

Introduction

- The bioelectric potentials generated in the body are ionic potentials produced by ionic current flow. measurement of these ionic potentials require conversion into electronic potentials.
- The devices that convert ionic potentials into electronic potentials are called electrodes.
- The measurement of ionic potential and the measurement of electric current in body need some interface between the body and the electronic measuring instrument.
- This function is achieved through biopotential electrodes. Potential measurement is done through current flow in the measuring circuit for some time over which the measurement is done.
- In ideal conditions, this current should be very small. The electrode should have the capability of conducting a current across the interface between the body and electronic measuring circuit.
- The electrode carries out a transducing function since current is carried out ~~in~~ the body through ions. It is carried in the electrodes and its lead wire by electrons.
- Electrode has a transducer to change an ionic current into an electric current.
- Here we are dealing with the basic theory of electrodes and then with the various types used.

Electrode Theory

- The interface of metallic ions in solution with their associated metals results in an electrical potential that is called as the electrode potential.
- This potential is a result of the difference in diffusion rates of ions into and out of the metal.
- Equilibrium is produced by the formation of a layer of charge at the interface. This charge is really a double layer, with the layer nearest the metal being of one polarity and the layer next to the solution being of opposite polarity.
- Non metallic materials such as Hydrogen also have electrode potentials when interfaced with their associated ions in solution.
- Another source of an electrode potential is the unequal exchange of ions across a membrane that is semipermeable to a given ion when the membrane separates liquid solutions with the different concentrations of that ion.

- The equation relating the potential across the membrane and the two concentrations of the ion is Nernst Equation and can be stated as

$$E = - \frac{RT}{nF} \ln \frac{C_1}{C_2} \frac{b_1}{b_2}$$

where R — gas constant

T — absolute temperature.

n — valence of the ion.

F — Faraday constant

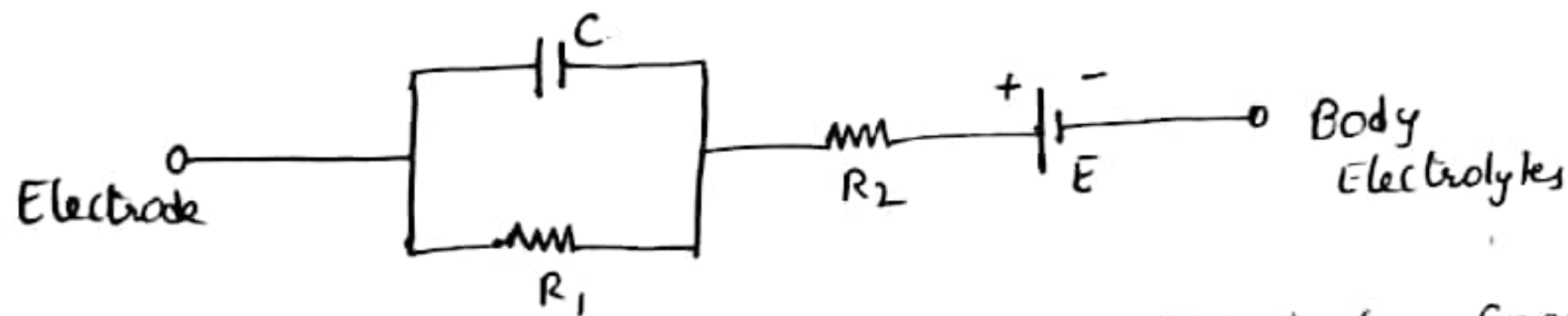
C_1, C_2 — Concentrations of ion on two sides of membrane

b_1, b_2 — Activity coefficients of ion on two sides

- In electrodes used for the measurement of bioelectric potentials, the electrode potential occurs at the interface of a metal and an electrolyte.
- In Biochemical transducers, both membrane barriers and metal-electrolyte interfaces are used.

Equivalent circuit of Electrode

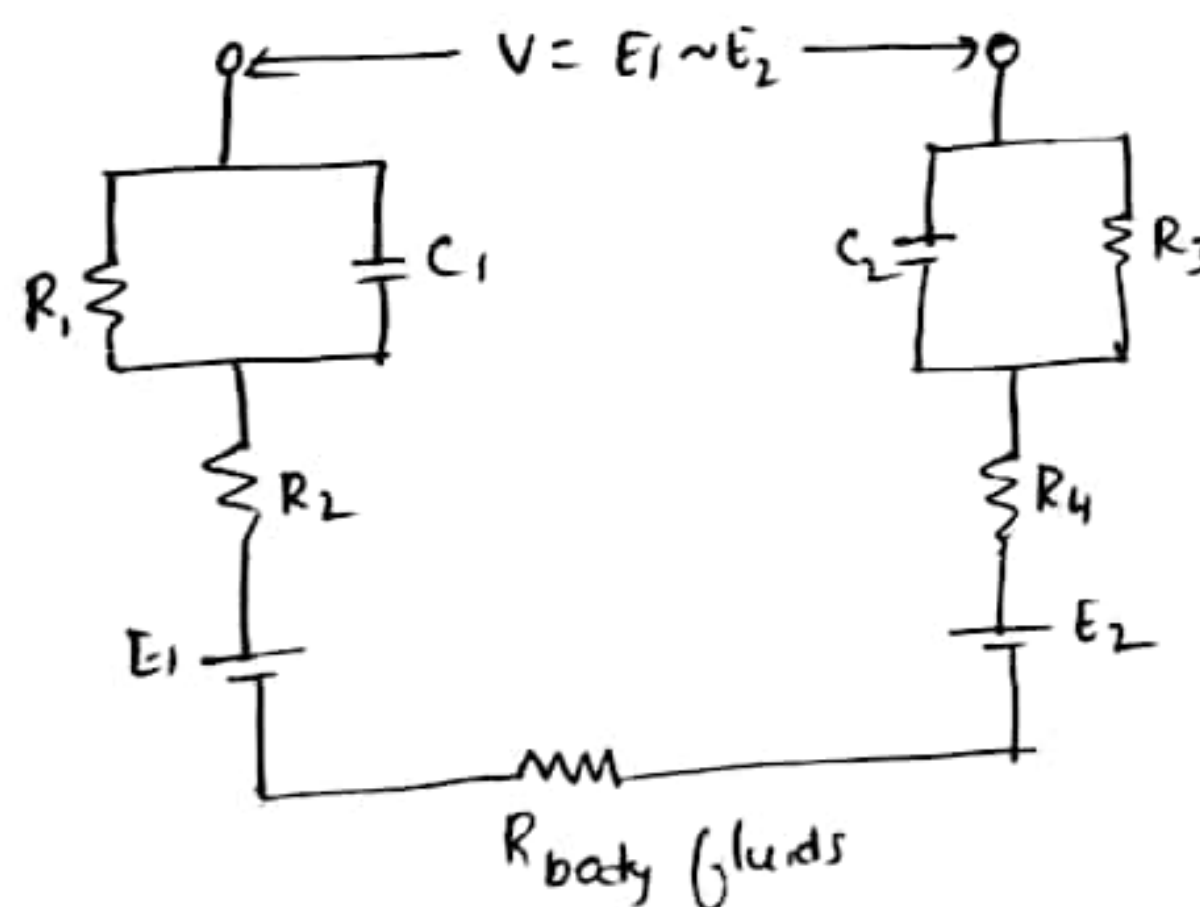
- In biopotential electrodes, an electrode potential is developed across the interface, proportional to the exchange of ions between the metal and the electrolytes of the body.
- The double layer of charge at the interface acts as a capacitor. The equivalent circuit is given as.



It consists of a voltage in series with a resistance - capacitance network.

Since the measurement of bioelectric potentials requires two electrodes, the voltage measured is really the difference between the instantaneous potentials of two electrodes.

- The arrangement of two electrodes is given as



- If the two electrodes are of same type, the difference is usually small and depends essentially on the actual difference of ionic potential between the two points of the body.
- If the two electrodes are different, however, they may produce a significant DC voltage. That can cause current to flow through both electrodes as well as through the input circuit of amplifier.

Microelectrodes

- These are electrodes with tips sufficiently small to penetrate a single cell in order to obtain readings from within the cell.
- The tip must be small enough to permit penetration without damaging the cell. There are generally two types
 - (1) metal microelectrode
 - (2) micropipet microelectrode

Metal microelectrode:

- * These are formed by electrolytically etching the tip of a fine tungsten or stainless-steel wire to the desired size.
- * The wire is coated almost to the tip with an insulating material. Some electrolyte processing can also be performed on the tip to lower the impedance.
- * The metal ion interface takes place where the metal tip contacts the electrolyte either inside or outside the cell.

Micropipet microelectrode

- * It is a glass micropipet with the tip drawn out to the desired size. The micropipet is filled with an electrolyte compatible with the cellular fluids.
 - * These electrodes have dual interface. One interface consists of a metal wire in contact with the electrolyte solution inside the micropipet. The other is the interface between the electrolyte inside the pipet and the fluids inside or immediately outside the cell.
- Because of their small surface areas, microelectrodes have impedances in the range of megaohms.
 - So amplifiers with extremely high impedances are required to avoid loading the circuit and to minimize the effects of small changes in interface impedance.

Needle Electrodes

The general structure of needle electrode is



- These are not inserted into the brain, they merely penetrate the skin. Generally they are simply inserted through a small section of the skin just beneath the surface and parallel to it.
- When a simultaneous measurement from various depths in the brain along a certain axis is required, special multiple depth electrodes have been developed.
- This type of electrode usually consists of a bundle of fine wires, each terminating at a different depth. These wires are brought out to a connector at the surface of the scalp.
- Needle electrodes for EMG consist merely of fine insulated wires, placed so that their tips, which are bare, are in contact with the nerve, muscle from which measurement is made.
- Wire electrodes of copper or platinum are often used for EMG pickup from specific muscles.
- The wires are either surgically implanted or introduced by means of a hypodermic needle, leaving the wire electrode in place.
- The wires forming the electrodes are carried inside the needle, which creates the hole necessary for insertion, protects the wires and acts as a grounded shield.
- A single wire inside the needle serves as unipolar electrode, which measures the potential at the point of contact with respect to some indifferent reference.
- If the two wires are placed inside the needle, the measurement is called bipolar and provides a very localized measurement between the two wire tips.

Body surface electrodes

Electrodes used to obtain bioelectric potentials from the surface of the body are in different sizes and forms.

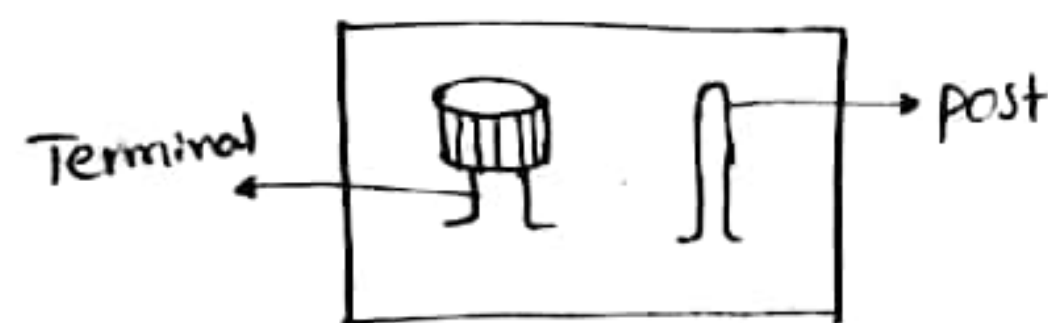
The first invented body surface electrode is immersion electrode.

Immersion electrodes

- These are simply buckets of saline solution into which the subject placed his hands and feet, one bucket for each.
- These electrodes have many difficulties such as restricted position of the subject and danger of electrolyte spillage.

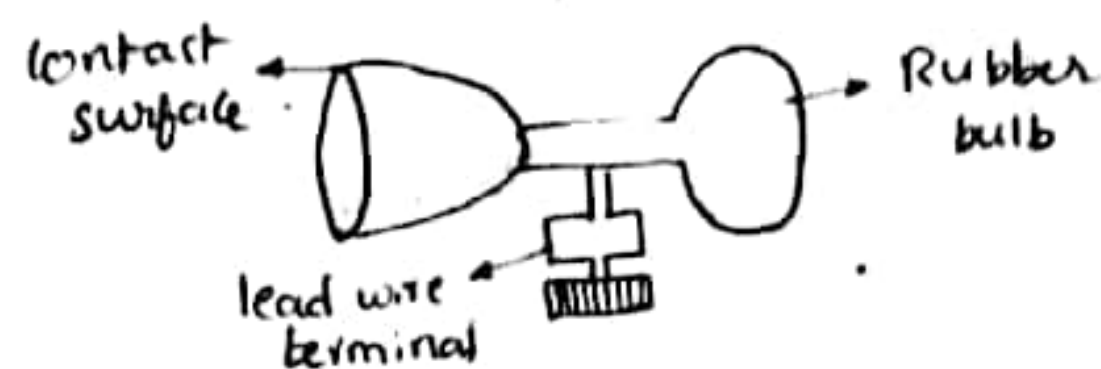
metal plate electrode

- These are introduced in 1917. These electrodes were separated from the subject's skin by cotton or felt pads soaked in a strong saline solution.
- Later a conductive jelly or paste replaced the soaked pads and metal was allowed to contact the skin through a thin coat of jelly.



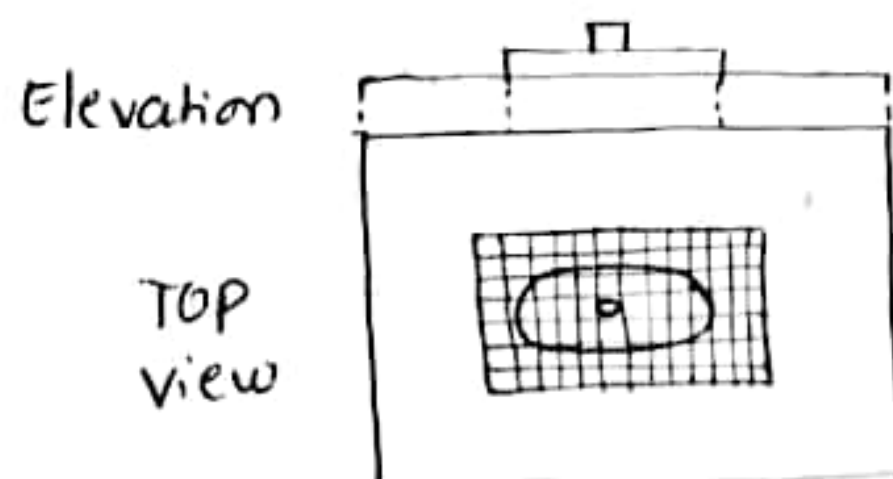
- * Rectangular or circular plates made up of German Silver or nickel plated steel are used.
 - * Typical impedance of the electrodes is in few hundred ohms. DC resistance varies from $2\text{ k}\Omega$ to $10\text{ k}\Omega$.
 - * A terminal is placed on its outer surface for lead wire. A post placed on the same side to connect a rubber strap to the electrode and to hold it in place on an arm or leg.
- This can be used as a chest electrode for ECG recording.
 - The difficulties in using plate electrodes is the possibility of electrode slippage or movement.

Suction cup electrode



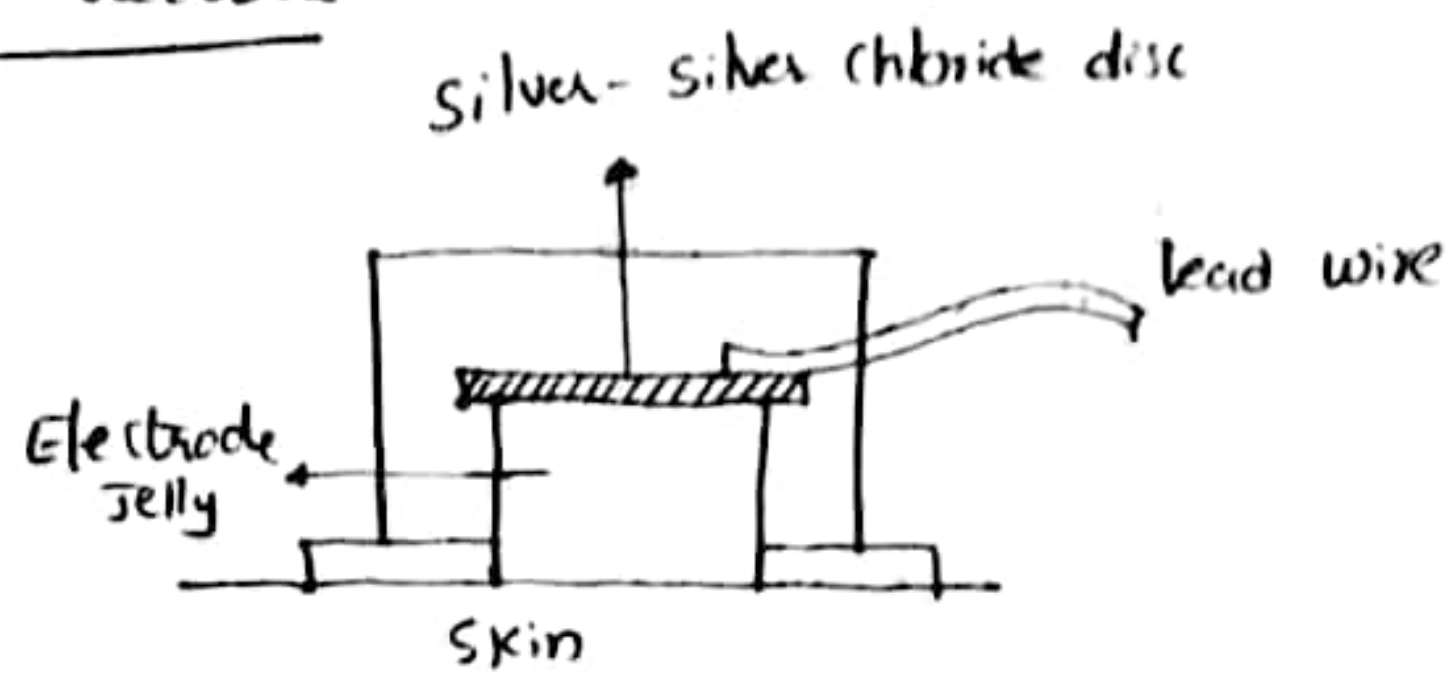
- * Here we can hold electrode at one place for sufficient duration.
- * It is frequently used as a electrode in ECG.
- * It consists of hollow metallic cylindrical electrode that makes contact with the skin.
- * A lead wire terminal is provided in the hollow metallic cylinder.
- * A rubber suction bulb fits over the hollow cylinder is squeezed to place the hollow metallic base on the chest wall.
- * Even though the electrode is large, its contacting surface is very small. So it has large impedance.
- * It cannot be held for long duration due to irritation in skin.

Adhesive Tape electrode



- * It consists of a relatively large disc of platinum foam material with a silver-plated flexible plate on one side and silver plated snap clothing on the other side.
- * This silver plated disc acts as an electrode. A silver chloride coat may be made on the electrode. A layer of electrolyte gel with an adhesive is coated over the electrode.
- * A protective release paper is provided over this adhesive coat. Finally it is packed in a foil cover so that to avoid evaporation of water component in the gel.
- * This electrode can be used as a peel and paste type. No need of any skill to use this electrode.

Floating electrode



- * Any displacement in the electrode may produce artifact in the electrodes. Use of these electrodes will reduce these artifacts.
- * Here the electrode does not come in direct contact with the skin. The gel in the cavity is in contact with the skin.
- * There is no mechanical movement of the gel even though the metal electrode moves so there is no artifact.

Spray-on-electrode

Here a small spot of conductive adhesive is sprayed or painted over the skin, which had previously been treated with an electrolyte coating.

Disposable electrode

These electrodes are of the floating type with simple snap connectors by which the leads, which are reusable are attached. They come pregelled, ready for immediate use. They are for single time usage.

Ear-clip electrode

Since it is connected to the ear it is named like that. Used in EEG measurements.

Scalp electrode

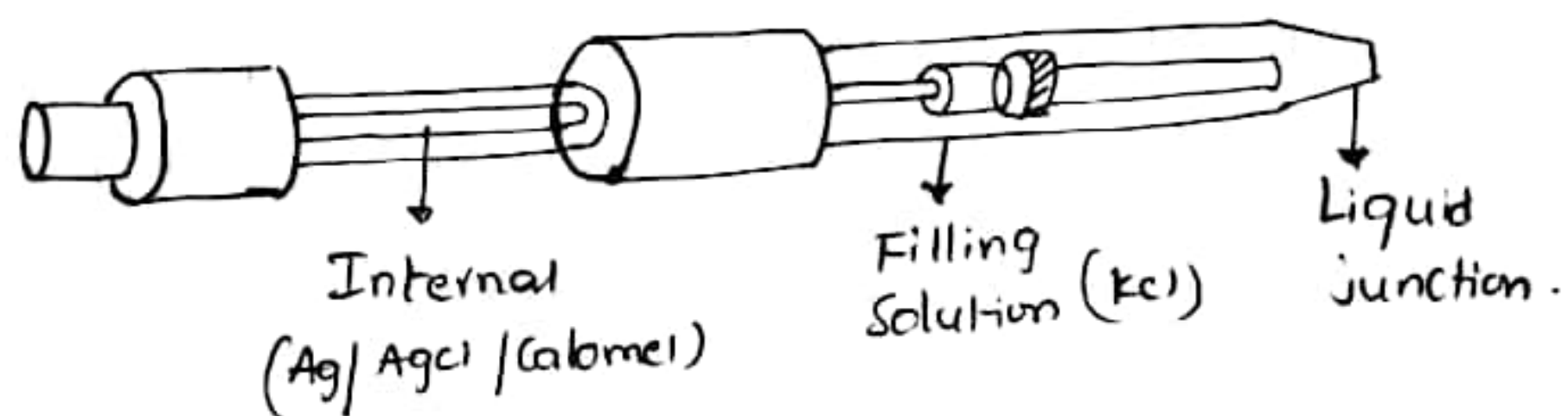
These electrodes are for EEG measurement. These are usually small disks about 7mm in diameter that are placed on the cleaned scalp using an electrolyte paste.

Bio chemical Transducers

An electrode potential is generated either at metal electrolyte interface or on either side of semipermeable membranes that separate two solutions concentration. Both methods are used to sense the gases dissolved in blood and other liquids. To measure this, two electrodes are required. one electrode is sensitive to changes in the subject and the other is reference electrode which is insensitive to the changes in the subject.

Reference Electrode

- Hydrogen ion interface has been designated as reference interface and it was being assigned an electrode potential of zero volt.
- Hence the hydrogen electrode was used as the reference in biochemical measurement.
- In this electrode, an inert metal like Platinum is partially immersed in the solution containing hydrogen ions and exposed to hydrogen gas passing through the electrode to generate potential.
- A lead wire is taken from the platinum electrode. The problem is the hydrogen electrode is not stable enough to act as reference electrode.
- There are two types of electrodes which have sufficiently stable interface to act as reference electrodes. They are Silver - Silver chloride electrode and Calomel electrode.
- The basic structure of reference electrode is.



* The Silver - silver chloride electrode interface is connected to the KCl solution by an electrolyte bridge.

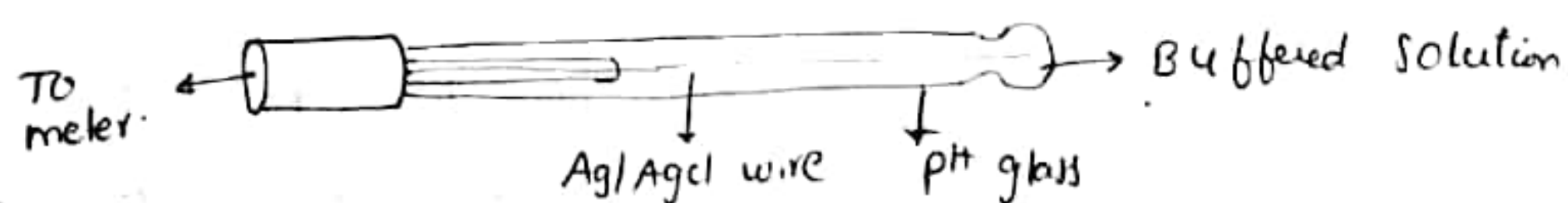
- * This filling solution has a liquid junction with Sample Solution.
- * The electrode can be successfully employed as a reference electrode if the KCl solution is saturated with AgCl.
- * The reference electrode potential is function of KCl Concentration. For 1 mole solution, it is 0.236 volt.
- * Another popular reference electrode is Calomel electrode. The interaction between mercury and mercurous chloride generates the electrode potential.
- * Calomel electrode produces 0.388 volt for 0.01 mole KCl solution and 0.247 volt for 3.5 mole KCl solution.

pH Electrode

→ The pH is directly related to the hydrogen ion concentration in a fluid. It is the logarithm of the reciprocal of $[H^+]$.

$$pH = -\log [H^+] = \log \frac{1}{[H^+]}$$

- pH is a measure of the acid-base balance of a fluid. A neutral solution has a pH of 7. Lower pH indicates acidity and higher indicates basic nature.
- The pH of normal arterial blood ranges between 7.38 to 7.42. pH of venous blood is 7.35.

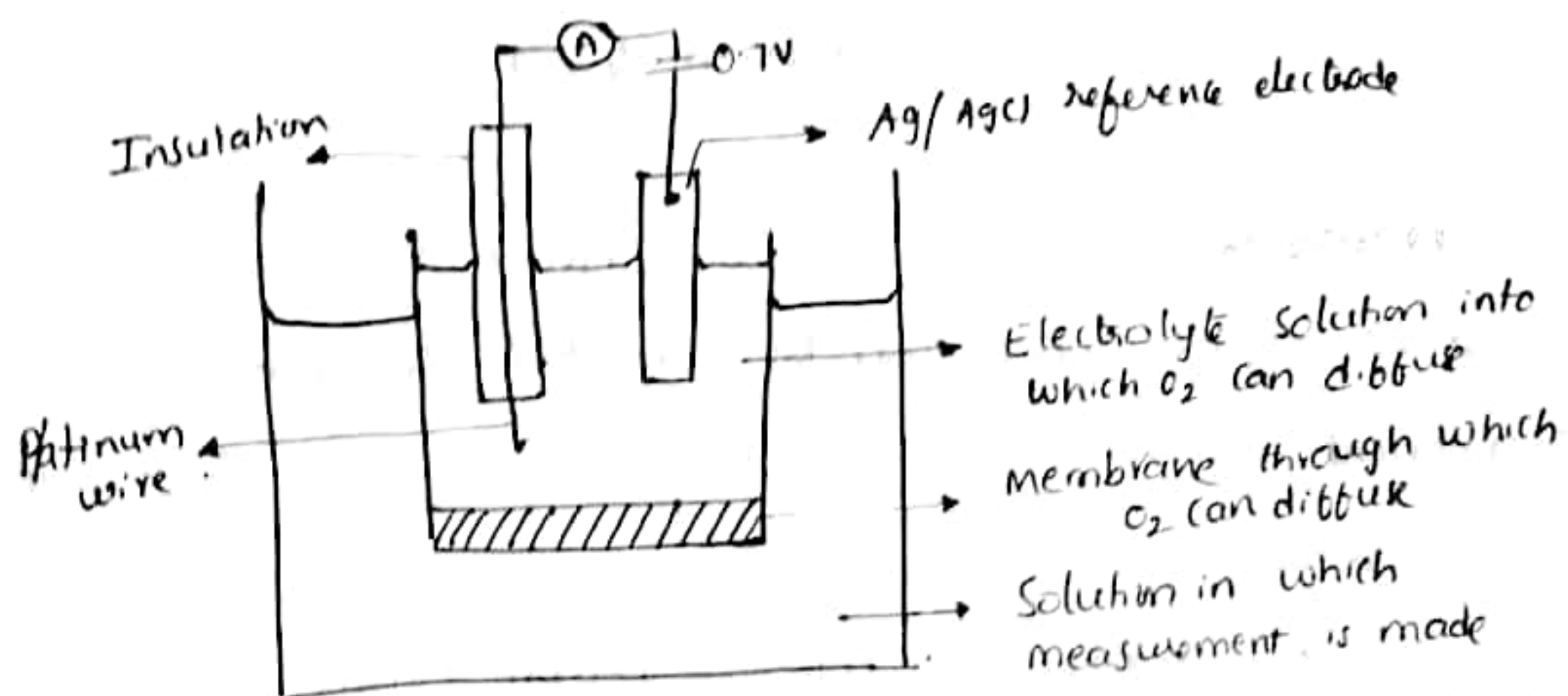


* Inside the glass bulb is a highly acidic buffer solution. Measurement of the potential across the glass interface is achieved by placing Ag/AgCl electrode in the solution inside the glass bulb and calomel reference electrode in the solution in which pH is being measured.

- * The sensitivity of pH electrode is 60 mV/pH.
- * The impedance range is 50 to 500 MΩ.

Blood gas electrode

- * In the physiological chemical measurements the partial pressures of oxygen and CO_2 in the blood is necessary.
- * The partial pressure of a dissolved gas is the contribution of that gas to the total pressure of all dissolved gases in the blood.
- * The partial pressure of a gas is proportional to the quantity of that gas in the blood. The effectiveness of respiratory and heart systems is reflected in these important parameters.



- A fine piece of platinum or some other metal wire, embedded in glass for insulation purposes, with only the tip exposed, is placed in an electrolyte into which oxygen is allowed to diffuse.
- If a voltage of about 0.7V is applied between the platinum & reference electrode, with the platinum as negative, reduction of the oxygen takes place at platinum cathode.
- The electrolyte is generally sealed into the chamber that holds the platinum wire and the reference electrode by means of a membrane across which the dissolved oxygen can diffuse from blood.
- The platinum cathode and reference electrode can be integrated into a single unit. This electrode can be placed in a chamber of blood for *in vitro* measurements.
- The major problem is reduction process actually removes a finite amount of oxygen from the immediate vicinity of cathode.

The Transducer and Transduction Principles

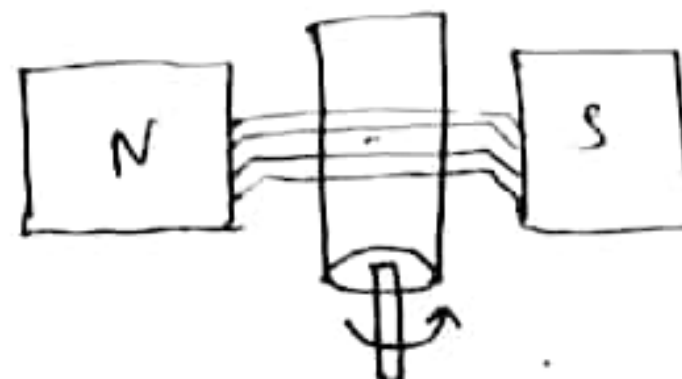
- A variable is any quantity whose value changes with time.
- A variable associated with the physiological processes of the body is called physiological variable.
- Examples of physiological variables are body temperature, electrical activity of heart, blood pressure, air flow.
- Physiological variables occur in many forms as ionic potentials and currents, mechanical movements, hydraulic pressures & flows, temperature variations.
- A Transducer is required to convert each variable into an electrical signal which can be amplified. So a transducer is a component which has non electrical variable as its input and an electrical signal as its output.
- Ideally the relationship between output and input should be linear i.e. the voltage at the output of a pressure transducer being proportional to the applied pressure.
- A linear relationship is not always possible. As long as the transduction function is non ambiguous it is possible to determine the magnitude of I/p variable from the electrical output signal.
- Two different principles are involved in the process of converting non electrical variables into electrical signals.
 - ① Energy conversion - Transducers based on this principle are called Active transducers.
 - ② Excitation voltage - Transducers based on this principle are called Passive transducers.

Active Transducers

- * All physical principles can be employed for converting non electrical activity in active transducers.
- * In Active transducers, in some cases the same transduction principle used to convert from a non electrical form of energy can also be used in reverse direction to convert electrical energy to non electrical forms.

Magnetic Induction Effect

- If an electrical conductor is moved in a magnetic field in such a way that the magnetic flux through the conductor is changed, a voltage is induced which is proportional to the rate of change of magnetic flux.
- Conversely, if a current is sent through the same conductor, a mechanical force is exerted upon it proportional to the current and the magnetic field.
- All the electrical motors and generators, such as solenoids and loud speakers utilize this principle.
- Magnetic induction plays an important role at the output of many biomedical instrumentation system.
- Analog meters using D'Arsonval movement, Light beam galvanometers in photographic recorders and pen motors in ink, Thermal recorders are all based on the principle of magnetic induction.
- The basic configuration of transducer that use the principle of magnetic induction for the measurement of rotatory motion is



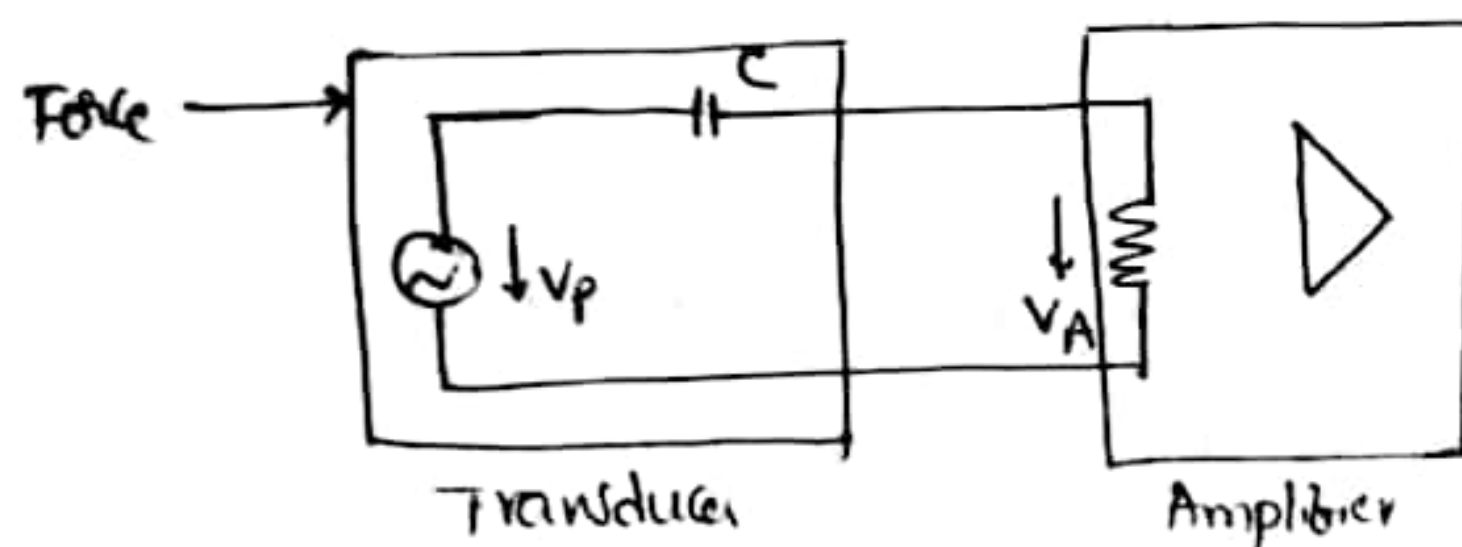
- The most important biomedical applications are
 - (a) Heart sound microphones
 - (b) pulse Transducers
 - (c) Electromagnetic Blood Flow meters.

Thermo electric effect

- * If two wires of dissimilar metals are connected so that they form a closed conductive loop, a voltage can be observed at any point of interruption of loop.
- * This voltage is proportional to the difference in temperature between the two junctions between the metals.
- * The polarity depends on which of the two junctions is warmer. The device formed on this fashion is called Thermocouple.
- * The sensitivity of thermocouple is small $40 \mu\text{V}/^\circ\text{C}$ for Copper-Constantin and $53 \mu\text{V}/^\circ\text{C}$ for iron-Constantan.
- * The delivery of electrical energy causes the transfer of heat from the hotter to colder junction, the hotter junction gets cooler while the colder gets warmer.
- * Because of their lower sensitivity, thermocouples are used for the measurement of physiological temperatures, where the temperature range is limited.
- * The process of converting from thermal energy to electrical energy is called Seebeck effect.
- * The flow of current causes one junction to heat and the other to cool so that electrical energy is converted into heat energy is called Peltier effect.

Piezo - Electric effect

- * If a varying potential is applied to the proper axis of the crystal it will change the dimensions of crystal there by deforming it. It is called piezo electric effect.
- * A piezo electric material is one which as electric potential appears across certain surfaces of a crystal if the dimensions of crystal are changed by the applications of the crystal are changed by the application of a mechanical force.
- * Piezo electric materials are Rochelle Salt, Ammonium dihydrogen phosphate, quartz. These materials are stable, high of sensitivity.
- * The electrical equivalent ckt is given as



- In the diagram, voltage source having a voltage V_p , proportional to applied mechanical force connected in series with a capacitor, which represent the conductive plates separated by the insulating piezoelectric material.
- The Capacitive properties of the piezoelectric transducer interacting with the input impedance of the amplifier to which they are connected effect response of transducer.
- * Piezo electric principle is used in microphone for heart sound or other acoustical signals from within the body.
- * Piezo electric transducers are used widely in ultrasonic instruments as transmitter and receiver of ultrasonic signals.

Photo electric effect

- * The Selenium cell has long been used to measure the intensity of light in photographic exposure meters or the light absorption of chemical solution.
- * The Silicon photo electric cell generally known as Solar Cell, has a much higher efficiency than the Selenium cell.
- * Its spectral sensitivity peaks in the infrared, however, while that of a Selenium cell is maximum in the visible light range.
- * When operated into a small load resistance and current delivered by either cell is proportional to the intensity of the incident light.
- * The voltage of these cells cannot exceed a certain value; if the light intensity or the load resistance is such that the output voltage approaches this value, it becomes non linear.

Passive Transducers

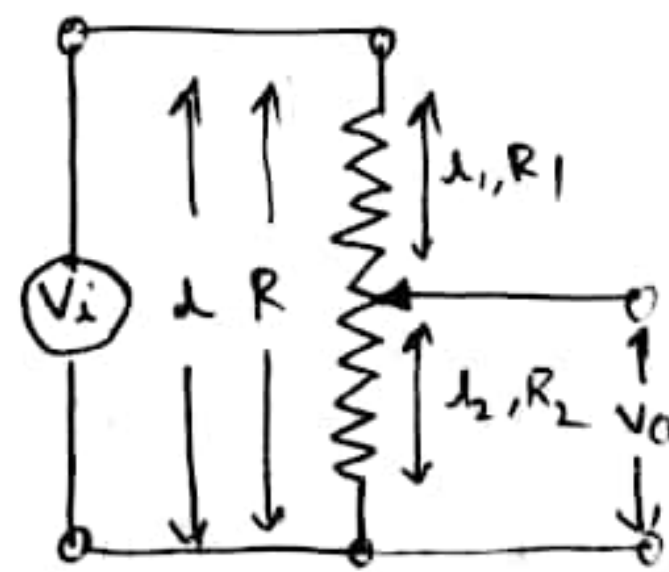
- * Passive transducers utilize the principle of controlling a DC excitation voltage or an AC carrier signal.
- * The actual transducer consists of a usually passive circuit element which changes its value as a function of the physical variable to be measured.
- * The transducer is a part of a circuit, which is powered by an AC or DC excitation signal. The voltage at the output of the circuit reflects the physical variable.
- * There are only three passive circuit elements that can be utilized as passive transducers: resistors, capacitors, inductors.
- * The passive transducers cannot be operated in the reverse direction i.e. to convert an electrical signal into a physical variable.

Resistive Transducers

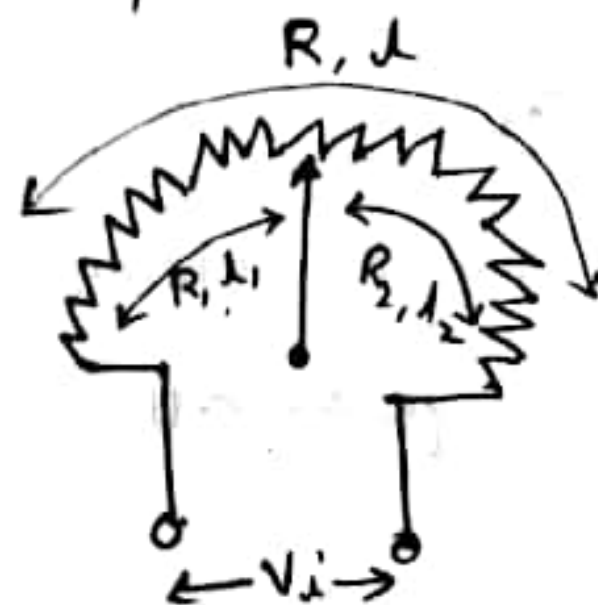
- * Any resistive element that changes its resistance as a function of a physical variable can be used as a transducer for that variable.
- * Resistive transducers operate on the formula
$$R = \frac{\rho L}{A}$$
Resistance can be changed by the change of any one of the parameters Resistivity (ρ), length (L), Area of cross section.
- * If resistance is changed by the change of length of a resistor, it is known as Potentiometer.
- * If the resistance is changed by the change of resistivity (ρ) of a resistor, it is known as photo cells.
- * If the resistance is changed by the change of Area of cross section of a resistor, it is known as strain gauge.

Potentiometer

- When the length of the resistor changes, the value of resistance of the resistor also changes.
- If the change in length of the conductor is due to the displacement, the change in the value of resistance becomes a measure of the displacement when calibrated.
- The potentiometer consists of an input voltage source. It also has a resistive element with a sliding contact called wiper.
- The displacement source which is to be measured is connected to the wiper.
- The wiper slides along the resistance wire proportional to the displacement. Due to the sliding action, the effective length of the resistor is changed.
- Change in length results in the change in resistance. The change in resistance becomes a measure of displacement.
- The linear potentiometer is given as.



- The Rotational potentiometer is given as



Strain gauge

- * When a resistor is stretched or compressed, its resistance changes due to the change in the length and diameter of the resistor.
- * It is a measurement transducer used to measure strain. It is a transducer because it converts information about relative change in dimension to a change in resistance.
- * The fractional change in resistance due to a unit change in length is called gauge factor.
- * The types of strain gauges are
 - ① unbonded strain gauge
 - ② Bonded strain gauge.

① Unbonded strain gauge

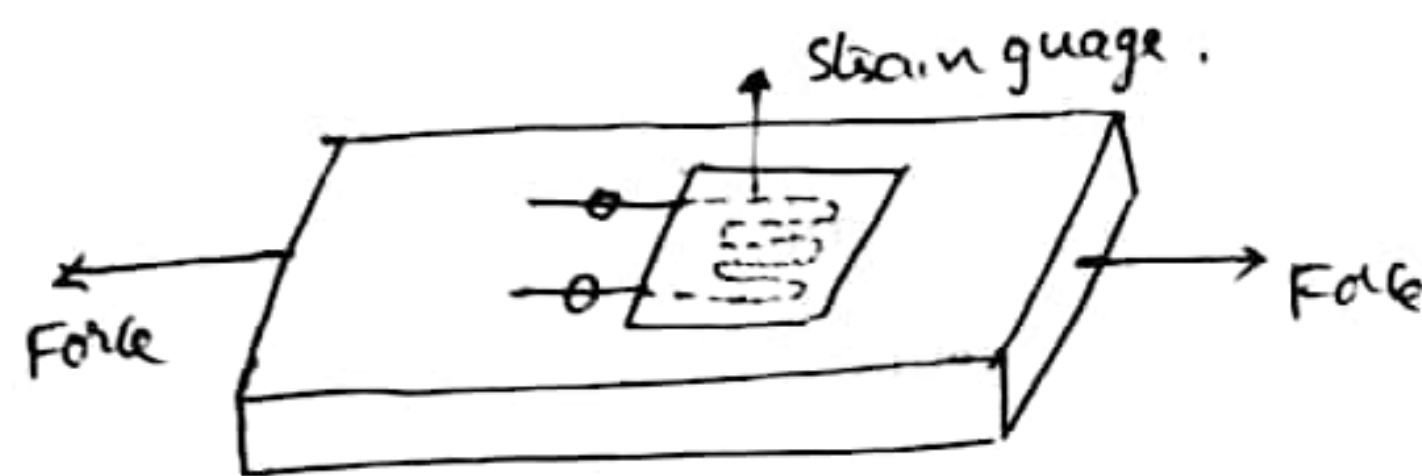
- These strain gauges are not directly bonded onto the surface of the structure under study.
- Here two frames can move relative with respect to each other and they are held together by a spring loaded mechanism.
- A fine wire resistance strain gauge is stretched between the insulated pins. The strain gauge is connected to wheatstone bridge.
- When a force is applied on the structure, one of the frame will move relative to other frame, due to this the strain gauge will change in length and cross-section.
- This strain changes the resistance of the strain gauge and this change in resistance of the strain gauge is measured using a wheatstone bridge.
- This change in resistance when calibrated becomes a measure of the applied force.

② Bonded strain gauge

- These gauges are directly bonded or pasted on the surface of the structure. Hence they are named as bonded gauges.
- We have three types
- (a) Five wire
 - (b) metal foil
 - (c) semiconductor

(a) Fine wire strain gauge

- A fine resistance wire of diameter 0.025 mm which is bent again and again. This is done to increase the length of the wire so that it permits a uniform distribution of stress.
- This resistance wire is placed between the two carrier bars which are cemented to each other. Leads are provided for electrically connecting the strain gauge to a measuring device.



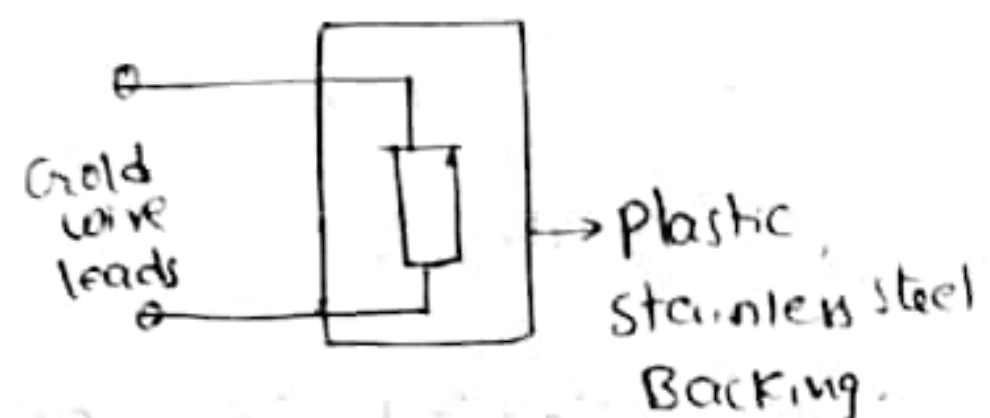
- By the application of force, the structure will change in its dimension. As the strain gauge is bonded to the structure, the strain gauge also will undergo change in length & cross-section.
- This strain & change in dimension changes the resistance of the strain gauge which can be measured with wheatstone bridge.

(b) Metal foil strain gauge

- The metal foil of 0.02 mm thick is produced using the printed circuit technique. Leads are soldered to the metal foil for electrically connecting the strain gauge to a measuring instrument.
- When a structure is subjected to force, the structure will change in dimension. As the gauge is bonded to structure, the gauge will undergo change both in length & cross-section.

(c) Semiconductor strain gauge

- The sensing element is a rectangular filament of a wafer from Silicon.



- This sensing element is attached to a plastic or stainless steel backing.
- Leads are drawn out from the sensing element for electrically connecting the strain gauge to a measuring device.

Photo devices

The principle is to convert light energy into electric energy. This is done by causing the radiation to fall on a photosensitive element and measuring the electrical current so generated with a sensitive galvanometer directly or after suitable amplification.

- Photo voltaic cells usually consist of a semiconducting substance, which is generally selenium deposited on a metal base which may be iron and which acts as one of the electrodes.
- The semiconducting substance is covered with a thin layer of silver or gold deposited by cathodic deposition in vacuum. This layer acts as a collecting electrode.
- When radiant energy falls upon the semiconductor surface, it excites the electrons at the silver-selenium interface. The electrons released are collected at the collector electrode.
- The cell is enclosed in a housing of insulating material and covered with a sheet of glass. The two electrodes are connected to two terminals which connect the cell with other parts of circuit.

Inductive Transducers

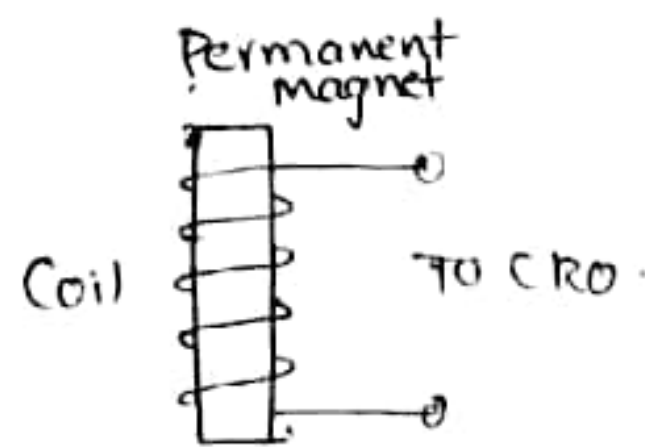
It is based on the principle of change in the reluctance, permeability, no. of turns in the coil which may produce a change in the inductance of transducer.

$$L = \frac{N^2 \mu A}{\lambda} = N^2 \mu G = \frac{N^2}{R}$$

where R — Reluctance A — Area of cross section
 N — No. of turns λ — length of coil
 μ — permeability G — form factor

Variable reluctance method

Consider a coil wound on a permanent magnet core. Any change in the permeance of magnetic circuit cause a change in flux. This change in flux is proportional to the voltage included in the coil.

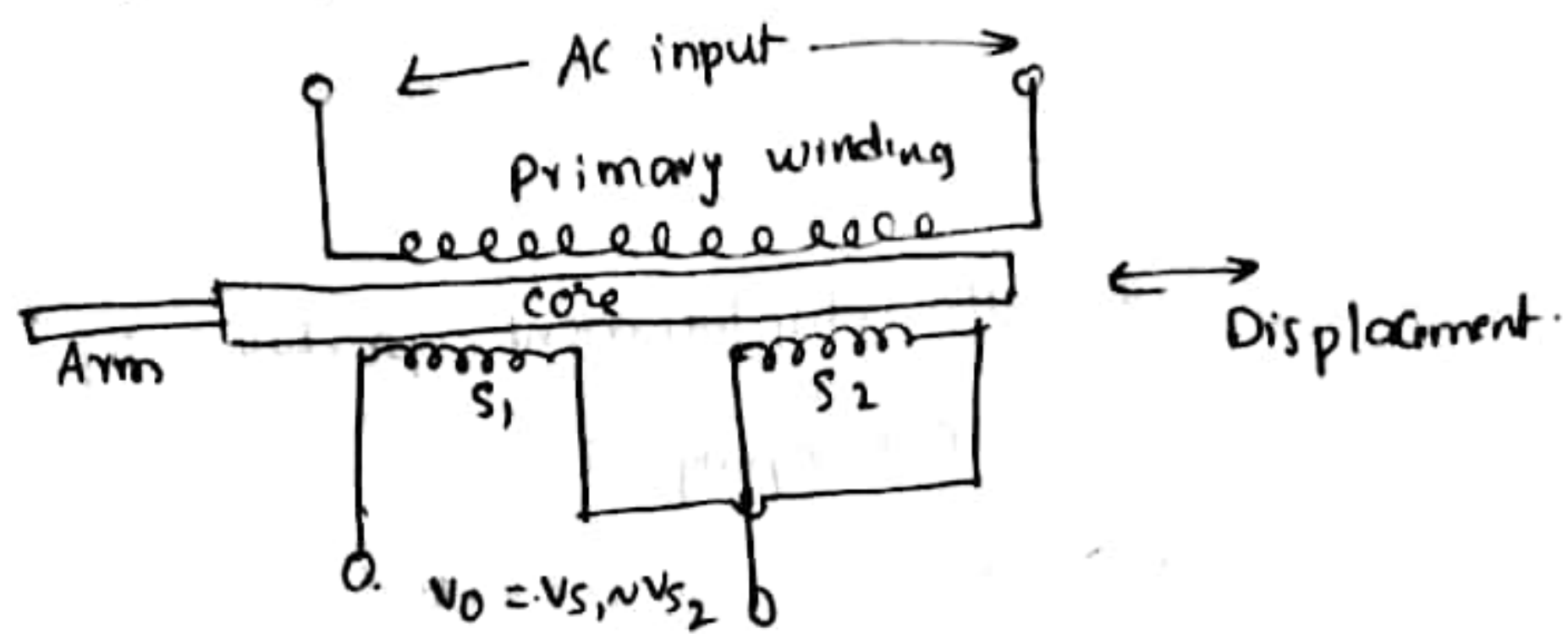


It consists of a permanent magnet core. The magnetic core is wound with a coil. The terminals of the coil are connected to CRO. When a change in flux takes place, electric impulses are generated in the CRO. The output is calibrated to read the changes.

Linear variable differential Transformer

LVDT converts linear motion into an electrical signal. It is used for measuring displacement.

- * It consists of a primary winding and two secondary windings which are wound on a cylindrical former.
- * The secondary windings have equal no. of turns. These are placed identically on either side of primary winding.
- * The primary winding is connected to an AC source. A movable core is placed inside the cylindrical former.



- The primary winding is connected to the AC source. It is excited and hence a magnetic field is produced. Due to this magnetic field, a voltage is induced in the secondary winding.
- The differential output is $V_0 = V_{S_1} - V_{S_2}$. When the core is in the normal position, V_{S_1} and V_{S_2} are equal. So $V_0 \approx \text{zero}$.
- When the core is moved to the right of the null position, more magnetic field links with the windings S_2 and less with the winding S_1 . So V_{S_2} will be larger than V_{S_1} . Therefore V_0 is in phase with V_{S_2} .
- When the core is moved to the left of the null position, more magnetic field links with S_1 . So V_{S_1} is larger than V_{S_2} . Therefore V_0 is in phase with V_{S_1} .
- The output voltage V_0 of the LVDT gives a measure of the physical position of the core and its displacement.
- It is generally used to measure displacement. It is also used to measure vibrations, pressure, force and weight.

Capacitive Transducers

- * It is used to measure the displacement produced by the bio variable by means of change in overlapping area of cross section of the conducting plates, thickness of the dielectric material and the distance between the conducting plates.

- * Capacitor consists of two conducting surfaces separated by a dielectric in the form of solid, liquid + gas

$$C = \frac{\epsilon A}{d}$$

The change in capacitance is normally measured through the frequency change in the oscillator circuit where the capacitive transducer forms a tank circuit.

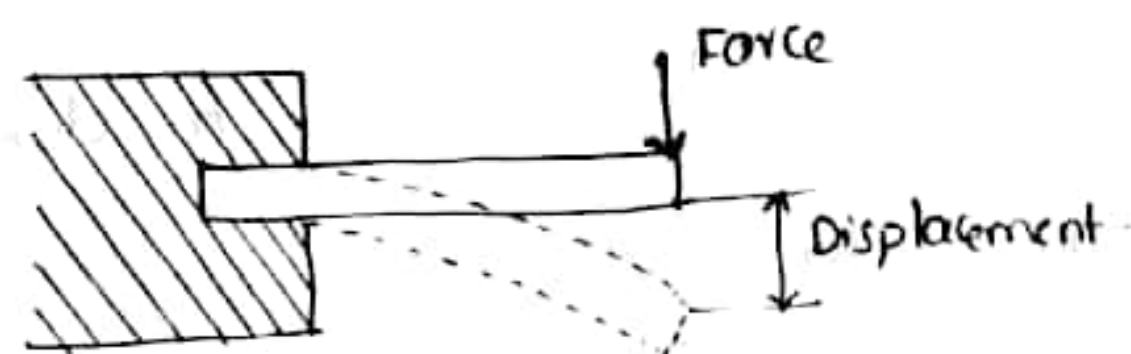
- * The capacitance is directly proportional to area of the plates and inversely proportional to the distance between the plates 'd'.
- * Variation of 'd' causes a corresponding variation in capacitance. When a force is applied on one plate of a capacitor, the distance between the plates is reduced or increased. The change of distance will change the capacitance.
- * Capacitance transducers are very sensitive displacement transducers. They are required to be thermally insulated and the connecting cables have to be made as small as possible in length.

Transducers for Biomedical Applications

<u>Physical Variable</u>	<u>Type of Transducer</u>
① Force (or) pressure	Piezo-electric, unbonded strain gauge
② Displacement	Variable R, L, C, LVDT
③ Surface strain	strain gauge
④ velocity	magnetic induction
⑤ Temperature	Thermocouple, Thermistor
⑥ Light	photo voltaic photo resistive
⑦ magnetic field	Hall effect

Force Transducers

* A design element frequently used for the conversion of physical variable is the force-summing member. The configuration is

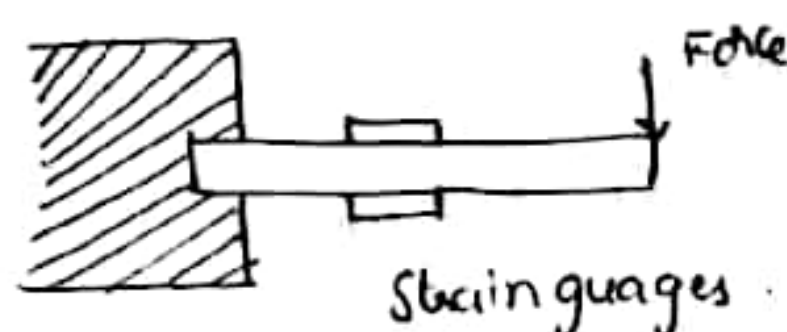


→ Here the force summing member is a leaf spring. When the spring is bent downward, it exerts an upward-directed force that is proportional to the displacement of the end of spring.

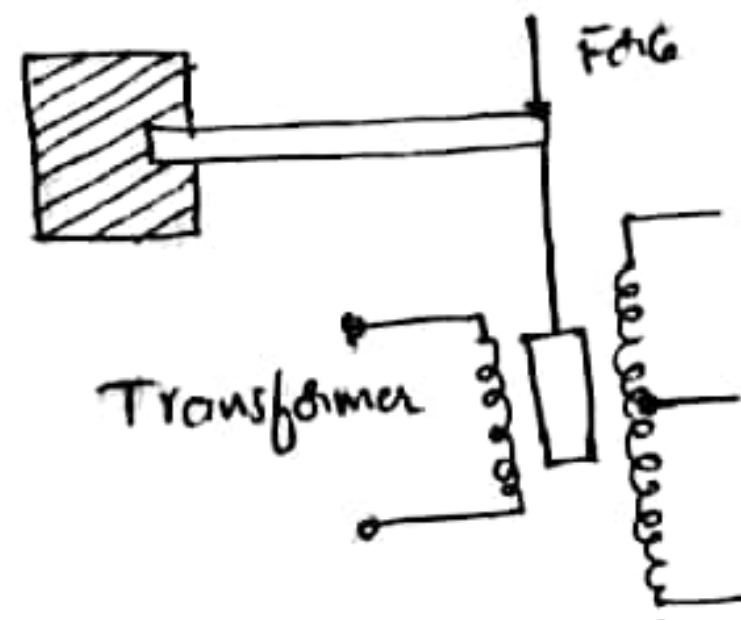
→ If a force is applied to the end of the spring in a downward direction, the spring bends until its upward-directed force equals the downward-directed applied force.

→ The force summing member can be used to convert a force into a variable for which transducers are readily available.

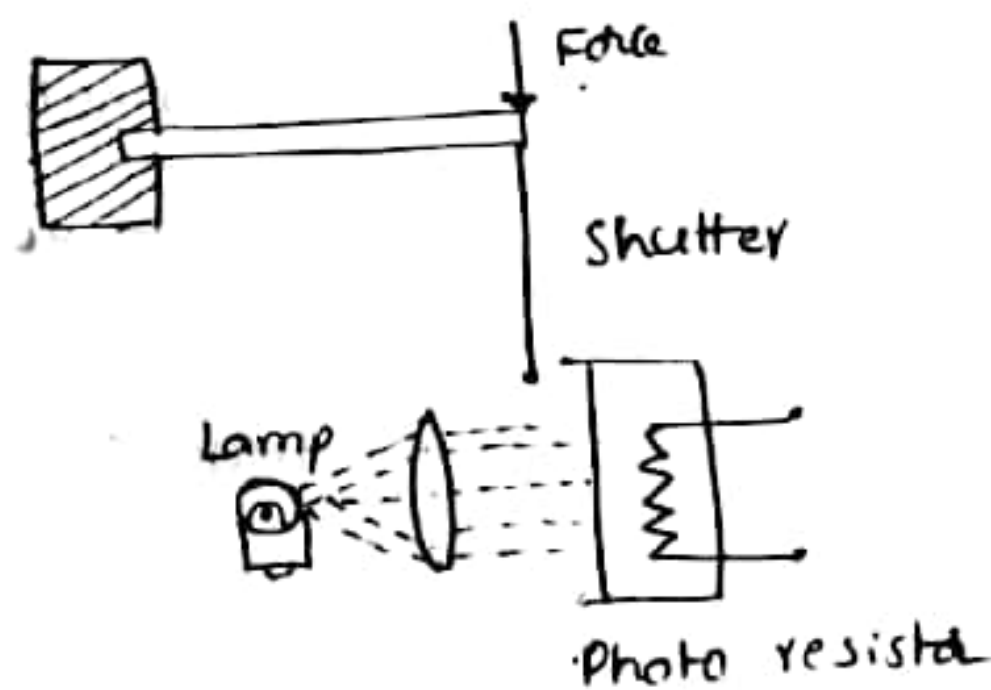
* The bending of the spring results in a surface strain that can be measured by means of bonded strain gauge.



* The force transducer using a differential transformer is



* The force transducer using a lamp and photo resistor to measure the displacement of force summing member is



Displacement Transducers

Displacement measurement means measuring the movement of a point from one position to another.

The various transducers that are sensitive to displacement are

- (1) Resistance potentiometers
- (2) Differential Transformers
- (3) Variable Inductance Transducers
- (4) Capacitance transducers
- (5) Piezo electric transducers.

Velocity Transducers

Velocity is the rate of change of displacement with respect to time. we have two types of velocities Linear & Angular.

Linear velocity refers to the velocity of a body moving in a linear manner. It is expressed in meter per second. The various types of transducers are

- (a) Electro magnetic transducers [moving magnet type
moving coil type
- (b) Digital transducers
- (c) Doppler Effect transducers

Angular velocity is measured with tachometers. They are classified as

- a) mechanical tachometers
- b) Electrical tachometers
- c) Contactless tachometers

Acceleration Transducers

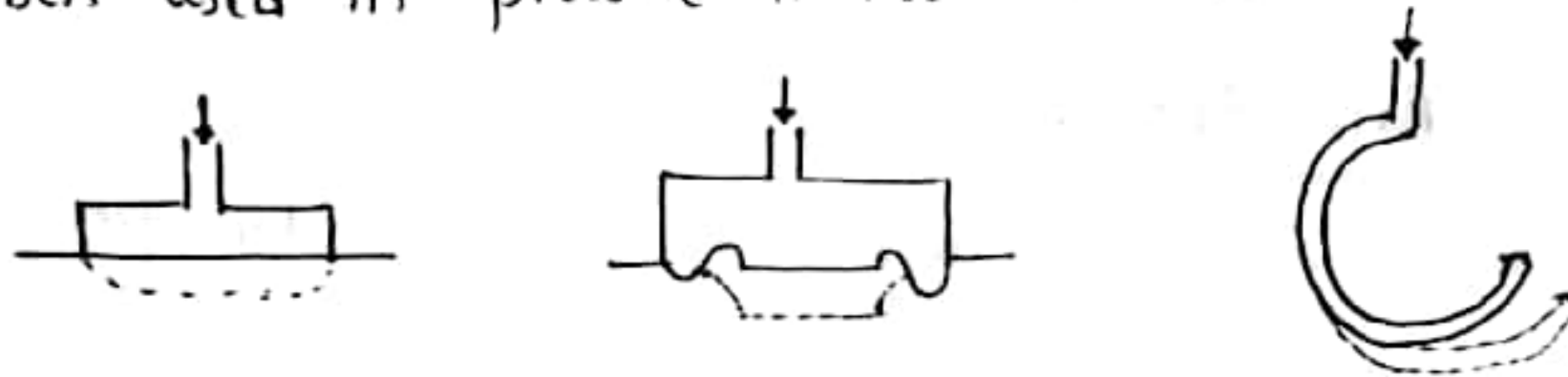
Acceleration is the rate of change of velocity w.r.t time. The instrument used to measure acceleration is called accelerometer.

The various types are

- (a) Piezo electric Accelerometer
- (b) LVDT Accelerometer
- (c) Seismic Displacement accelerometer

Pressure Transducers

* These are closely related to force transducers. The force summing members used in pressure transducers are:



- * Pressure transducers utilizing flat diaphragms normally have bonded or semiconductor strain gauges attached directly to diaphragms.
- * Flat or Corrugated diaphragms have been used in transducers which employ the variable reluctance or variable capacitance principles.
- * Bourdon tube transducers are used for high pressure gauges.
- * The amount of deformation of the force summing member in a pressure transducer actually depends on the difference in the pressure between the two sides of diaphragm.
- * If Absolute pressure is to be measured, there must be a vacuum on one side of the diaphragm.
- * It is common to measure the pressure relative to atmospheric pressure by exposing one side of diaphragm to atmosphere.

Pulse Sensors

- * Each time heart muscle contracts, blood is ejected from the ventricles. Consequently, a pulse pressure is transmitted through the circulatory system.
- * This pulse causes vessel-wall displacement while travelling through the vessels. The displacement is measurable at various points of the peripheral circulatory system.
- * The pulse sensing can be done by placing finger tip over the radial artery in wrist or some other location where an artery is just below the skin.
- * The pulse pressure can be measured by various transducers as
 - (1) photo electric pulse transducer
 - (2) Piezo electric arterial pulse receptor
 - (3) Strain gauge pulse transducer.

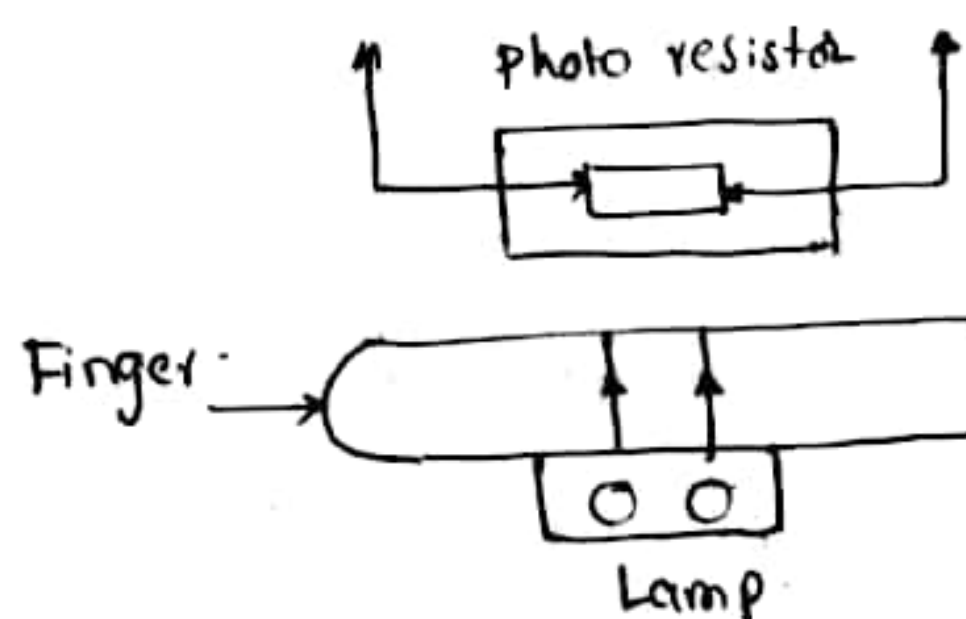
① Photo electric Pulse transducer

Pulsatile blood volume changes are detected by photo-electric method using photo resistors. The methods used are

- (a) Transmittance method
- (b) Reflectance method

① Transmittance method

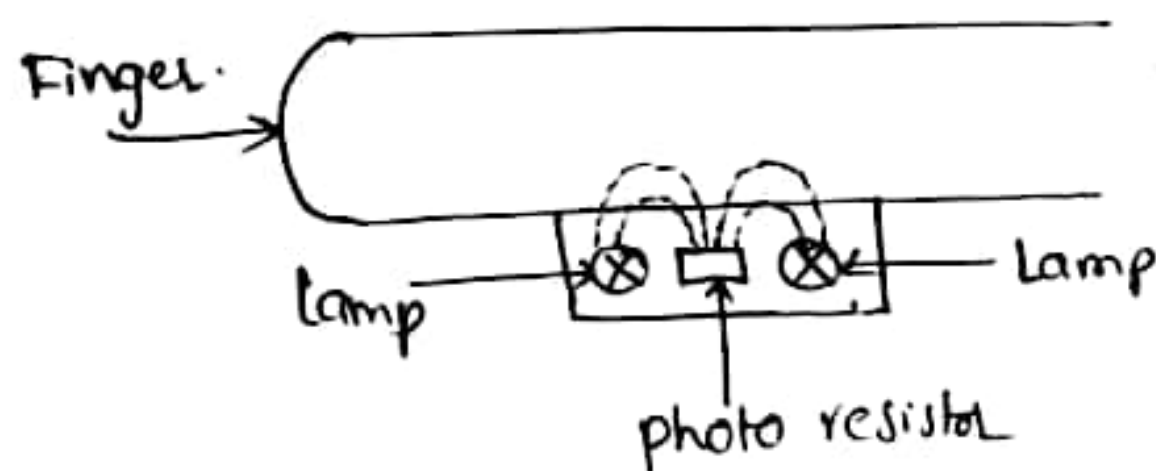
- It has a miniature lamp and photo resistor mounted in an enclosure which fits over the tip of subject's finger
- Light is transmitted through the finger tip of the patient's finger and the resistance photo resistor is determined by the amount of light reaching photo resistor



- Blood is forced to the extremities and the amount of blood in finger increases with each contraction of heart.

- This alters optical density and consequently the light transmission through the finger reduces and accordingly the resistance of the photo resistor increases.
- The photo resistor is a part of a voltage divider circuit which produces a voltage. The voltage varies with the amount of blood in the finger.
- This voltage closely follows the pulse pressure and its wave shape can be recorded or displayed on CRO.

⑥ Reflectance method



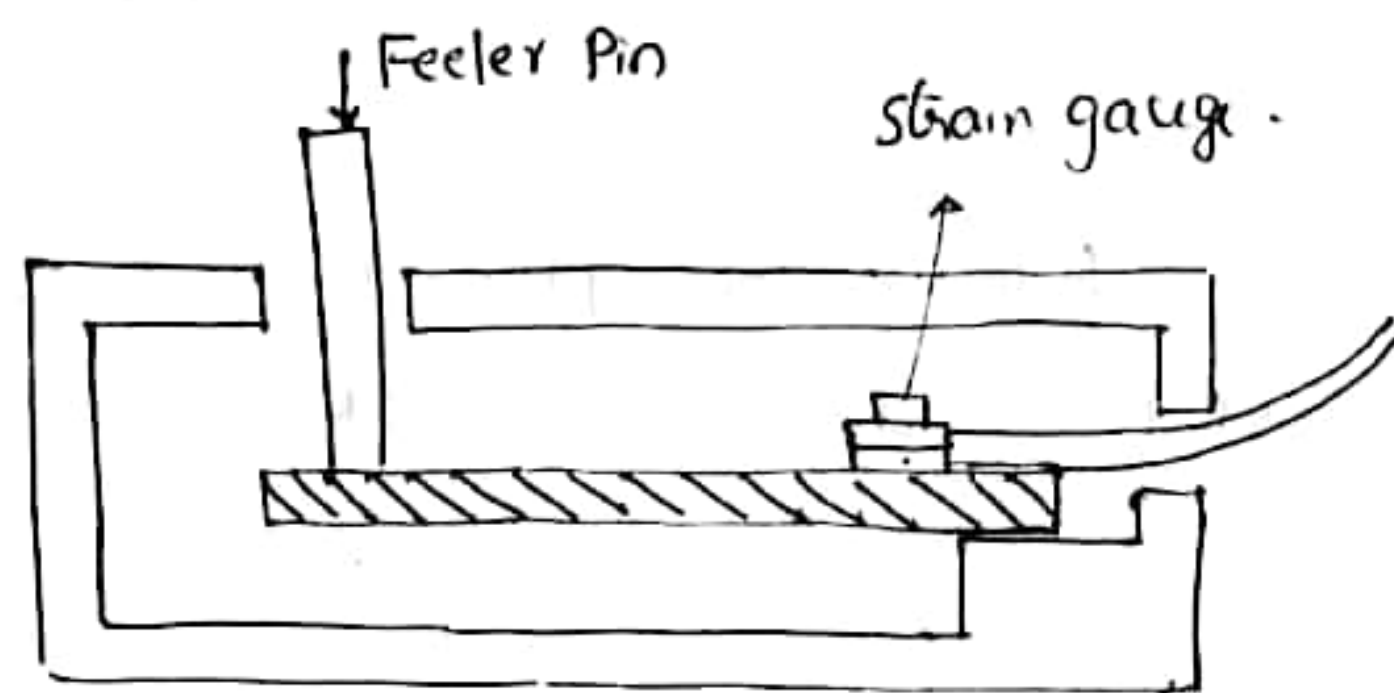
- The photo resistor is placed adjacent to the exciter lamp. Only a part of light rays, emitted by the lamp, is reflected and scattered from the skin & tissue is made to fall on photo resistor.
- The blood saturation of the capillaries determines the quantity of light reflected. The resistance of photo resistor varies due to the above.
- The voltage across the photo resistor which is connected as a voltage divider, varies in proportion to the volume changes of blood vessels of the body of the subject.

⑦ Piezoelectric Arterial Pulse Receptor

- * It consists of piezoelectric crystal clamped in a sealed capsule which is subjected to the displacement stresses.
- * The displacement is transmitted to the crystal through a soft rubber diaphragm. The pulse pressure waveform is recorded by connecting the crystal to ECG recorder.
- * The volume of blood in finger, varies during cardiac cycle which causes change in size of finger. These changes are transmitted as pressure variations in the air column inside the plastic tubing.

* At the end of the tube, a piezo electric transducer converts the pressure changes to electrical signal. This electrical signal is amplified and displayed or recorded.

③ Strain Gauge Pulse Transducer



- Displacement of the vessel wall is transferred to semiconductor strain gauge by means of a feeler pin and a leaf spring.
- The strain gauge is firmly attached to the leaf spring on one side and to feeler pin on the other side leaf.
- one ring around the feeler pin of the transducer helps in minimizing the interference caused by unsteadiness of application of transducer to subject's skin.
- The transducer output range is 50 mV for 0.1 mm displacement.

Respiration Sensor

Tissues receive oxygen and give away CO_2 in the respiration system. The breathing action is controlled by muscular action causing volume of lung to increase and decrease to achieve a precise and sensitive control of the content of CO_2 in the arterial blood. We have two types

① Strain gauge type chest Transducer

- Thoracic volume change is observed in respiratory cycle. This is sensed by means of a displacement transducer with the help of strain gauge.
- An elastic band holds the transducer around the chest. The respiratory movements result in the resistance changes of strain gauge, which is connected to one arm of bridge circuit.
- The output voltage of bridge varies with chest expansion which gives signals corresponding to respiratory activity of subject.

② Thermistor based Transducer

- * During respiration, there is a difference in temperature of inspired and expired air. This is sensed by using a thermistor placed in front of nostrils, using holding device.
- * If the difference in temperature of outside air and that of expired air is small, thermistor can be initially heated to a suitable temperature and the variation of its resistance in synchronism with respiration rate, as a result of cooling effect of air stream.
- * This can be achieved with thermistor dissipations of about 5mw to 2.5 mw range, by placing a voltage dividing circuit or in a bridge circuit whose unbalanced signal gives respiratory signal.

Transducers with Digital Output

- * BMT systems are utilizing digital methods for processing of data which require that any data entered into the system be in digital rather than in analog form.
- * Analog to Digital converters can be used to convert an analog transducer output into digital form.
- * The transducer whose output is in digital form uses encoding disks with digital pattern, photographically etched on glass plates.
- * A light source and an array of photo detectors are used to obtain a digital signal in parallel format that indicates the position of encoding plate and thereby represents the displacement being measured.