, and a **T** wave. In addition to the wave components of the ECG, there are intervals and segments.

- The **isoelectric line** is a point of departure of the electrical activity of depolarizations and repolarizations of the cardiac cycles and indicates periods when the ECG electrodes did not detect electrical activity.
- An **interval** is a time measurement that includes waves and/or complexes.
- A **segment** is a time measurement that does not include waves and/or complexes.



Components of the ECG (Lead II) & Electrical and mechanical events of the cardiac cycle

Table 1 Components of the ECG & Typical Lead II Values*

ECG COMPONENT		*Measurement area…*	*Represents…*	**Duration** *(seconds)*	**Amplitude** (millivolts)
Waves	**P**	begin and end on isoelectric line (baseline); normally upright in standard limb leads	depolarization of the right and left atria.	0.07 – 0.18	< 0.25
	QRS complex	begin and end on isoelectric line (baseline) from start of Q wave to end of S wave	depolarization of the right and left ventricles. Atrial repolarization is also part of this segment, but the electrical signal for atrial repolarization is masked by the larger QRS complex (see Fig. 5.2)	0.06 – 0.12	0.10 – 1.50
	T	begin and end on isoelectric line (baseline)	repolarization of the right and left ventricles.	0.10 – 0.25	< 0.5
Intervals	**P-R**	from start of P wave to start of QRS complex	time from the onset of atrial depolarization to the onset of ventricular depolarization.	0.12-0.20	
	Q-T	from start of QRS complex to end of T wave	time from onset of ventricular depolarization to the end of ventricular repolarization. It represents the refractory period of the ventricles.	0.32-0.36	
	R-R	from peak of R wave to peak of succeeding R wave	time between two successive ventricular depolarizations.	0.80	
Segments	**P-R**	from end of P wave to start of QRS complex	time of impulse conduction from the AV node to the ventricular myocardium.	0.02 – 0.10	
	S-T	between end of S wave and start of T wave	period of time representing the early part of ventricular repolarization during which ventricles are more or less uniformly excited.	< 0.20	
	T-P	from end of T wave to start of successive P wave	time from the end of ventricular repolarization to the onset of atrial depolarization.	0.0 – 0.40	

Leads

The particular **bipolar** arrangement of two electrodes (one **positive**, one **negative**) with respect to a third electrode (the **ground**) is called a **lead**. The electrode positions for the different leads have been standardized. Typical Lead II values are shown above in Table.

The dominant ECG component in any normal standard lead record is the QRS complex. Usually, in a Lead II recording the Q and S waves are small and negative and the R wave is large and positive as shown in Fig. However, it is important to note many factors, normal and abnormal, determine the duration, form, rate, and rhythm of the QRS complex.

- Normal factors include body size (BSA) and distribution of body fat, heart size (ventricular mass,) position of the heart in the chest relative to lead locations, metabolic rate, and others.

For example, in a person who has a high diaphragm, the apex of the heart may be shifted slightly upward and to the person's left. This change in the position of the heart alters the "electrical picture" of ventricular depolarization seen by the Lead II electrodes, resulting in decreased positivity of the R wave and increased negativity of the S wave. In other words, the positive amplitude of the R wave decreases and the negative amplitude of the S wave increases.

Similar changes in the Lead II QRS complex may be observed in a person, an athlete for example, who has no cardiac disease but does have a larger than normal left ventricular mass. In fact the decrease in R wave positivity coupled with the increase in S wave negativity may be so extreme as to give rise to the mistaken impression that the R wave has become inverted, when in reality the inverted spike is an enlarged S wave preceded by a much smaller but still positive R wave. When the amplitudes of Lead II Q, R, and S waves are all negative, the result is an abnormal inverted QRS complex.

Significant diagnostic features of the ECG signal are:

- Duration of component parts of the signal
- Polarities and magnitudes
- The details of the ECG signal and the degree of variability in different parts of the ECG signal is shown below:

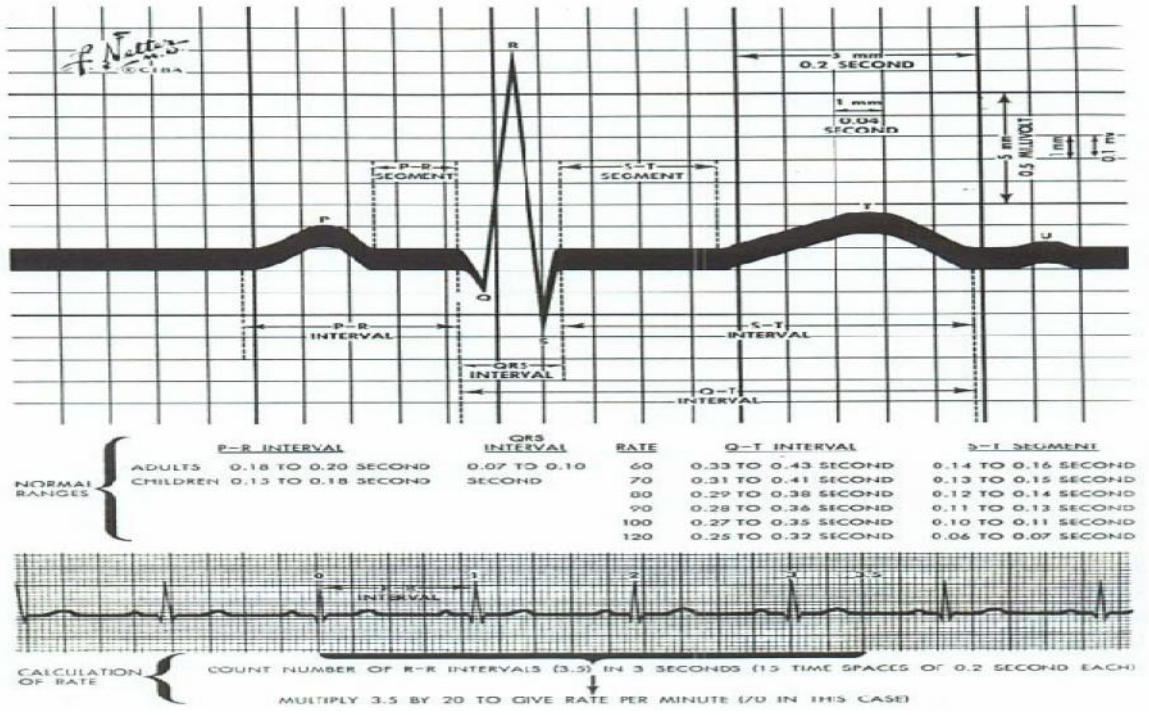


Figure _ _ ECG Signal

- The QRS amplitude, polarity, time duration, the RR interval (indicator of heartbeat per min.) and the T-wave amplitude are some very important and distinctive features of the ECG signal.
- The heart rate in BPM = Beats Per Minute) is simply = 60 (RR interval in seconds)

Some ECG waveform abnormalities that may indicate illness are:

- An extended PR interval may be diagnosed as AV node block
- A widening of the QRS complex may indicate conduction problems in the bundle of His
- An elevated ST segment may indicate occurrence of myocardial Infarction (MI)
- A negative polarity in the T wave may be due to coronary insufficiency

ECG Leads

A Normal ECG recording for the standard lead connections leads I, II and III (Lead II provides the strongest signal)

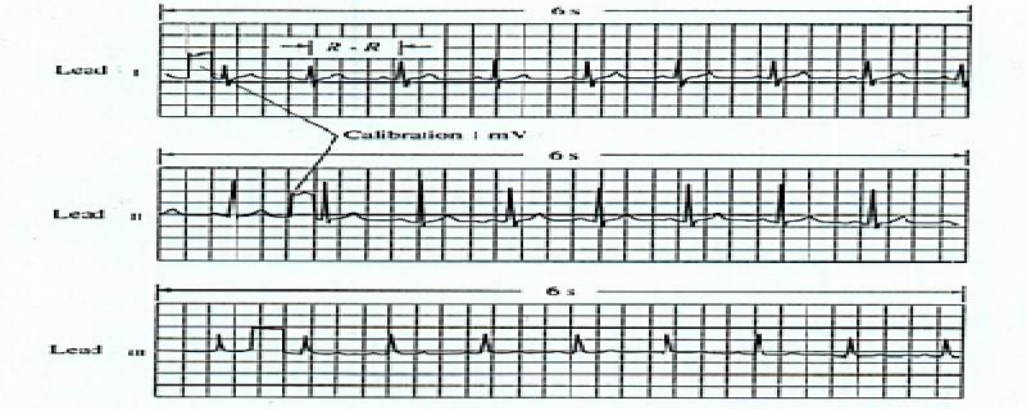


Figure Normal ECG waveforms

Obviously, all human hearts are not the same and this results into a high degree of **variability.**

Some abnormalities that may indicate illness:

- An extended P-R interval may be diagnosed as AV node block
- Widening of the QRS complex conduction problems in the bundle of His
- Elevated ST segment may indicate occurrence of MI
- Negative polarity T wave may be due to coronary insufficiency QRS amplitude, polarity, time domain, PR interval (indicator of heat beat per min. & T-wave amplitude are some very important.
- **Distinctive features**.
  1.Loss

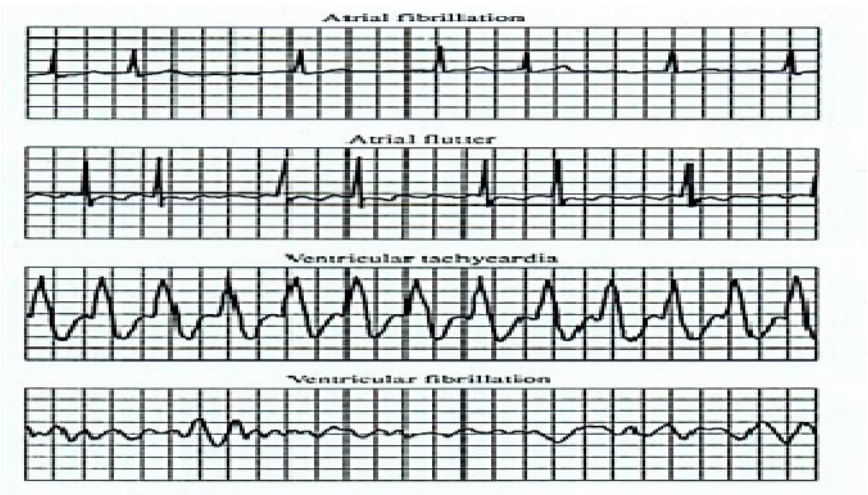


Figure ECG Abnormal waveforms

2. Origin of the ECG signal

- We have already covered this concept extensively in the previous lectures (The Dipole filed of the heart, the Eindhoven's Triangle, the electrical circuit model for the electrocardiographic problem, etc.)

Standard Limb Leads (I, II, III)

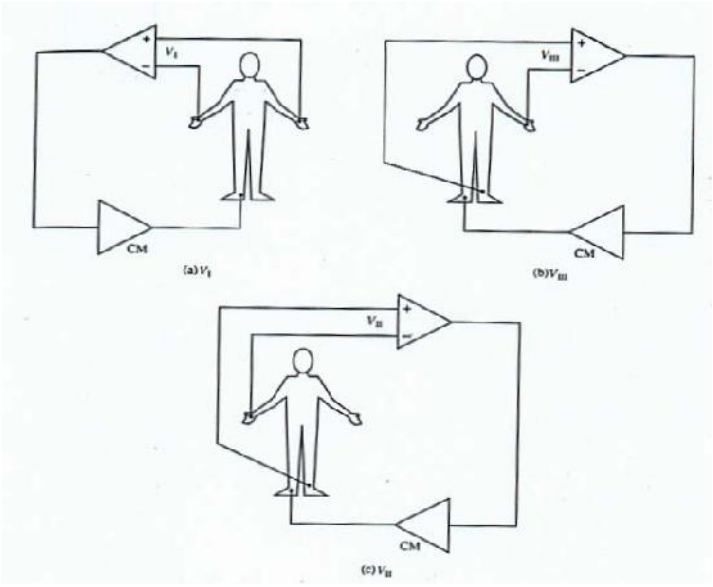


Figure origin of ECG Signal

- The lead wires are color-coded according to some conventions. One example is: White – RA (Right Arm), Black – LA (Left Arm), Green – RL (Right Leg), Red – LL (Left Leg), and Brown – C (Chest)

Augmented Limb Leads

- These leads offer a free 50% increase over leads VR, VL, and VF connections (unipolar leads) with respect to Wilson terminal AVR = -I – III/2, AVL = I – II/2, aVF = II – I/2

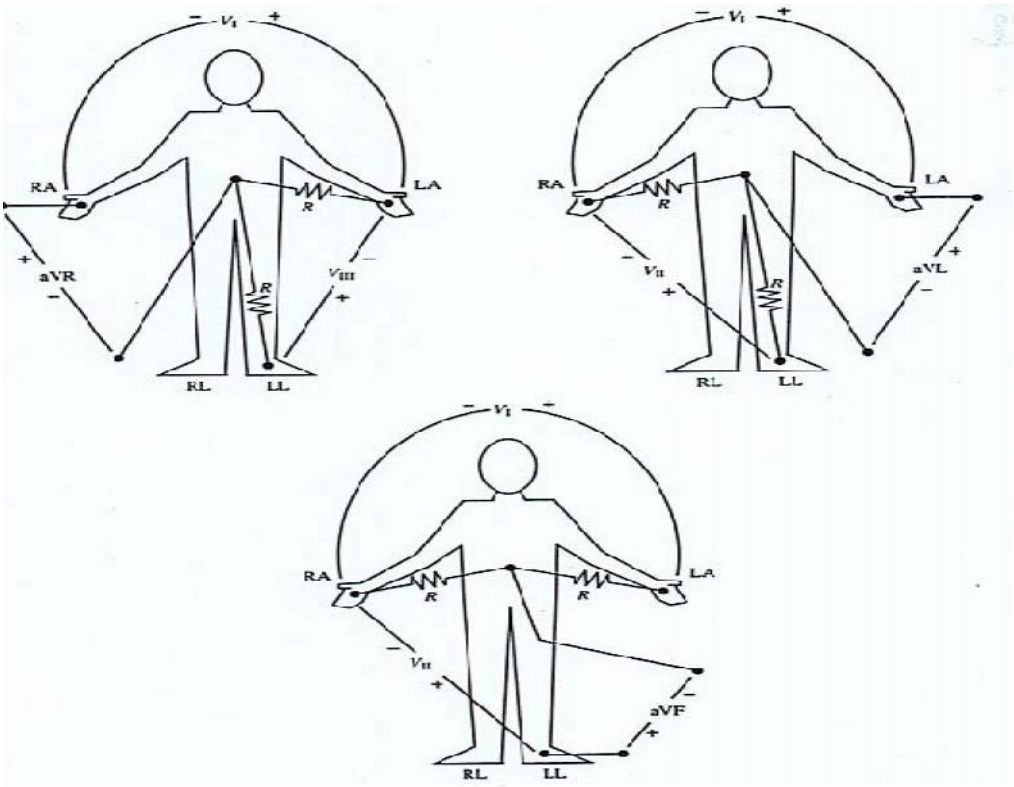


Figure Augmented Limb Leads

Each measurement is made from the reflected limb and the average of the other two limbs.

The ECG Machine

Most representative Specs:

- Zin = 10 MΩ
- Frequency response = 0.05 –100 Hz
- Strip Chart Recorder Speed = 25 mm/sec.
- Fast Speed = 100 mm/sec.

For detailed Specs. Refer to the Table in your text “Summary of performance requirements for electrocardiographs”

Location of the Heart

- The heart is located between the lungs behind the sternum and above the diaphragm.
- It is surrounded by the pericardium.
- Its size is about that of a fist, and its weight is about 250-300 g.
- Its center is located about 1.5 cm to the left of the midsagittal plane.

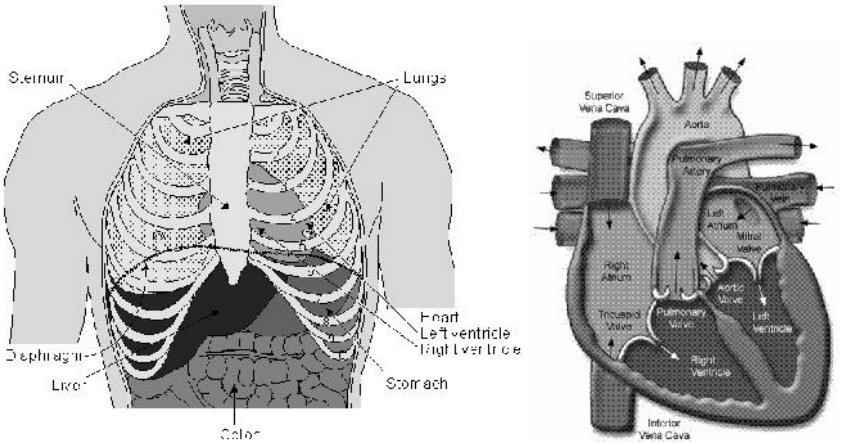


Figure 3 Location of Heart

Anatomy of the heart

- The walls of the heart are composed of cardiac muscle, called myocardium.
- It consists of four compartments:
  - the right and left atria and ventricles

The Heart Valves

- The tricuspid valve regulates blood flow between the right atrium and right ventricle.
- The pulmonary valve controls blood flow from the right ventricle into the pulmonary arteries
- The mitral valve lets oxygen-rich blood from your lungs pass from the left atrium into the left ventricle.
- The aortic valve lets oxygen-rich blood pass from the left ventricle into the aorta, then to the body.

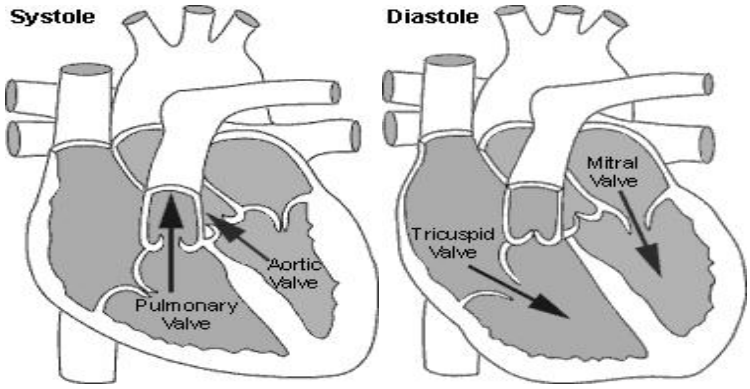


Figure Heart Valves

Blood circulation via heart

- The blood returns from the systemic circulation to the right atrium and from there goes through the tricuspid valve to the right ventricle.
- It is ejected from the right ventricle through the pulmonary valve to the lungs.

- Oxygenated blood returns from the lungs to the left atrium, and from there through the mitral valve to the left ventricle.
- Finally blood is pumped through the aortic valve to the aorta and the systemic circulation.

Electrical activation of the heart

- In the heart muscle cell, or *myocyte*, electric activation takes place by means of the same mechanism as in the nerve cell, i.e., from the inflow of Na ions across the cell membrane.

- The amplitude of the action potential is also similar, being 100 mV for both nerve and muscle
- The duration of the cardiac impulse is, however, two orders of magnitude longer than in either nerve cell or sceletal muscle cell.
- As in the nerve cell, repolarization is a consequence of the outflow of K ions.
- The duration of the action impulse is about 300 ms

Mechanical contraction of Cardiac Muscle

- Associated with the electric activation of cardiac muscle cell is its mechanical contraction, which occurs a little later.
- An important distinction between cardiac muscle tissue and skeletal muscle is that in cardiac muscle, activation can propagate from one cell to another in any direction.
- Electrical signal begins in the sinoatrial (SA) node: "natural pacemaker." causes the atria to contract.
- The signal then passes through the atrioventricular (AV) node.
  - sends the signal to the ventricles via the “bundle of His”
  - Causes the ventricles to contract.

The Conduction System

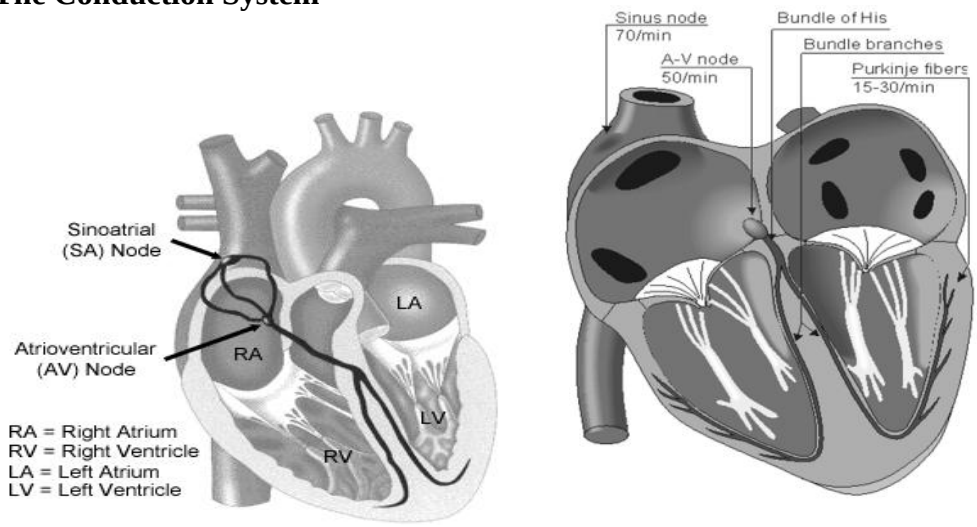


Figure Conduction System

The Action Potential

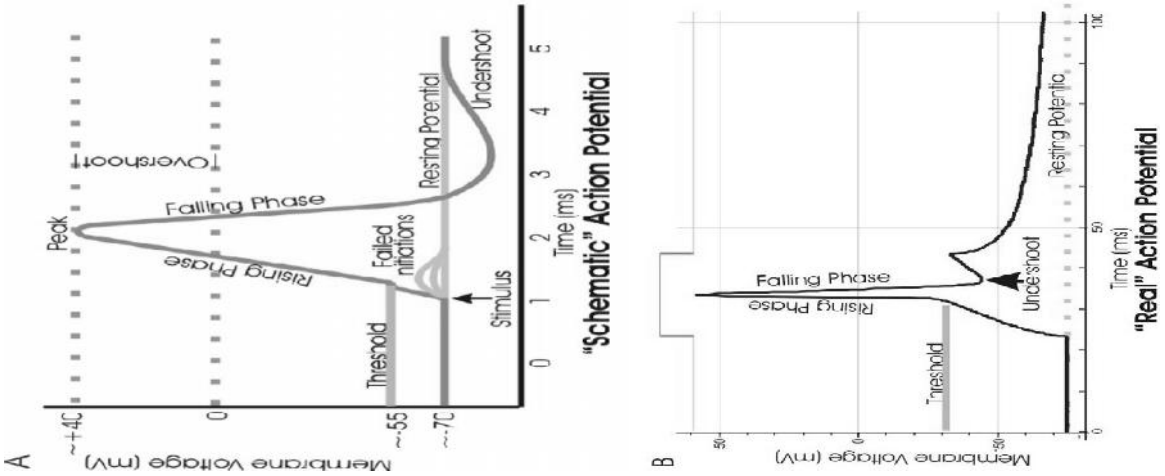


Figure Action Potential

Recording an AP requires the isolation of a single cell.

- Microelectrodes (with tips a few μm across) are used to stimulate and record the response. A typical AP is 2-4ms long with an amplitude of about 100Mv

ELECTROENCEPHALOGRAM (EEG)

- EEG is the recorded representation of bioelectric potentials generated by the neuronal activity of the brain.
- Basically, the brain is a gelatinous mass suspend in the meanings, the cerebrospinal fluid, skull and scalp.
- The brain is composed of three major subdivisions:
    1. Cerebellum,
    2. Brainstem
    3. (Medulla, pons, midbrain, diencephalon) and
    4. Cerebrum

The cerebellum is mainly involved with skeletal muscle functions and maintenance of balance. It coordinates smooth and directed movements.

- The brain stemis the stalk of the brain and serves as a relay station for all afferent (sensory) and efferent (motor) nerve fibers between the spinal cord and higher brain canters. It also gives rise to ten of the twelve cranial nerves, which supply the muscles and glands of the head and major organs in the thoracic and abdominal cavities
- Throughout the entire brainstem runs a core of tissue called the reticular formation, which serves as a highly complex cluster of neurons involved in integration of information from many afferent pathways as well as from numerous other parts of the brain.

- The cerebrum consists of the right and left hemispheres. The outer part of the cerebral hemispheres, the cerebral cortex, is a cellular shell 1.5 – 4 mm thick of grey matter.
- The cerebral cortex is highly convoluted and is the most complex integrating center of the nervous system. It brings together basic sensory information into meaningful perceptual images and formulates ultimate decisions for control over the motor systems of the body.
- The cerebral cortex is comprised of two layers: the pale cortex and the neocortex.
- The pale cortex is located on the median surface and the base of the brain and the neocortex is present on the superior and lateral aspects of the cerebral hemispheres.
- The neocortex is composed of six layers and its cells can be categorized as pyramidal and non-pyramidal cells. There are approximately 1010 neurons in the human cerebral cortex, about 75% of, which is pyramidal.
- Pyramidal cells, named originally after their shape, have several characteristics. Their cell bodies are commonly triangular in shape, with the base down and the apex directed toward the cortical (superficial) surface.
- The cell bodies vary in size, from axial dimensions of 15 x 10 μm up to 120 x 90 μm. A typical pyramidal cell consists of a long apical dendrite, about 2 mm long, that ascends from the apex of the cell body and enters the overlaying layers and terminally branches within the outermost layer of the neocortex.
- There is a dominant apical dendrites tree, looking like a forest of similarly oriented, densely packed units in the superficial layers of the neocortex, where extensive branching occurs.

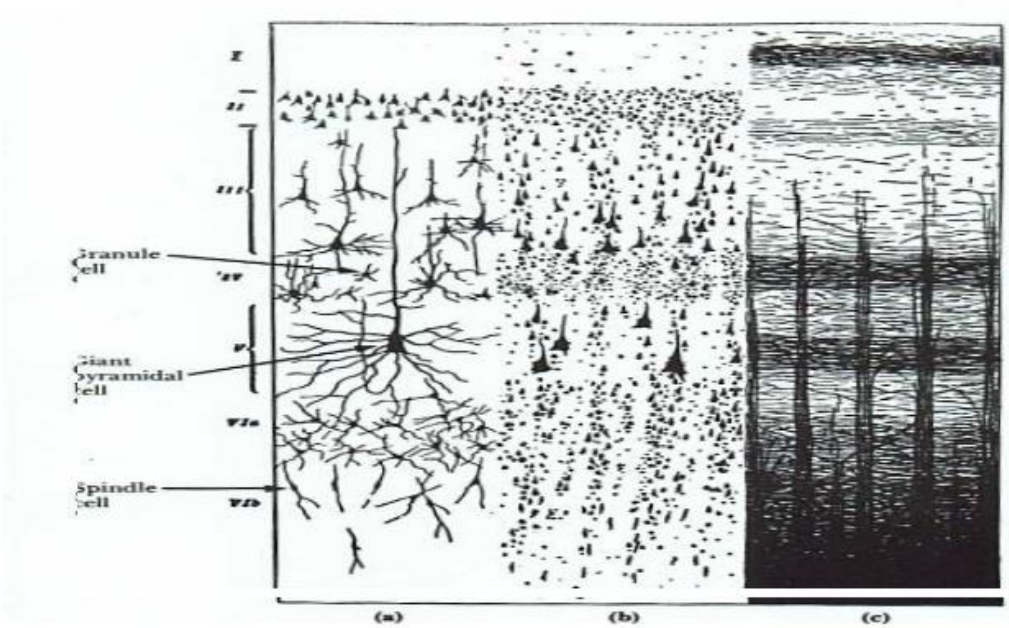


Figure EEG

- There is also a basilar dendritic system that extends out spherically from the cell body.
- Pyramidal cells also have an axon that emerges from the cell body and enters the sub cortical white matter.
- The axons of all pyramidal cells terminate in excitatory synapses. The initial segment of pyramidal cells is unmyelinated,as their recurrent branches

- Axons of some pyramidal cells turn back toward the cortical surface to end via their many dendritic branches on the dendrites of other cells.
- It has been shown by electrophysiological studies that under normal circumstances, propagating action potentials in axons do not contribute significantly to surface cortical recordings.
- There reason being that action potentials travel in large number of axons (running in many different directions relative to the surface) in a temporally a synchronized way. Therefore, their net contribution to the surface EEG is minimal and negligible.
- It has been shown that the vertically oriented pyramidal cells with their long apical dendrites running parallel to one another are the major contributors to the electro genesis of the cortical field potentials (EEG signal).

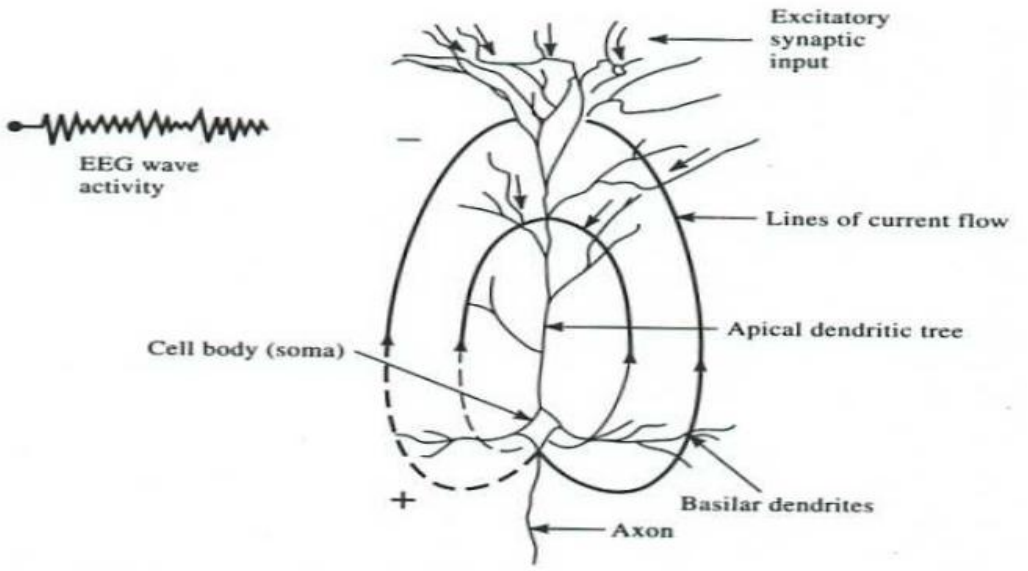


Figure Cerebrum

A highly schematic representation of a pyramidal cell and its role in the generation of surface EEG signal. Let's consider a single pyramidal cell, and explain how potential changes in one part of the cell relative to other parts could generate the EEG signal.

- Excitatory synaptic inputs to the branches in the apical dendritic tree of the pyramidal cells cause depolarization of the dendritic membrane.
- This leads into generation of an excitatory postsynaptic potential (EPSP)
- As a result, a radially oriented dipole is set up and sub threshold current flows in a closed path through the cytoplasmic core of the dendrites and cell body of the cell, returning to the synaptic sites via the conducting extracellular medium
- The lines of current flow make the extracellular medium close to the cell body act as a source with + polarity and the upper part of the apical dendritic tree to act as a sink with – polarity.
- This leads into recording a negative potential at the cortical surface
- In case of inhibitory synaptic inputs to the branches in the apical

dendritic tree, an inhibitory postsynaptic potential (IPSP) is generated with a reversal in the polarity of the current dipole, which leads into a generation of a positive cortical recording.
- Therefore, the influence of a particular dendritic postsynaptic potential on the cortical recording depends on its net excitatory or inhibitory effect and on its location relative to the measurement site.

The EEG (electroencephalogram) signal is a recording of the electrical activity of the brain. The EEG signal recorded at the cortex or the scalp is generated by the polled activity of billions of cortical and sub cortical regions. The origin of the EEG signal is based on the electrical activity of the pyramidal cells. The EEG potentials primarily reflect the summated fluctuations of excitatory and inhibitory postsynaptic potentials in the pyramidal cells of the upper layers of the cerebral cortex. For reasons of geometry as well as because of extreme extracellular attenuation, action potentials from firings of pyramidal cells contribute only minimally or not all to the generation of the EEG signal.

- All we need to contend ourselves with at this stages that the EEG or brain waves are summation of neural depolarization sin the brain due to the stimuli from the five senses as well as from thought processes (indeed a very complex source). More on this in physiology in the Nervous System topic.
- EEG potentials have random-appearing waveforms with peak-to-peak amplitudes ranging from less than 10 mV to over 100mV. Required bandwidth is from below 1 Hz to over 100 Hz.

EEG is recorded with 3 types of electrodes:

1. Scalp
2. Cortical Electrocardiogram (recording from surface of cortex)
3. Depth Electrodes recording from depth of brain (thin insulated needles of various designs)

- No matter where the recording is obtained from (scalp, cortex or depth of the brain), the fluctuating potentials represent a superposition of the volume conductor fields produced by a huge variety of active neuronal current-generators.
- On the surface of the brain (i.e. Electrocardiogram), we can record voltages on the order of 10 mV! But, typical EEG electrodes measure the electrical activity propagated through skull bone and is attenuated from 1 to 100 μV.
- EEG potentials vary as a function of position over the surface of the skull, making it necessary to select sets of electrodes grouped around Frontal, Parietal, Temporal and Occipital lobes.

The EEG Signal

- The character of the EEG signal is highly dependent on the degree of the activity of the cerebral cortex, i.e. waves change markedly between states of wakefulness and sleep.
- Much of the time, EEGs are irregular and no general pattern can be observed. Other times, distinct patterns emerge
- The EEG waveform is divided into four wave groups:

    1. The Alpha Waves (α) 8-13 Hz

2. The Beta Waves (β) 14-30 Hz (The Gamma Waves (γ) 22-30 Hz or higher)
3. The Theta Waves (θ) 4-7 Hz
4. The Delta Waves (δ) <3.5 Hz

Note: During periods of mental activity, the waves usually become asynchronous rather than synchronous, so the magnitude of summed potentials decreases in spite of cortical activity.

- In general there is a relationship between cerebral activity and the frequency of the EEG rhythm
- Frequency increases progressively with higher degrees of activity

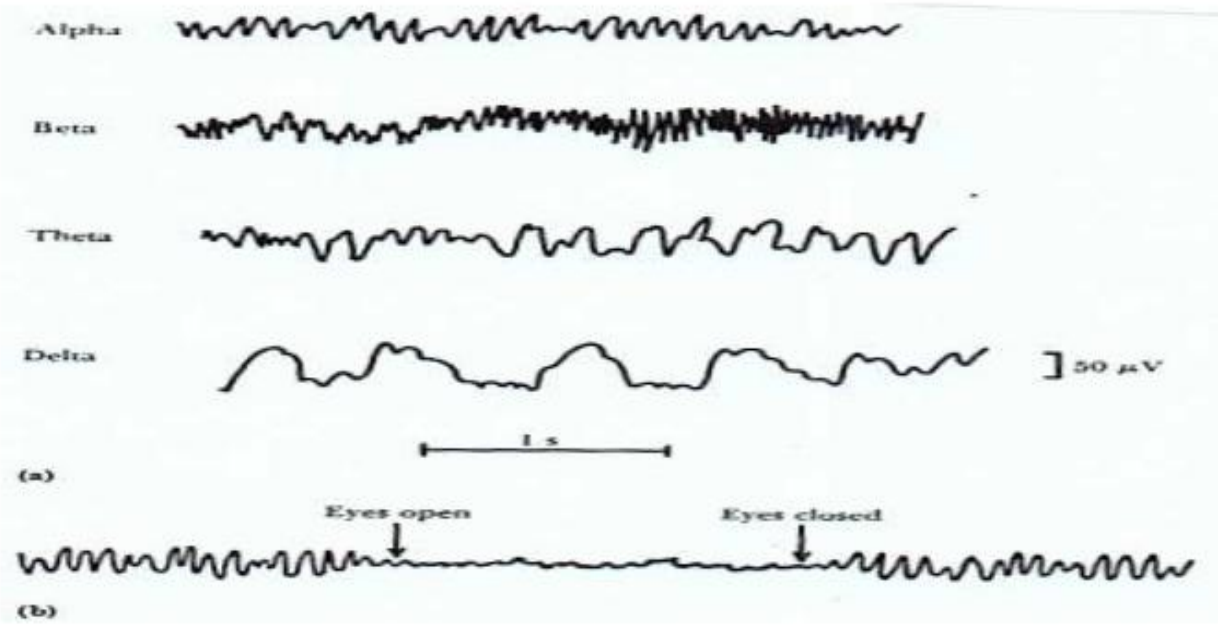


Figure · EEG waveform

Examples:

- δ-Waves(<3.5 Hz) occur in surgical anesthesia and sleep
- θ-Waves(4-7 Hz) occur in emotional stress and frustration
- α-Waves(8-13 Hz) occur during relaxed states
- β-Waves(14-30 Hz)occur during intense mental activity

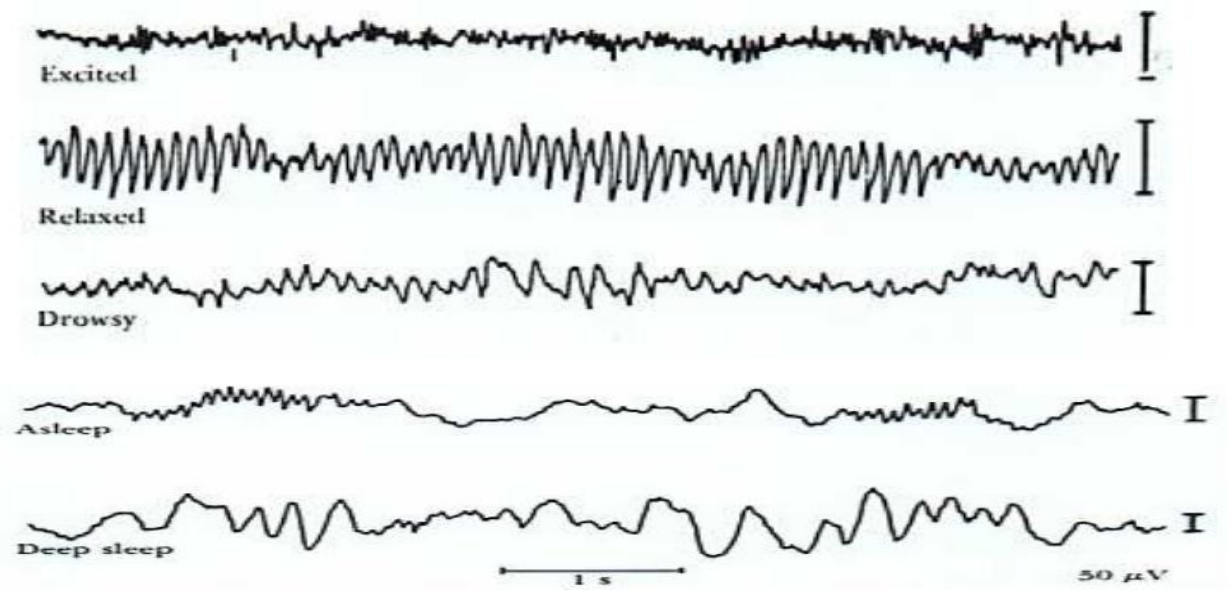


Figure Different EEG waveforms

The EEG changes that occur as a human subject goes to sleep.

EEGs in Diagnosis

The purpose of the clinical EEG is to help neurologists diagnose disease. The pathological states most commonly diagnosed using EEG are:

- Brain death (legal death)
- Brain tumors
- Epilepsy
- Multiple Sclerosis
- Sleep Disorder
- Evoked responses (diseases of the audio, visual and tactile senses)
- Modern life sustaining equipment like respirators, kidney dialyzers, ventilators, artificial heart pumps have changes the definition of death
- A sustained absence of EEG signal is a clinical measure of brain death and can be used in deciding whether to transplant a heart, liver, or lung or whether to shut down the life sustaining equipment

Some Representative Abnormal EEGS

Petit mal epilepsy– Minor for of seizure, clouding of consciousness and loss of contact with the environment

Grand mal epilepsy– Sudden loss of consciousness, falling down, tonic contractions (stiffening of muscles) followed by twitching and jerking movements of the limbs

Psychomotor seizures are parietal seizures characterized by: semi-purposeful movements, changes in consciousness, hallucinations and illusions.

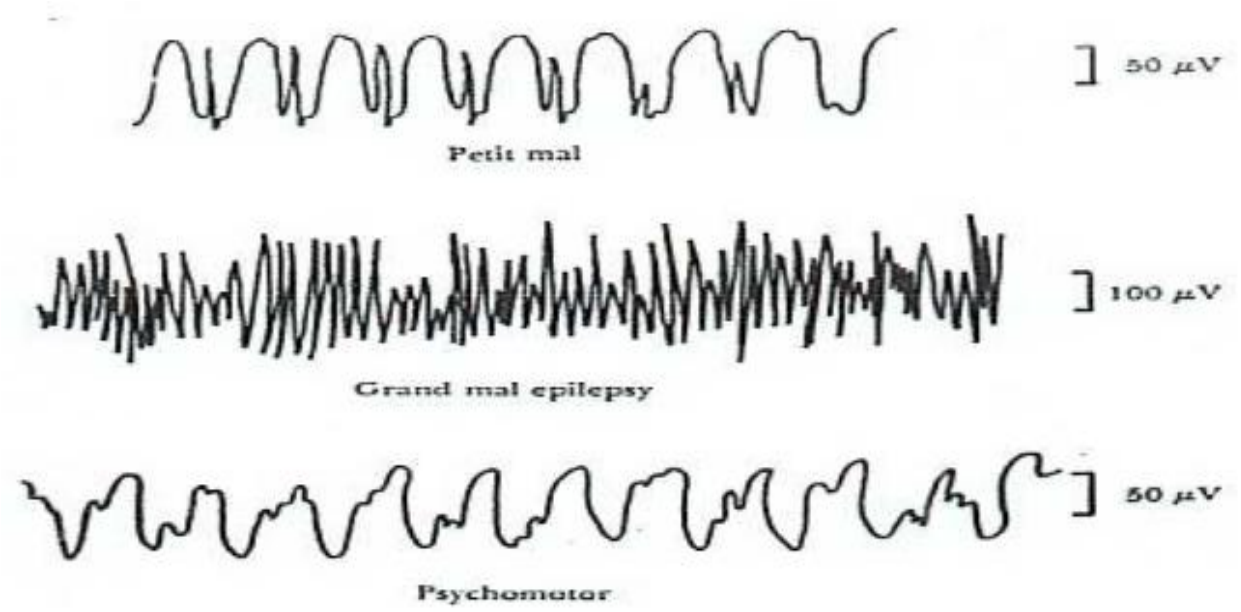


Figure Abnormal EEGs

EEG Electrode Positions

- In electroencephalography, the electrodes are placed in an arrangement referred to as the 10-20 system
- This is a placement scheme devised by the International Federation of Societies of Electroencephalography
- The electrodes are placed along a line drawn on the skull from the root of the nose, the nasion, to the classification (bump on the occipital lobe)
- The first mark is placed 10% of the distance along this line and others are arranged at 20% intervals

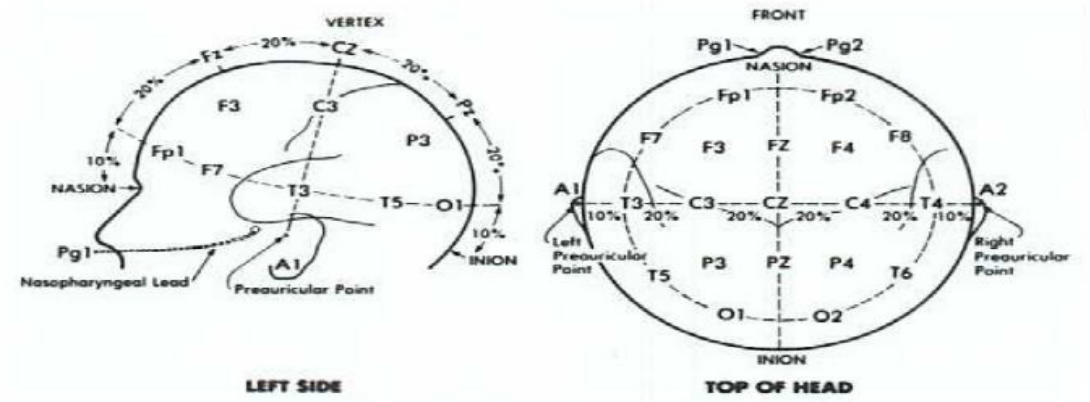


Figure EEG Electrode position

Electroencephalograph Signal Path

The EEG signal path is comprised of: Scalp (biosignal source) EEG electrodes , Junction box ,channel selector , differential amplifier, bank filters, display .

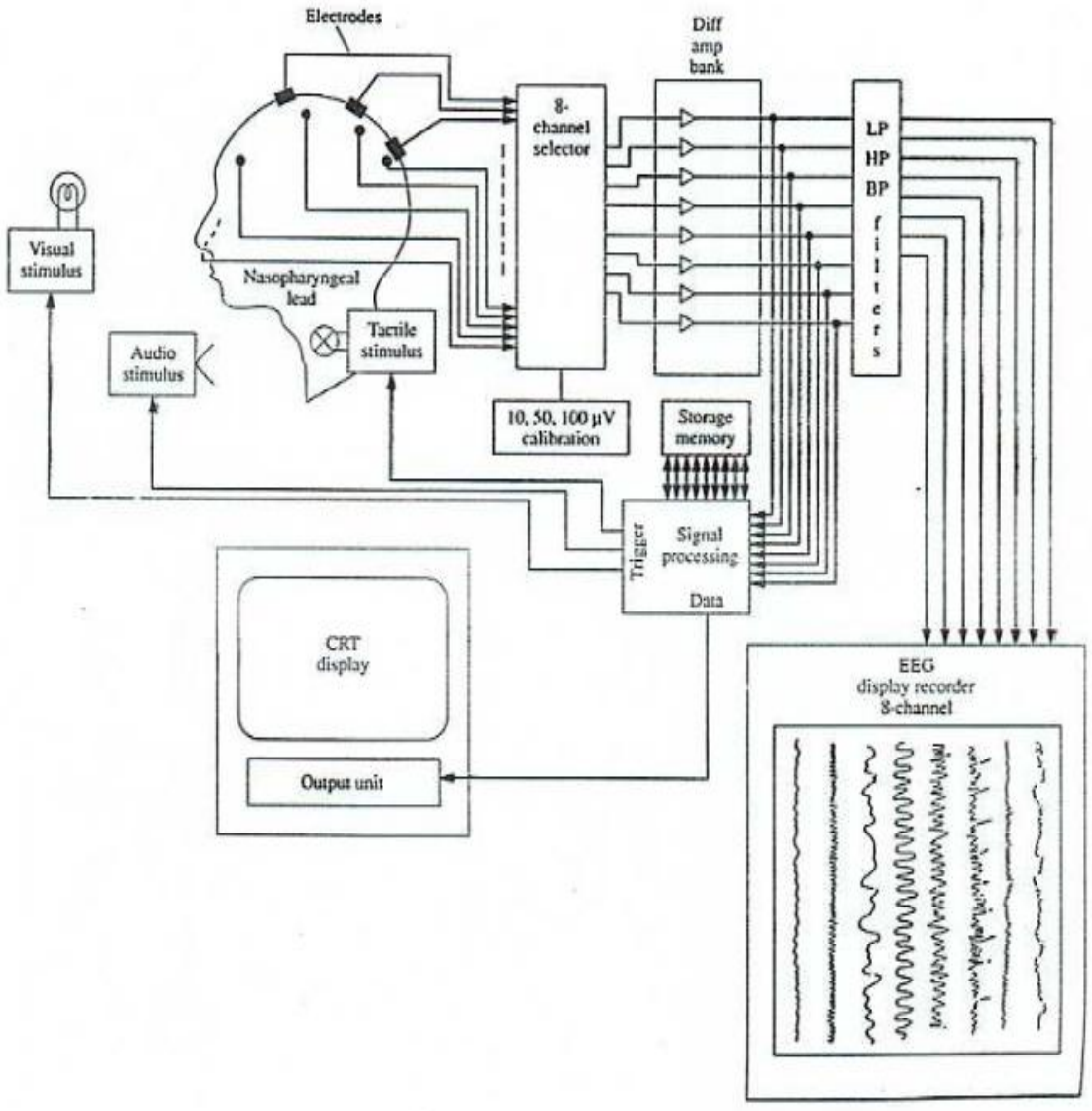


Figure Block diagram of Electroencephalograph Signal Path

- It shows the modern 8 channel EEG recorder. The patient cable consists of 21 electrodes and is connected to the 8 channel selector.
- The electrodes are attached to the channel selector in groups of 8 called a montage of electrodes.

- The right ear electrode acts as reference electrode for the right brain electrodes and left ear electrode act as reference electrode for left brain electrodes.
- The 50 Hz interference is reduced by employing differential amplifiers as preamplifiers with more than 80 dB CMRR and by use of 50 Hz notch filters.
- The effect of notch filter on signal distortion is not so much because important EEG signals have frequencies below 30 Hz.
- The output voltage from the amplifier may either be applied directly to the eight channel display through the filter bank or it may be stored as data on a tape recorder or in a computer memory for further processing.

EMG (ELECTRO MYOGRAPH)

It is an instrument used for recording the electrical activity of the muscles to determine whether the muscle is contracting or not. Study of neuromuscular function is also possible by using EMG. Muscular contractions are caused by the depolarization of muscle fibers. Similarly the recording of peripheral nerves action potentials is called as electro neurography.

ELECTRODES USED FOR EMG

Two types of electrodes:

Surface electrodes- Usually this electrode is used for EMG. But by using this electrode, it is not possible to take the deeper potential.

Needle electrodes – These are inserted into tissue or closer to tissue to measure the electrical activity of muscle.

EMG RECORDING SYSTEM

EMG potentials are taken from the tissue by using electrodes. These EMG potentials are given to differential amplifier. This is the high gain amplifier. Its frequency range is given as 10 Hz to 10 KHz.

Bandwidth of EMG is large. CMRR (Common mode Rejection Ratio) of this differential amplifier is 80 to 100 db.Input Impedance of this amplifier is 10 MΩ. Here there is no lead selector switch. Because only two electrodes are available. The output of the differential amplifier is given to loudspeaker system, tape recorder and CRO.

Before giving the output of differential amplifier to loudspeaker, it is given to power amplifier. Power amplifier amplifies the signal that is received by loudspeaker.

The amplified signal from the output of the differential amplifier is displayed by using CRO. Here storage oscilloscope is used. Output cab be displayed and the same can be stored in the CRO. The signal from the differential amplifier is recorded by using tape recorder. It is used for the future purpose.

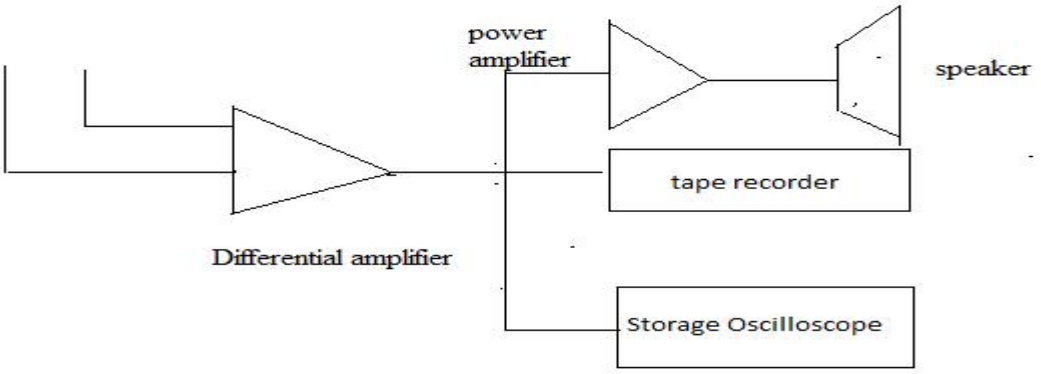


Figure EMG Recording System

MEASUREMENT OF CONDUCTION VELOCITY IN MOTOR NERVES

In modern EMG systems, nerve conduction time and nerve velocity are measured. For this measurement, initially nerve is stimulated and EMG is measured.This conduction velocity measurement is used to indicate the location and type of nerve lesion.

Steps involved in measurement of conduction velocity

- Stimulte is applied at point A
- Electrical activity of muscle is measured at point B
- The space between A and B is noted as l_1 meters.
- The time delay between applying stimulus and receiving action potential is known as latency. This time delay is detoned as t_1 second.
- Now change the position of A into C. Now the space is reduced. It is noted as l_2 meters.
- The time delay noted is t_2 second.
- Usually, $l_2 < l_1$ and $t_2 < t_1$.
- Now , the conduction velocity is given as , $V = l_1.l_2/t_1.t_2$.
- Usually V= 50 m/sec.
- If V<40 m/s. It means there is some disorder in nerve conduction.
- Thus conduction velocity is measured in motor nerves.
- Skeletal muscle is organized functionally on the basis of the motor unit.

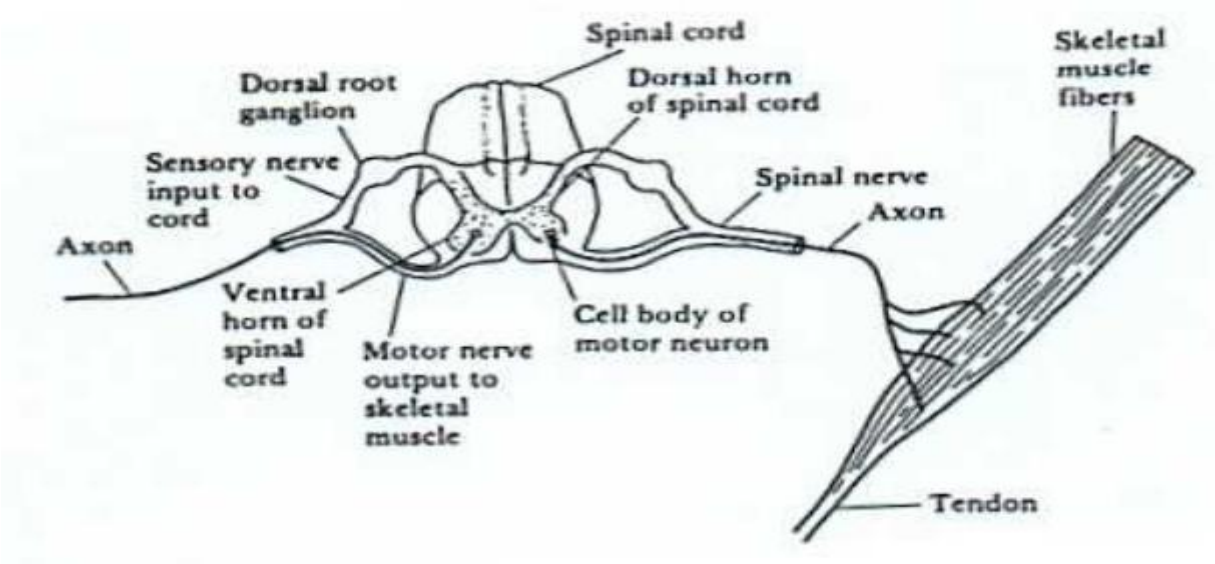


Figure Conduction Velocity In Motor Nerves

Single Motor Unit (SMU)

- The motor unit is the smallest unit that can be activated by a volitional effort (all constituent muscle fibers are activated synchronously)
- Single motor unit (SMU) consists of a single motor neuron and the group of skeletal muscles that it innervates
- SMU is a distributed unit bioelectric source in a volume conductor consisting of all other muscle fibers, both active and inactive.
- The evoked extracellular field potential from the active fibers of an SMU has a triphasic form of 3-15 ms duration and 20-2000 μV amplitude depending on the size of SMU
- The figure below shows motor unit potentials from normal muscle under graded levels of contraction. At high levels of activity, many sophisticated motor unit responses give rise to a complicated response (interference pattern)

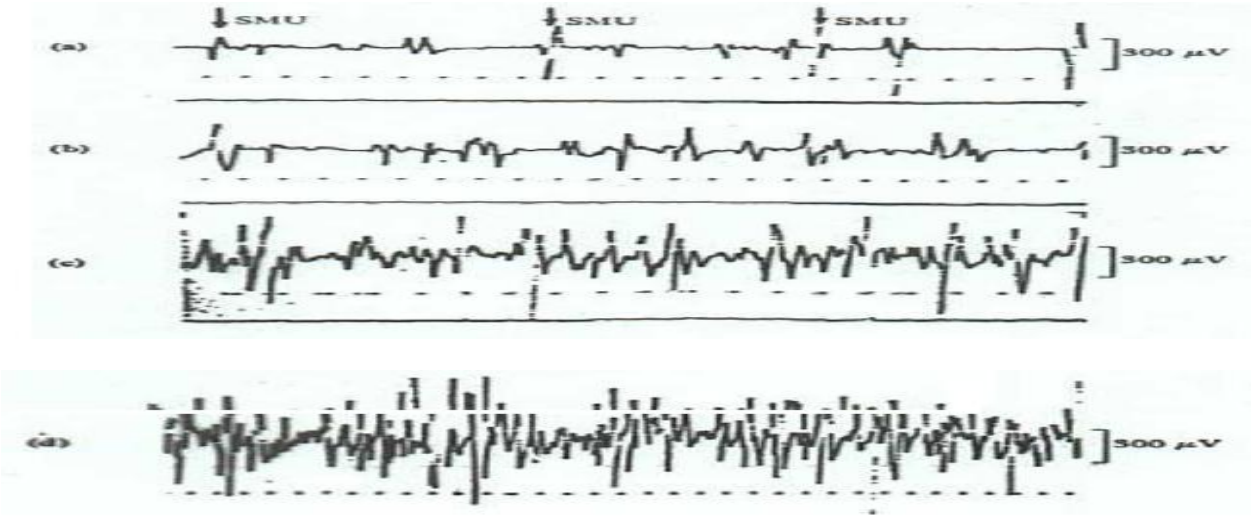


Figure EMG Recording

- A variety of electrodes have been developed for EMG recording
- The figure below shows the needle and wire electrodes used in recording the EMG signal
- The EMG is also of considerable clinical value
- The shape of SMU potentials is modified by disease

The figure below shows the EMG response for a normal subject and one with neuropathy

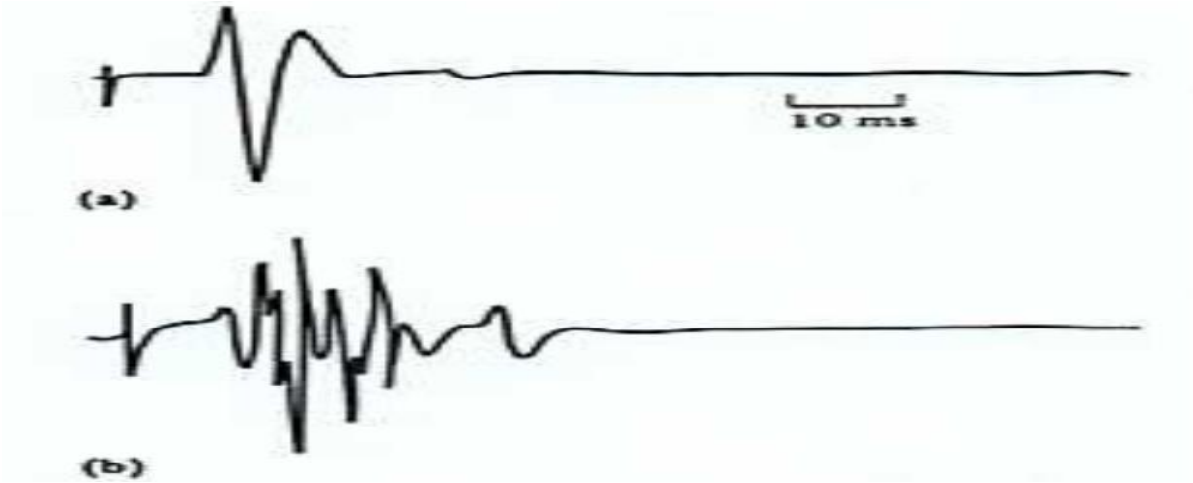


Figure : EMG response of a normal and an abnormal waveforms

Applications of EMG:

EMG is used in the field of:

- Electrophysiological testing.
- Clinical neurophysiology.
- Neurology.
- Psychiatry.

EOG (ELECTROCULOGRAM)

EOG is the recording of the biopotentials generated by the movement of eyes. Here, corneal-retinal potentials associated with eye movement is recorded. Electrode used in EOG: surface electrodes are used to measure EOG.

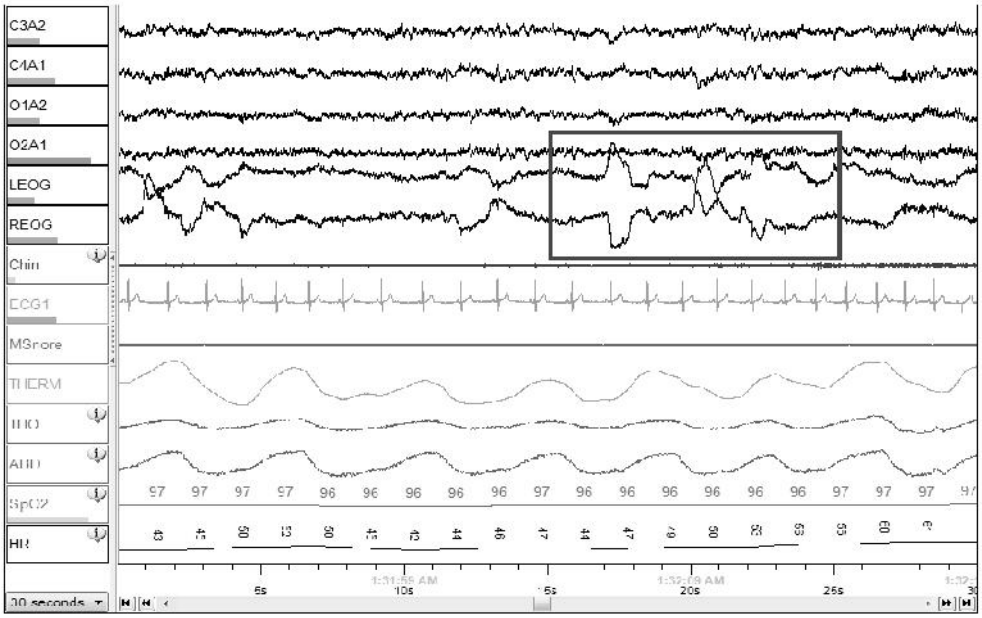


Figure EOG Waveforms

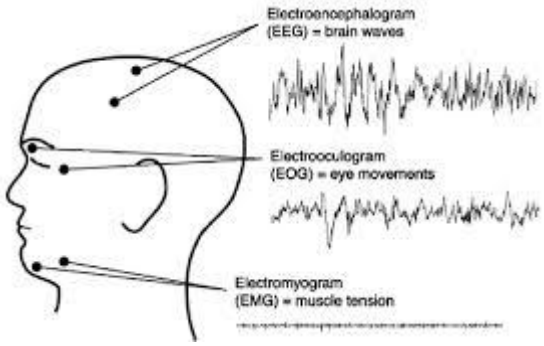


Figure Recording of Electroculogram

EOG MEASUREMENT

- ✓ Block diagram of EOG measurement system is shown. In the figure, position of electrodes is shown.
- ✓ One pair of electrodes is placed above and below the nose. These electrodes are used to measure the vertical movement of eye. The signals from these two pairs of electrodes are given to the amplifier.
- ✓ Another pair of electrodes is placed in the left side and right side of the eye. Horizontal movement of an eye is measured by using these electrodes.
- ✓ The signals from these electrodes are given to the amplifier circuit.

Applications of EOG

- ✓ The effect of some drugs on the eye movement systems can be identified by using EOG.
- ✓ It is used to analyze the state of semicircular canals.
- ✓ Diagnosis of the neurologic disorders is possible.
- ✓ The level of anesthesia can be indicated by the characteristic of eye movement

PCG (PHONO CARDIOGRAM)

The graphical record of heart sound is known as Phono Cardiogram. Here Cardio means the heart. The device which is used to measure heart sound is known as phonocardiograph. Auscultation: The technique of listening sound produced by organs and vessels of the body is known as auscultation.

In PCG, different types of heart sounds are measured. These heart sounds are due to the vibrations set up in the blood inside the heart by the sudden closure of valves. In abnormal heart additional sounds are heard between the normal heart sound. These additional sounds are known as murmurs.Murmers is generally caused by improper opening of the valves or by regurgitation.

CLASSIFICATION OF HEART SOUND

It is divided into four types

- ✓ Valve closure sound
- ✓ Ventricular filling sound
- ✓ Valve opening sound
- ✓ Extra cardiac sound

Valve closure sound

This sound occurs at the beginning of systole and at the beginning of diastole.

Ventricular filling sound

This sound is occurred at the time of filling of the ventricles.

Valve opening sound

This sound occurs at the time of opening of atrio- ventricular valves and semi lunar valves.

Extra cardiac sound

This sound occur in mid systole or late systole or early diastole

Systole: The contraction of the heart muscle. The systolic pressure is 120mm of Hg.

Diastole: The relaxation of the heart muscle. The diastolic pressure is 80 mm of Hg.

PCG RECORDING SYSTEM

Microphone is used to convert heart sound into the electrical signals. Certain positions are recommended to pick up the heart sound by using microphone. The electrical signal picked up by the microphone is amplified by the amplifier block. The amplified output is given to filter block.

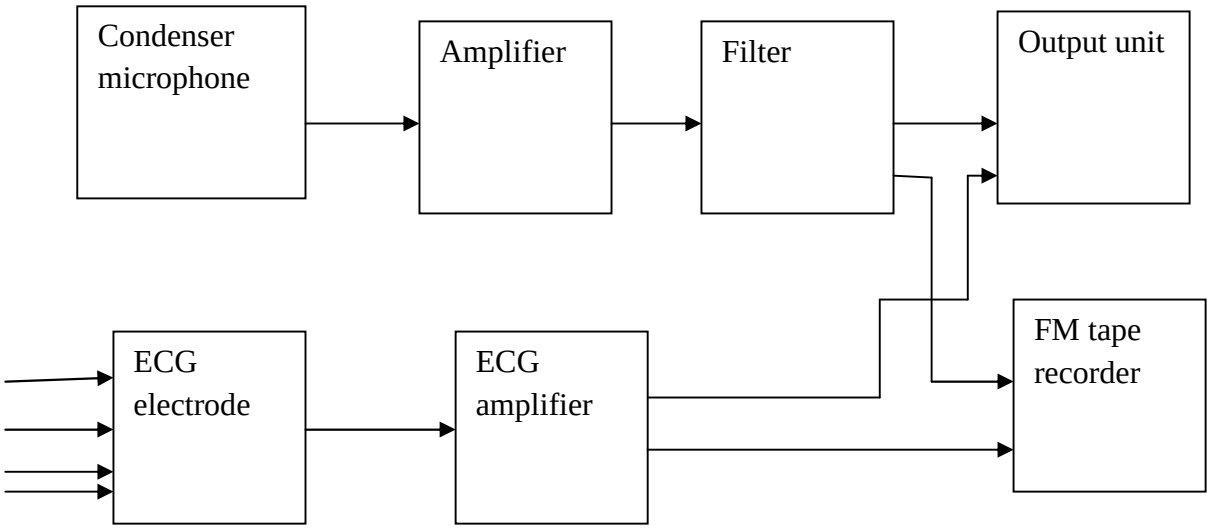


Figure Block Diagram of PCG Recording System

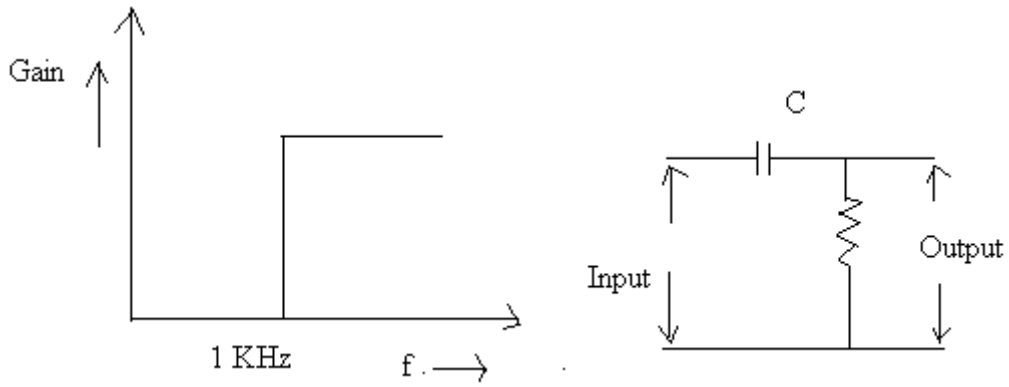


Figure Characteristics and Filter circuit

Here high pass filter is used. Its cut of frequency is 1 kHz. Here ECG electrode system and ECG amplifiers are usedfor reference for PCG. So ECG and PCG outputs are connected to FM tape recorder and output display unit.

TYPES OF MICROPHONES USED IN PCG

1. Air coupled microphone- Movement of chest is transferred through the air cushion. It provides low mechanical impedance to the chest.
2. Contact microphone – it is directly coupled to the chest wall and provides high impedance, high sensitivity, and low noise. Its light weight is also one of the advantageous factor.

The first heart sound is developed during the opening of aortic valve and during the closing of mitral valve

PCG waveform

Frequency of first heart sound consists of 30 to 45 Hz. Second heart sound is usually higher in pitch than the first. Its frequency range is 50Hz to 70 Hz. Third heart sound is extremely weak vibrate sound is extremely weak vibration. Its frequency is below 600 Hz.

Aortic stenos are murmur occurred when the blood is ejected from the left ventricle through aortic valve due to resistance to ejection, the pressure in the left ventricle increased. So turbulent blood flow occur.This turbulent blood impinging the aortic valve. So intense vibration is produced. It produces loud murmur.

Mitral regurgitation murmur- In this murmur, blood flows in backward direction through the mitral valve during systole.

Aortic regurgitation murmur – During diastole, sound is heard. In diastole blood flows in the backward direction from aorta to left ventricles when valves are damaged, then this sound is heard.

Mitral stenosis murmur – This murmur is produced when blood is passed from left atrium to left ventricle. This sound is very weak.

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

Need for Bio-amplifier:

Generally, biological/bioelectric signals have low amplitude and low frequency. Therefore, to increase the amplitude level of biosignals amplifiers are designed. The outputs from these amplifiers are used for further analysis and they appear as ECG, EMG, or any bioelectric waveforms. Such amplifiers are defined as Bio Amplifiers or Biomedical Amplifiers.

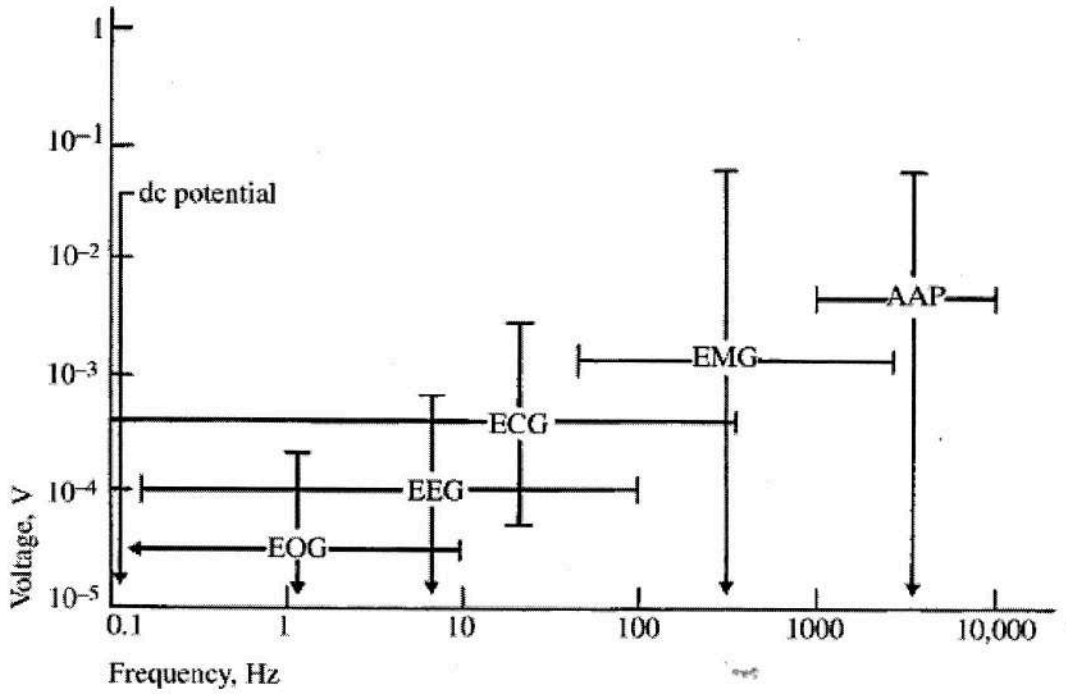
Basic Requirements for Biological Amplifiers

1. The **biological amplifier** should have a high input impedance value. The range of value lies between 2 MΩ and 10 MΩ depending on the applications. Higher impedance value reduces distortion of the signal.
2. When electrodes pick up biopotentials from the human body, the input circuit should be protected. Every bio-amplifier should consist of isolation and protection circuits, to prevent the patients from electrical shocks.
3. Since the output of a bioelectric signal is in millivolts or microvolt range, the voltage gain value of the amplifier should be higher than 100dB.
4. Throughout the entire bandwidth range, a constant gain should be maintained.
5. A bio-amplifier should have a small output impedance.
6. A good bio-amplifier should be free from drift and noise.
7. Common Mode Rejection Ratio (CMRR) value of amplifier should be greater than 80dB to reduce the interference from common mode signal.
8. The gain of the bio-amplifier should be calibrated for each measurement.

Types of Bio Amplifiers

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

Voltage and Frequency ranges of Some common Bio potential Signals:



The above figure shows the ranges of amplitude and frequencies covered by several of the common bio potential signals. Depending on the signal frequency ranges from dc to about 10 kHz. Amplitudes can range from tens of microvolts to approximately 100micro volts. the amplifier for a particular bio potential must be designed to handle that potential and to provide an appropriate signal at its output.

Differential Amplifier

Medical amplifiers designed for use in the input stage (preamplifiers) are mostly of the differential type. These type have three input terminals out of which one is arranged at the reference potential and the other two are live terminals.

The differential amplifier is employed when it is necessary to measure the voltage difference between two points, both of them varying in amplitude at different rates and in different patterns.

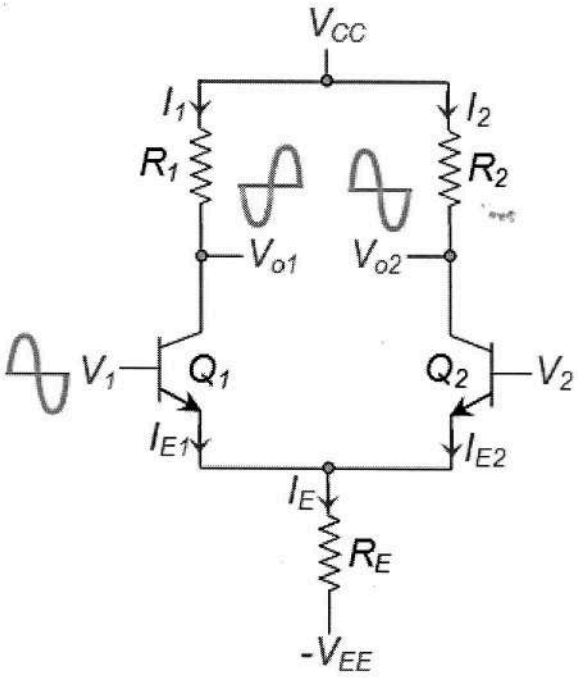
Heart-generated voltages picked up by means of electrodes on the arms and legs, and brain-generated voltages picked up by the electrodes on the scalp are typical examples of signals whose measurement requires the use of differential amplifiers.

The differential amplifier is an excellent device for use in the recording systems. Its excellence lies in its ability to reject common-mode interference signals which are invariably picked up by electrodes from the body along with the useful bioelectric signals.

Also, as a direct coupled amplifier, it has good stability and versatility. High stability is achieved because it can be insensitive to temperature changes which is often the source of excessive drift in other configurations.

It is versatile in that it may be adapted for a good many applications, e.g. applications requiring floating inputs and outputs or for applications where grounded inputs and/or outputs are desirable.

Figure 1 shows such a circuit made of two BJTs (Q_1 and Q_2) and two power supplies of opposite polarity viz., V_{CC} and $-V_{EE}$ which uses three resistors among which two are the collector resistors, R_{C1} and R_{C2} (one for each transistor) while one is the emitter resistor R_E common to both transistors.



A BJT Differential Amplifier

In this case, if the V_1 at Q_1 is sinusoidal, then as V_1 goes on increasing, the transistor starts to conduct and this results in a heavy collector current I_{C1} increasing the voltage drop across R_{C1}, causing a decrease in V_{o1}. Due to the same effect, even I_{E1} increases which increases the common emitter current, I_E resulting in an increase of voltage drop across R_E.

This means that the emitters of both transistors are driven towards positive which inturn implies that the base of Q_2 would start to become more and more negative. This results in a decrease of collector current, I_{C2} which inturn decreases the voltage drop across the collector resistor R_{C2}, resulting in an increase in the output voltage V_{o2}. This indicates that the changes in the sinusoidal signal observed at the input of transistor Q_1 is reflected as such across the collector terminal of Q_2 and appear with a phase difference of 180° across the collector

terminal of Q_1. The differential amplification can be driven by considering the output in-between the collector terminals of the transistors, Q_1 and Q_2.

On the other hand, if the signal applied to each input terminal is equal in amplitude and is in the same phase (called the common-mode input signal), the change in current flow through both transistors will be identical, the bridge will remain balanced, and the voltage between the output terminals will remain zero. Thus, the circuit provides high gain for differential mode signals and no output for all common mode signals.

The ability of the amplifier to reject these common voltages on its two input leads is known as common-mode rejection and is specified as the ratio of common-mode input to differential input to elicit the same response. It is abbreviated as CMRR (Common-mode rejection ratio).

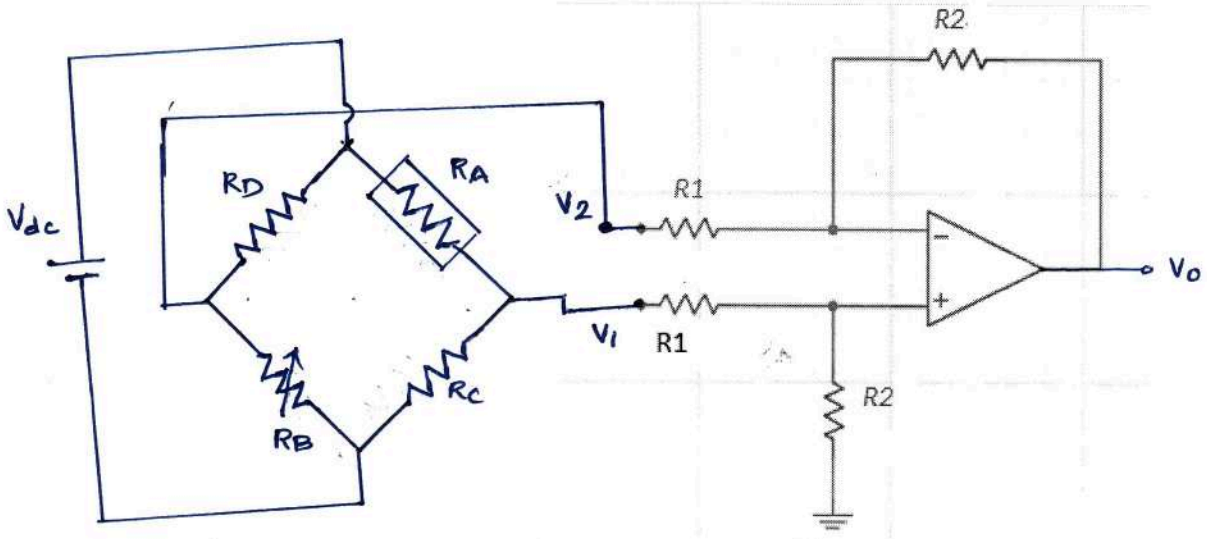
CMRR is an important specification referred to the differential amplifier and is normally expressed as decibels. CMRR of the preamplifiers should be as high as possible so that only the wanted signals find a way through the amplifier and all unwanted signals get rejected in the preamplifier stage.

Op-amp Differential Amplifier:

The design of a good differential amplifier essentially implies the use of closely matched components which has been best achieved in the integrated circuit form. High gain integrated dc amplifiers, with differential input connections and a provision for external feedback have been given the name operational amplifiers because of their ability to perform mathematical operations.

These amplifiers are applied for the construction of ac or dc amplifiers, active filters, phase inverters, multivibrators and comparators, etc. by suitable feedback arrangement, and therefore find a large number of applications in the medical field.

Figure 3 shows a single op-amp in a differential amplifier configuration.



R_A → Main Electrode

R_B → Reference Electrode

Input V_1=0, the circuit act as a inverting amplifier. So the output of inverting amplifier

$$V_{01} = -\frac{R_2}{R_1} V_1$$

If the input V_1 =0 ,the circuit act as a Non inverting amplifier. The voltage at the non-inverting terminal

$$V_N = V_2 \frac{R_2}{R_1 + R_2}$$

The non inverting amplifier output is

$$V_{02} = \left(1 + \frac{R_2}{R_1}\right) V_N$$

The total output voltage of differential amplifier,

$$V_0 = V_{01} + V_{02}$$

$$V_0 = -\frac{R_2}{R_1} V_1 + \left(1 + \frac{R_2}{R_1}\right) V_N$$

$$V_0 = -\frac{R_2}{R_1} V_1 + \left(1 + \frac{R_2}{R_1}\right) V_2 \frac{R_2}{R_1 + R_2}$$

$$V_0 = \frac{R_2}{R_1} (V_1 - V_2)$$

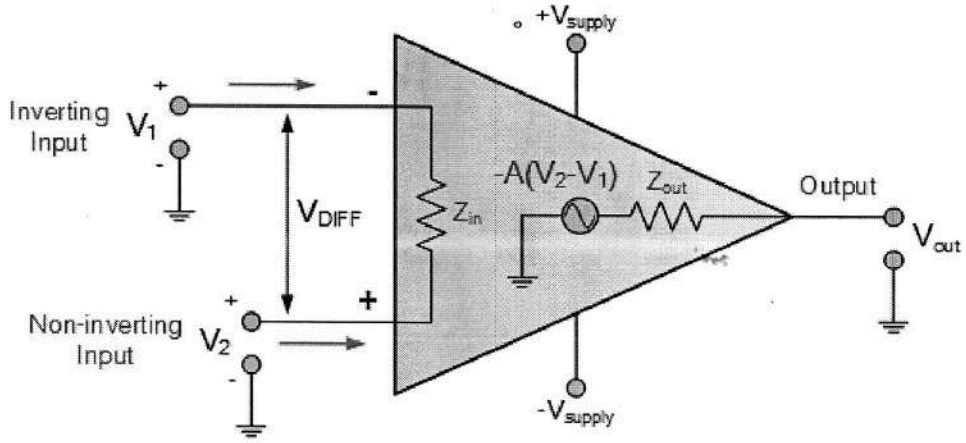
The common mode rejection for most op-amps is typically between 60 dB and 90 dB. This may not be sufficient to reject common mode noise generally encountered in biomedical measurements. Also, the input impedance is not very high to handle signals from high impedance sources. One method to increase the input impedance of the op-amp is to use field effect transistors (FET) in the input differential stage. A more common approach is to use an instrumentation amplifier in the preamplifier stage.

Operational Amplifier Configurations:

An Op-amp is a high gain differential amplifier. The best way to approach the design of a circuit that uses Op-amp is first to assume that the Op-amp is ideal.

Ideal Characteristics:

An Op-amp ideal equivalent circuit is shown in the figure.



The voltage at the inverting input terminal V_1 and Non inverting input terminal V_2.The voltage difference at the input side $V_d=V_2-V_1$.
Op-amp output voltage $V_0= A(V_2-V_1)$.

Ideal Op-amp Characteristics:

Ideal Op-amp characteristics are given below. The values are compared with practical Op-amp.

Parameter	Ideal Op-amp	Typical Op-amp
Differential Voltage Gain	∞	10^5-10^9
Common mode Voltage gain	0	10^{-5}
Input resistance	∞	10^6
Output resistance	0	100-1000 Ω
Bandwidth	∞	Few MHz
Offset Voltage and Current	0	Few Microvolts and micro amps

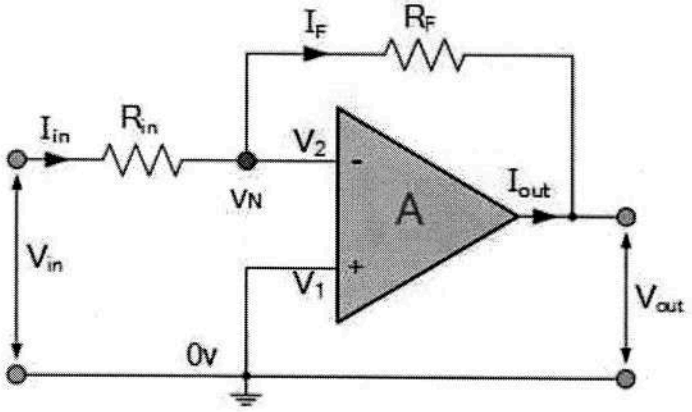
Inverting Amplifier:

While on the one hand, operational amplifiers offer very high gain, it makes the amplifier unstable & hard to control. Some of this gain can be lost by connecting a resistor across the amplifier from the output terminal back to the inverting input terminal to control the final gain of the amplifier. This is commonly known as negative feedback and produces a more stable op-amp.

Negative feedback is the process of feeding a part of the output signal back to the input. But to make the feedback negative, it is fed to the negative or "inverting input" terminal of the op-amp using a resistor. This effect produces a closed loop circuit resulting in Closed-loop Gain. A closed-loop inverting amplifier uses negative feedback to accurately control the overall gain of the amplifier, but causes a reduction in the amplifiers gain

In an inverting amplifier circuit, the operational amplifier inverting input receives feedback from the output of the amplifier. Assuming the op-amp is ideal and applying the concept of virtual short at the input terminals of op-amp, the voltage at the inverting terminal is equal to non-inverting terminal. The non-inverting input of the operational amplifier is connected to ground.

As the gain of the op amp itself is very high and the output from the amplifier is a matter of only a few volts, this means that the difference between the two input terminals is exceedingly small and can be ignored. As the non-inverting input of the operational amplifier is held at ground potential this means that the inverting input must be virtually at earth potential.



Derive the output voltage expression of this inverting amplifier, V_N=0, Due to Virtual Ground.

$$I_{in} = I_F$$

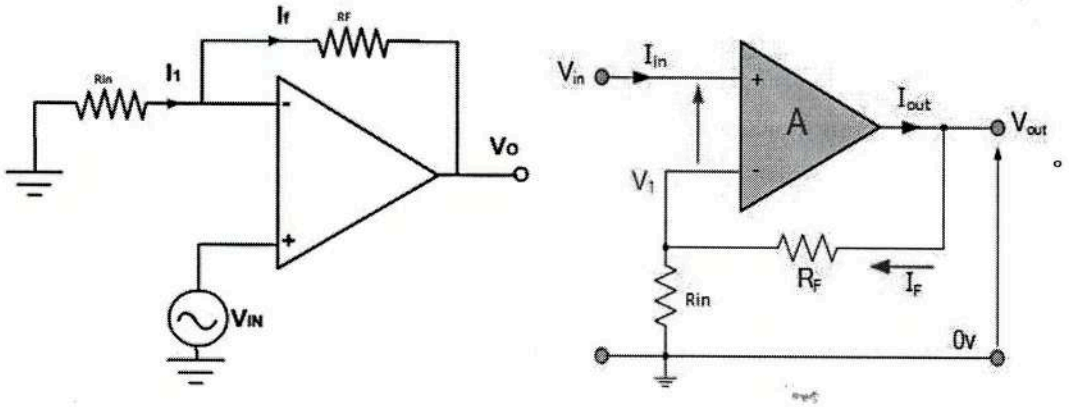
$$\frac{V_{in}-V_N}{R_{in}} = \frac{V_N-V_{out}}{R_F}$$

$$V_{out} = -\frac{R_F}{R_{in}} V_{in}$$

$$Gain\ A = \frac{R_F}{R_{in}}$$

Non-Inverting Amplifier:

The non-inverting amplifier is one in which the output is in phase with respect to the input. The feedback is applied at the inverting input. However, the input is now applied at the non-inverting input. The output is a non-Inverted (in terms of phase) amplified version of input. The gain of the non-inverting amplifier circuit for the operational amplifier is easy to determine.



Just rotate inverting and non-inverting terminal

$$V_1 = V_{in}$$

$$V_{in} = V_{out}\ \frac{R_{in}}{R_F + R_{in}}$$

$$V_{out} = V_{in}\ \frac{R_F + R_{in}}{R_{in}}$$

$$V_{out} = V_{in}\ (1 + \frac{R_F}{R_{in}})$$

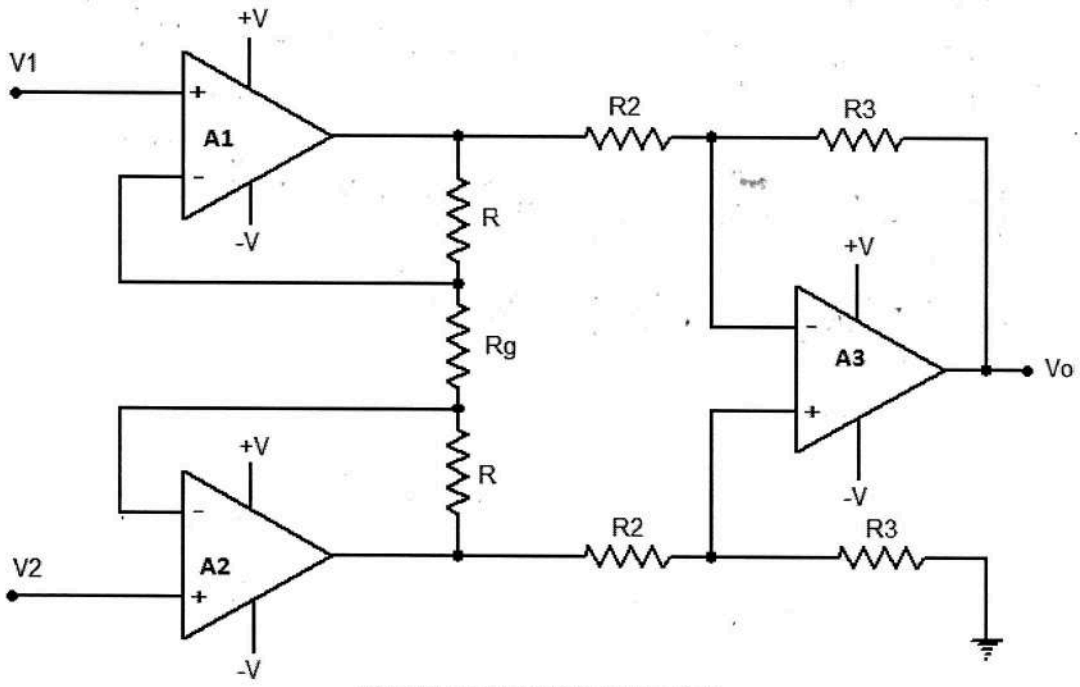
$$Gain\ A = (1 + \frac{R_F}{R_{in}})$$

Impedance matching circuit:

Instrumentation Amplifier:

Instrumentation amplifier is a kind of differential amplifier with additional input buffer stages. **The addition of input buffer stages makes it easy to match (impedance matching) the amplifier with the preceding stage.** Instrumentation are commonly used in industrial test and measurement application.

The instrumentation amplifier also has some useful features like low offset voltage, high CMRR (Common mode rejection ratio), high input resistance, high gain etc. The circuit diagram of a typical instrumentation amplifier using opamp is shown below.



INSTRUMENTATION AMPLIFIER

A circuit providing an output based on the difference between two inputs (times a scale factor) is given in the above figure. In the circuit diagram, opamps labelled A1 and A2 are the input buffers. Anyway the gains of these buffer stages are not unity because of the presence of R' and Rg. Op amp labelled A3 is wired as a standard differential amplifier. R3 connected from the output of A3 to its non inverting input is the feedback resistor. R2 is the input resistor. The voltage gain of the instrumentation amplifier can be expressed by using the equation below.

Op-amp A3 working as a differential amplifier. The output voltage expression of differential amplifier,

$$V_0 = \frac{R_3}{R_2}(V_2' - V_1') \quad \text{---------- (1)}$$

$$V_1' = -R'I + V_1 \quad \text{---------- (2)}$$

$$V_2' = R'I + V_2 \quad \text{---------- (3)}$$

Let $I = \frac{V_2 - V_1}{R_g}$

Substitute I in Eq. (2) and (3) and derive V_1' and V_2'

$$V_1' = -R'\left(\frac{V_2 - V_1}{R_g}\right) + V_1$$

$$V_1' = -\frac{R'}{R_g}V_2 + \frac{R'}{R_g}V_1 + V_1$$

$$V_1' = -\frac{R'}{R_g}V_2 + V_1\left(1 + \frac{R'}{R_g}\right)$$

$$V_2' = R'\left(\frac{V_2 - V_1}{R_g}\right) + V_2$$

$$V_2' = \frac{R'}{R_g}V_2 - \frac{R'}{R_g}V_1 + V_2$$

$$V_2' = -\frac{R'}{R_g}V_1 + V_2\left(1 + \frac{R'}{R_g}\right)$$

Substitute V_1' and V_2' in Eq.(1)

$$V_0 = \frac{R_3}{R_2}\left[-\frac{R'}{R_g}V_1 + V_2\left(1 + \frac{R'}{R_g}\right) + \frac{R'}{R_g}V_2 - V_1\left(1 + \frac{R'}{R_g}\right)\right]$$

$$V_0 = \frac{R_3}{R_1}\left[\frac{R'}{R_g}(V_2 - V_1) + \left(1 + \frac{R'}{R_g}\right)(V_2 - V_1)\right]$$

$$V_0 = \frac{R_3}{R_2}\left(1 + 2\frac{R'}{R_g}\right)(V_2 - V_1)$$

If need a setup for varying the gain, replace Rg with a suitable potentiometer. Instrumentation amplifiers are generally used in situations where high sensitivity, accuracy and stability are required.

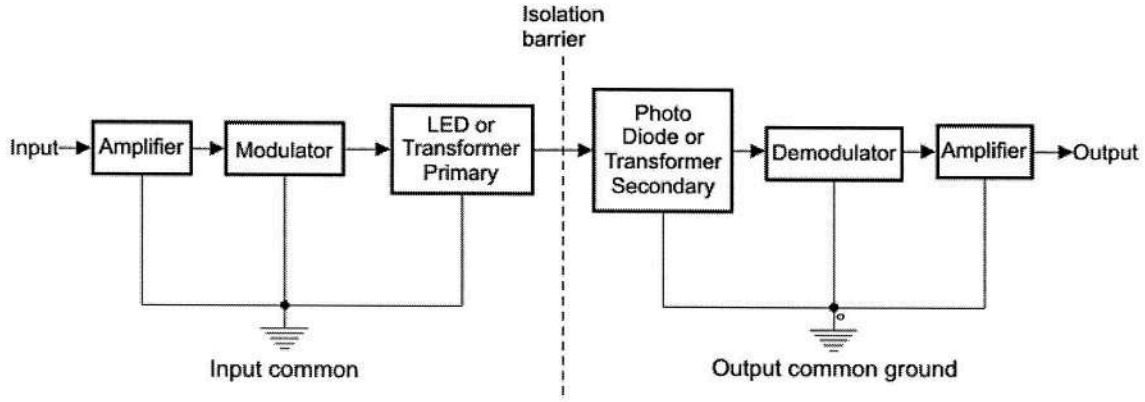
Isolation Amplifier:

For safety, it is important to protect the user from the hazards of electrical shock. Electrical shock can always present a safety risk with electrical circuits and it is important to consider the problem seriously.

It is worth highlighting that it is current, not voltage, which is the real hazard here. Current flow in tissue can cause excessive resistive heating, leading to burns, electrochemical heating, and electrical stimulation of neuromuscular systems.

Isolation amplifiers can be used to break ground loops, eliminate source ground connections, and provide isolation protection to patient and electronic equipment. In a biopotential amplifier, the main purpose of the isolation amplifier is the protection of the patient by

eliminating the hazard of electric shock resulting from the interaction among patient, amplifier, and other electric devices in the patient's environment, specifically defibrillators and electrosurgical equipment. It also adds to the prevention of line frequency interferences.

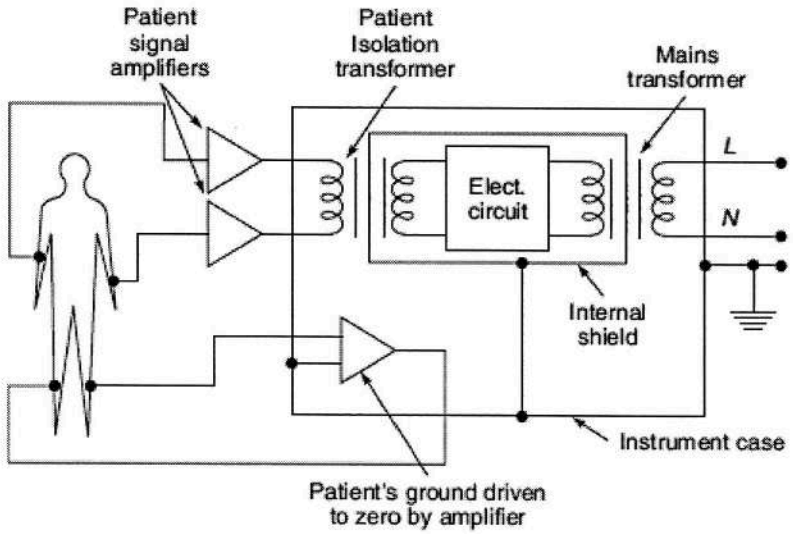


Block Diagram of Isolation Amplifier

Three methods are used in the design of isolation amplifiers: (i) transformer isolation (ii) optical isolation (iii) capacitive isolation.

(i) Transformer isolation type:

The transformer approach is shown in Fig.(It uses either a frequency-modulated or a pulse width modulated carrier signal with small signal bandwidths up to 30 kHz to carry the signal. It uses an internal dc–to-dc converter comprising of a 20 kHz oscillator, transformer, rectifier and filter to supply isolated power.

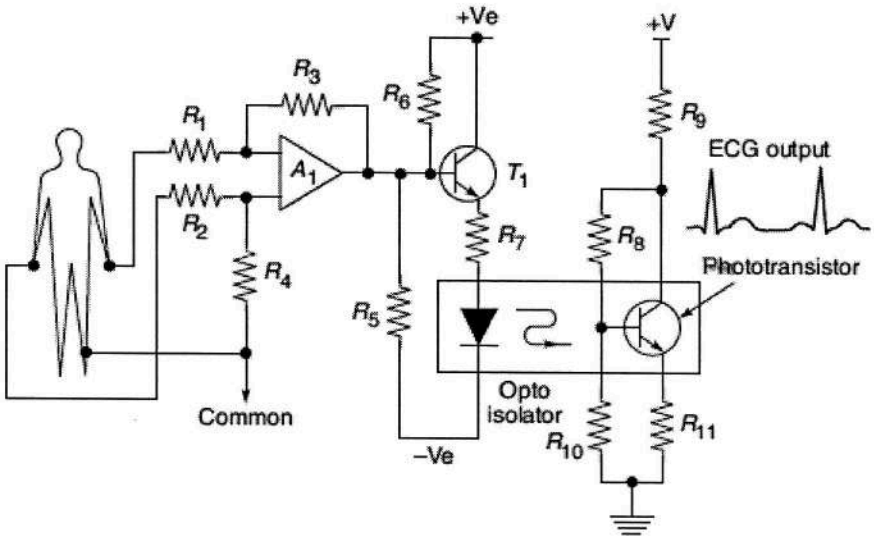


Transformer isolation type

(ii) Optical isolation type:

Isolation could also be achieved by optical means in which the patient is electrically connected with neither the hospital line nor the ground line. A separate battery operated circuit supplies power to the patient circuit and the signal of interest is converted into light by a light source (LED).

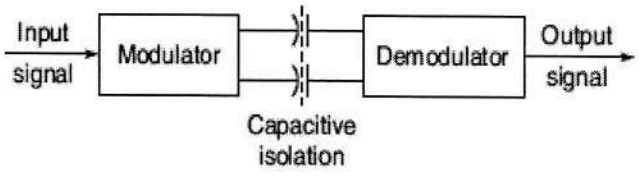
This light falls on a phototransistor on the output side, which converts the light signal again into an electrical signal (Fig.), having its original frequency, amplitude and linearity. No modulator/ demodulator is needed because the signal is transmitted optically all the way.



Optical isolation type

(iii) Capacitive isolation type:

The capacitive method (Fig.) uses digital encoding of the input voltage and frequency modulation to send the signal across a differential capacitive barrier. Separate power supply is needed on both sides of the barrier. Signals with bandwidths up to 70 kHz can be conveniently handled in this arrangement.



- It uses digital encoding of the input voltage and frequency modulation.
- The input voltage is converted to proportional charge on the switched capacitor.
- It has modulator and demodulator circuits.
- The signals are sent across a differential capacitive barrier.

- Separate supplies given on both sides.

Advantages:

- Ripple noises are removed.
- It avoids device noise, radiated noise and conducted noise.
- High immunity to magnetic noise.
- High gain stability and linearity.

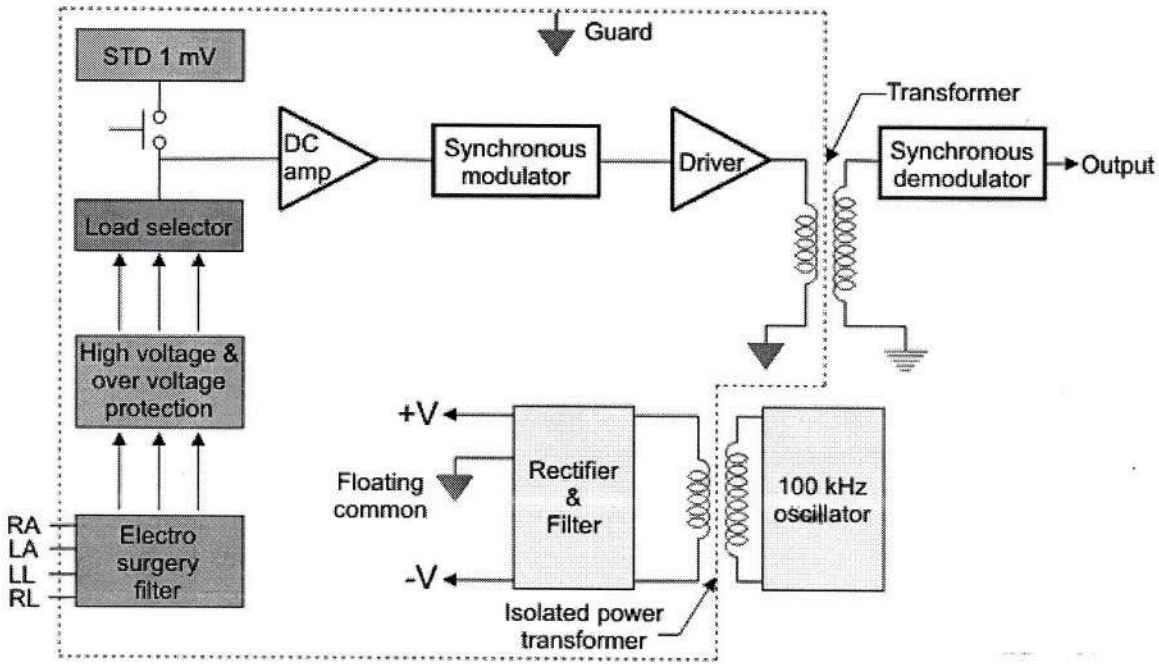
The relative merits of the three types of isolation techniques are:

- All three types are in common use, though the transformer isolation amplifier is more popular.
- Opto-coupled amplifier uses a minimum number of components and is cost effective, followed by the transformer coupled amplifier. The capacitor coupled amplifier is the most expensive.
- Opto-isolated amplifiers offer the lowest isolation voltage (800 V continuous) between input and output; transformer coupled 1200 V and capacitance coupled 2200 V.
- Isolation resistance levels are of the order of 10^{10}, 10^{12} and 10^{12} ohms for transformer coupled, opto-coupled and capacitance coupled amplifiers respectively.
- Gain stability and linearity are best for capacitance coupled versions—0.005%, and transformer and opto-coupled amplifier—0.02%.

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. 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.

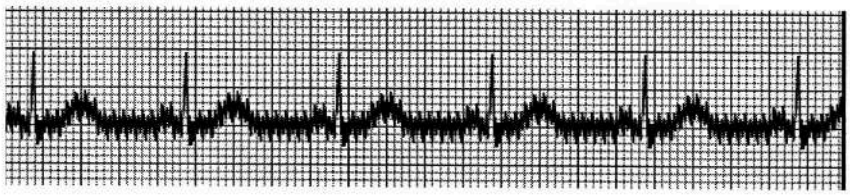
ECG Isolation Amplifier:



Power Line Interference:

Power line interference is easily recognizable since the interfering voltage in the ECG would have a frequency of 50 Hz (Fig3.7(a)). This interference may be due to the stray effect of the alternating current on the patient or because of alternating current fields due to loops in the patient cable.

Other causes of interference are loose contacts on the patient cable as well as dirty electrodes. When the machine or the patient is not properly grounded, power line interference may even completely obscure the ECG waveform.



(a) ECG wave due to power line interference

The most common cause of 50 Hz interference is the disconnected electrode resulting in a very strong disturbing signal. It is often strong enough to damage the stylus of an unprotected direct writing recorder, and therefore needs quick action.

Electromagnetic interference from the power lines also results in poor quality tracings. Electrical equipment such as air-conditioners, elevators and X-ray units draw heavy power-line current, which induce 50 Hz signals in the input circuits of ECG machines. Due to unbalanced linkages, common mode rejection circuits almost prove ineffective against them.

A practical solution to minimize this problem is physical separation between the interference causing sources and the patient. Levkov *et al* (1984) developed a method of digital 50 Hz interference elimination by computing the interference amplitudes and subtracting these data from the original signal, thereby greatly reducing the requirements of amplifiers, shielding, earthing, electrode quality and application procedures.

Electrical power systems also induce extremely rapid pulses or spikes on the trace, as a result of switching action. Use of a transient suppressor in the mains lead of the machines helps to solve this problem.

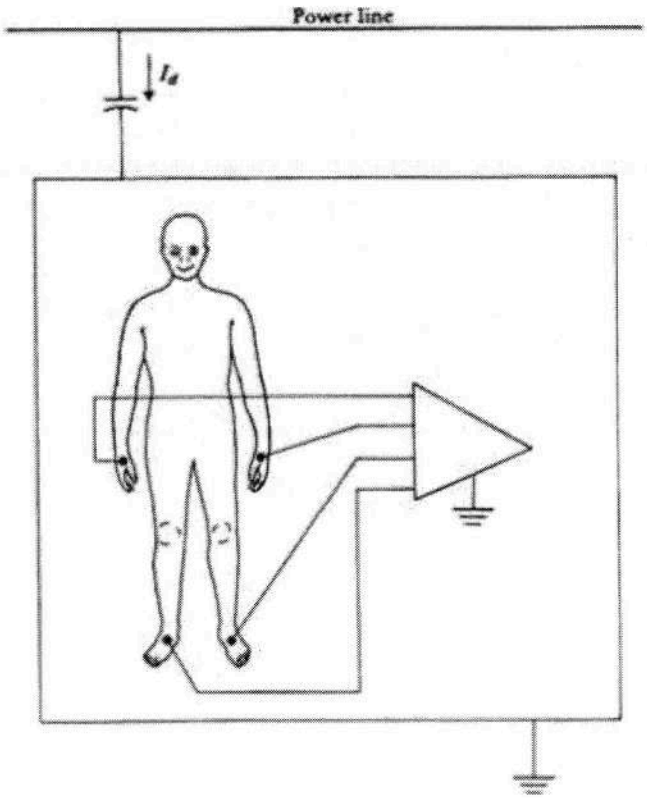
Shielding techniques to eliminate the interferences in ECG waveform.

1. Electro static shielding:- Place a ground conducting plane between the source of the electric field and the measurement system.

2. Magnetic shield: Use high permeability materials.

3. Use twisted cables to reduce magnetic flux and loop area.

Electro static shielding:



Electrostatic shielding used to remove electric field interference on an electrocardiograph.

Isolation capacitor used to isolate patient from power line.

Right Leg driven ECG amplifier:

A Driven Right Leg Circuit or DRL circuit is an electric circuit that is often added to biological signal amplifiers to reduce Common-mode interference. Biological signal amplifiers such as ECG (Electrocardiogram) EEG (Electroencephalogram) or EMG circuits measure very small electrical signals emitted by the body, often as small as several micro-volts (millionths of a volt).

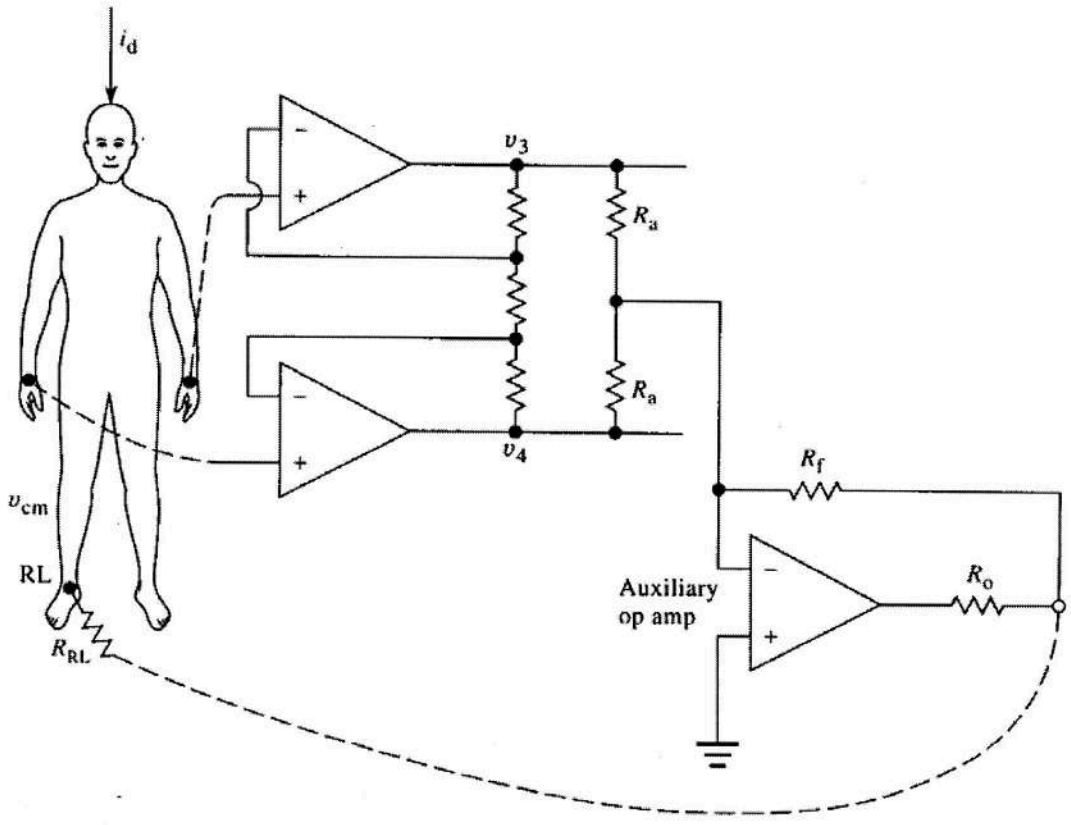
Unfortunately, the patient's body can also act as an antenna which picks up electromagnetic interference, especially 50/60 Hz noise from electrical power lines. This interference can obscure the biological signals, making them very hard to measure. Right Leg Driver circuitry is used to eliminate interference noise by actively cancelling the interference.

Objective:

- Reduce interference in amplifier
- Improve patient safety

Approach:

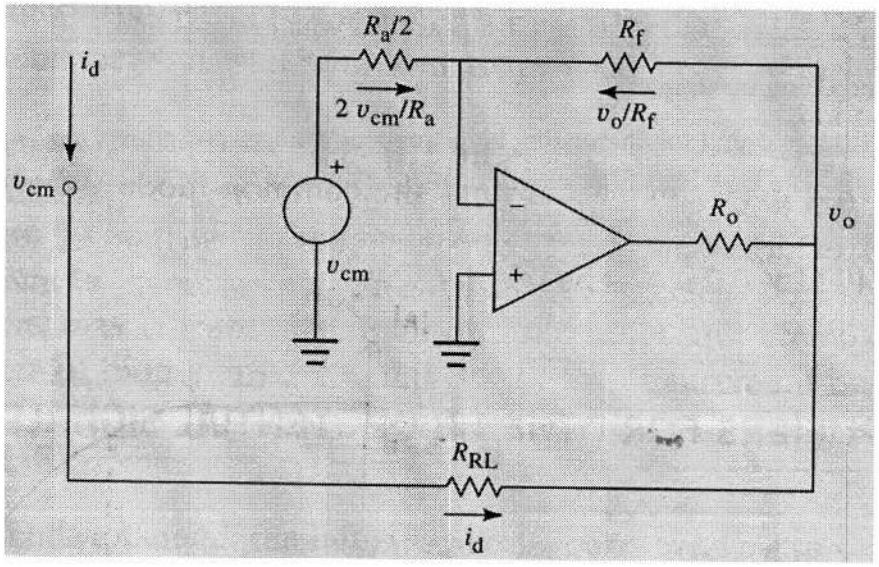
- Patient right leg tied to output of an auxiliary amp rather than ground.
- Common mode voltage on body sensed by averaging resistors, Ra's & R_F fed back to right leg.
- Provides negative feedback to reduce common mode voltage.
- If high voltage appears between patient and ground, auxiliary Op-amp effectively un-grounds the patient to stop current flow.



Determine the common-mode voltage Vcm on the patient in the driven right- leg circuit of when a displacement current id flows to the patient from the power lines.

Choose appropriate values for the resistances in the circuit so that the common-mode voltage is minimal and there is only a high-resistance path to ground when the auxiliary operational amplifier saturates.

Equivalent circuit to determine common mode gain,



KCL at point x

$$\frac{2v_{cm}}{R_a} + \frac{v_o}{R_f} = 0$$

i.e.

$$v_o = -\frac{2R_f}{R_a} v_{cm}$$

But

$$v_{cm} = R_{RL} i_d + v_o$$

Therefore

$$v_{cm} = \frac{R_{RL}}{1 + 2\,R_f / R_a} i_d$$

V_{cm} as small as possible choose large R_f and small Ra.

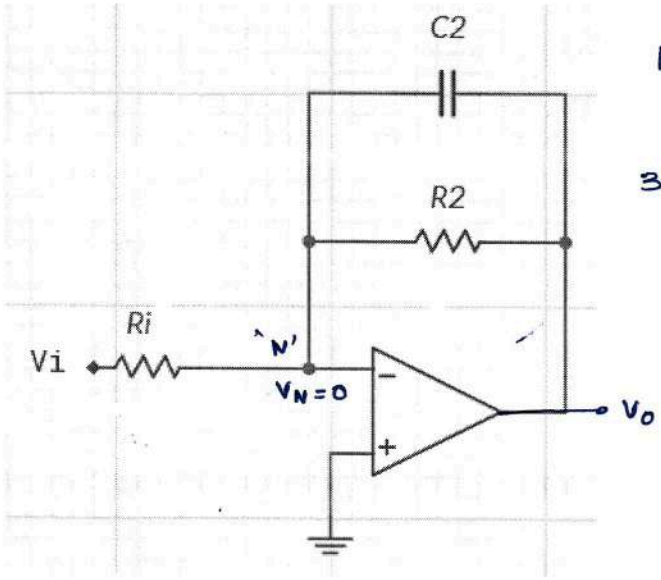
Band Pass Filter:

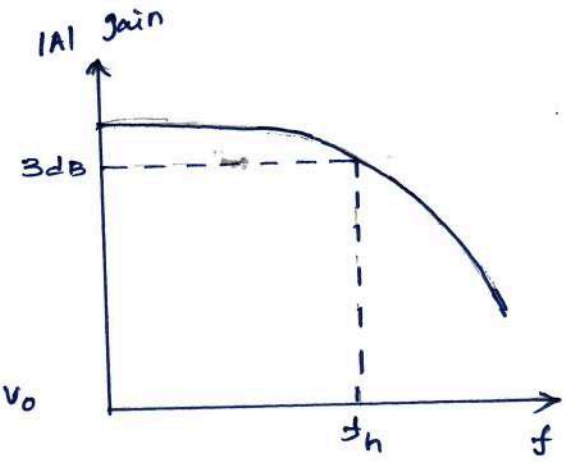
In general, the ECG signal is nature weak and only around 1mV amplitude. Therefore filter and amplifier circuits were designed into 3 stages with a total gain of 1000 to bring the signal to around 1V. Circuit designed included of instrumentation amplifier, bandpass filter and notch filter. The frequency bandwidth of ECG is between 0.05Hz until 100Hz.

Band pass filter is designed by cascading High pass filter with low pass filter.

Low pass Filter Using op-amp:

The Low pass filter is useful for attenuating high frequency noises and allows the low frequency signals. The Low Pass filter circuit using one op-amp shown in the fig





Apply KCL at node 'N'

$$\frac{V_i'}{R_i'} = -\frac{V_o}{R_2 \,||\, \frac{1}{j\omega C_2}}$$

$$\frac{V_i'}{R_1} = -\frac{V_o}{\frac{R_2 \times 1/j\omega C_2}{R_2 + 1/j\omega C_2}}$$

$$\frac{V_i'}{R_1} = -\frac{V_o}{\frac{R_2}{1+j\omega R_2 C_2}}$$

$$\frac{V_i'}{R_1} = -\frac{V_o\,(1+j\omega R_2 C_2)}{R_2}$$

$$\frac{V_o}{V_i'} = -\frac{R_2}{R_1}\,\frac{1}{1+j\omega R_2 C_2}$$

$$\frac{V_o}{V_i'} = -\frac{R_2}{R_1}\,\frac{1}{1+j\omega \tau}$$

where $\tau = R_2 C_2$, time constant

let $f_h = \frac{1}{2\pi R_2 C_2}$, $\omega = 2\pi f$

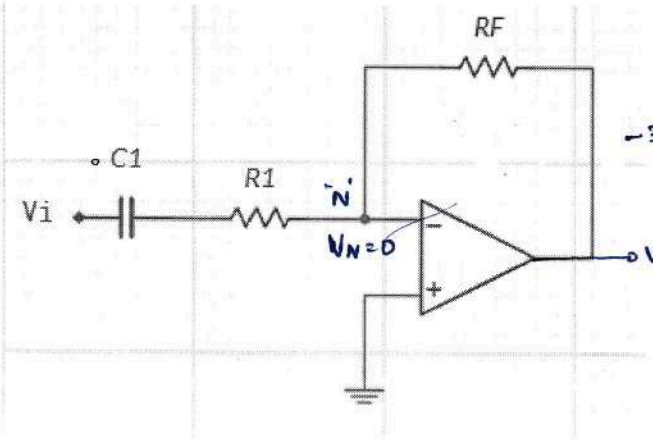
$$\frac{V_o}{V_i'} = -\frac{R_2}{R_1}\left(\frac{1}{1+j\,2\pi f R_2 C_2}\right)$$

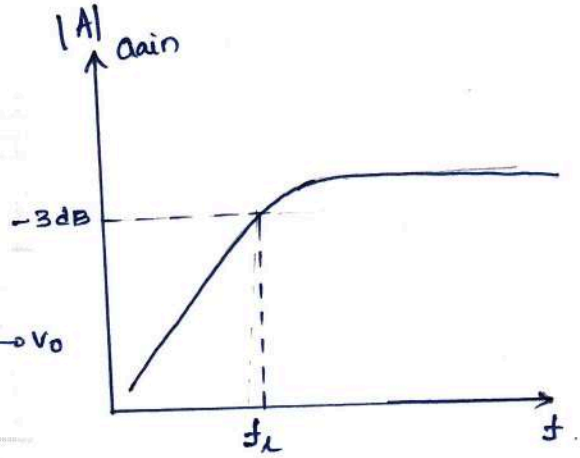
$$\frac{V_o}{V_i'} = -\frac{R_2}{R_1}\left(\frac{1}{1+j\,(f/f_h)}\right)$$

where $f_h \Rightarrow$ Higher cut off frequency of LPF.

High Pass filter:

High pass filter allows the higher frequencies which are above lower cut off frequency. Such a circuit is useful for amplifying a small ac voltage that rides on top of a large dc voltage,because Ci block dc.





$$\frac{V_i}{R_1 + 1/j\omega C_1} = -\frac{V_o}{R_F}$$

$$\frac{V_i}{\frac{1 + j\omega R_1 C_1}{j\omega C_1}} = -\frac{V_o}{R_F}$$

$$\frac{j\omega C_1}{1 + j\omega R_1 C_1} V_i = -\frac{V_o}{R_F}$$

$$\frac{V_o}{V_i} = -R_F \frac{j\omega C_1}{1 + j\omega R_1 C_1}$$

Multiply & divided by R_1

$$\frac{V_o}{V_i} = -\frac{R_F}{R_1} \frac{j\omega R_1 C_1}{1 + j\omega R_1 C_1}$$

where Time constant $\tau = R_1 C_1$

$$\frac{V_o(j\omega)}{V_i(j\omega)} = A = -\frac{R_F}{R_1} \frac{j\omega\tau}{1 + j\omega\tau}$$

Let $f_L = \frac{1}{R_1 C_1 2\pi}$

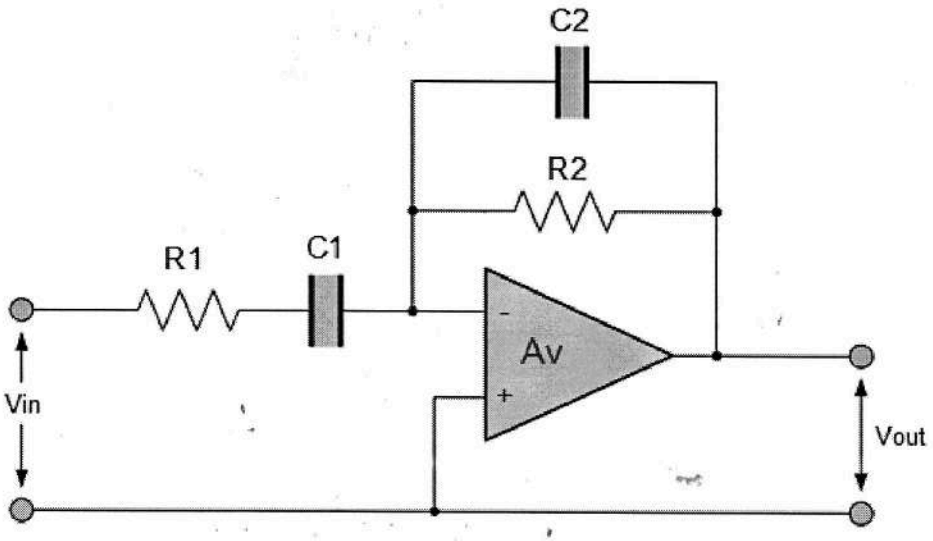
$$A = -\frac{R_F}{R_1} \frac{j\omega\tau}{1 + j\,2\pi f R_1 C_1}$$

$$A = -\frac{R_F}{R_1} \frac{j\omega\tau}{1 + j\,(f/f_L)}$$

where f_L is Lower cut off frequency of HPF.

Band pass filter:

Cascading of High pass filter followed by Low pass filter results in a band pass filter. Band pass filter which amplifies frequencies over a desired range and attenuates higher and lower frequencies. But this configuration having two op-amp. The band pass filter is designed by one op amp is given in the fig.



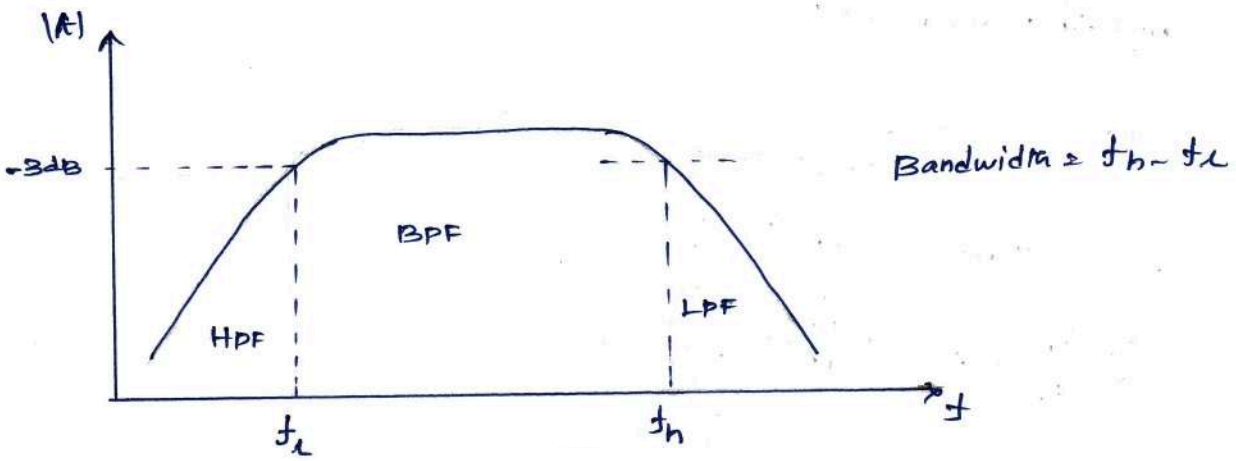
Band pass filter is the cascading of HPF and LPF.

So, the frequency response of BPF.

$$\frac{V_0(j\omega)}{V_i(j\omega)} = -\frac{R_2}{R_1}\frac{j\omega\tau}{1+j2\pi f R_1 C_1} \cdot -\frac{R_2}{R_1}\frac{1}{1+j2\pi f R_2 C_2}$$

$$\frac{V_0(j\omega)}{V_i(j\omega)} = \left(\frac{R_2}{R_1}\right)^2 \frac{j\omega\tau}{(1+j2\pi f R_1 C_1)(1+j2\pi f R_2 C_2)}$$

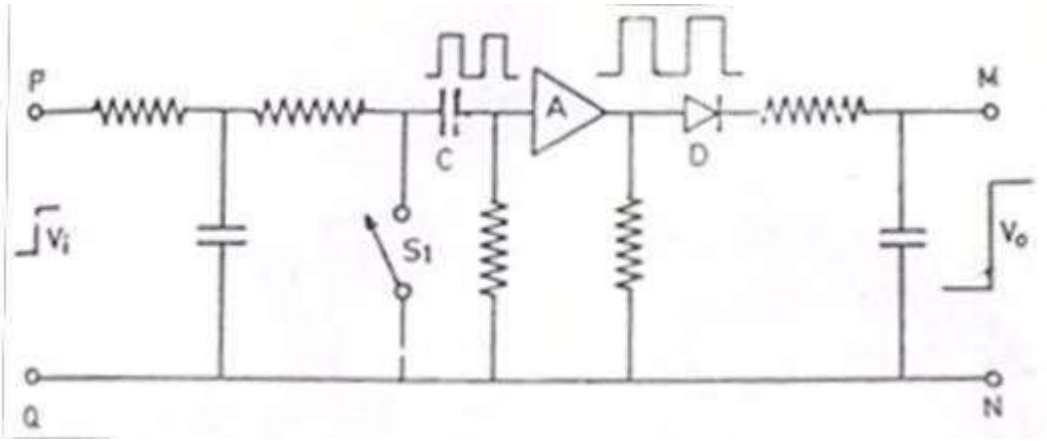
$$\frac{V_0(j\omega)}{V_i(j\omega)} = \left(\frac{R_2}{R_1}\right)^2 \frac{j\omega\tau}{(1+j f/f_L)(1+j f/f_h)}$$



Chopper Amplifier:

The chopper is used to convert low frequency signal into a high frequency signal. The modulated high frequency signal is amplified and finally the amplified signal is demodulated and filtered to get low frequency signal. Chopper amplifier has no drift. Chopper amplifiers are available in the form in the form of mechanical and non-mechanical chopper.

i) Mechanical Chopper Amplifier:

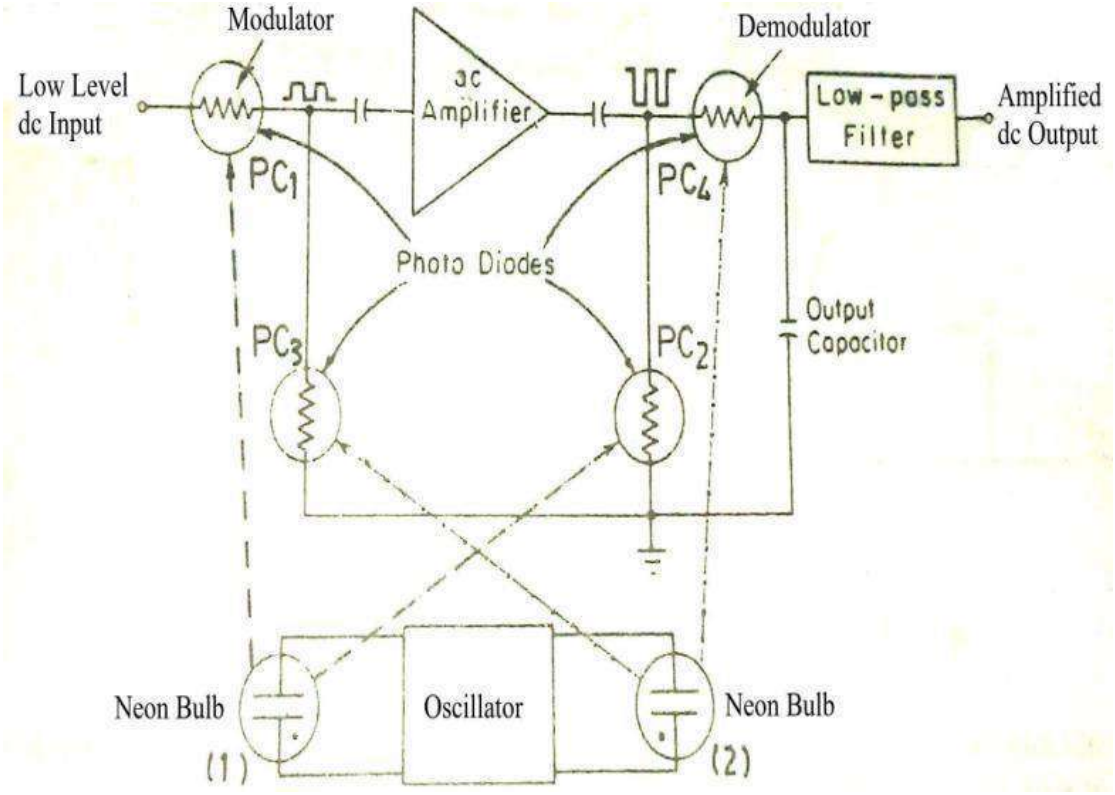


Chopper amplifier using a mechanical switch

Chopper S1 is an electromagnetically operated switch or relay. S1 connect the input terminal of amplifier _A‘to reference terminal _Q‘which is connected to ground. When the amplifier input terminal is connected with Q, it is short circuited and the input voltage is zero. When S1 is open, the amplifier receives the signal voltage from P.

ii) Non mechanical Chopper Amplifier:

iii)



Non Mechanical Photoconductive Chopper Amplifier

Photoconductors or photodiodes are used as non mechanical chopper for modulation and demodulation. When there is no incident light on photoconductor, its resistance is high and hence it is in RB and no current flows through it. When there is incident light on photoconductor, its resistance is very low and hence it is in FB and current flows through it. Thus it can act as a switch by means of incident light.

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.

RESPIRATORY RATE MEASUREMENT

Respiratory system provides a means of acquiring oxygen and eliminating CO_2. Various laws are involved in the understanding of respiratory functions.

Various Gas laws are given below:

1. **BOYLE'S LAW:** It states that at constant temperature, the volume of gas varies inversely with the pressure.

   $V_2/V_1 = P_1/P2$ here temperature T= constant
   V_2= Final volume
   V_1 = Initial volume
   P_1 = Original (initial) pressure
   P_2 = Final pressure

2. **CHARLE'S LAW:** It states that, at constant pressure, the volume of gas isdirectly proportional to the absolute temperature.

   $V_2/V_1 = T_2/T_1$ Here pressure P=constant
   V_2, V1 =Final, initial volume
   T_1 =original temperature
   T_2 = Final temperature

3 . **HENRY'S LAW :** It states that, if the temperature is constant, the quantity of a gas that goes into a solution is directly proportional to the partial pressure of that gas . The gas with the greater partial pressure will have more mass in solution.

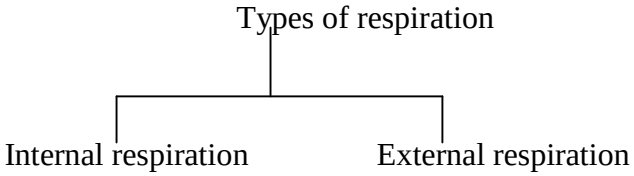
4. **DALTON'S LAW :** It states that, the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of various gases.

$P_T = P_1 + P_2 + \ldots\ldots\ldots\ldots + P_n$

P_T = total pressure

P_1, P_2, P_3 = partial pressure of various gases

TYPES OF RESPIRATION



Respiration is nothing but the interchange of gases between an organism and the living medium **Internal respiration** is the exchange of gases between the blood stream and nearby cells .**External respiration** is the exchange of gases between the lungs and blood stream .

Lungs Volumes and Capacities (Respiration Parameters) Or (LVC)

Respiration parameters are used to indicate the state of respiratory function , including lung volumes and capacities , airway resistance , lung compliance , etc .

Dead Air

Only a portion of the air entering the respiratory system actually reaches the alveoli . The volume of air that is not available for gas exchange with the blood is known as dead air . The total dead space is less less than 30 percentage of the total volume .

Tidal Volume (TV)

Tidal volume is the depth of breathing or the volume of gas inspired or expired during each respiratory cycle. It is equal to 500 ml for a normal person .

Inspiratory Reserve Volume (IRV)

It is the maximal amount of gas that can be inspired from the end- inspiratory position (Extra inspiration from the high peak tidal volume . It is equal to 3600 ml for a normal person

Expiratory reserve volume (ERV)

It is the maximal amount of gas that can be end expiratory level. It is equal to 1200 ml.

Residual Volume(RV)

It is the amount of gas remaining in the lungs at the end of maximal expiration. It is equal to 1200 ml.

Minute Volume (MV)

It is the volume of air breathed normally for 1 minute.

Total Lung Capacity(TLC)

It is the amount of gas contained in the lungs at the end of maximal inspiration and it is the sum of inspiratory capacity(IC) and functional residual capacity (FRC). TLC is of 6000 ml for a normal person.

Vital Capacity(VC)

It is the maximum amount of gas that can be expelled from the lungs by forceful effort from maximal inspiration. It is 4800 ml for a normal person.

Inspiratory Capacity(IC)

It is the maximum amount of gas that can be inspired from the resting expiratory level and it is the sum of tidal volume and inspiratory reserve volume. It is equal to 3600 ml for a normal person.

Functional Residual Capacity(FRC)

It is the amount of gas remaining in the lungs at the resting expiratory level.

FRC = ERV + RV

Airway resistance

It relates to the ease with air flows through tubular respiratory structures. In smaller tubes, airway resistance is high.

Lung Compliance

It is the ability of the alveoli and lung tissue to expand on inspiration**.**

Lung Elasticity

It is the ability of the lung's elastic tissues to recoil during expiration

Intra thoractic Pressure

It is the positive and negative pressure occur within the thoracic cavity

Types of respiration rate measurement

1. Displacement method
2. Thermistor method
3. Impedance pneumography
4. CO_2 method
5. Apnoea detectors

Displacement Method

In this method the transducer is hold by an elastic band which goes around the chest.The respiratory movements results in a corresponding resistance changes of the strain gauge. It is connected as one arm of a wheatstone bridge circuit. Its output varies with chest expansion. This output corresponds to the respiration activity.

Thermistor Method

Generally there is a temperature difference between inspired and expired air. This temperature is sensed by placing thermistor in front of nostrils. Thermistor is placed by using suitable stand. The thermistor is connected with the bridge circuit. So unbalance signal is amplified to get the respiratory activity.

IMPEDANCE PNEUMOGRAPHY

This is the indirect method of measurement . impedance pneumography is based on the fact that , the a.c impedance across the chest of a patient changes as respiration occurs . 50-50KHz a.c signal is produced by oscillator circuit and is given to the chest of the patient through electrodes .The signal voltage applied to the amplifier (Differential amplifier) block is the voltage drop across the resistance .

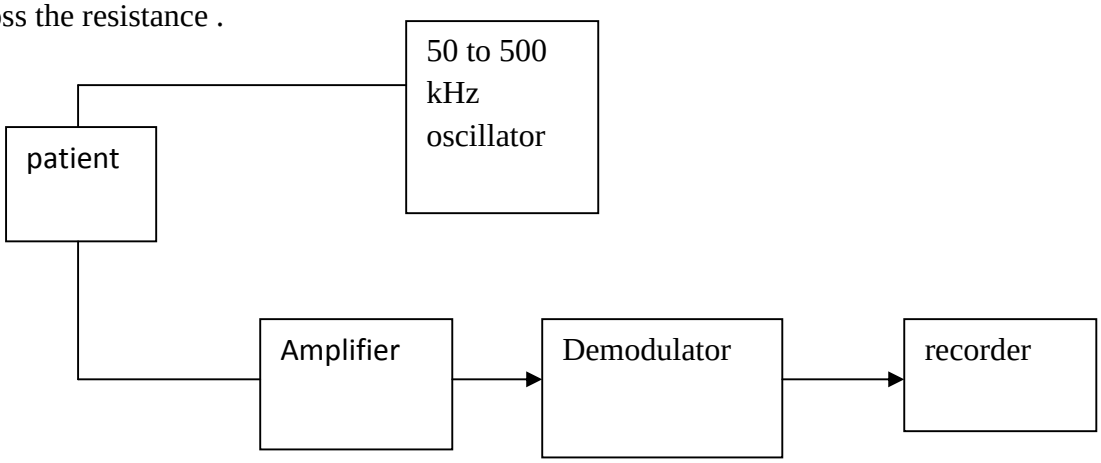


Figure Impedance pneumography

$$V = I(R+ R)$$

Where V= Output voltage (V)
I= Current through the chest (A)
R= chest impedance without respiration (R)
R= change of chest impedance due to respiration (Q)

The output of the amplifier is given to demodulator and filter block. Hence low pass filter is used to remove the residual carrier signal. The output of the impedance pneumograph contains respirating rate data.

CO_2 Method

Respiration rate can be measured by measuring CO_2 in expired air. This CO_2 method of measurement is based on the absorption property of infrared rays by certain gases .When infrared rays are passed through the expired air which contains certain amount of CO_2, some of radiations are absorbed by it. So, there is loss of heat energy associated with the rays .The detector changes the loss in heating effect of the rays into an electrical signal. It is used to get the average respiration rate. Two infrared sources are available in this set up. The beam from one infrared source falls on the test cuvette side. The beam from another infrared source falls on the reference cuvette side.

The detector has two identical portions. These portions are separated by a thin, flexible metal diaphragm. The detector is filled with a sample of pure CO_2. Because of the absorption of CO_2 in the test cuvette. The beam falling on the test side of the detector is weaker that falling on the reference side. The gas in reference side is heated more than that on the test side. So diaphragm is pushed slightly to the test side of the detector. This diaphragm forms one plate f a

capacitor. The a.c signal appears across the detector is amplified and recorded using recorder. The amplified output is integrated. It is used for continuous monitoring the respiration rate.

Apnoea Detectors

Apnoea is the stopping of breathing. It leads to the arrest of the circulation. It can be occurred at the conditions like head injury, drug overdose, etc. It can also occur in premature babies during the first week of life because of their immature nervous system. If apnoea persists for a prolonged period, then brain functions can be severly damaged. So apnoea patients are closely monitored. Apnoea monitor is used to watch the apnoea patients respiration rate. Apnoea monitor gives audio signals and visual signals, when no inspiration occurs for a particular period of time. Input from the sensor is connected with the amplifier circuit having high input impedance.

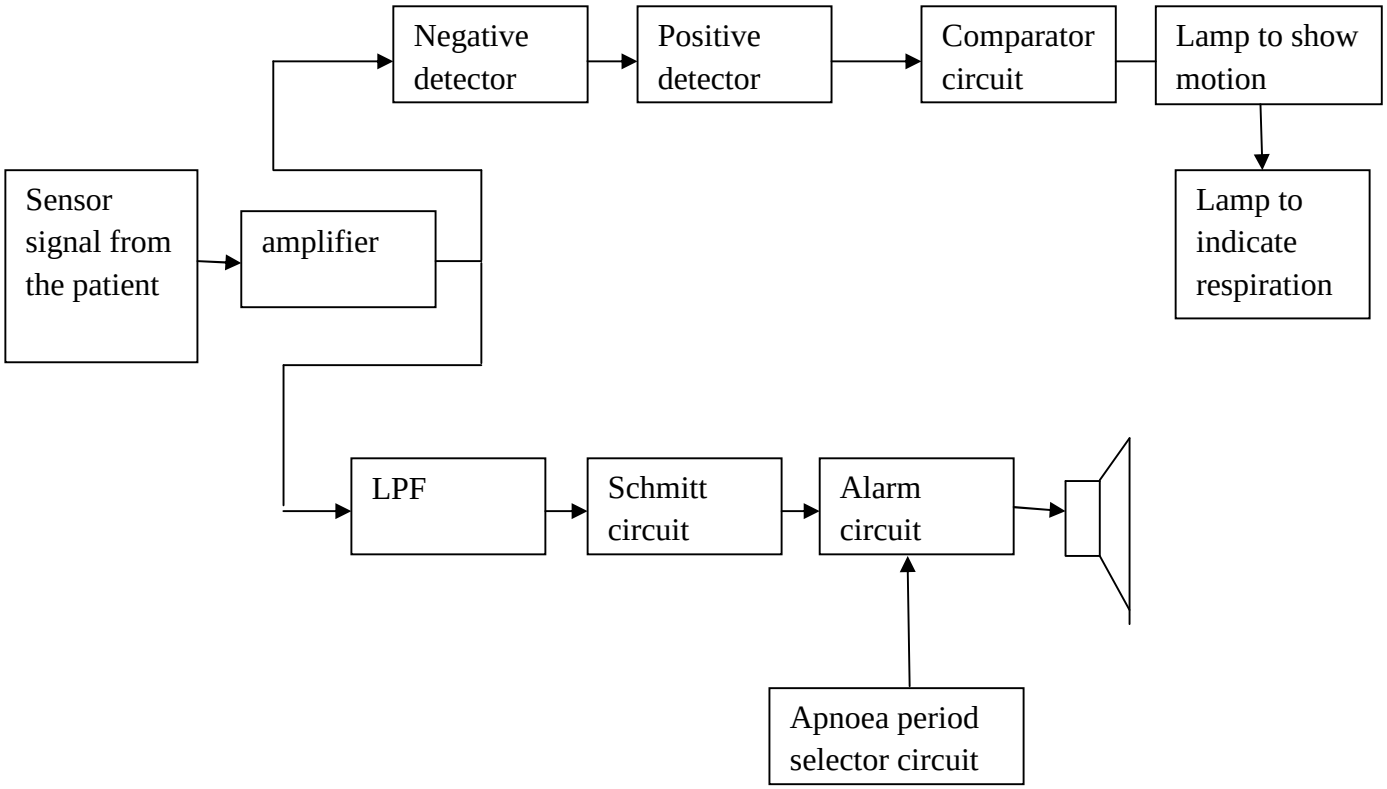


Figure Block diagram of apnoea monitor

The output of the amplifier circuit is connected with motion and respiration channel blocks. Motion channel block differentiates motion and the respiration based on the frequency. The frequency below 1.5 Hz is identified as respiration. The frequency above 1.5 Hz is identified as motion. High frequency signal above the threshold is sensed by positive detector.

The frequency below the threshold is sensed by negative detector. The output of the motion channel is connected with comparator circuit. It compares the amplitude of motion and respiration. Based on the output corresponding lamp will glow. In the respiration channel, low pass filter is used to remove high frequency signal. If there is no respiration, then schmid trigger circuit gives the output to switch on the alarm.

Apnoea period selector circuits contain low frequency alarm oscillator and tone oscillator, and audio amplifier. Apnoea period selector circuit drives the alarm circuit. The output of alarm circuit is connected with the speaker. So, where there is no respiration for a period of 10 or 20 sec, then audio signal through the speaker and visual signal through the flash light is delivered**.**

BLOOD PRESSURE

One of the oldest physiological measurements.Observation of blood pressure allows dynamic tracking of pathology and physiology affecting to the cardiovascular system, which has profound effects to all other organs of the body

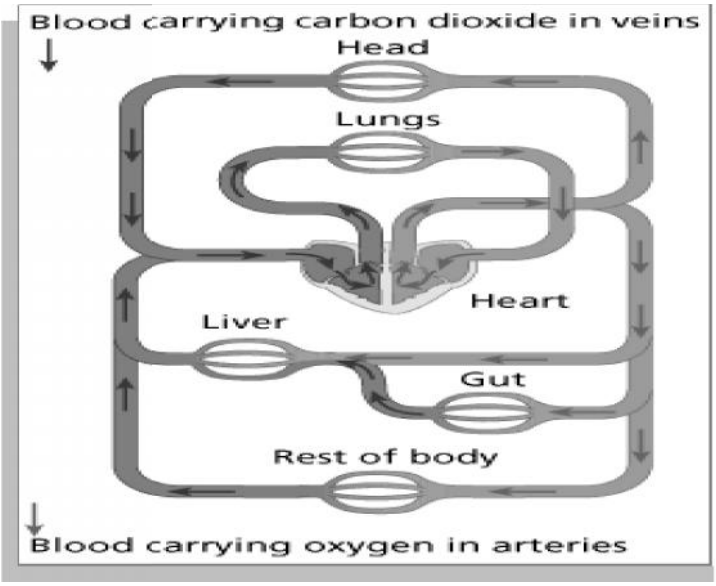


Figure Observation of blood pressure

- Originates from the heart
- Commonly refers to arterial blood pressure

Value depends on 3 factors:

- cardiac output diameter of arteries the quantity of blood
- Values should be lower than 120 / 80 mmHg(systolic pressure (SP) / diastolic pressure (DP))
- *High value* increases the risk of heart attack and strokes
- *Low value* increases the risk of lower oxygen perfusion e.g. in brains.

However, the ’normal values’ differ from person to another

Pulse Pressure(PP) = SP - DP

Mean pressure (MP)

Average pressure during one cardiac cycle driving force of the peripheral perfusion.
an estimate can be done by using an empirical formula:

MP = DP+PP/3

SP and DP may vary significantly throughout the arterial system but MP is quite uniform (in normal situations)

1. Non-Invasive

Palpatory Method(Riva-Rocci Method)
Auscultatory Method
Ultrasonic Method
Oscillometric Method
Tonometry

2. Invasive

Extravascular Sensor
Intravascular Sensor
General on System Parameters

INDIRECT METHODS IN BLOOD PRESSURE MEASUREMENTS

Indirect measurement = non-invasive measurement

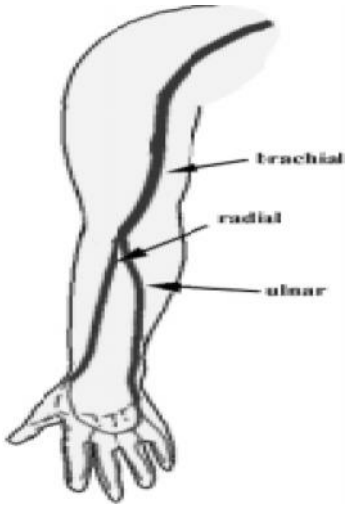


Figure ... Blood pressure measurements

Brachial artery is the most common measurement site
Close to heart
Convenient measurement

Other sites are e.g.:
forearm / radial artery wrist (tends to give much higher SP)

The most common indirect methods are auscultation and oscillometry an occlusive cuff is placed on arm and inflated to P > SP. Then the cuff is deflated gradually and the measurement of blood flow is done .

The occlusive cuff should be of a correct size in order to transmit the pressure to the artery evenly and thus to obtain accurate results .A short cuff requires special attention in placement. Longercuff reduces this problem. The cuff should be placed at the heart level in order to minimize the hydrostatic effects .

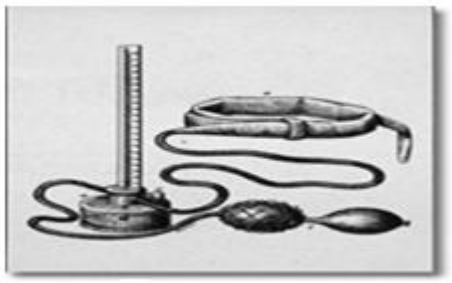


Figure Sphygmomanometro

PALPATORY METHOD (RIVA-ROCCI METHOD)

When the cuff is deflated, there is a palpable pulse in the wrist. P = BP .Several measurements should be done as the respiration and vasomotor waves modulate the blood pressure levels

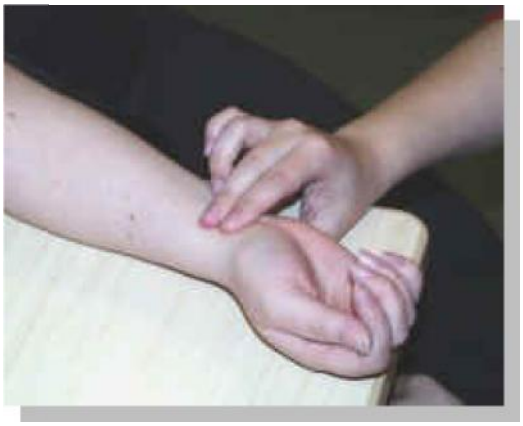


Figure Palpatory Method

Advantages

The blood pressure can be measured in noisy environment too
Technique does not require much equipment

Disadvantages

Only the systolic pressure can be measured (not DP)
The technique does not give accurate results for infants and hypotensive patients

AUSCULTATORY METHOD

Pulse waves that propagate through the brachial artery, generate Korotkoff sounds. There are 5 distinct phases in the Korotkoff sounds, which define SP and DP The Korotkoff sounds are ausculted with a stethoscope or microphone (automatic measurement

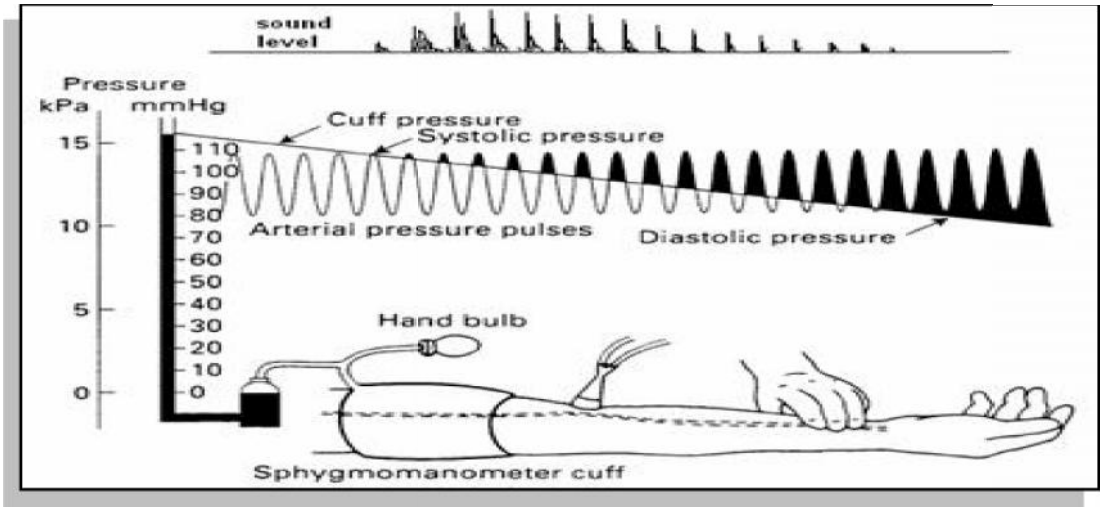


Figure Auscultatory Method

The frequency range is 20-300 Hz and the accuracy is +/- 2mmHg (SP) and +/- 4mmHg (DP). Also with this method, several measurements should be done.

Advantages

Auscultatory technique is simple and does not require much equipment

Disadvantages

Auscultatory tecnique cannot be used in noisy environment

The observations differ from observer to another

A mechanical error might be introduced into the system e.g. mercury leakage, air leakage, obstruction in the cuff etc.

The observations do not always correspond with intra-arterial pressure

The technique does not give accurate results for infants and hypotensive patients

ULTRASONIC METHOD

A transcutaneous (through the skin) Doppler sensor is applied here. The motion of blood-vessel walls in various states of occlusion is measured. The vessel opens and closes with each heartbeat when DP < P < SP .

The frequency difference between transmitted (8 MHz) and received signal is 40-500 Hz and it is proportional to velocities of the wall motion and the blood. As the cuff pressure is increased, the time between opening and closing decreases until they coincide.

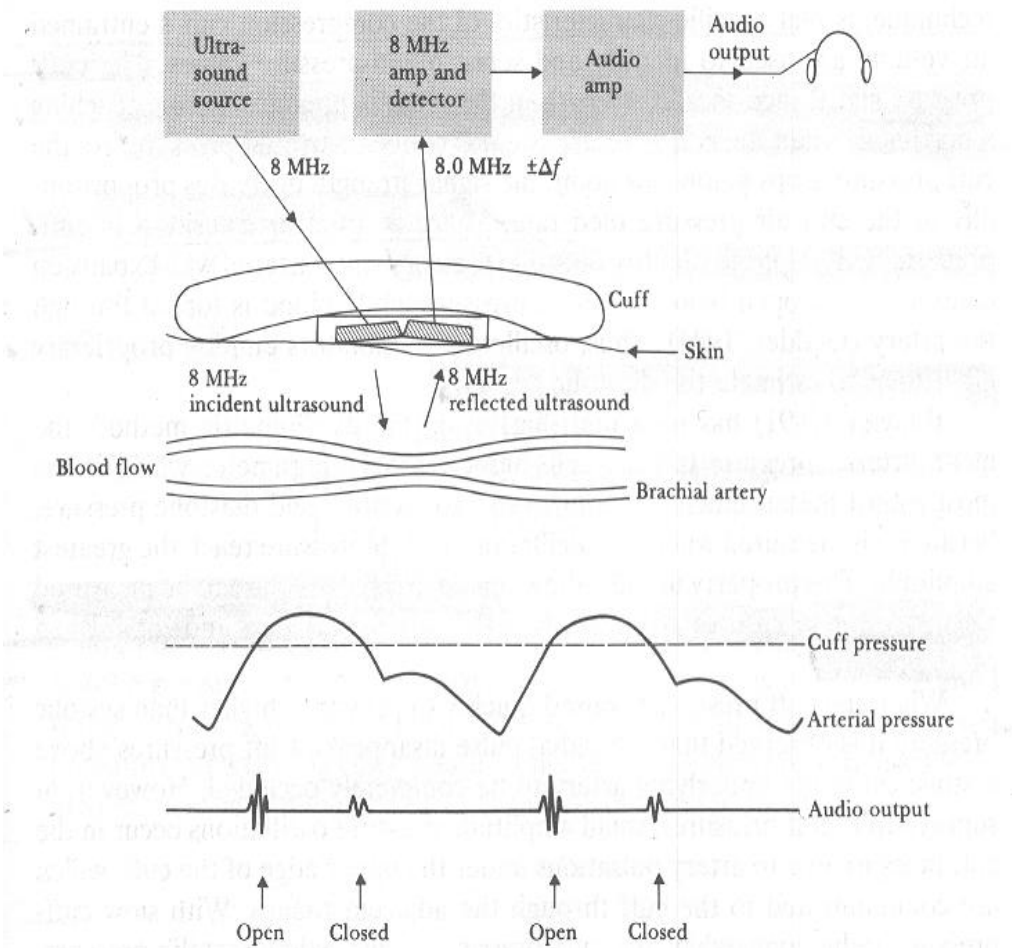


Figure Ultrasonic Method

Advantages & Disadvantages

Can be also used in noisy environment

Can be used with infants and hypotensive individuals

Subject's movements change the path from sensor to vessel

OSCILLOMETRIC METHOD

The intra-arterial pulsation is transmitted via cuff to transducer (e.g. piezo-electric) .The cuff pressure is deflated either linearly or stepwise.The arterial pressure oscillations (which can be detected throughout the measurement i.e. when P > SP and P < DP) are superimposed on the cuff pressure SP and DP are estimated from the amplitudes of the oscillation by using a (proprietary) empirical algorithm.

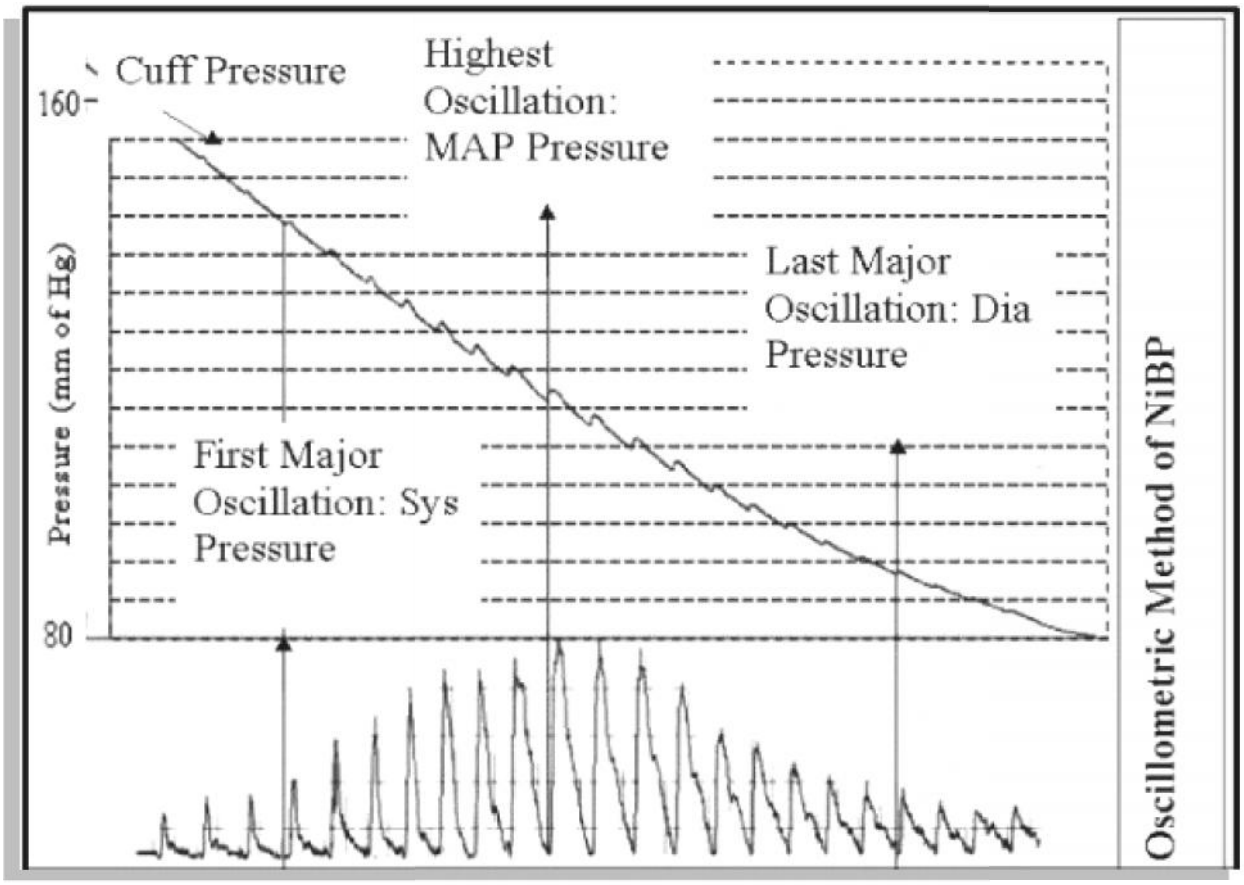


Figure Oscillometric Method

Advantages

In the recent years, oscillometric methods have become popular for their simplicity of use and reliability.

MP can be measured reliably even in the case of hypotension

Disadvantage

Many devices use fixed algorithms leading to large variance in blood pressures

TONOMETRY

Linear array of pressure sensors is pressed against a superficial artery, which is supported from below by a bone (radial artery). A sensor array is used here, because at least one of the pressure sensors must lay directly above the artery .When the blood vessel is partly collapsed, the surrounding pressure equals the artery pressure

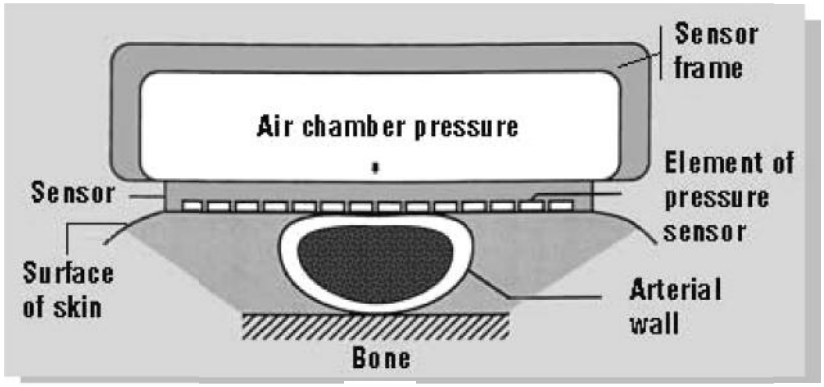


Figure Tonometry

The pressure is increased continuously and the measurements are made when the artery is half collapsed. The hold-down pressure varies between individuals and therefore a ’calibration’ must be done

Advantages

Can be used for non-invasive, non-painful, continuous measurement

Disadvantages

Relatively high cost

The wrist movement and tendons result in measurement inaccuracies

DIRECT METHODS IN BLOOD PRESSURE MEASUREMENTS

Direct measurement = Invasive measurement

A vessel is punctured and a catheter (a flexible tube) is guided in The most common sites are brachial and radial arteries but also other sites can be used e.g. femoral artery A division is made into extravascular and intravascular sensor systems .This method is precise but it is also a complex procedure involving many risks Used only when essential to determine the blood pressure continuously and accurately in dynamic circumstances

EXTRAVASCULAR SENSOR

The sensor is located behind the catheter and the vascular pressure is transmitted via this liquid-filled catheter.

The actual pressure sensor can be e.g. strain gage,variable inductance,variable capacitance Optoelectronic,piezoelectric, etc…

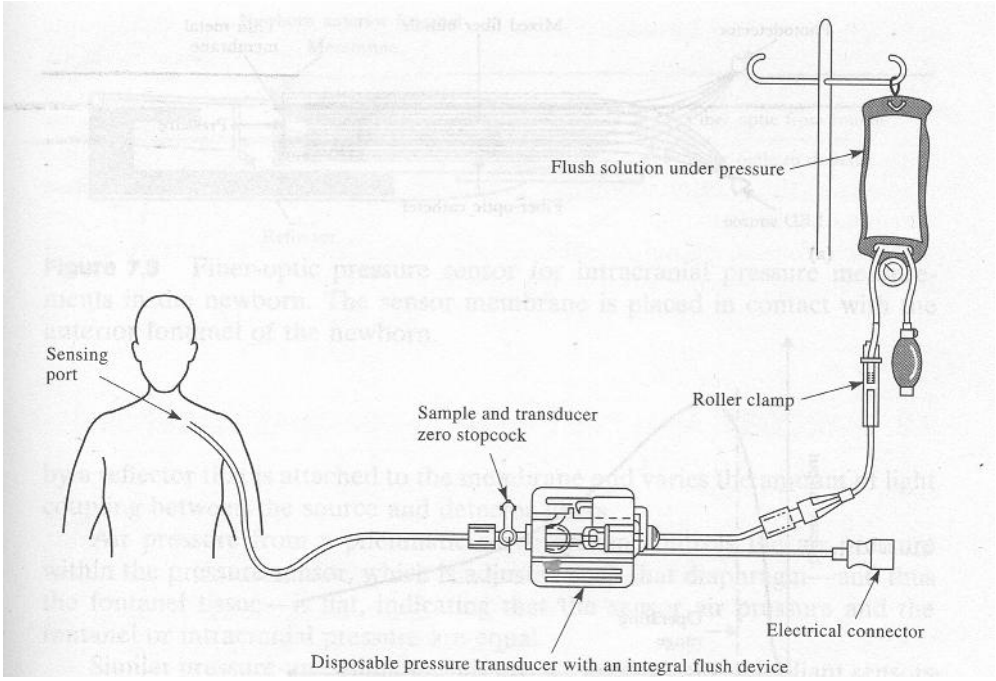


Figure Extravascular Sensor

The hydraylic link is the major source of errors. The system's natural frequency may be damped and degraded due (e.g.):

too narrow catheter
too long tubing
various narrow connections
air bubbles in the catheter

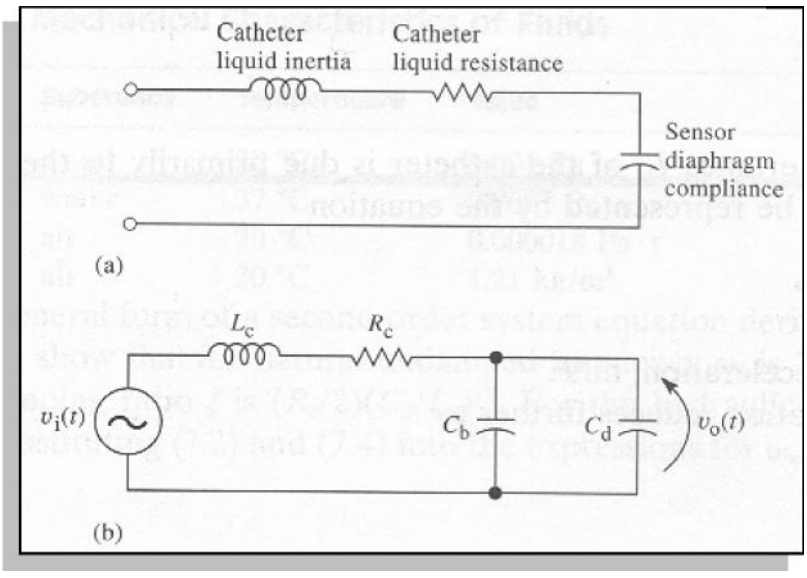


Figure Catheter sensor system

The catheter-sensor system must be flushed with saline-heparine solution every few minutes in order to prevent blood from clotting at the tip.

Normally the interesting frequency range is 0 – 100 Hz. If only MP is measured the bandwidth is 20 Hz (harmonics > 10 are ignored)

INTRAVASCULAR SENSOR

sensor is located in the tip of the catheter. This way the hydraulic connection is replaced with an electrical or optical connection .The dispacement of the diaphragm is measured .The frequency response is not limited by the hydraulic properties of the system.

No time delay.

Electrical safety and isolation when using fiber optics

Breaks easily

More expensive

Disposable Sensors

Disposable sensors decrease the risk of patient cross-contamination and reduce the amount of handling by hospital personnel

Cheaper and more reliable than reusable pressure sensors

GENERAL ON SYSTEM PARAMETERS

Even minute air bubbles in catheter have a dramatic effect on frequency response

The natural frequency and the length of the catheter have a following relationship:

$$f_n = 1/\sqrt{L}$$

The catheter diameter has a linear relationship to natural frequency Stiffer catheters have a higher frequency response

TEMPERATURE MEASUREMENT:

Temperature is one of the inductor of the general well being. Two types of temperature measurements can be obtained from the body. These are

- Systematic temperature
- Surface temperature

Systematic temperature is the temperature of the internal region of the body. Usually, the heat is generated by the active tissues of the body and heat is lost by the body to the environment. But, the temperature of the body is maintained carefully. The normal mouth temperature is 37^0C. the normal underarm temperature is about 1^0C lower than the above temperature. Systemic temperature is measured accurately at tympanic membrane of ear. The brain contains the temperature control centre for the body.

Systemic body temperature measurement

Mercury thermometer is used to measure the systemic temperature. It is inexpensive to use.. when continuous temperature recording is necessary, then, thermocouple or thermistor can be used. In thermocouple, a junction of two dissimilar metals produces an output voltage. This is proportional to the temperature at that junction.

Thermistor is a temperature sensing device. Its resistance varies with the temperature. This is mostly preferred in the biomedical field compared with thermocouple. Thermistor can be manufactured in a various shapes. In this thermistor, the relationship between resistance change and temperature is nonlinear. The resistance of the thermistor is given by using the expression,

$$R_t = R_r e^{\beta}(1/T_1 - 1/T_0)$$

R_t =resistance at temperature T_t
R_r = resistance at temperature T_0
T_1 = temperature at which measurement is taken
T_0 = reference temperature
B = temperature cosfficient

Special circuits are used to overcome the nonlinear characteristics of thermistors. This special circuit consists of 2 matched thermistors.

Problems associated with thermistor

Self heating is very important problem in thermistor. This problem can be overcome by limiting the current used in measurement. The power dissipation of thermistor is to be maintained in milliwatts range to overcome this problem.

Thermistor probe should be chosen correctly based on

- Resistance range
- Sensitivity

Skin temperature measurement

Skin temperature is not constant throughout the body. It is varied from 30^0C to 35^0C. Various factors affect the skin temperature are given below

- How fat covers over capillary area
- How the skin portion is exposed to ambient temperature
- Blood circulation pattern beneath the skin

Probe used for measurement

A small flat thermistor probe is used to measure the skin temperature.

Infrared thermometer

It is a device used to measure skin surface temperature. It is used to locate breast cancer. It is also used to identify the spots in which blood circulation is poor.

PULSE MEASUREMENT

When heart muscle contracts , blood is ejected from the ventricles and a pulse of pressure is transmitted through the circulatory system. This pulse can be measured at various points. We can sense the pulse by placing our finger tip over the radial artery in the wrist. This pulse travels at the speed of 5 to 15m per second. Photoelectric method is commonly employed to measure the pulse.

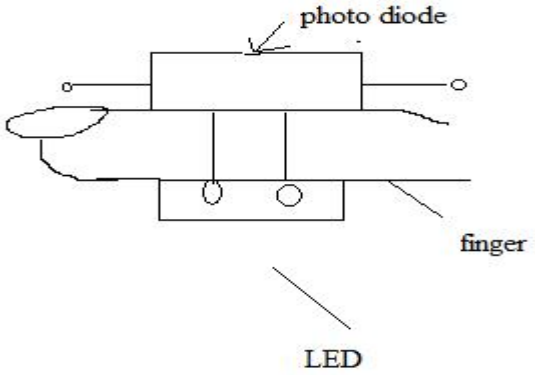
Types:

Photoelectric method consists of two types

- Tramsmittance method
- Reflectance method

TRANSMITTANCE METHOD OF PULSE MEASUREMENT

LED and photoresistor are used in this method. These are mounted in a enclosure that fits over the tip of the finger. Light is produced by the LED. The same light is passed through the finger. For each heart pulse , blood is forced to the extremities and the amount of blood in the finger is increased. So optical density is changed. So, the light transmitted through the finger is decreased. This light is received by the photo resistor. This photo resistor is connecte with the part of voltage divider circuit. The voltage produced by this circuit is directly proportional to the amount of blood flow in the figure. The output ius recorded by using strip chart recorder.



Figuer Transmittance Method Of Pulse Measurement

REFLECTANCE METHOD

N reflectance method, LED is placed adjacent to the photoresistor. LED emits the light. This light is reflected form the skin and the tissues falls on the photo resistor. The reflected light varies depending upon the blood flow in the finger. The photo resistor is connected as a part of the voltage divider circuit. The output obtained is directly proportional to the amount of blood in the finger. The output can be recorder using strip chart recorder.

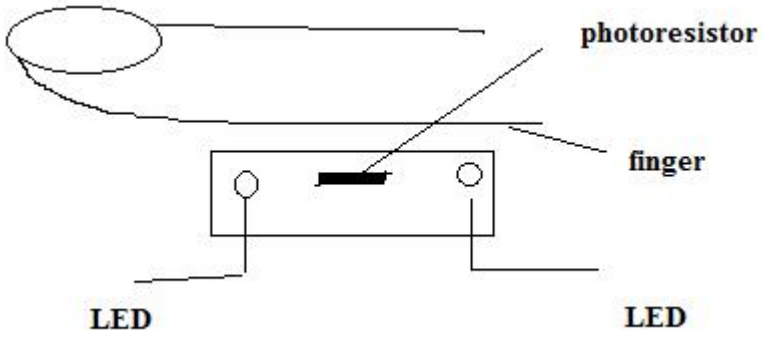


Figure Reflectance Method

BLOOD FLOWMETER

Blood flow meters are used to monitor the blood flow in various blood vessels and to measure cardiac output.

Blood flow is the continuous circulation of blood in the cardiovascular system. The science dedicated to describe the physics of blood flow is called hemodynamics. Usually the blood flow measurements are more invasive than blood pressure measurements / ECG

The abnormal changes in the blood flow or blood velocity gives rise to malformation of vessels.

Blood flow is nothing but the volume of blood per time [ml/min].

Typical values for blood flow [cm/s]:

1. Aorta 100 – 250
2. Abdominal 100
3. Vena Cava 5 – 40

Types

· Electromagnetic blood flow meters

· Ultrasonic blood flow meters

· Laser based blood flow meters

ELECTROMAGNETIC FLOWMETERS

- Electromagnetic blood flow meters measure blood flow in blood vessels
- Consists of a probe connected to a flow sensor box

Figure . Blod flow meter

An Electromagnetic Flow Meter is a device capable of measuring the mass flow of a fluid. Unlike the common flow meter you can find on the market it has no moving parts, and for this reason it can be made to withstand any pressure (without leakage)and any fluid(corrosive and non corrosive). This kind of flow meter use a magnet and two electrodes to peek the voltage that appears across the fluid moving in the magnetic field.

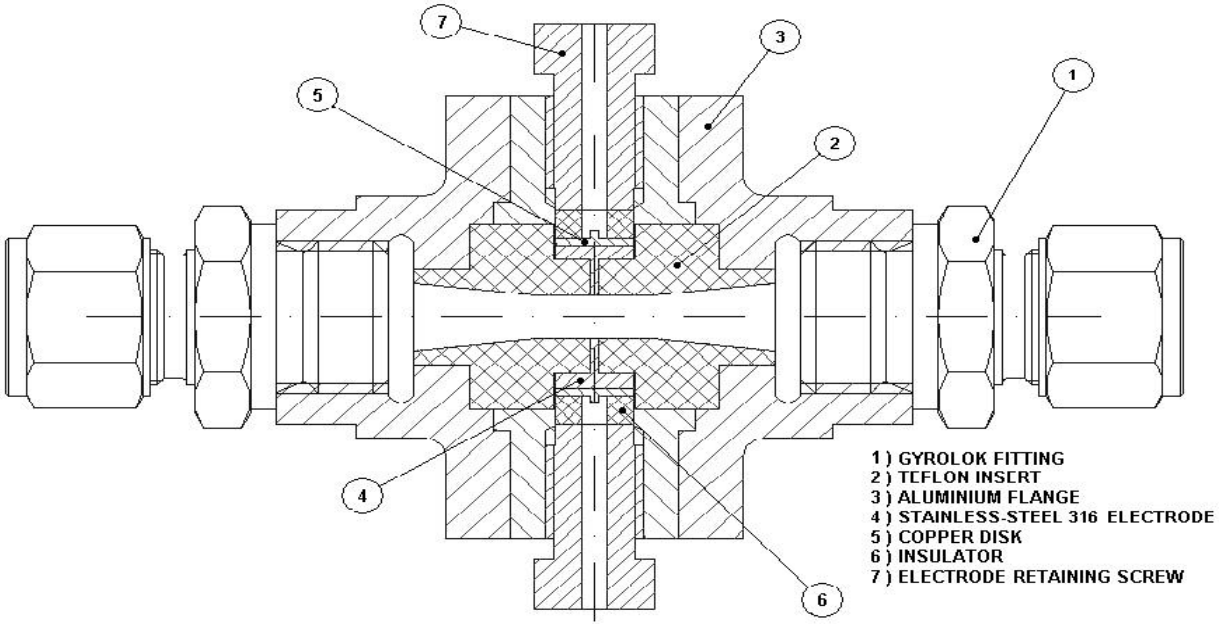


Figure Electromagnetic Flowmeter

The Neumann Law (or Lenz Law) states that if a conductive wire is moving at right angle through a magnetic field, a voltage ***E*** [Volts] will appear at the end of the conductor (Fig.):

$$E=B*L*V$$

Where
B = Magnetic Induction [Weber/m2]
L = Length of the portion of the wire 'wetted' by the magnetic field [m]
V = Velocity of the wire [m/sec]

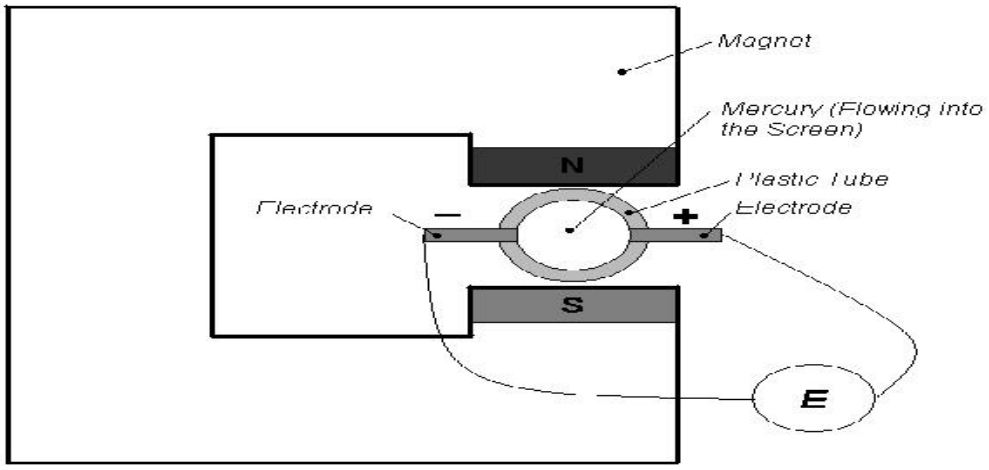


Figure Magnetic Blood flowmeter priciple

Now imagine you have a plastic tube with two electrodes on the diameter and Mercury flowing into it (fig.). A voltage will appear on the electrodes and it will be

$$E=B*L*V$$

As in the previous example (***L*** in this case is the inner diameter of the tube).Mercury as tiny conductive wires next to each other: each wire, moving in the tube, will touch the two electrodes ,and thus you can measure their voltage.

An interesting fact is that if you reverse the flow, you still get a voltage but with reverse polarity (Fig.1). Till now we have talked about a conductive fluid ,Mercury, but this stuff will also work with non conductive fluid, provided that you use an alternating magnetic field. Two physicists, Middleman and Cushing, in an unpublished work, stated that when using a non conductive fluid, if the frequency of the alternating magnetic field is ***v*** the voltage at the electrodes will be attenuated by a factor ***a*** so that:

Measuring the flow

`A perfect axisimmetric construction cannot be achieved and thus some magnetic flux lines will 'wet' the connecting wires to the electrodes. The alternating magnetic field will create an offset voltage in this wire and even if the fluid is not moving, the measured voltage will not be zero.

ULTRASONIC FLOWMETERS

The blood cells in the fluid scatter the Doppler signal diffusively.In the recent years ultrasound contrast agents have been used in order to increase the echoes.The ultrasound beam is focused by a suitable transducer geometry and a lens.

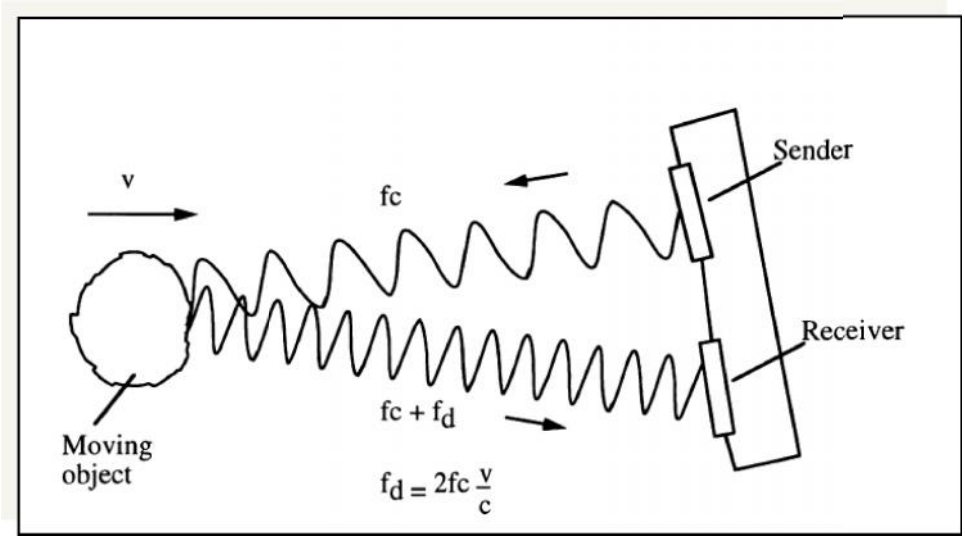


Figure Ultrasonic flowmeters

$f_d = 2f_c v/c$

f = 2- 10 MHz

c = 1500 - 1600 m/s (1540 m/s)

f = 1,3 – 13 kHz

In order to know where along the beam the blood flow data is colledted, a pulsed Doppler must be used.The flow velocity is obtained from the spectral estimation of the received Doppler signalThe ultrasound Doppler device can be either *a continuous wave* or *a pulsed Doppler*

A Continuous Wave

No minimum range
Simpler hardware
Range ambiguity
Low flow cannot be detected

A Pulsed Doppler

Accuracy
No minimum flow
Minimum range

(Maximum flow) x (range)= limited the power decays exponentially because of the heating of the tissue. The absorption coefficient ~ proportional to frequency the far field operation should be avoided due to beam divergence.

$$D_{nf} = D^2 / 4\lambda$$

D = Transducer diameter (e.g. 1 – 5 mm) the backscattered power is proportional to *f* .The resolution and SNR are related to the pulse duration. Improving either one of the parameters always affects inversely to the other

LASER DOPPLER FLOWMETRY

The principle of measurement is the same as with ultrasound Doppler.The laser parameter may have the following properties:5 mWHe-Ne-laser 632,8 nm wavelength.

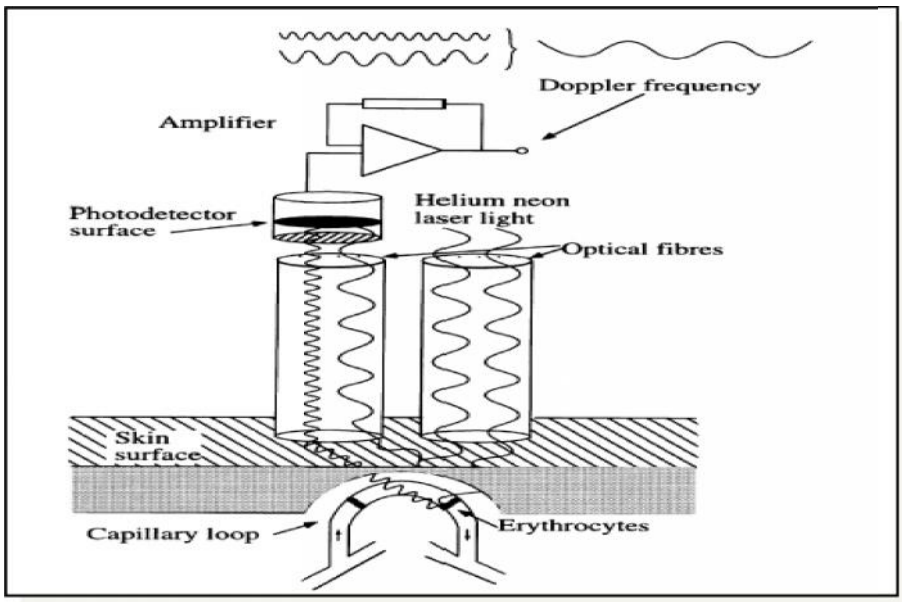


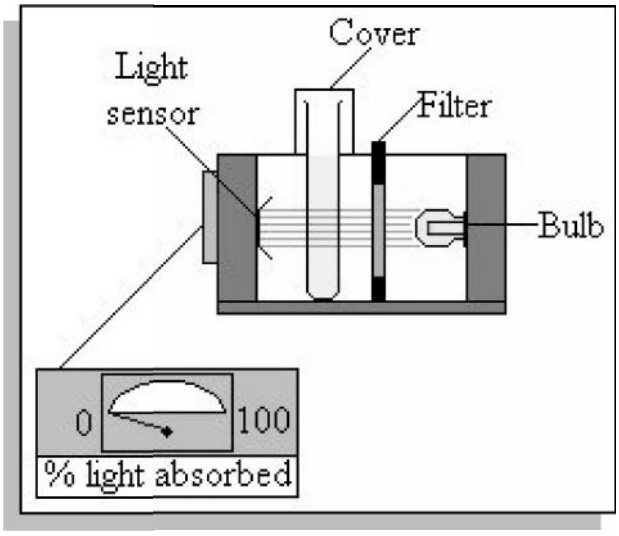
Figure Laser Doppler flowmeter

The moving red blood cells cause Doppler frequency 30 – 12 000 Hz.The method is used for capillary (microvascular) blood flow measurements

Indicator Dilution Methods

Dye Dilution Method

A bolus of indicator, a colored dye *(indocyanine green),* is rapidly injected in to the vessel. The concentration is measured in the downstream The blood is drawn through a colorimetric cuvette and the concentration is measured using the principle of absorption photometry



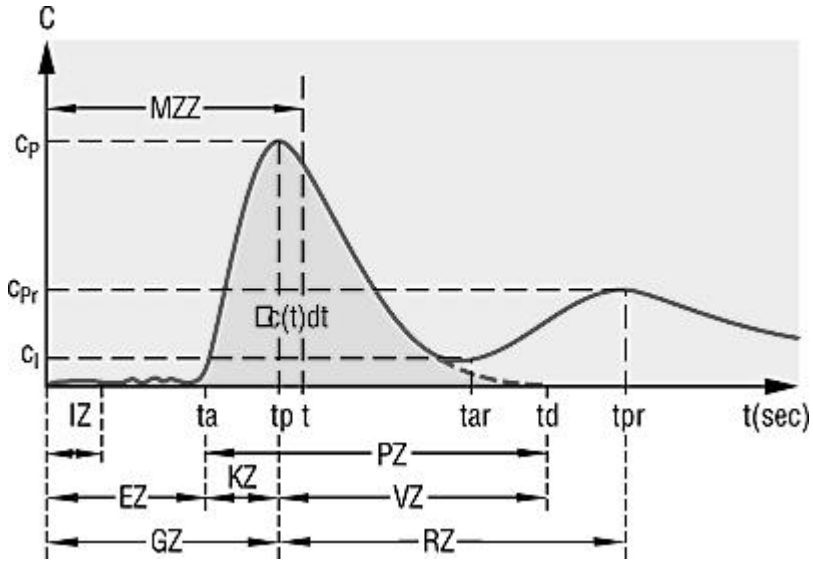


Figure Dye Dilution Method

Thermal Dilution Method

A bolus of chilled saline solution is injected into the blood circulation system (right atrium). This causes decrease in the pulmonary artery temperature. An artery puncture is not needed in this technique.Several measurements can be done in relatively short time .A standard technique for measuring cardiac output in critically ill patients

Photoelectric Method

A beam of IR-light is directed to the part of the tissue which is to be measured for blood flow (e.g. a finger or ear lobe)

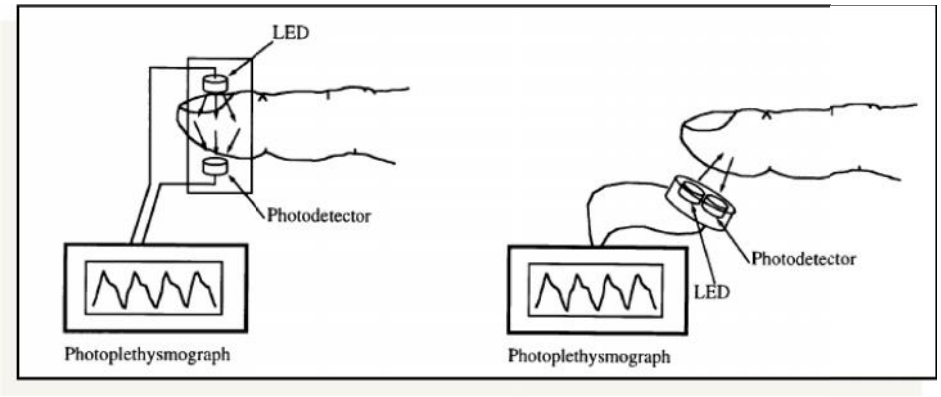


Figure Photoelectric Method

The blood flow modulates the attenuated / reflected light which is recorded.The light that is transmitted / reflected is collected with a photodetector

Radioisotopes

A rapidly diffusing, inert radioisotope of lipid-soluble gas (Xe or Kr) is injected into the tissue or passively diffused

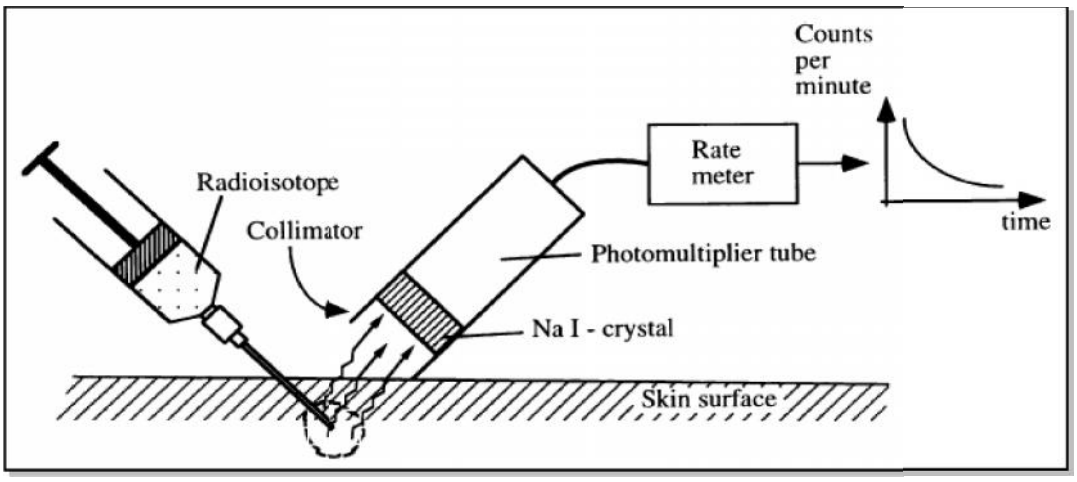


Figure Radioisotopes

The elimination of the radioisotope from microcirculatory bed is related to the blood flow:

Thermal Convection Probe

- This is one of the earliest techniques for blood flow measurements
- The rate of heat removal from the tissue under probe is measured
- The concentric rings are isolated thermally & electrically from each other

The central disk is heated 1 – 2 C over the temperature of tissue.A temperature difference of 2- 3 C is established between the disks.The method is not very common due extreme nonlinear properties and difficulties in practical use (e.g. variable thermal characteristics of skin)

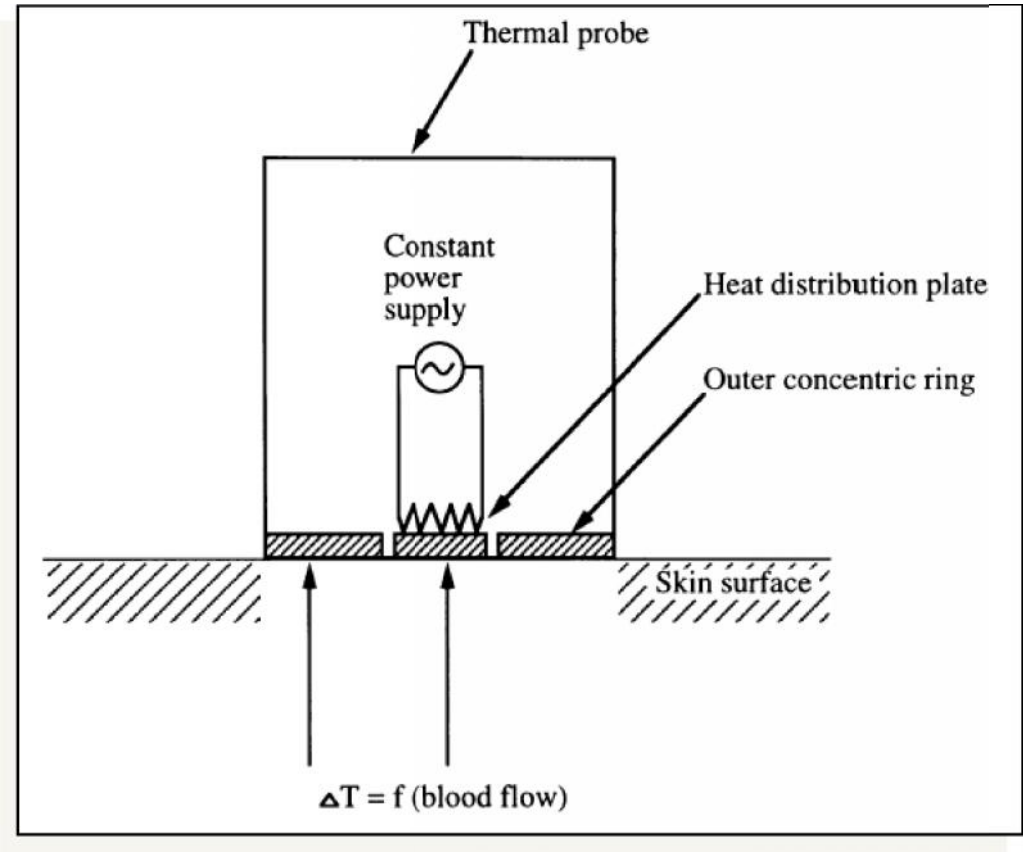


Figure Thermal Convection Probe

CARDIAC OUTPUT

Definition: Volume of blood pumped by the heart per min

CO = SV x HR
Norm ~ 5 l/min
Cardiac index – corrected for body surface area

Affected by :

Met. Rate – pregnancy, hyperthyroid, septic
Preload / contractility / afterload

Clinical indicators of CO imprecise

Affected by anaesthetic agents used in everyday practice
Provides estimate of:

- whole body perfusion
- oxygen delivery
- left ventricular function

Persistently low CO associated with poor outcome

Methods: Fick method

Dilution techniques – dye / thermal / lithium
Pulse contour analysis- LiDCO & PiCCO
Oesophageal doppler
TOE
Transthoracic impedance plethysmography
Inert gas through flow
Non-invasive cardiac output measurement

Fick Principle: Measure volume displacement 1st proposed 1870 –the total uptake or release of a substance by an organ is the product of the blood flow through that organ and the arteriovenous concentration difference of the substance. Limited by cumbersome equipment, sampling errors need for invasive monitoring and steady-state haemodynamic and metabolic conditions

Indicator dilution techniques

An indicator mixed into a unit volume of constantly flowing blood can be used to identify that volume of blood in time, provided the indicator remains in the system between injection and measurement and mixes completely in the blood.

Dye dilution

- Inert dye – indocyanin green
- Injected into pulmonary artery and arterial conc. measured using a calibrated cuvette densitometer
- Plot indicator dilution curve (see diagram) CO derived from area under curve.

Indicator Dilution Curve

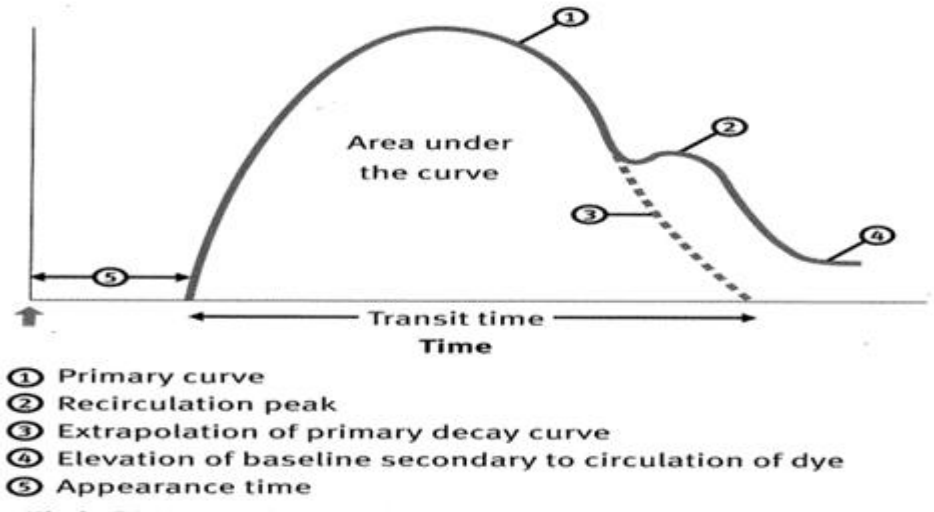


Figure Indicator dilution curve

Cardiac Output Measurement

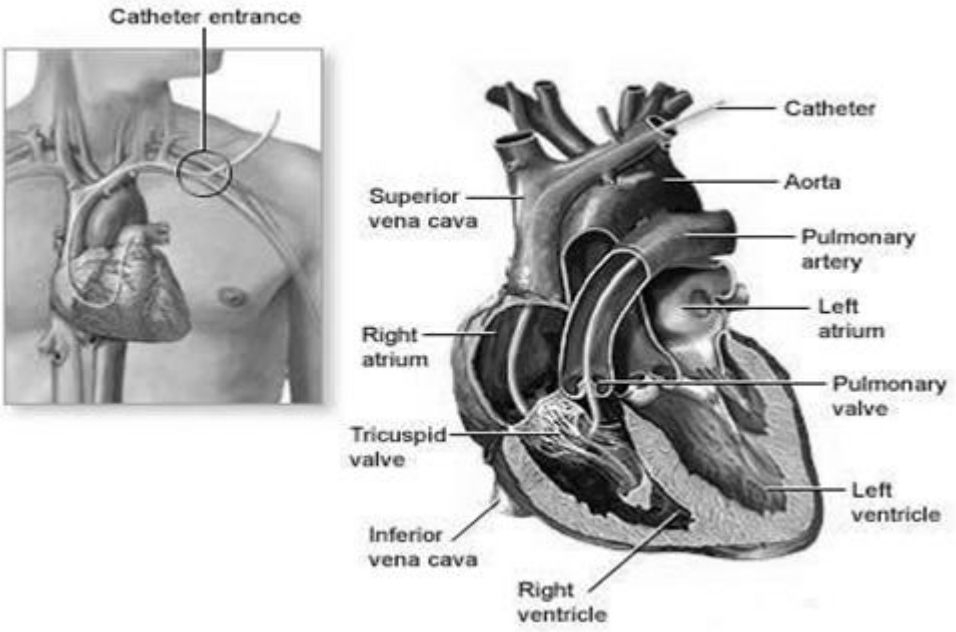


Figure Cardiac output measurement

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).

Blood pH Measurement

- In chemistry, **pH** is the negative log of the activity of the hydrogen ion in an aqueous solution.
- Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline.
- Pure water has a pH of 7.
- Mathematically, pH is the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the hydronium ion concentration
- Blood pH is an important factor to determine the acid base balance in the human body.
- Blood pH level plays an important role for your overall health, because if your blood pH level is acidic, your cells cannot function properly.
- One of the major contributors to acidosis is carbon dioxide, a byproduct of metabolism.
- Carbon dioxide combines with water to form carbonic acid. The normal pH of blood is between 7.35-7.45.
- The increase in hydrogen ion concentration causes the pH of the body fluids to decrease.
- If the pH of the body fluids falls below 7.35, symptoms of respiratory acidosis become apparent.
- Blood gas analyzers are used to measure pH, pCO2 and pO2 etc
- pH of biological fluids is measured using a glass electrode.

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.

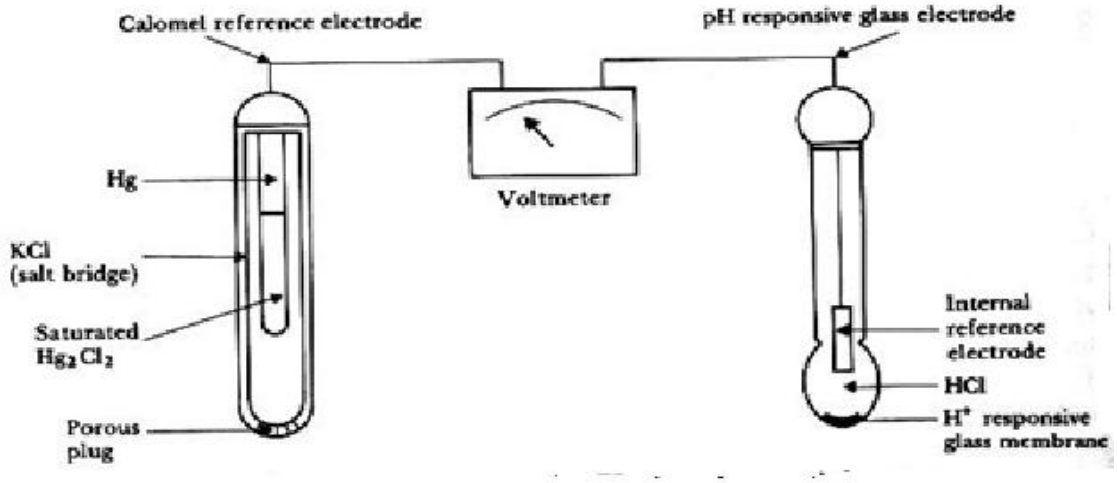


Figure pH Electrode

For easier ph measurement combination electrodes are used. In this type both the active glass electrode and reference electrode are present in the same meter. The glass electrodes are suitable only to measure ph values around 7. Since this type of glass electrodes produce considerable errors during the measurement of high Ph values, special type of Ph electrodes are used. After every measurement the pH meter is washed with 20% ammonium biflouride solution, for accurate results. The Ph meter with hydroscopic glass absorbs water readily and provides best pH value.

pO_2 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.

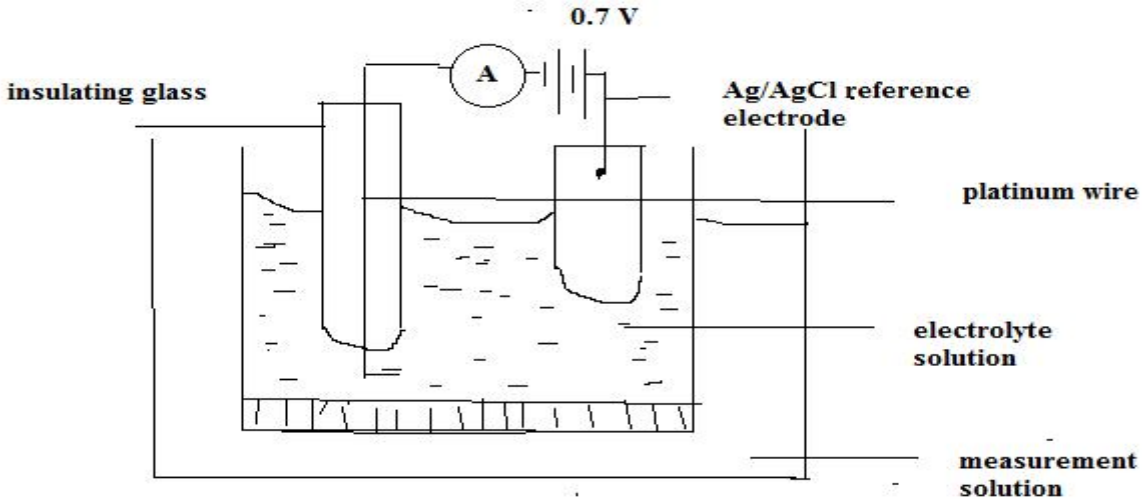


Figure pO_2 Electrode

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 pO_2 measurement. They are

I) Vitro measurement
II) Vivo measurement

In case of dark electrode the platinum cathode and the reference electrode is 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 pO_2 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 pO_2 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 pO_2 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 pO_2 electrodes reduce the errors.

pCO_2 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 pCO_2 electrodes. Since there is a linear relationship between the logarithm of pCO_2 and pH of a solution. The pCO_2 measurement is made by surrounding a pH electrode with a membrane selectively permeable to CO_2.

The modern improved pCO_2 electrode is called as severinghous electrode. In this electrode the membrane permeable to CO_2 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 CO_2 gas molecules to diffuse through it.

One of the demerits in older CO_2 electrode is, it requires a length of time for the CO_2 molecules to diffuse through the membrane. The modern CO_2 electrode is designed in such a way to overcome this demerit. Here the CO_2 molecules diffuse rapidly through the membrane and the measurement can be done easily.

MEASUREMENT OF $PHCO_3$

- Blood gas analyzers are used to measure the content of pH, pCO and PO_2 from the blood.
- Two gases of accurately known O_2 and CO_2 percentages are required for calibrating the analyzer in pO_2 and pCO_2 modes. These gases are used with precision regulators for flow and pressure control.

- Two standard buffers of known pH are required for calibration of the analyzer in the pH mode.
- Input signal to the calculator is obtained from the outputs of the pH and pCO_2 amplifiers
- The outputs are adjusted by multiplying with a constant and are given to an adder circuit
- The output of adder is passed to antilog generators circuit. Then it is passed to A/D converter for display. Resistance R is used to adjust zero at the output.
- Total CO_2 is calculated by summing the output signals of the calculators and the output of the pCO_2 amplifier

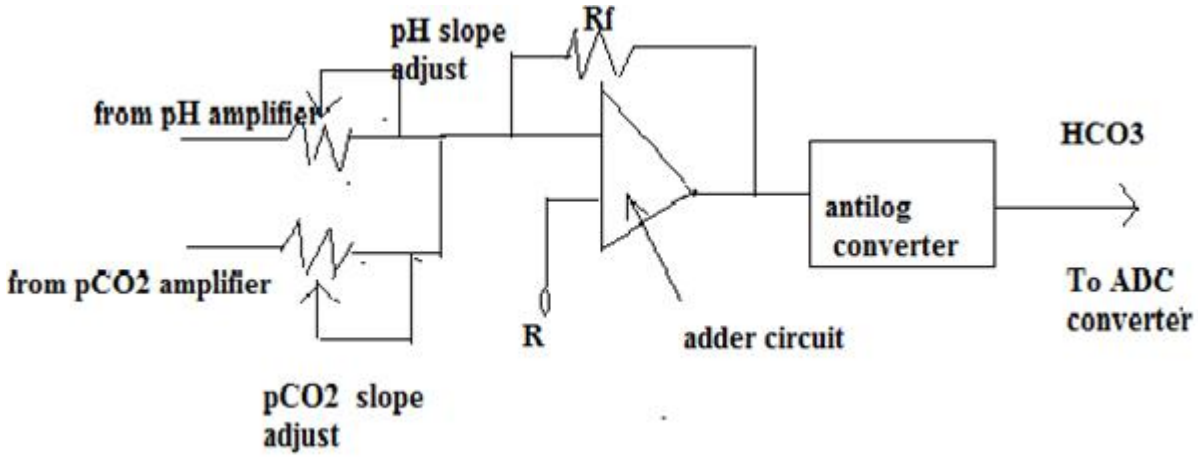


Figure circuit diagram of computation of bicarbonate

The base excess calculator consists of three stages.

In the first stage, the output of pH amplifier is inverted in an operational amplifier, whose gain is controlled by a potentiometer.

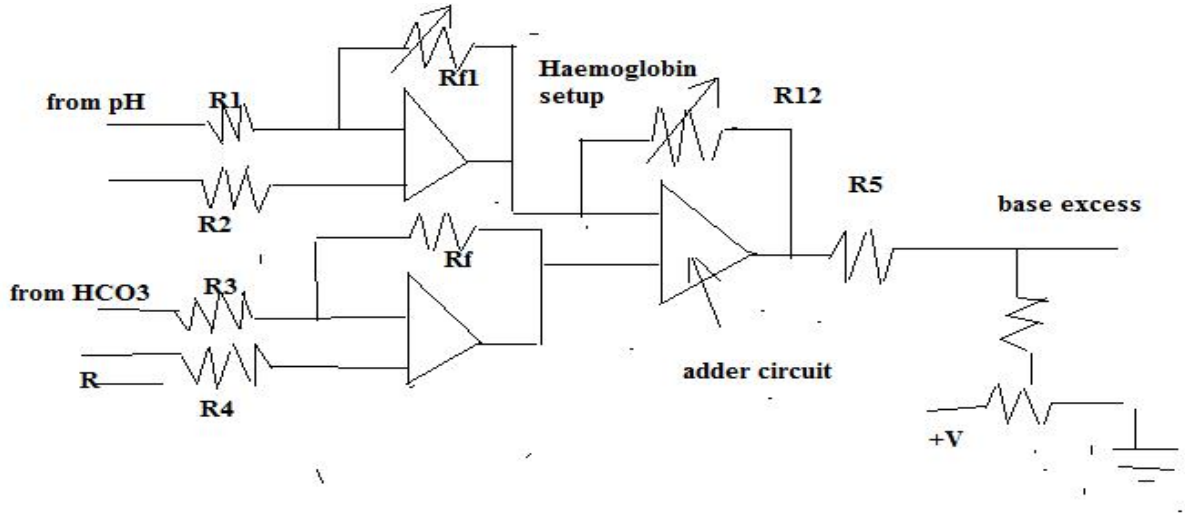


Figure Circuit diagram for computation of base excess

The output of HCO_3^- calculator is inverted in the second stage.
The third stage is a summing amplifier A_3 whose output is given to A/D converter, that gives a digital read out.

ELECTROPHORESIS

In clinical laboratories, various devices are used based on the electrophoretic principle. These devices are used for the following applications.

- To measure the quantity of protein in plasma, urine, etc.
- To separate enzymes into their components is enzymes.
- To identify antibodies.

Basic principle

Electrophoresis is defined as the movement of a solid phase with respect to a liquid. The buffer solution is used to carry the current and to maintain the pH value of the solution as a constant one during the migration.

In this title, zone electrophoresis is explained. In this technique, the sample is applied to the medium and under the effect of the electric field, group of particles that are similar in charge, size, and shape migrate at the same rate. So the particles are separated into zones.

Factors Affect the Speed of Migration

Magnitude of charge:

The mobility of a given particle is directly related to the net magnitude of the particles charge. Mobility is defined as, the distance in cm, a particle moves in unit time per unit field strength.

Ionic Strength of Buffer

If the buffer is more concentrated then the migration of the particles is slow. Because, if greater the proportion of buffer ions present, then greater the proportion of the current they carry.

Temperature:

Mobility is directly related to temperature. Heat is produced when the current flows through the resistance of the medium. So, the temperature of the medium is increased and resistance is decreased. Finally, the rate of migration is increased.

The water is evaporated from the surface of the medium due to heat. So, the concentration of particle is increased. Finally the rate of migration is increased. When the gel is used as a medium; this heat will create a problem. So, for this medium, constant current sources are used to minimize the heat production.

Time: The distance of migration is related to the time period during which electrophoresis takes place.

Types of Support Media:

Cellulose acetate, starch gel and sucrose are used as support media in various electrophoretic applications. We can see the cellulose acetate electrophoresis in the following sections**.**

Cellulose Acetate Electrophoresis

Cellulose acetate strip is saturated with the buffer solution and placed in the membrane holder. It is otherwise known as bridge. The two ends of the bridge are placed in the cuvette in which buffer solution is available.

The sample for each test is placed on the strip at a marked location. Then, the constant electric potential(250 V) is applied across the strip 4 – 6 mA of initial current is obtained **.**After 15-20mins, the electric voltage is removed, then, migrated protein band is stained with buffer and it is dried in preparation for densitometry.

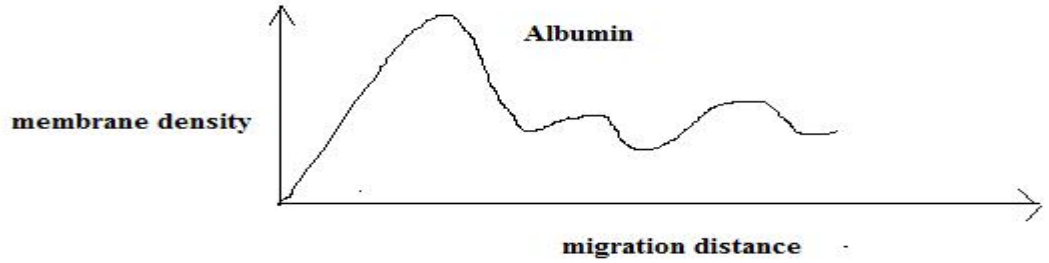


Figure Pattern

The membrane is placed in the holder of densitometer. The path of the migration of one of the specimen is scanned. The low voltage output is amplified and recorded using x-y recorder.

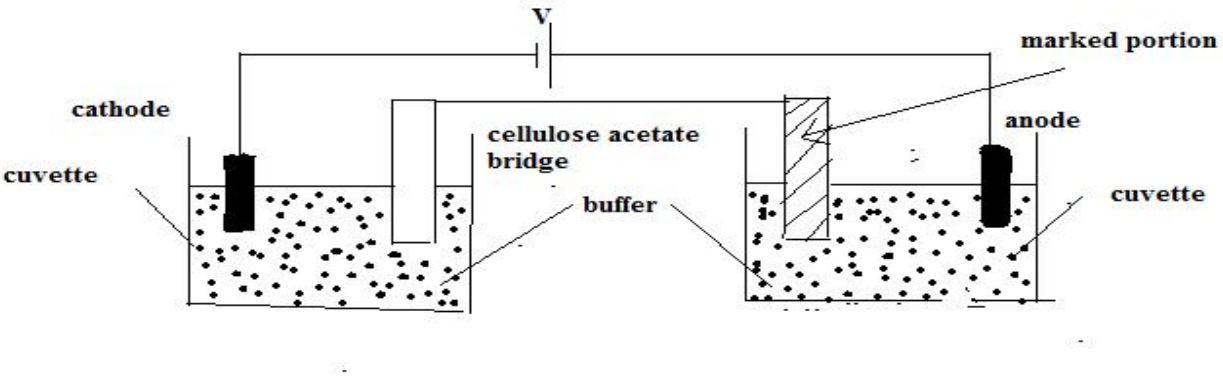


Figure Cellulose acetate electrophoresis

COLORIMETER

- Measures the color concentration of a substance in a solution by detecting the color light intensity passing through a sample containing the substance and a reagent
- Optical color filters are used to detect the color 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 color.

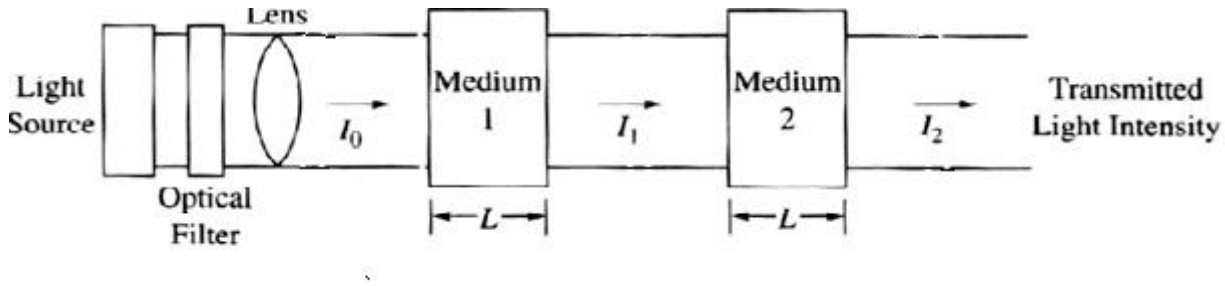


Figure Colorimeter

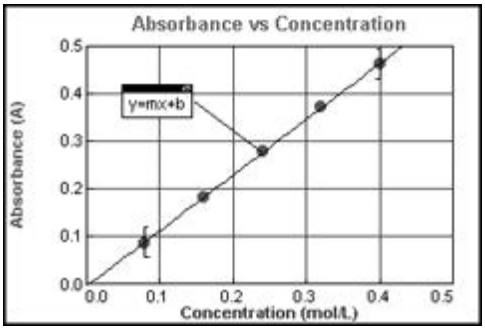


Figure Concentration vs Absorbance

Transmittance

$T= I_1/I_0 * 100\%$

Absorbance

$A= - \log I_1/ I_0$

$A=\log 1/T$

If the path length or concentration increases, the transmittance decreases and absorbance increases, a phenomenon expressed by Beer's Law.

Absorbtivity related to the nature of the $A=aCL$ absorbing substance and optical wavelength (known for a standard solutionconcentration).

C: Concentration

L: Cuvette path length

PHOTOMETER

FLAME PHOTOMETER

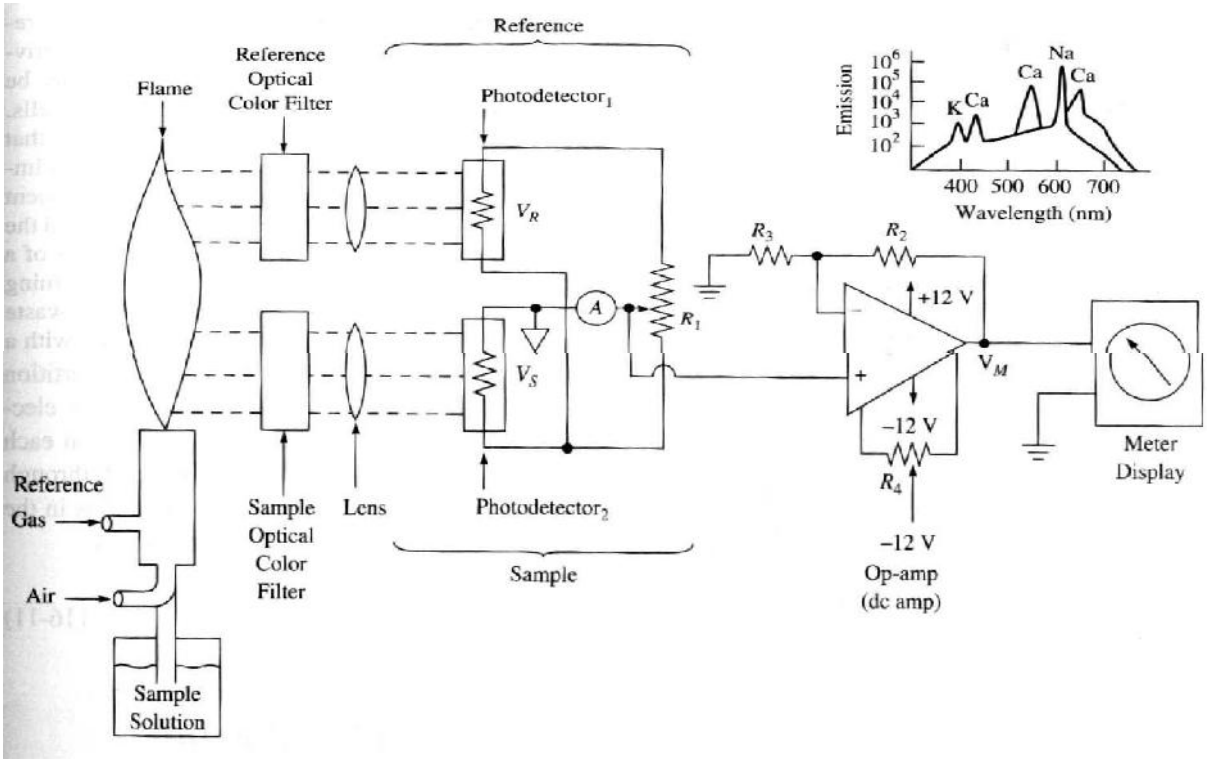


Figure Flame Photometer

Measures the color 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 conc. 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 consists 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 S_0 into its spectral components.
- Slit S_1 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.

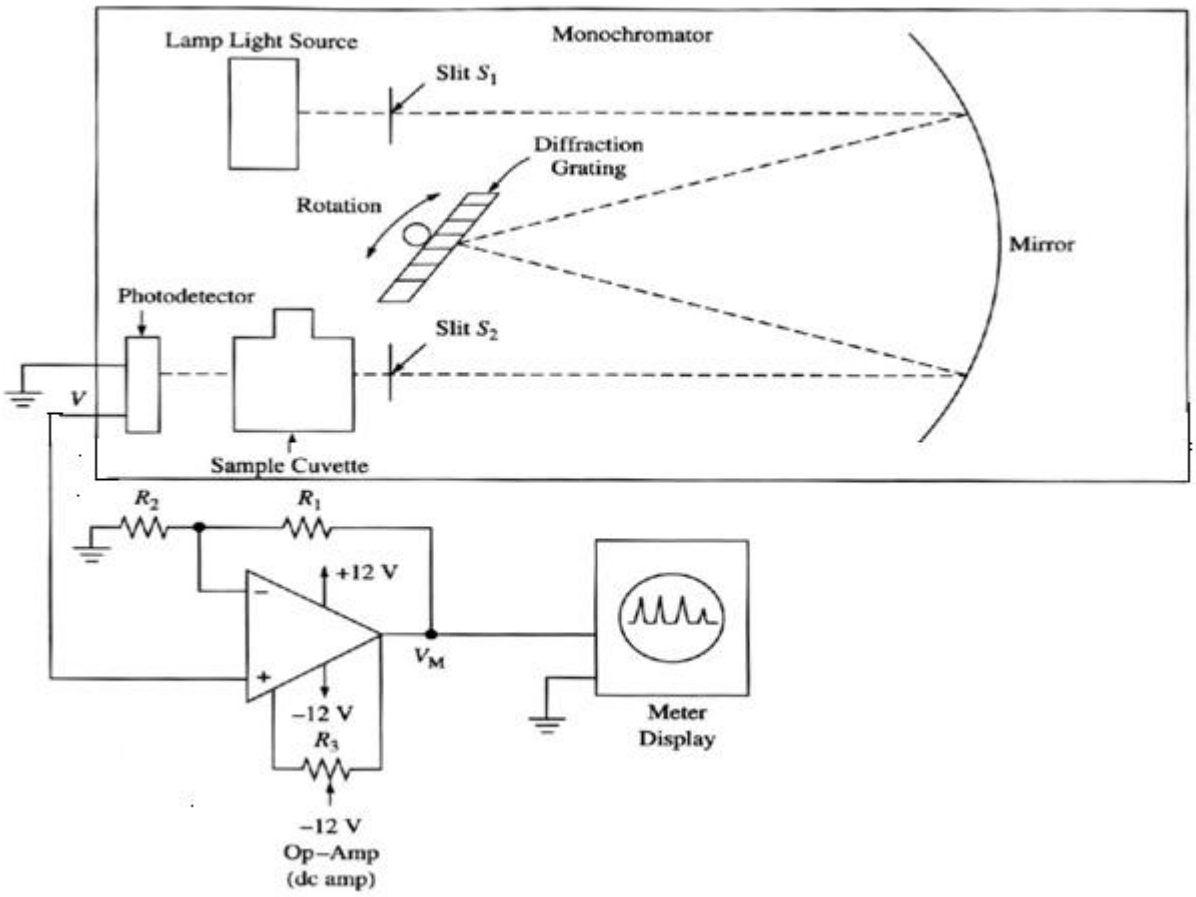


Figure Spectrophotometer

AUTOANALYZER

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

Itconsists of

- **Sampler:** Aspirates samples, standards, wash solutions into the system
- **Proportioning pump:** Mixes samples with the reagents so that proper chemical color reactions can take place, which are then read by the colorimeter
- **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 color development
- **Colorimeter:** monitors the changes in optical density of the fluid stream flowing through a tubular flow cell. Color intensities proportional to the substance concentrations are converted to equivalent electrical voltages.
- **Recorder:** Displays the output information in a graphical form.

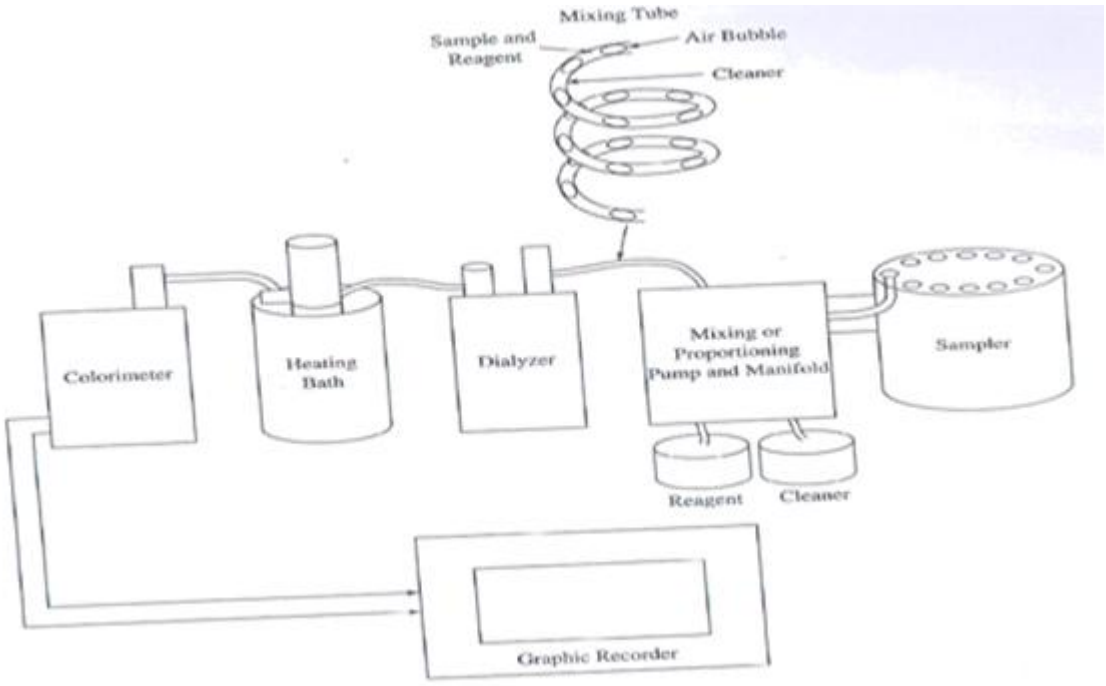


Figure Block diagram of Autoanalyzer

BLOOD CELL COUNTER

- The blood cell counter count the number of RBC or WBC per unit of volume of blood using either of two method:
  - 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 then 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

- The sensor consist 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 tow halves of the cell
- Ohmmeter measure the change on the resistance when the blood cell pass the aperture

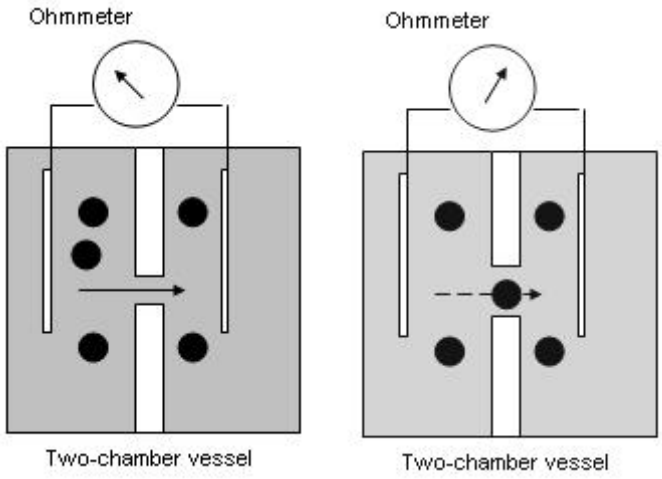


Figure Blood cell sensing

COULTER COUNTER

- Constant current source (CCS) and voltage amplifier replace the ohmmeter
- R_A is the resistance of the aperture and will be either high or low, depending on whether or not the blood cell is inside the aperture.
- Amplifier convert the current pulse to voltage pulse

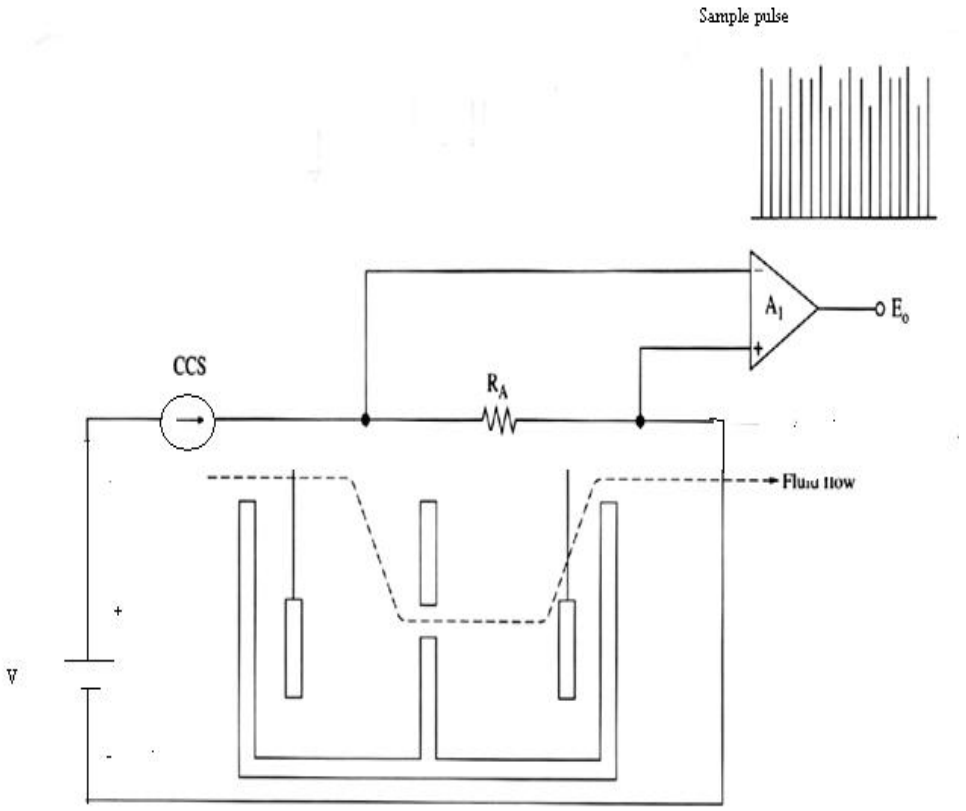


Figure ' Block diagram of Coulter Counter

FLOW CYTOMETRY CELL COUNTERS

Optical flow cytometry sensing

- The optical cytometry sensor consists of a quartz sensing sheath designed with a
  - hydrodynamic focusing region
  - cell path region that passes only a single cell at time.

- Focusing is done by decreasing the diameter of the aperture.
- Light source is (He-Ne) Laser

- Two Photodetectors (photosensors)
  - Photodetector A detects forward scatted light
  - Photodetector B detects orthogonal scatted light

- blood sample enters the analyzer
  - Optical counter → WBC count
  - Colorimeter → hemoglobin
  - Optical flow sensor → RBC count

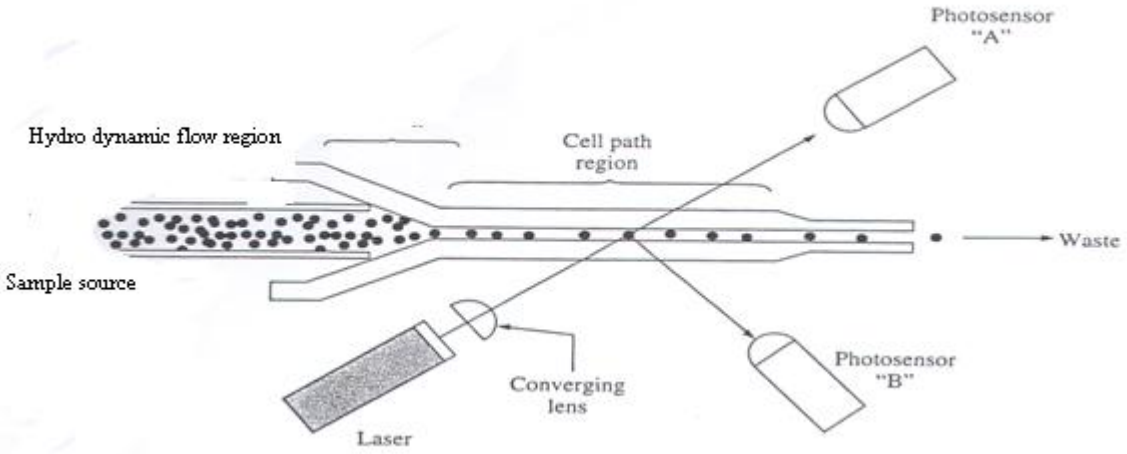


Figure Optical flow cytometry

The blood is actually split into different chambers, where in each chamber it is diluted / mixed to differentiate different cell types. WBC and RBC are separated (using lysing)