JEPPIAAR INSTITUTE OF TECHNOLOGY

"Self-Belief | Self Discipline | Self Respect"

DEPARTMENT
OF
ELECTRONICS AND COMMUNICATION ENGINEERING

LECTURE NOTES
OMD551– BASICS OF BIOMEDICAL INSTRUMENTATION
(Regulation 2017)

Year/Semester: III/V ECE
2021 – 2022

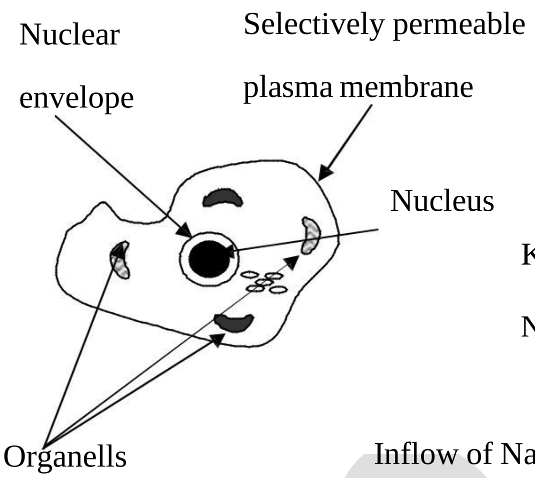
UNIT I BIO POTENTIAL GENERATION AND ELECTRODE TYPES 9

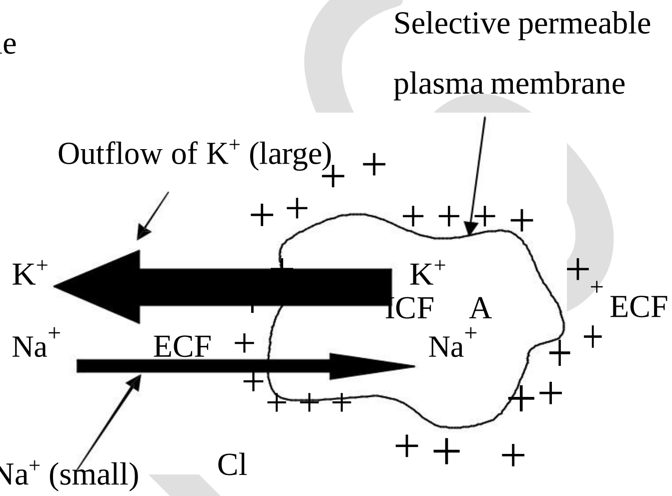
Origin of bio potential and its propagation. Types of electrodes - surface, needle and micro electrodes and their equivalent circuits. Recording problems - measurement with two electrodes

Origin of biopotential:

Cell is the basic building unit of human body.

Structure of a cell:





A cell consists of a plasma membrane, a nucleus and cytoplasm.

Plasma membrane: It is selectively permeable to (various ions such as) Na^+, K^+ and intracellular anions. The fluid inside the plasma membrane called the ***intracellular fluid*** (ICF). The fluid outside the plasma membrane is called the ***extracellular fluid*** (ECF). The plasma membrane separates the cell's contents from its surroundings.

Nucleus: It is the largest single organized cellular component. It is a distinct spherical or oval structure located near the center of the cell. It is covered by a double-layered membranous structure.

Cytoplasm: It is a gel-like mass with membrane-bound structures suspending in it.

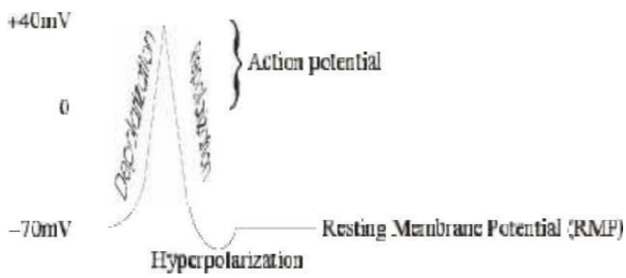
Resting membrane potential:

(i) Na^+ is large in the ECF while K^+ is large in the ICF.

(ii) When the cell is at rest, the inflow of Na^+ is very small but the outflow of K^+ is large.

(iii) Due to these facts, the inside of the cell membrane is more negative than its outside. This leads to a potential difference across the cell membrane called the ***resting membrane potential*** (RMP). This has a value of 70mV to 90mV.

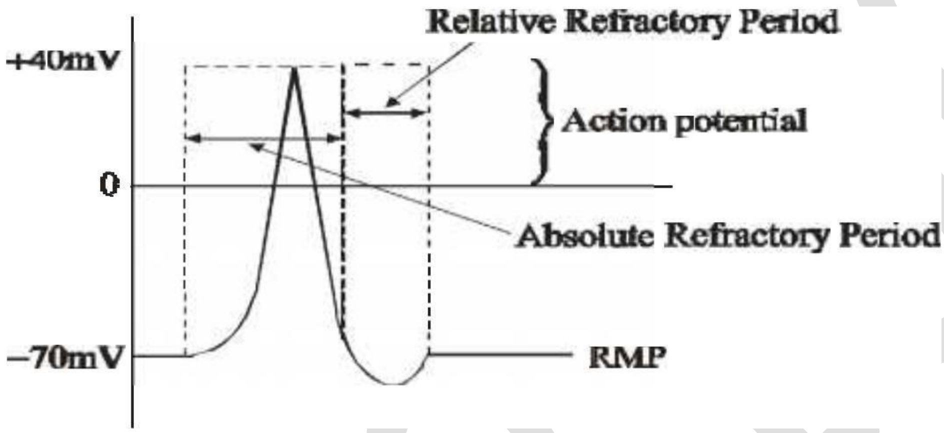
Action potential:



When cell is excited, the permeability of the plasma membrane to Na^+ suddenly increases 600 times greater than that to K^+ & a sudden large inflow of Na^+ takes place. As the inflow of Na^+ exceeds the outflow of K^+ by several times, the membrane potential suddenly decreases from 70mV to zero and then shoots up to 40mV. This positive shoot over the neutral level (0mV) is called the action potential. Once generated, the action potential travels down the nerve for a long distance.

After certain (very short) period, the permeability of the plasma membrane returns to equilibrium conditions causing the membrane potential to return to the resting value i.e., RMP value. However, the membrane potential does not immediately return to the resting value rather it goes more negative than the RMP; this cools the cell membrane that has become hot due to the generation of the action potential. After a very short period, the membrane potential returns to the resting value.

Refractory period: Absolute and relative:



Absolute refractory period: During a short period after the generation of an action potential, the cell does not respond to any stimulus at all. This period is known as the ***absolute refractory period***.

Relative refractory period: It is the time period between the instant when the membrane potential becomes negative again and the instant when the membrane potential returns to RMP. During this period, the cell responds to a stimulus but less strongly than usual.

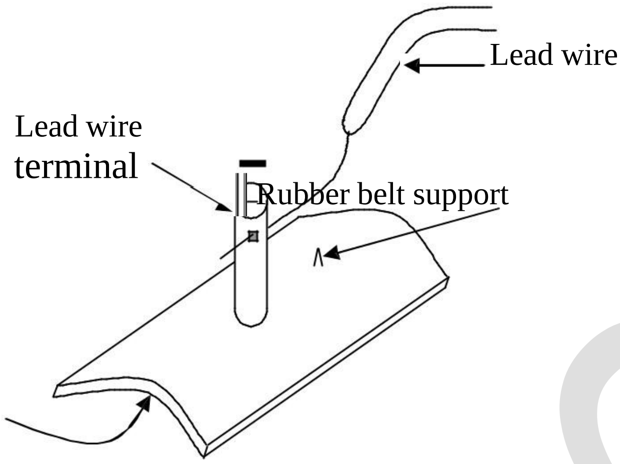
Types of Electrodes: The major categories are the (I) Surface electrodes, (II) Internal or sub-cutaneous electrodes and (III) Micro electrodes.

(I) Surface electrodes:

The surface electrodes are used to pick up bio-potentials non-invasively from the surface of the skin. This provides sufficient information for most of the clinical purposes.

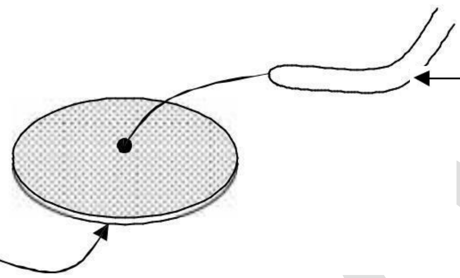
There is a variety of surface electrodes intended for variety of clinical purposes. Here are some of them.

(i) 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.

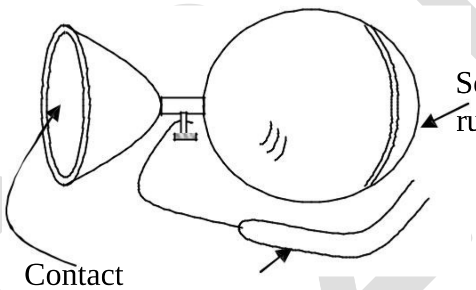

Lead wire
Lead wire
terminal
Rubber belt support

Contact
surface

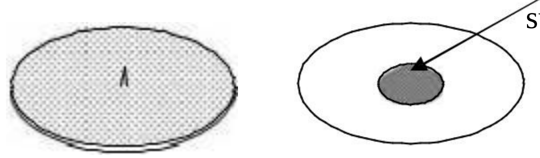
(ii) <u>Metal disc electrode:</u> It is made up of Ag-AgCl. It is used to pick up EEG from the scalp. It is fixed to the scalp by means of adhesive tape.



(iii) <u>Metallic suction electrode:</u> 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.

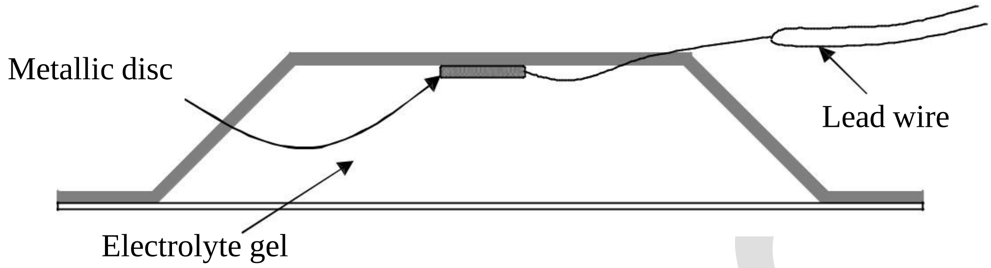


(iv) <u>Disposable foam-pad electrode:</u> It is made up of Ag-AgCl. It is used to pick up ECG or EEG for those patients with contagious skin diseases. It is fixed to the skin surface by means of adhesive tapes attached to the electrode.

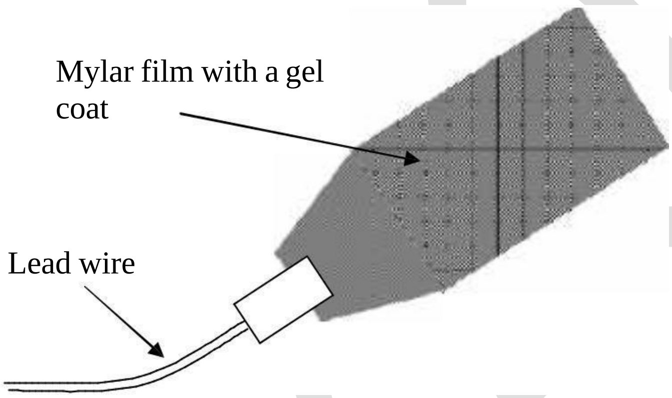


Top view Bottom view

(v) Floating electrode: This type of electrode is used to prevent the motion-artifact from being picked up.



(vi) Flexible electrode: It is used to pick up bio-potentials from irregular body surface like back. It is also used as indifferent electrode in electrosurgery.



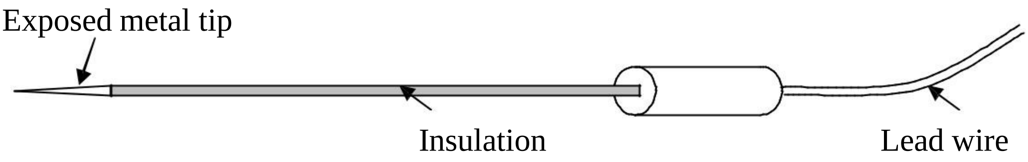
(II) Internal or sub-cutaneous electrodes:

The internal or sub-cutaneous electrodes are used to make measurements at sub-cutaneous level. There are many different designs for internal electrodes. The investigator studying a particular bioelectric phenomenon by using internal electrodes often designs his/her, own electrodes. The most commonly used internal electrodes are the needle and wire electrodes.

The needle electrodes are used for acute recordings as their stiffness and size make them uncomfortable for long term implantation.

The wire electrodes are used for chronic recordings.

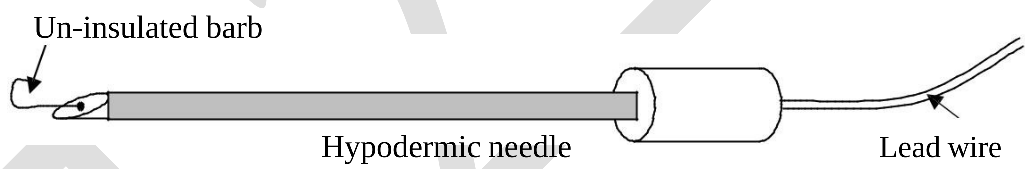
The following figures show three needle electrodes (a, b and c) and a wire electrode (d).



a) Needle electrode

b) Coaxial needle electrode

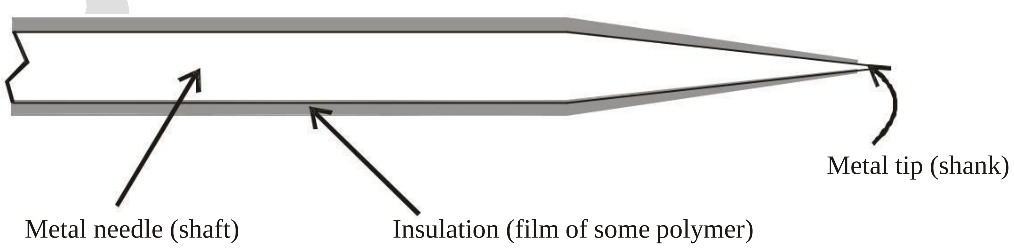
c) Bipolar needle electrode



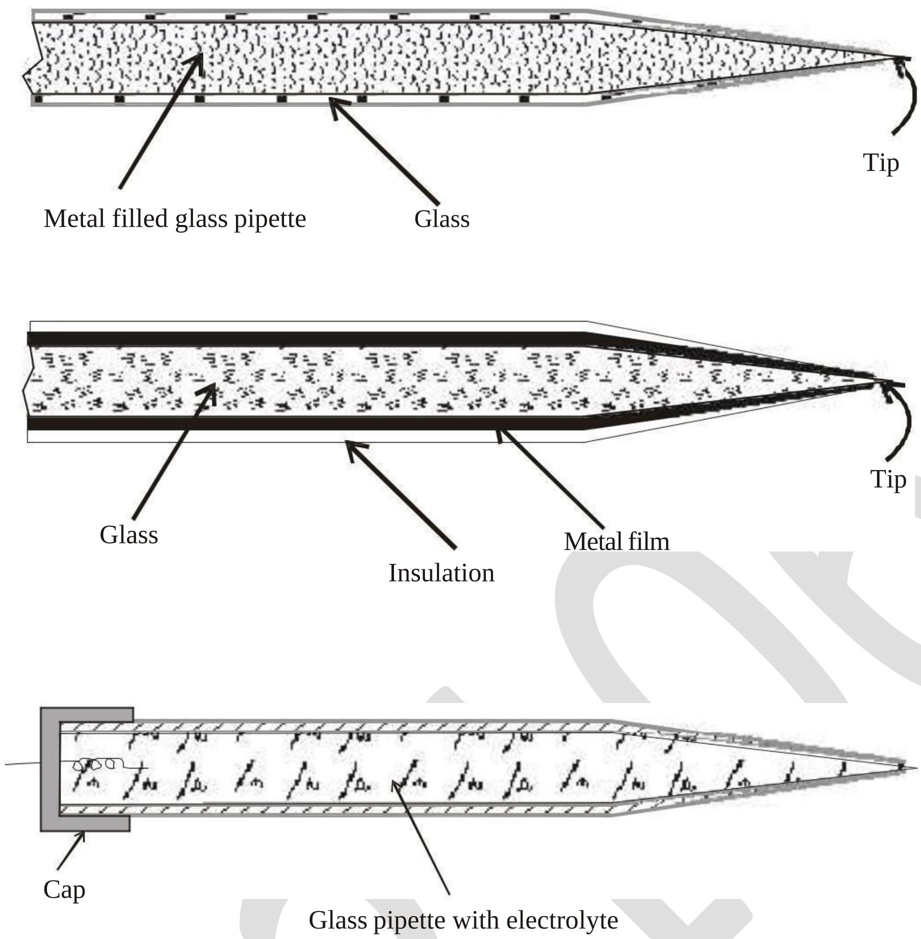
d) Wire electrode

(III) Micro electrodes:

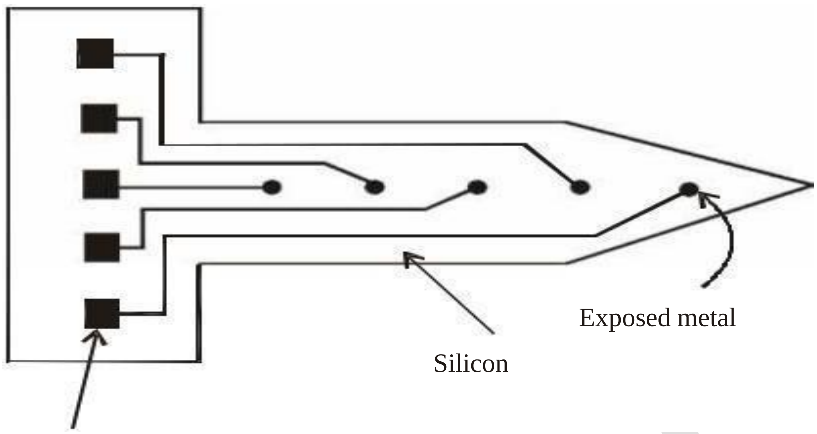
The micro electrodes are used to make measurements at cellular level. The most commonly used micro electrodes are the metal micro electrodes, supported-metal micro electrodes, micropipette electrodes and microelectronically fabricated micro electrodes. They have different designs to meet different needs. Some are shown below.



Metal microelectrode



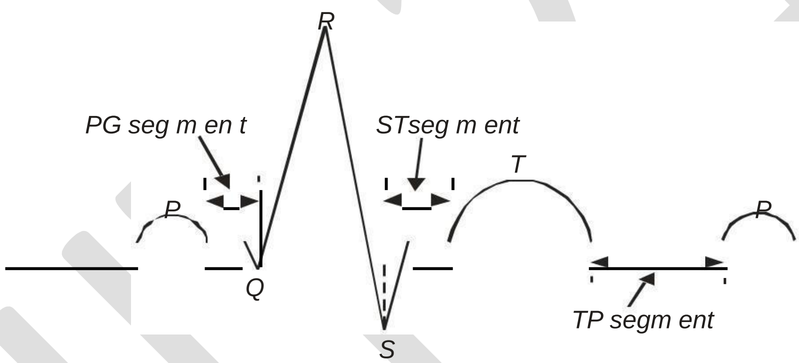
Supported-metal microelectrodes



Microelectronically fabricated microelectrode

Some important biopotentials & their signal characteristics:

ECG: ElectroCardioGram: ECG is the record of electrical activity of the heart.
Typical bandwidth: 0.5 – 125 Hz
Typical amplitude: 1 – 10 mV
Typical waveform: Rhythmic waveform



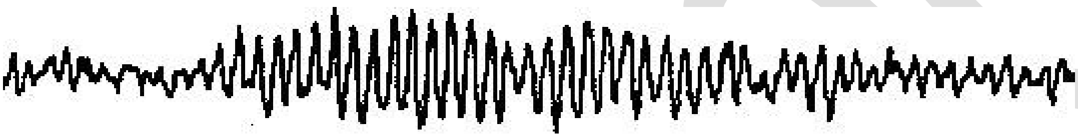
Characteristic waves of ECG:

P wave – Atrial depolarization
PQ segment – AV nodal delay
QRS complex – ventricular depolarization (atrial repolarization)
ST segment – ventricular ejection period
T wave – ventricular repolarization
TP segment – ventricular filling period

Clinical significance: ECG record helps in the diagnosis of various heart arrhythmias such as tachycardia, bradycardia, heart block etc.

EEG: ElectroEncephaloGram: EEG is the record of sum of biopotentials generated by individual neurons or electrical activities of the brain.

Typical bandwidth: 0.1 – 100 Hz
Typical amplitude: 10 – 100 V
Typical waveform: Highly random



Subdivided into five bands namely

Delta (d): 01 – 4 Hz; found in children; if found in alert adult it is abnormal
Theta (q): 4 – 8 Hz; found in children of 2-5 year old; if found in alert adult it is abnormal
Alpha (a): 8 – 13 Hz; found in alert adult with eyes closed (under relaxed conditions)
Beta (b): 13 – 22 Hz; found in alert adult with eyes open (under active conditions)
Gamma (g): >22 Hz.

Clinical Significance: EEG record helps in the diagnosis of brain asymmetry, epilepsy, mental disorders etc and in the study of sleep patterns.

PCG: PhonoCardioGram: Record of heart sounds – 1st and 2nd heart sounds are heard well but 3rd and 4th are not. Heart sounds are generally used for diagnosis of valve-related diseases. Such abnormal heart sounds are called murmurs.

1st heart sound: due to closure of AV valves – long, soft & low-pitched sound – sounds like 'lubb' – 0.14-0.2 sec – 30-40 Hz.

2nd heart sound: due to closure of semilunar valves – short, sharp & high-pitched sound – sounds like 'dub' – 0.08-0.1 sec – 50-70 Hz.

3rd heart sound: due to ventricular vibrations resulting from on-rush of blood immediately after the opening of AV valves – very short – 0.04 sec.

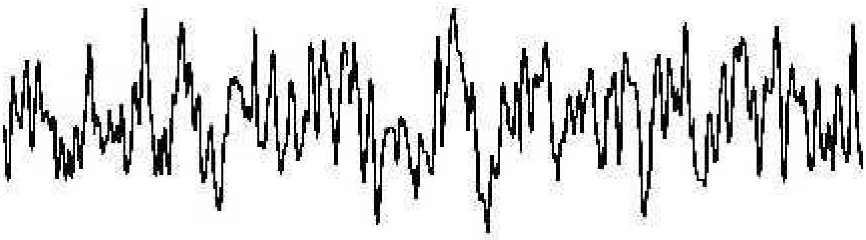
4th heart sound: due to atrial contraction.

EOG: ElectroOculoGram: Steady corneal-retinal potential – used to record eye movements in sleep and dream to evaluate reading ability and visual fatigue – eye movements less than 1^{o} and greater than 30^{o} is difficult to record because of lack of accuracy and lack of proportion.

EMG: ElectroMyoGram: EMG is the record of electrical activity of muscles.

Typical bandwidth: 300-3000 Hz
Typical amplitude: 10-100 mV

Typical waveform: Highly random.



ECG lead systems:

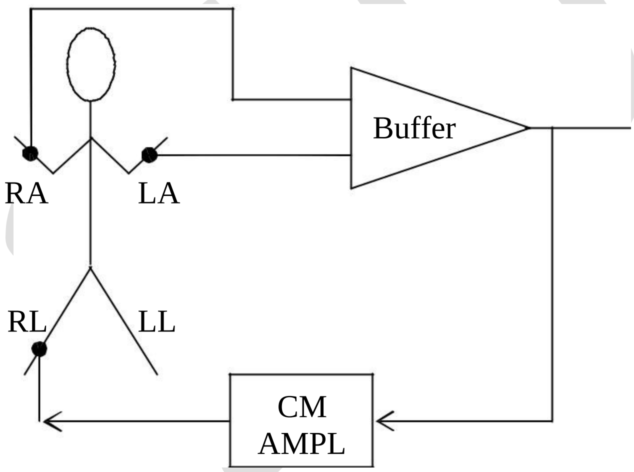
(i) Limb lead systems and (ii) Chest lead systems

(i) Limb lead systems:

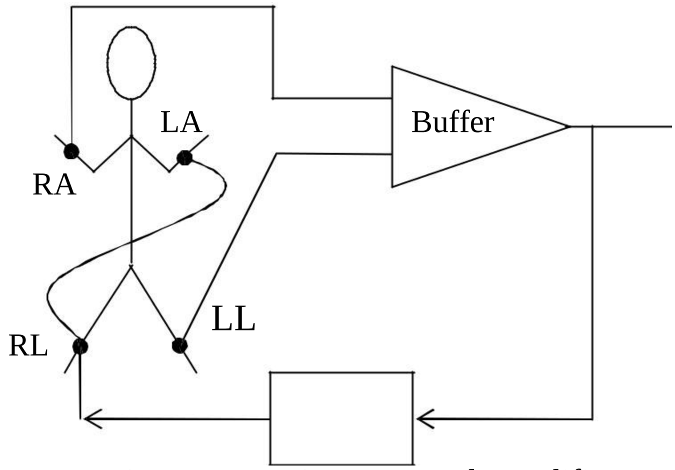
(a) Bipolar limb lead systems and (b) Unipolar or augmented limb lead systems.

(a) Bipolar limb lead systems: Potential between any two limb leads is measured with RL grounded.

(i) *Lead I:* Potential between LA & RA with RL grounded.

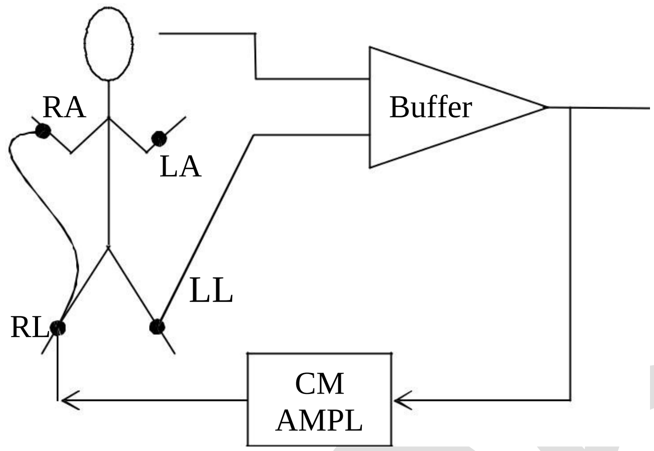


(ii) Lead II: Potential between RA & LL with LA tied to RL & RL grounded.



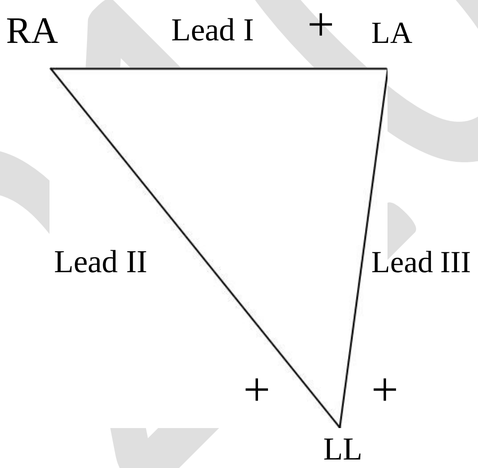
CM AMPL – Common mode amplifier

(iii) Lead III: Potential between LA & LL with RA tied to RL & RL grounded.



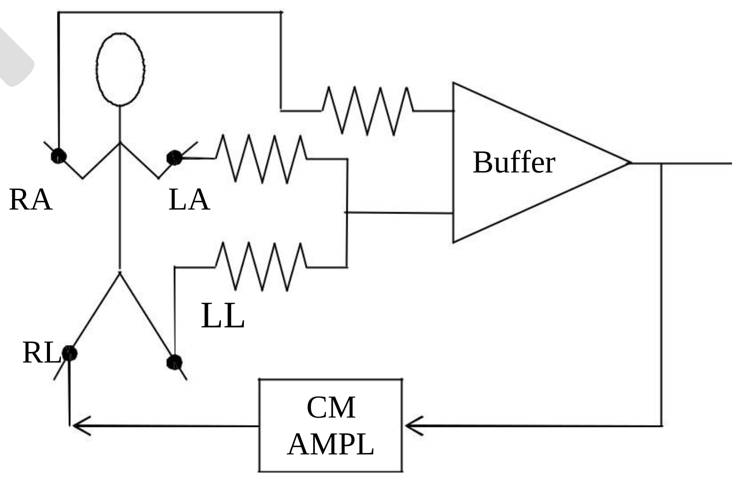
CM AMPL – Common mode amplifier

Lead I, II and III together form a triangle known as Einthoven triangle.



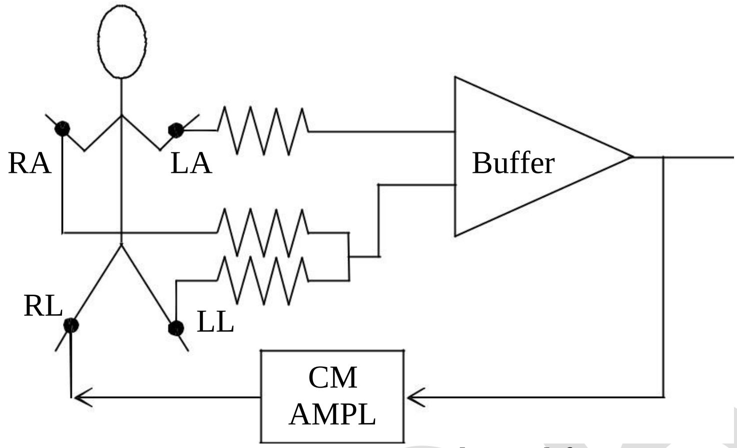
(b) Unipolar or augmented limb lead systems: Potential at a particular limb lead with other two limb leads augmented. This increases the amplitude of the ECG signal without changing its waveform.

(i) Lead aVR: Potential at RA with LA & LL augmented & RL grounded.



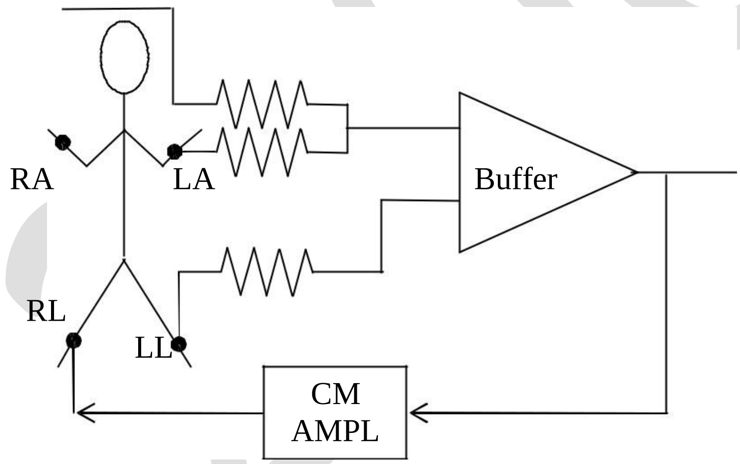
CM AMPL – Common mode amplifier

(ii) Lead aVL: Potential at LA with RA & LL augmented & RL grounded



CM AMPL – Common mode amplifier

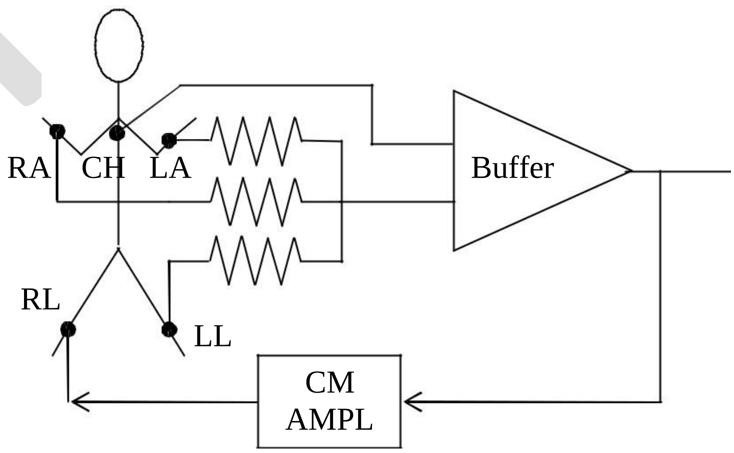
(iii) Lead aVF: Potential at LL with RA & LA augmented & RL grounded



CM AMPL – Common mode amplifier

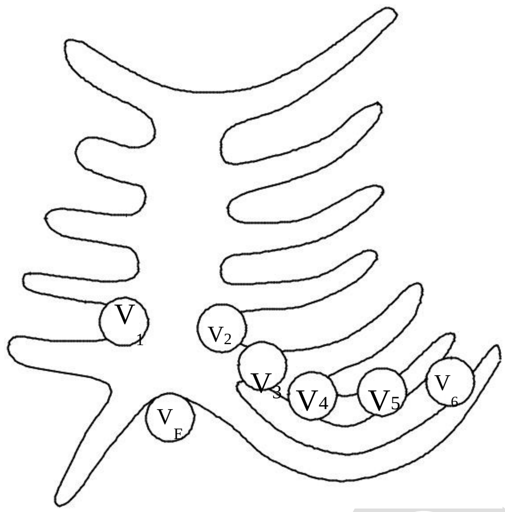
(ii) ***Chest lead systems:*** Potential at one of six chest leads with RA, LA & LL augmented and RL grounded.

(i) Lead V:



CM AMPL – Common mode amplifier

CH positions:



V_1 – Fourth intercostals space at right sternal margin

V_2 – Fourth intercostals space at left sternal margin

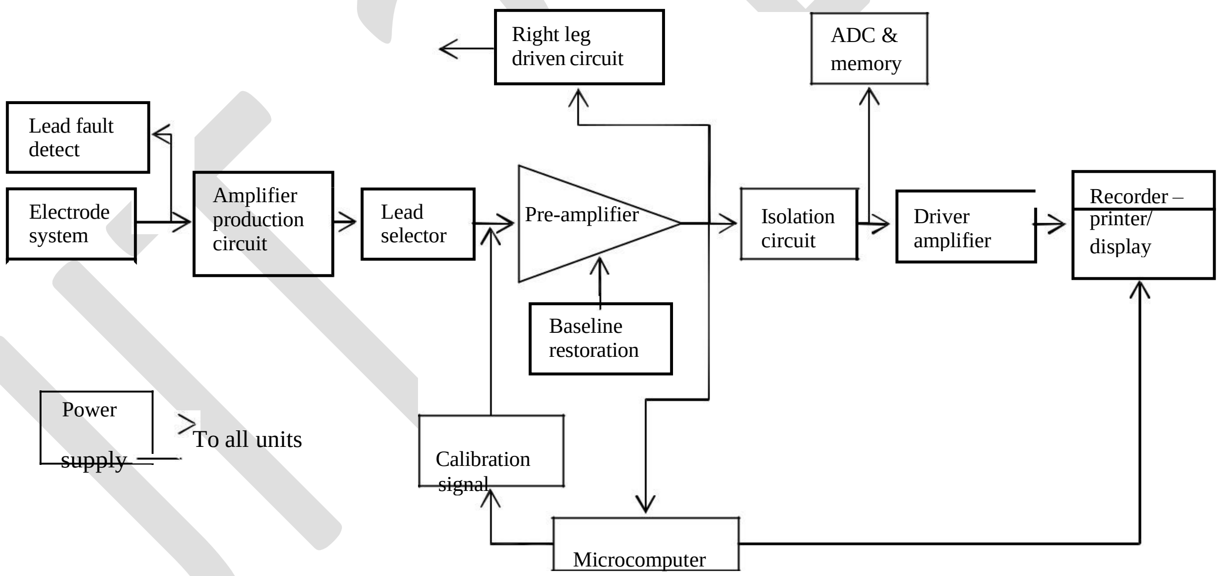
V_3 – midway between V_2 and V_4

V_4 – Fifth intercostals space at mid-davicular line

V_5 – Same level as V_4 on anterior axillary line

V_6 – Same level as V_4 on mid axillary line

Block diagram of a ECG recording system:



Electrode system: Metal plate electrodes made of Ag/AgCl are placed at desired limb positions. Good contact between electrodes & skin is ensured with the help of gel and belts.

Lead fault detect: The function of this block is to detect the improper connection of the electrodes on to the skin by continually measuring the contact resistance and to warn the operator of this via either an audible tone or a visual indication.

Amplifier protection circuitry: The function of this block is to protect the remaining part of the circuit from large electrical discharges resulting from defibrillation process.

Lead selector: The function of this block is to select a desired lead system from 12 possible lead systems. This can be carried out either manually by an operator or automatically by microprocessor or microcontroller or microcomputer.

Preamplifier: The function of this block is to eliminate noise such as other biopotentials and various electromagnetic interferences resulting from nearby communication links etc. Generally, a differential amplifier with high input impedance and CMRR is used for this purpose.

Calibration signal: The function of this block is to calibrate the display or the recorder for predetermined amplitude. A sine wave of 1 mV is generally used for this purpose.

Baseline restoration: The function of this block is to restore any baseline shift resulting from the low operating frequency of the amplifier.

Right leg driven system: The function of this block is to provide a reference point on the patient generally at ground potential.

Isolation circuitry: The function of this block is to provide electrical isolation between the high-power section that is generally driven by 230 V 50 Hz ac mains and the low power patient section that is generally driven by a low power battery. This is required to protect the patient from any electrical hazards resulting from leakage currents.

Driver amplifier: The function of this block is to amplify the ECG signal sufficiently to level required for the display or the recorder.

ADC & memory: The ECG signal can be digitized and stored for future analysis.

Microcomputer: A microcomputer along with a user-friendly software package developed on a high-level language such as VC++ can be used

(i) to control the entire process of acquiring the ECG and
(ii) to analyze it automatically for various parameters such as heart rate, PR interval, QRS interval etc using sophisticated digital signal processing techniques.

Recorder-printer/display: A heat sensitive paper can be used to get a hard copy of the ECG signal obtained or a CRO can be used to display the ECG signal obtained for visual analysis.

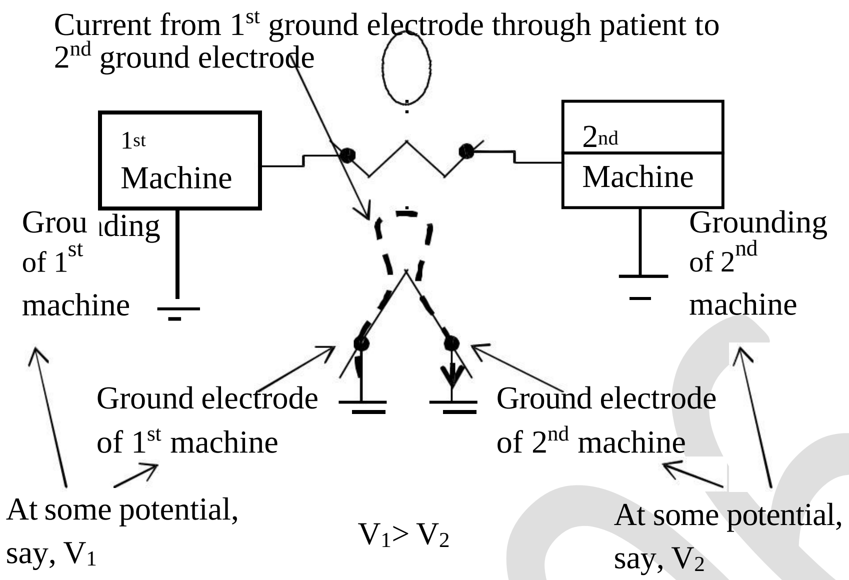
Holter ECG: Continuous recording of ECG at a stretch up to 24 hour and playing it in as minimum as 12 minutes – used to diagnose certain arrhythmias which occur under certain physiological conditions such as emotional stress.

Problems frequently encountered during ECG recording:

(1) ***Frequency distortion:*** *High frequency distortion* rounds off sharp corners of ECG waveforms and reduces the amplitude of QRS complex. *Low frequency distortion* shifts the base line causing monophasic waves in ECG to be biphasic.

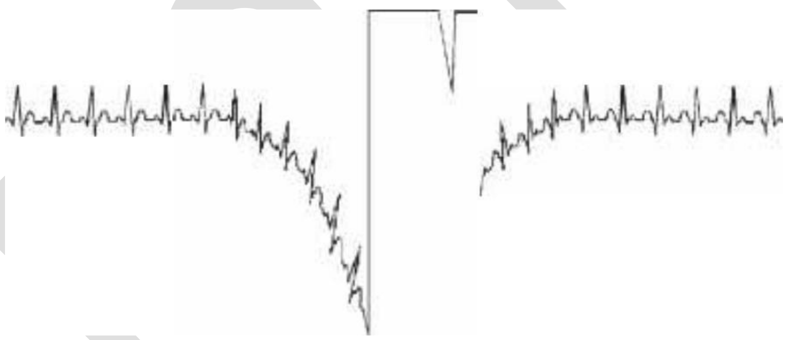
(2) ***Saturation or cutoff distortion:*** High offset voltages at the electrodes or amplifier produce saturation or cutoff distortion – peaks of QRS complex are cut off due to this.

(3) ***Ground loop:*** When two or more equipments are grounded via different outlets, there may exist a potential difference among these grounds. This leads to a current from one ground through the patient to another ground as shown below. This can be fatal.

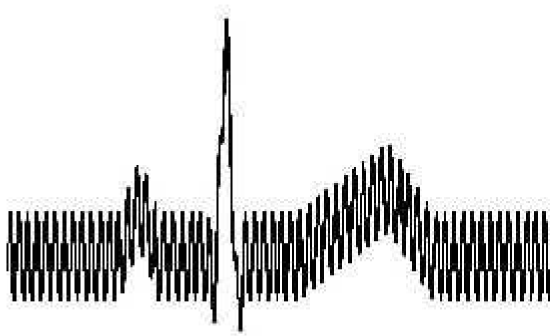


(4) ***Open lead wires:*** Due to rough handling or bad wiring, one or more lead wire may become disconnected from the electrodes. This leads to invalid signals.

(5) ***Artifacts:*** Due to large electrical discharges from defibrillation process or patient's large movements, serious artifacts are produced in the recorded ECG signal.



(6) ***Electromagnetic interferences:*** Electromagnetic interferences from ac mains power supply, other electrical equipments and large communication equipments produces noise in the recorded ECG signal. Of these, the 50 Hz power supply interference shown below is quite common. It is normally eliminated by a notch filter.



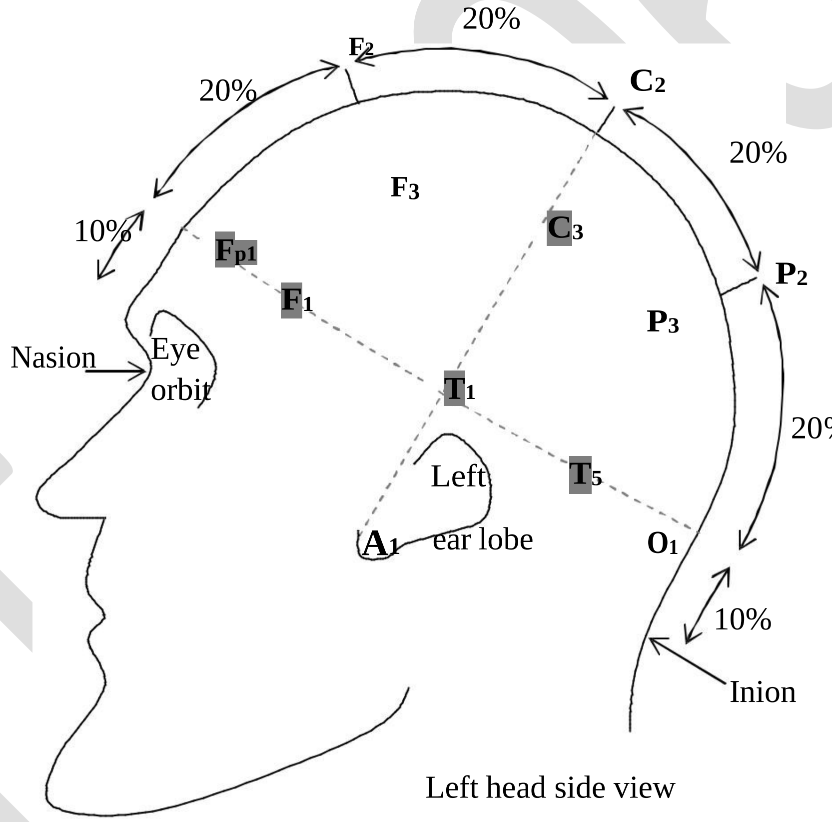
Heart arrhythmias and clinical significance of ECG:

ECG record helps in the diagnosis of various heart arrhythmias – abnormal cardiac rhythm - such as tachycardia, bradycardia, heart block etc. For example,

(1) Tachycardia – fast heart rate (>100 bpm) – shorter R-R interval
(2) Bradycardia – slow heart rate (<60 bpm) – longer R-R interval
(3) Atrial flutter – saw-toothed P-wave
(4) Atrial fibrillation – unrecognizable P-wave and irregular R-R interval
(5) Ventricular tachycardia – wide, bizarre QRS complexes
(6) Ventricular fibrillation – irregular, high frequency ECG waveform

EEG lead system:

The most popular scheme of placing the surface electrodes (usually Ag/AgCl discs) on the scalp is the ***10-20 electrode placement system*** suggested by the ***International Federation of EEG Societies***. In this scheme, the shaved head is mapped by four points: (i) nasion, (ii) inion, (iii) left preauricular point and (iv) right preauricular point as shown below.



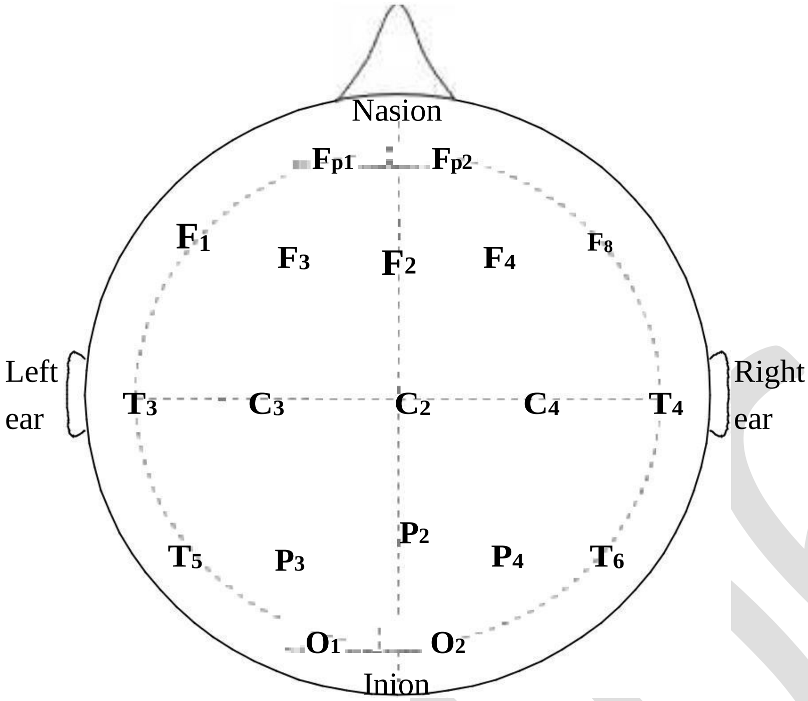
Left head side view

Three electrodes are placed (***1 in frontal lobe, 1 in central lobe and 1 in parietal lobe***) by measuring the ***nasion-inion distance via the vertex*** and marking points on the shaved head ***at 10%, 20%, 20%, 20%, 20% and 10% of this length***.

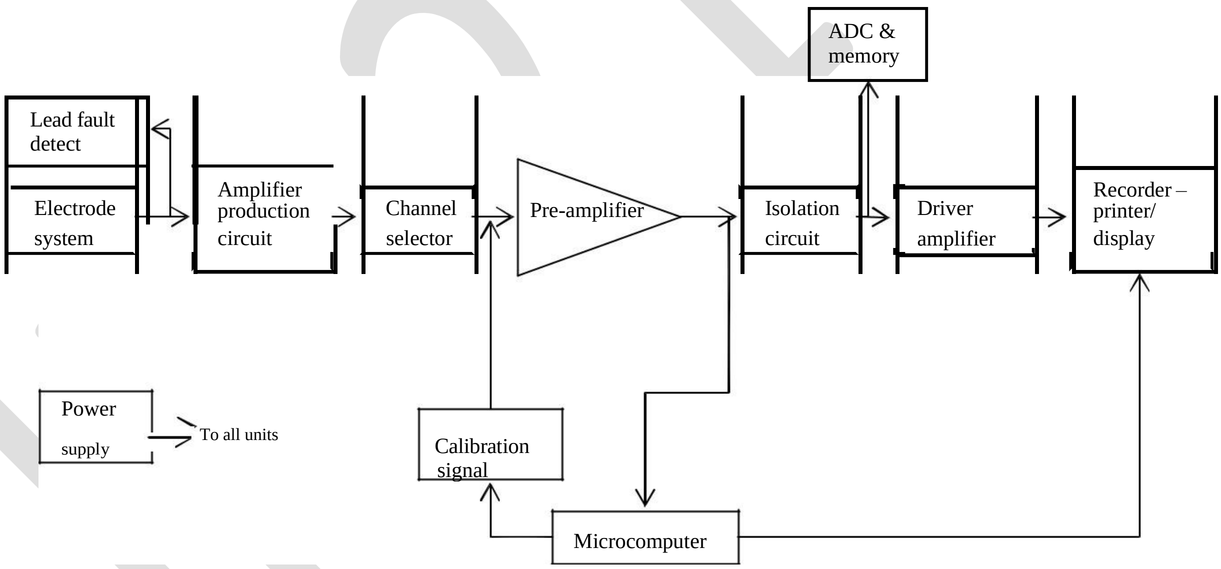
Similarly, ***five electrodes*** are placed ***on either side*** (***2 in frontal lobe, 2 in temporal lobe and 1 in occipital lobe***) by measuring the nasion-inion distance via the temporal lobes and marking points on the shaved head ***at 10%, 20%, 20%, 20%, 20% and 10% of this length on either side***.

The remaining ***six electrodes*** (***2 in frontal lobe, 2 in central lobe and 2 in parietal lobe***) are placed on the peripheries of the circles joining these electrodes.

Thus, there are 19 electrodes on the scalp plus one electrode for grounding the subject(usually at ear lobes). This makes the popular 10-20 EEG electrode system.



Block diagram of a EEG recording system:



Electrode system: Metal disc electrodes made of Ag/AgCl are placed at scalp positions. Good contact between electrodes & skin is ensured with the help of gel and adhesive tapes.

Channel selector: The function of this block is to select a desired combination of 19 possible electrodes. This can be carried out either manually by an operator or automatically by microprocessor or microcontroller or microcomputer.

Preamplifier: The function of this block is to eliminate noise such as other biopotentials and various electromagnetic interferences resulting from nearby communication links etc. Generally, a differential amplifier with high input impedance and CMRR is used for this purpose. A minimum gain of 1000 is required as typical amplitude range of EEG is from 1 to few microvolts.

Calibration signal: The function of this block is to calibrate the display or the recorder for predetermined amplitude. A sine wave of 1 V is generally used for this purpose.

Isolation circuitry: The function of this block is to provide electrical isolation between the high-power section that is generally driven by 230 V 50 Hz ac mains and the low power patient section that is generally driven by a low power battery. This is required to protect the patient from any electrical hazards resulting from leakage currents.

Driver amplifier: The function of this block is to amplify the EEG signal sufficiently to level required for the display or the recorder.

ADC & memory: The EEG signal can be digitized and stored for future analysis.

Microcomputer: A microcomputer along with a user-friendly software package developed on a high-level language such as VC++ can be used

(iii) to control the entire process of acquiring the EEG and

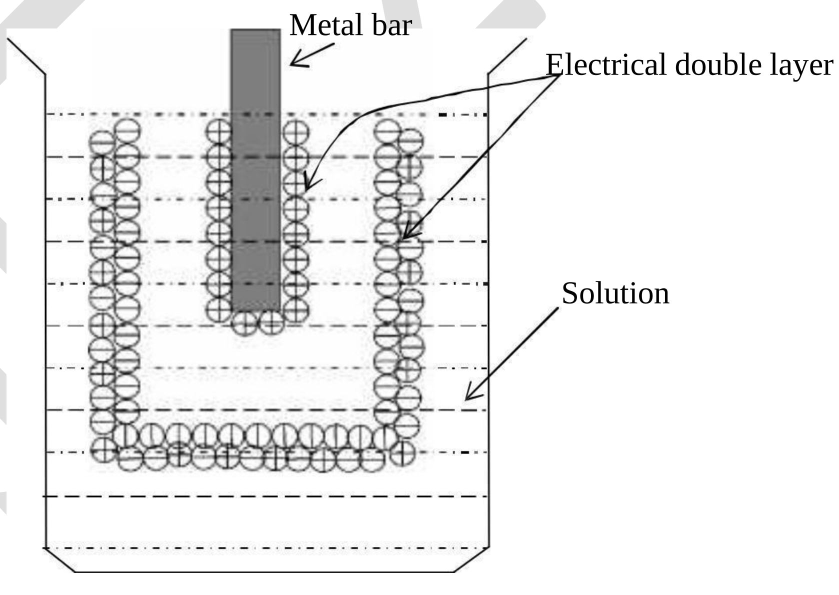
(iv) to analyze it automatically for various parameters using sophisticated digital signal processing techniques.

Recorder-printer/display: A heat sensitive paper can be used to get a hard copy of the EEG signal obtained or a CRO can be used to display the EEG signal obtained for visual analysis.

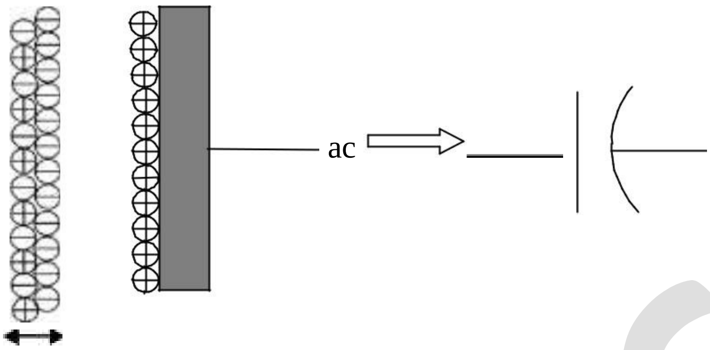
Biopotential electrodes:

Electrode behaviour & circuit model:

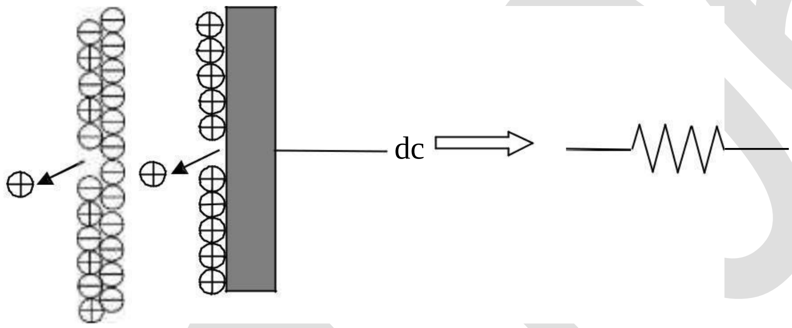
When a bar of metal is immersed in a solution, it becomes ionized at the vicinity of contact with a cloud of electrons inside and ***an adsorbed layer of positive ions*** at the bar's surface. This adsorbed fixed layer of positive ions attracts nearby negative ions drifting around in the solution. This forms ***a diffused mobile layer of negative ions*** near the bar's surface. These two layers form the ***electrical double layer***.



When an ac signal is applied, the double layer behaves like ***an ideal capacitor***. When a dc signal is applied, the double layer behaves like ***a resistor*** called Faradic resistor. Thus an electrode in a solution (under the influence of ac & dc signals) can be modeled as ***a leaky capacitor*** i.e., ***an ideal capacitor in parallel with a resistor***.



Behaviour of electrical double layer under the application of ac & its equivalence to an ideal capacitor

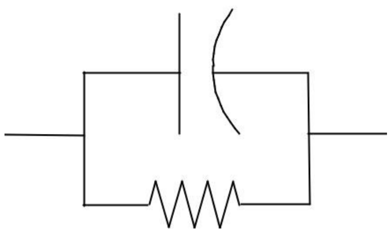


Behaviour of electrical double layer under the application of dc & its equivalence to a resistor

A potential difference is developed across the electrode-solution interface due to the formation of the double layer. This potential is known as the ***electrode or half-cell potential***. Different materials generate different half-cell potential.

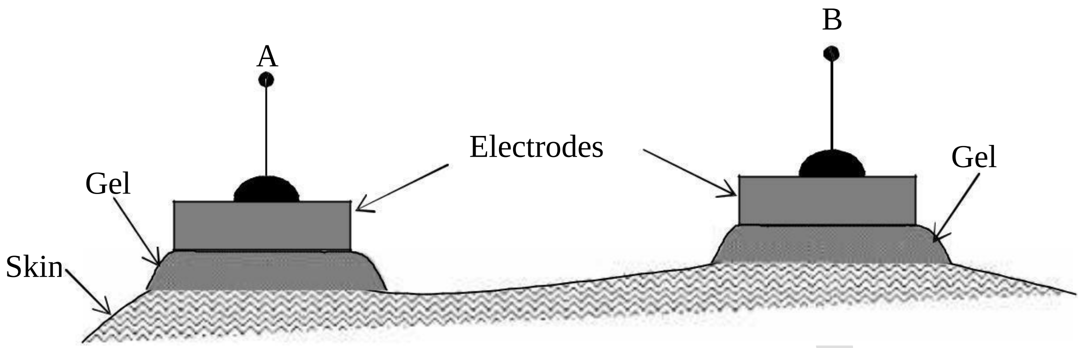
Al: 1.66 V
Fe: 0.44 V
Ag: +0.8 V
Cu: +0.34 V
H: 0 V (reference)

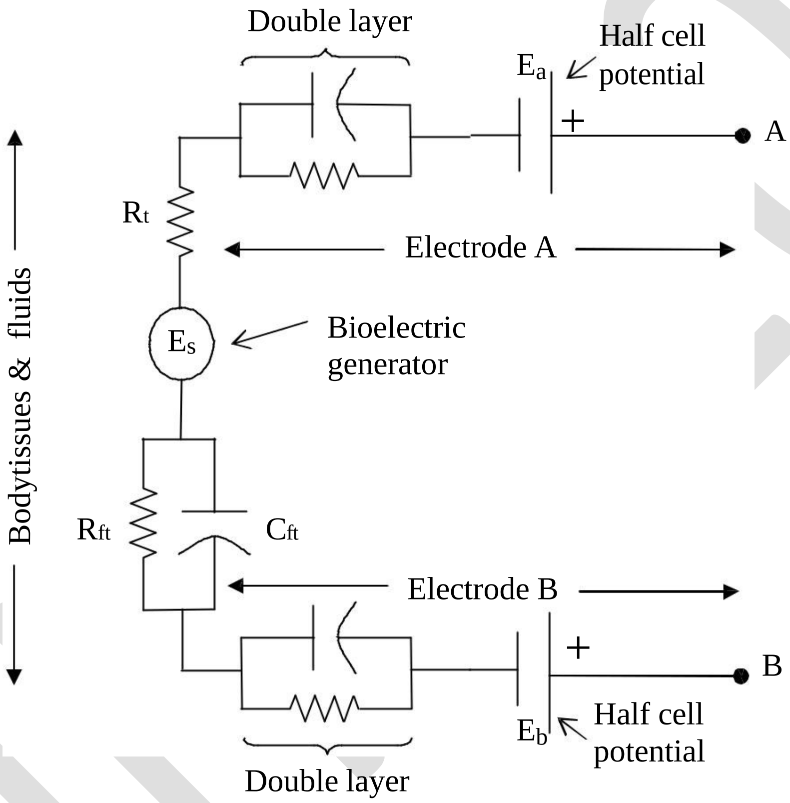
Thus the circuit model of an electrode-gel interface can be a leaky capacitor in series with a half-cell as shown below.



Equivalence of an electrical double layer under the application ac as well as dc to a leaky capacitor

Circuit model of surface electrode:





Circuit model of surface electrodes

where

E_a, E_b – half-cell potentials of electrodes A & B respectively at the electrode-gel interface

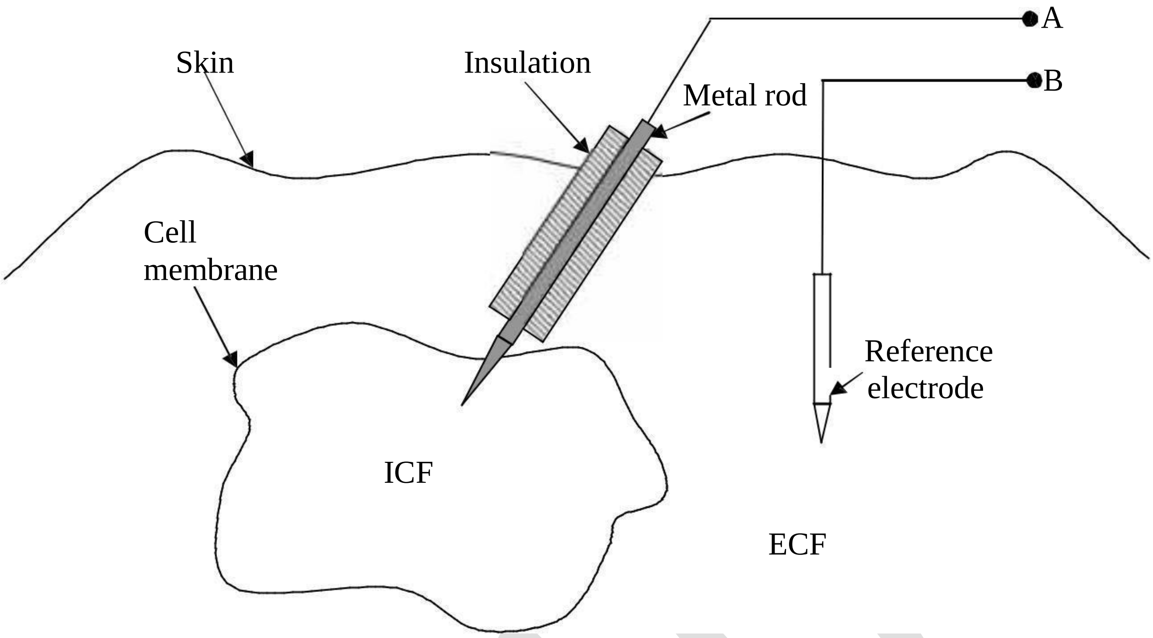
C_{da}, R_{fa} & C_{db}, R_{fb} – double layers of electrodes A & B respectively at the electrode-gel interface

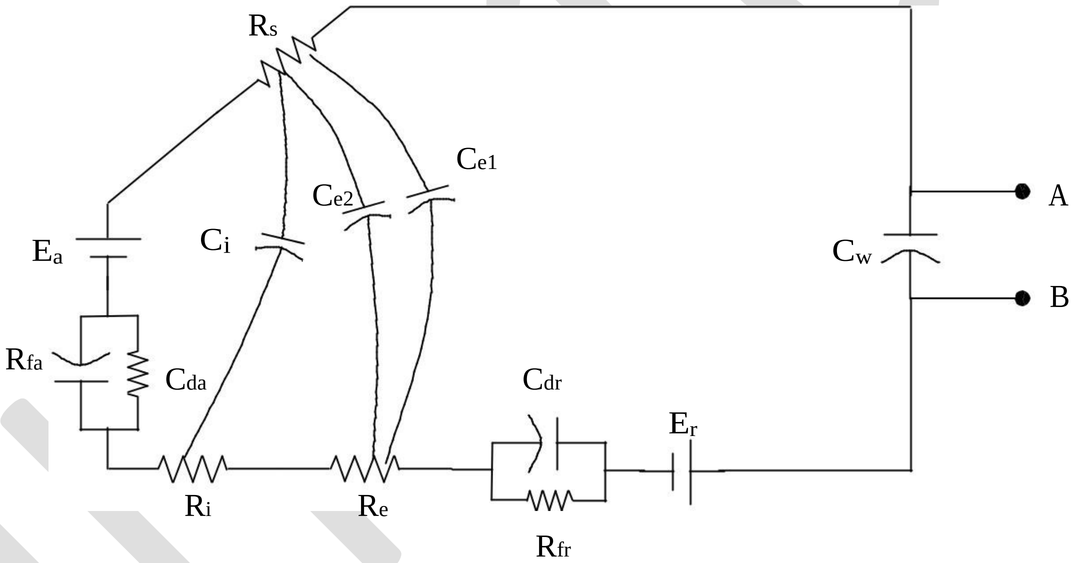
R_t – total series resistance offered by skin, massive tissues & gel

E_s – biopotential to be measured

C_{dt}, R_{ft} – effective double layer formed by body tissues and fluids

<u>Circuit model of a micro electrode:</u>





where

R_s – series resistance offered by metal rod

E_a, C_{da}, R_{fa} – half-cell potential & double layer at the microelectrode-ICF interface
E_r, C_{dr}, R_{fr} – half-cell potential & double layer at the reference electrode-ECF interface

C_i – distributed capacitance between metal and ICF
R_i – series resistance offered by ICF
C_e – distributed capacitance between metal and
ECF R_e – series resistance offered by ECF C_w – distributed wiring capacitance