UNIT-2

ELECTRODES & TRANSDUCERS

Measurement electrodes are simply electrical terminals or contact points from which voltages can be obtained atthe surface of the body. Bioelectric potentials generated in the body are ionic potentials, produced by ionic current flow. Efficient measurement of these ionic potentials requires that they be converted into electronic potentials before they can be measured by conventional methods. **Devices that convert ionic potentials into electronic potentials are called electrodes.**

Theory of Electrodes:

The interface of metallic ions in solution with their associated metalsresults in an electrical potential that is called the electrode potential. Thispotential is a result of the difference in diffusion rates of ions into and outof the metal.

Equilibrium is produced by the formation of a layer of chargeat the interface. It is impossible to determine the absolute electrode potential of a single electrode, for measurement of the potential across the electrode andits ionic solution would require placing another metallic interface in thesolution.

Another source of an electrode potential is the unequal exchange ofions across a membrane that is semipermeable to a given ion when the membrane separates Liquid solutions with different concentrations of that ion.

An equation relating the potential across the membrane and the two concentrationsof the ion is called the Nernst equation and can be stated asfollows:

$$\boldsymbol{E = -\frac{RT}{nF} ln \frac{c_1 f_1}{c_2 f_2}}$$

Where R = gas constant (8.315 x 107 ergs/mole/degree Kelvin)

T = absolute temperature, degrees Kelvin

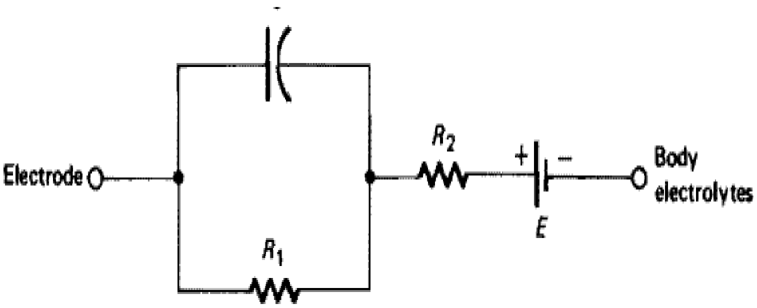
n = valence of the ion (the number of electrons added or removed to ionize the atom)

F = Faraday constant (96,500 coulombs)

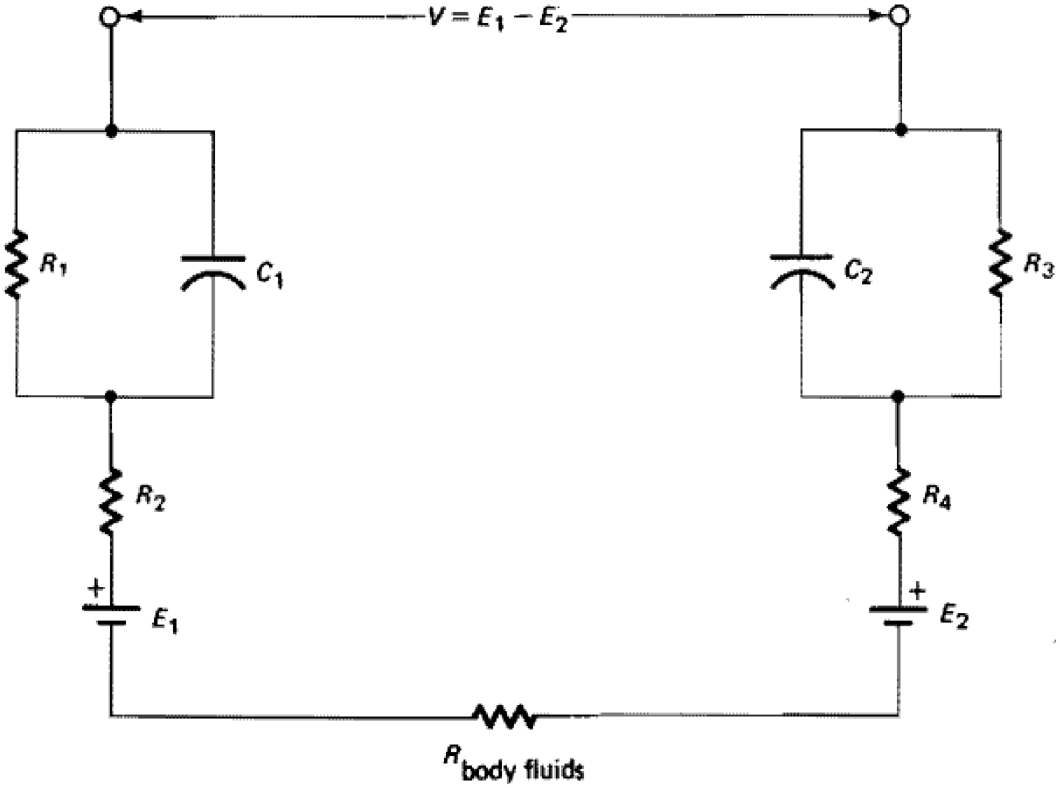
C1, C2 = two concentrations of the ion on the two sides of the membrane

F1, F2 = respective activity coefficients of the ion on the two sides of the membrane

All three types of bio potential electrodes have the metal-electrolyte interface described in the previous section. In each case, 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. Thus, the equivalent circuit of bio potential electrode in contact with the body consists of a voltage in series with a resistance-capacitance network of the type shown in Figure



Since measurement of bioelectric potentials requires two electrodes,the voltage measured is really the difference between the instantaneouspotentials of the two electrodes, as shown in Figure.



Measurement of biopotentials with two electrodes—equivalent

If the two electrodesare of the same type, the difference is usually small and dependsessentially on the actual difference of ionic potential between the two pointsof the body from which measurements are being taken. If the two electrodesare different, however, they may produce a significant dc voltage that cancause current to flow through both electrodes as well as through the inputcircuit of the amplifier to which they are connected. The dc voltage due tothe difference in electrode potentials is called the electrode offset voltage.

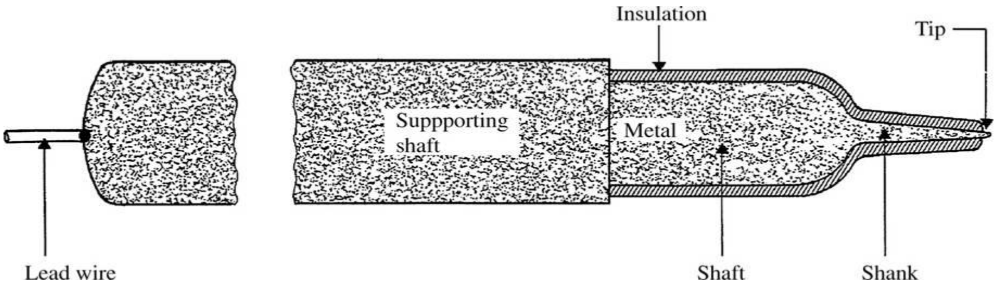
BIOPOTENTIAL ELECTRODES

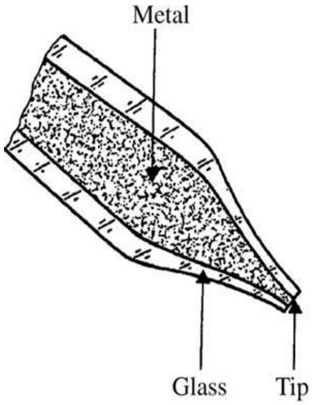
A wide variety of electrodes can be used to measure bioelectric events, but nearly all can be classified as belonging to one of three basic types:

- **Microelectrodes**: Electrodes used to measure bioelectric potentials near or within a single cell.
- **Skin surface electrodes**: Electrodes used to measure ECG, EEG, and EMG potentials from the surface of the skin.
- **Needle electrodes**: Electrodes used to penetrate the skin to record EEG potentials from a local region of the brain or EMG potentials from a specific group of muscles.

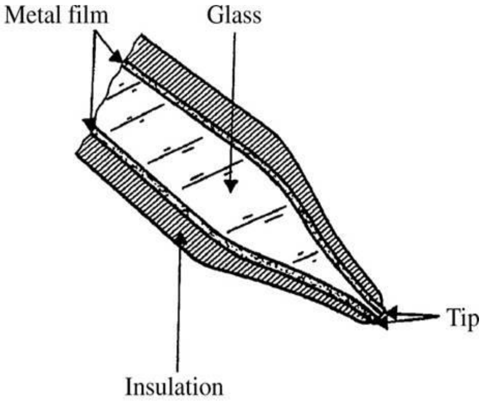
Microelectrodes:

- Microelectrodes 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. This action is usually complicated by the difficulty of accurately positioning an electrode with respect to a cell.
- Microelectrodes are generally of two types: metal and micropipette. Metal microelectrodes are formed by electrolytically etching the tip of a fine tungsten or stainless-steel wire to the desired size.
- Then the wire is coated almost to the tip with an insulating material. Some electrolytic processing can also be performed on the tip to lower the impedance. The metal-ion interface takes place where the metal tip contacts the electrolytes either inside or outside the cell.
- The micropipette type of microelectrode is a glass micropipette with the tip drawn out to the desired size. The micropipette is filled with an electrolyte compatible with the cellular fluids. This type of microelectrode has a dual interface.
- One interface consists of a metal wire in contact with the electrolyte solution inside the micropipette, while the other is the interface between the electrolyte inside the pipet and the fluids inside or immediately outside the cell. A commercial type of microelectrode is shown in Figure.





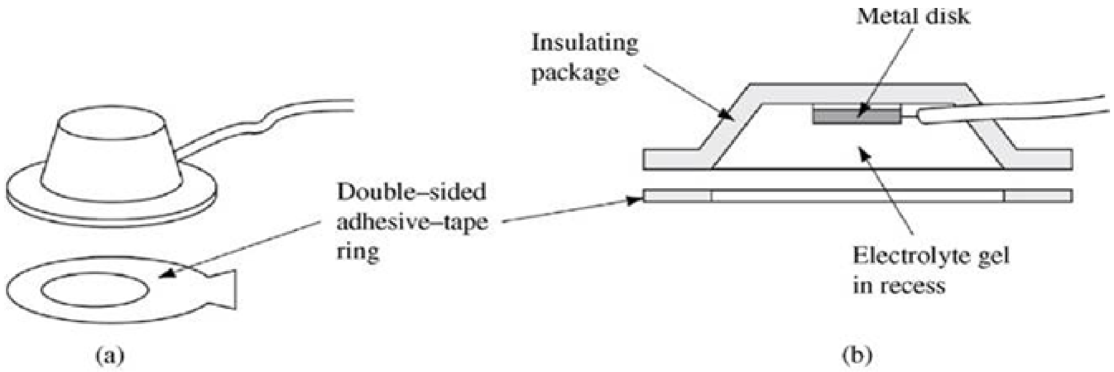
(a)



(b)

Body Surface Electrodes:

- Electrodes used to obtain bioelectric potentials from the surface of the body are found in many sizes and forms.
- Although any type of surface electrode can be used to sense EGG, EEG, or EMG potentials, the larger electrodes are usually associated with EGG, since localization of the measurement is not important, whereas smaller electrodes are used in EEG and EMG measurements.
- All the preceding electrodes suffer from a common problem. They are all sensitive to movement, some to a greater degree than others.
- Even the slightest movement changes the thickness of the thin film of electrolyte between metal and skin and thus causes changes in the electrode potential and impedance.
- Later, a new type of electrode, the floating electrode, was introduced in varying forms by several manufacturers. The principle of this electrode is to practically eliminate movement artifact by avoiding any direct contact of the metal with the skin.
- The only conductive path between metal and skin is the electrolyte paste or jelly, which forms an electrolyte bridge. Figure shows a cross section of a floating electrode.



- Floating electrodes are generally attached to the skin by means of two sided adhesive collars (or rings), which adhere to both the plastic surface of the electrode and the skin.
- Various types of disposable electrodes have been introduced in recent years to eliminate the requirement for cleaning and care after each use primarily intended for ECG monitoring.
- Special types of surface electrodes have been developed for other applications. For example, a special ear-clip electrode was developed for use as a reference electrode for EEG measurements.

Needle Electrodes:

To reduce interface impedance and, consequently, movement artifacts,some electroencephalographers use small sub dermal needles to penetratethe scalp for EEG measurements.

These needle electrodes, shown in Figure, are not inserted into the brain; they merely penetrate the skin.Generally, they are simply inserted through a small section of the skin justbeneath the surface and parallel to it.

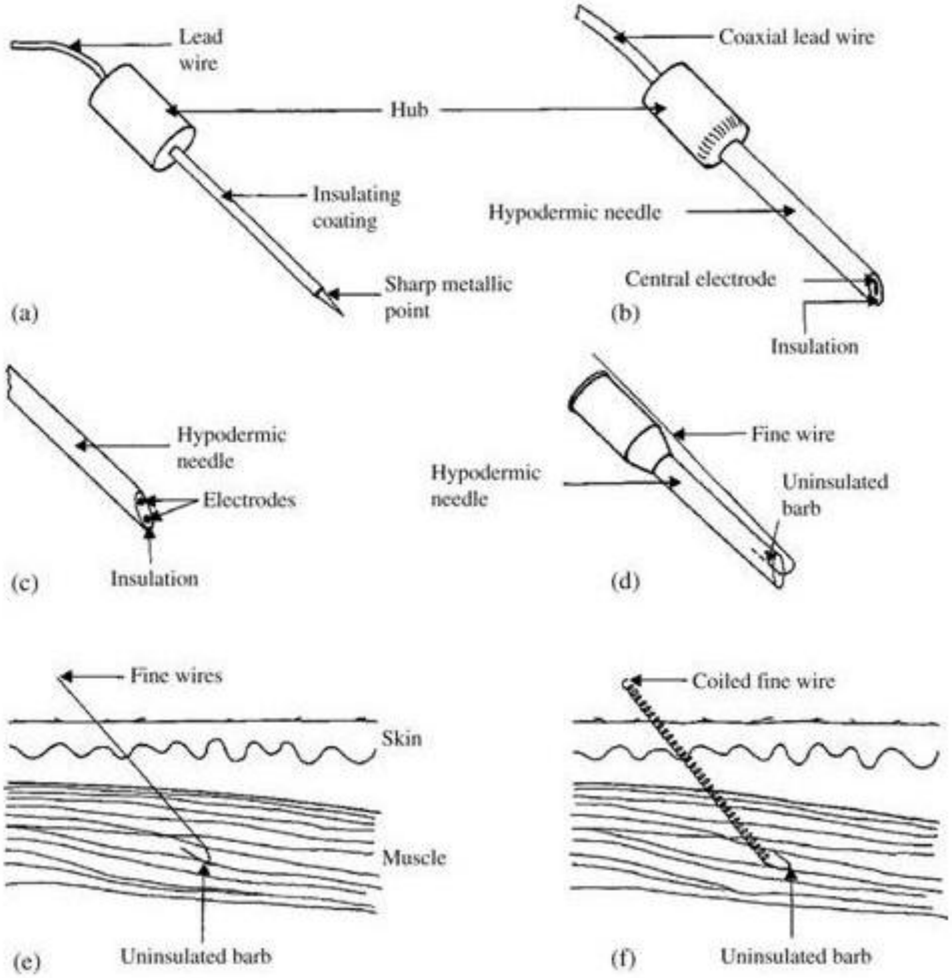
In animal research (and occasionally in man) longer needles are actually inserted into the brain to obtain localized measurement of potentials from a specific part of the brain. This process requires longer needles precisely located by means of a map or atlas of the brain.

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, or other tissue from which the measurement is made.

The remainderof the wire is covered with some form of insulation to prevent shorting.Wire electrodes of copper or platinum are often used for EMG pickupfrom specific muscles.

The wires are either surgically implanted or introducedby means of a hypodermic needle that is later withdrawn, leaving the wireelectrode in place.

With this type of electrode, the metal-electrolyte interfacetakes place between the uninsulated tip of the wire and the electrolytesof the body, although the wire is dipped into an electrolyte paste before insertionin some cases.

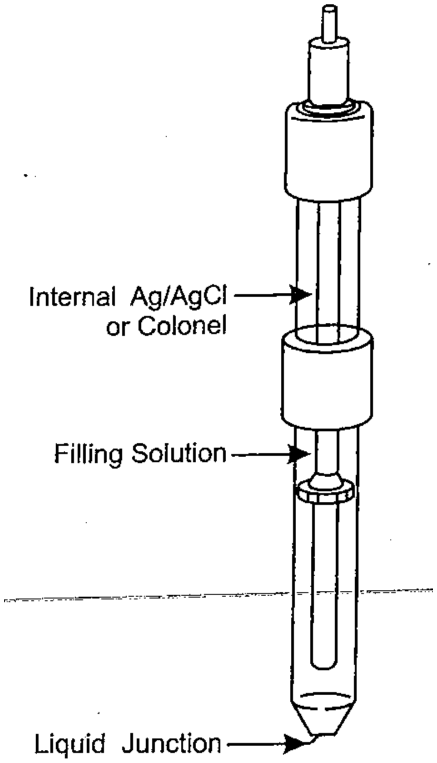


BIOCHEMICAL TRANSDUCERS:

Reference Electrodes:

The hydrogen gas/hydrogen ion interface has been designated as the reference interface and was arbitrarily assigned an electrode potential of zero volts. For this reason, it would seem logical that the hydrogen electrode should be used as the reference in biochemical measurements. These electrodes make use of the principle that an inert metal, such as platinum, readily absorbs hydrogen gas. If a properly treated piece of platinum is partially immersed in the solution containing hydrogen ions and is also exposed to hydrogen gas, which is passed through the electrode, an electrode potential is formed. The electrode lead is attached to the platinum.

Two types of electrodes have interfaces sufficiently stable to serve as reference electrodes—the silver-silver chloride electrode and the calomel electrode. Their basic configurations are shown in Figure.



The silver-silver chloride electrode used as a reference in electrochemical measurements utilizes the same type of interface for bioelectric potential electrodes.An equally popular reference electrode is the calomel electrode. Calomel is another name for mercurous chloride, a chemical combination of mercury and chloride ions.The interface between mercury and mercurous chloride generates the electrode potential.

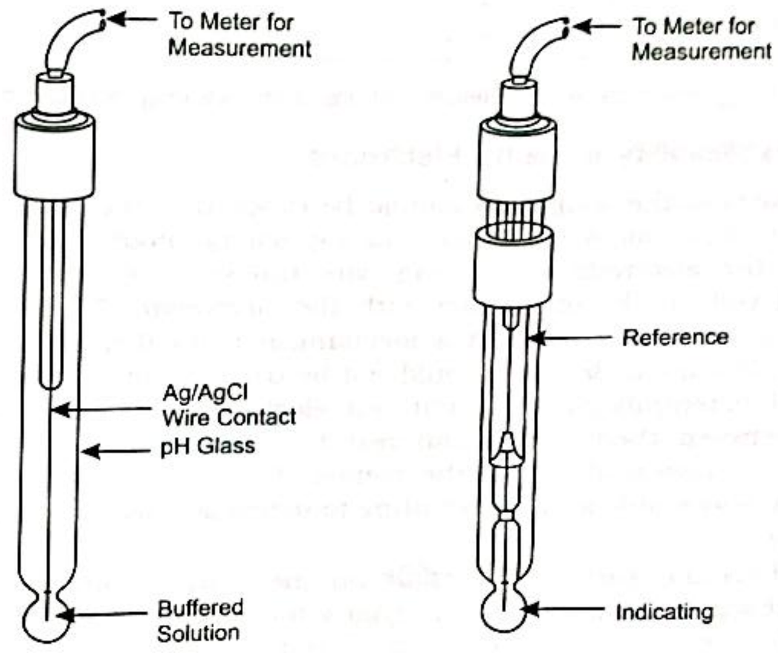
The p^H Electrode:

The most important indicator of chemical balance in the body is the pH of the blood and other body fluids. The pH is directly related to the hydrogen ion concentration in a fluid. Specifically, it is the logarithm of the reciprocal of the **H^+ ion** concentration. In equation form,

$$\mathbf{p^H = -\log[H^+] = \log_{10}\frac{1}{[H^+]}}$$

The pH is a measure of the acid-base balance of a fluid. A neutral solution (neither acid nor base) has a pH of 7. Lower pH numbers indicate acidity, whereas higher pH values define a basic solution. Most human body fluids are slightly basic. The pH of normal arterial blood ranges between 7.38 and 7.42. The pH of venous blood is 7.35, because of the extra CO2.

To facilitate the measurement of the pH of a solution, combination electrodes of the type shown in Figure are available, with both the pH glass electrode and reference electrode in the same enclosure.



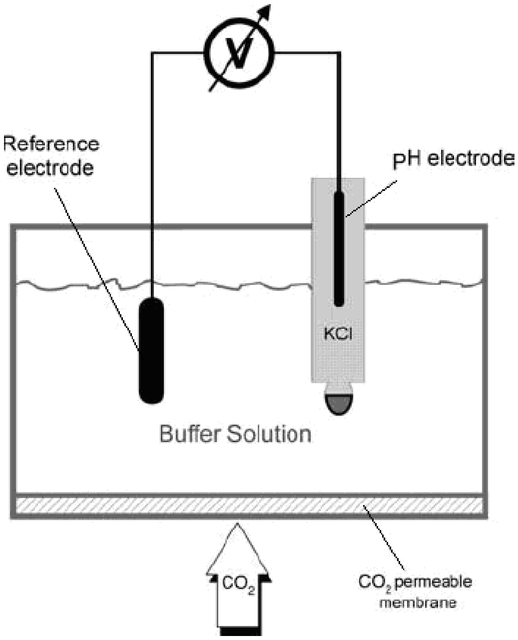
Blood Gas Electrodes:

Among the more important physiological chemical measurements are the partial pressures of oxygen and carbon dioxide in the blood. 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 partial pressure of oxygen, often called oxygen tension, can be measured both in vitro and in vivo. The basic principle is shown in Figure.

A fine piece of platinum or some other noble 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 0.7 V is applied between the platinum wire and a reference electrode (also placed into the electrolyte), with the platinum wire negative, reduction of the oxygen takes place at the platinum cathode.



Thus, an oxidation-reduction current proportional to the partial pressure of the diffused oxygen can be measured. 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 the blood.

Transducer Principles

Physiological variables occur in many forms: as ionic potentials and currents, mechanical movements, hydraulic pressures and flows, temperature variations, chemical reactions, and many more.

A transducer is required to convert each variable into an electrical signal which can be amplified or otherwise processed and then converted into some form of display.

The device that performs the conversion of one form of variable into another is called a transducer. In this book the primary concern is the conversion of all other forms of physiological variables into electrical signals. In this way, a transducer is a component which has a nonelectrical variable as its input and an electrical signal as its output.

Types of Transducers:

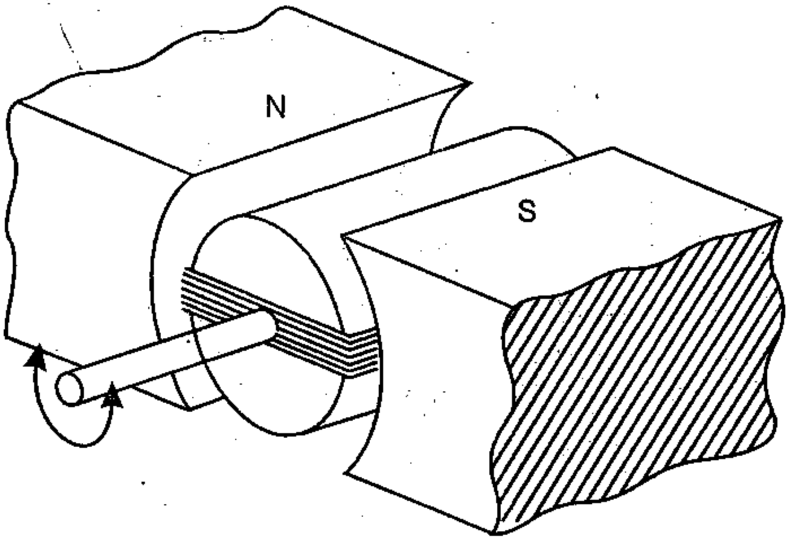
Based on the excitation principle transducers are divided in to two categories. They are

- **a) Active Transducers**
- **b) Passive Transducers**

Magnetic Induction

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 the 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 electrical motors and generators and a host of other devices, such as solenoids and loudspeakers, utilize this principle.

Two basic configurations for transducers that use the principle of magnetic induction for the measurement of linear or rotary motion are shown in Figure.

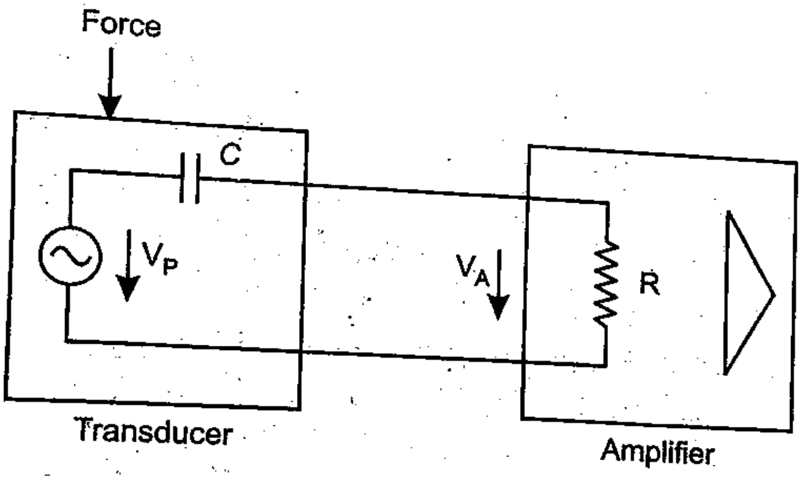


Magnetic induction also plays an important role at the output of many biomedical instrumentation systems. The principle of magnetic induction has an electrostatic equivalent called electric induction.

The Piezoelectric Effect

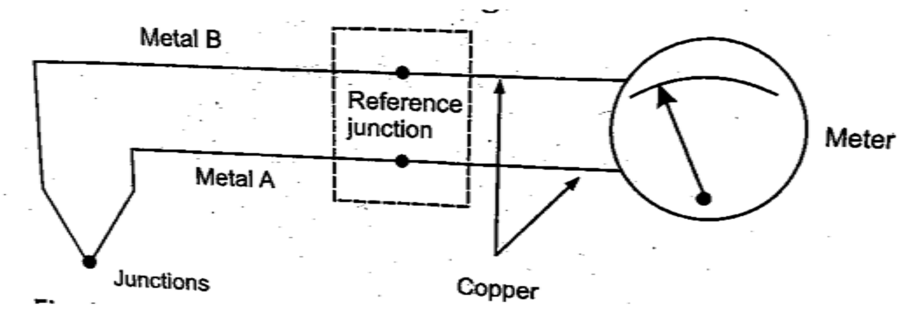
When pressure is applied to certain nonconductive materials so that deformation takes place as shown in Figure. a charge separation occurs in the materials and an electrical voltage,V_p, can be measured across the material. The natural materials in which this piezoelectric effect can be observed are primarily slices from crystals of quartz (SiO_2) or Rochelle salt (sodium-potassium tartrate, $KNaC_4H_40_64H_20$).

The piezoelectric process is reversible. If an electric field is applied to a slab of material that has piezoelectric properties, it changes its dimensions.The electrically equivalent circuit of a piezoelectric transducer, shown in Figure that of a voltage source having a voltage, Vp, proportional to the applied mechanical force connected in series with a capacitor, which represents 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 affect the response of the transducer.



Thermoelectric Effect

If two wires of dissimilar metals (e.g., iron and copper) are connected so that they form a closed conductive loop as shown in Figure. A voltage can be observed at any point of interruption of the loop which 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 is called as Thermocouple as shown in the figure.



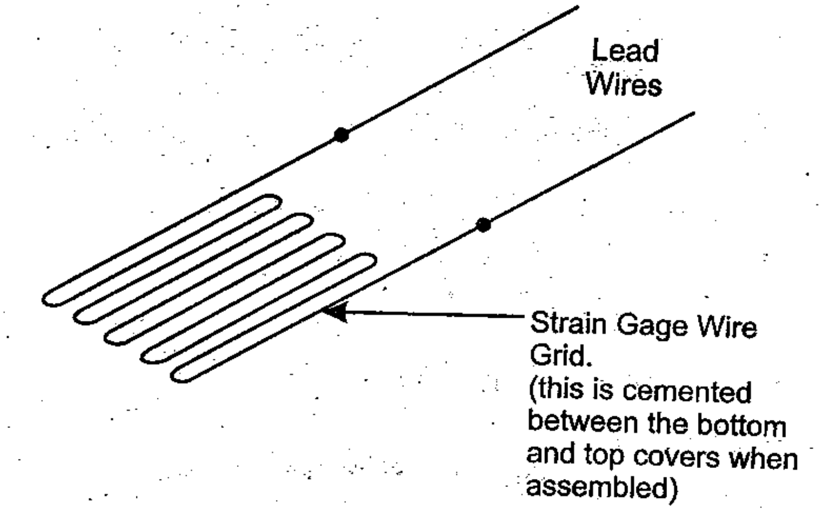
In the case of the thermocouple it might not be obvious how the thermal energy is converted. The delivery of electrical energy causes the transfer of heat from the hotter to the colder junction; the hotter junction gets cooler while the colder junction gets warmer. In most practical applications of thermocouples this effect can be neglected. Because the thermocouple measures a temperature difference rather than an absolute temperature, one of the junctions must be kept at a known reference temperature, usually at the freezing point of water (0°C or 32 °F).

The use of the thermoelectric effect to convert from thermal to electrical energy is called the Seebeck effect. In the reverse direction, it is called the Peltier effect, where the flow of current causes one junction to heat and the other to cool.

Strain Gauge

Any resistive element that changes its resistance as a function of a physical variable can, in principle, be used as a transducer for that variable.Most transducers used for mechanical variables utilize a resistive element called the strain gage. The principle of a strain gage can easily be understood with the help of Figure shows a cylindrical resistor element which has length, L, and cross-sectional area, A. If it is made of a material having a resistivity of r ohm-cm, its resistance is

$$\boldsymbol{R = \frac{rL}{A}\ (ohms)}$$



If an axial force is applied to the element to cause it to stretch, its length increases by an amount, ΔL, as shown in Figure. This stretching, on the other hand, causes the cross-sectional area of the cylinder to decrease by an amount A. Either an increase in L or a decrease in A results in an increase in resistance. The ratio of the resulting resistance change ΔR/R to the change in length ΔL/L is called the gage factor, G. Thus

$$\boldsymbol{G = \frac{(\frac{\Delta R}{R})}{(\frac{\Delta L}{L})}}$$

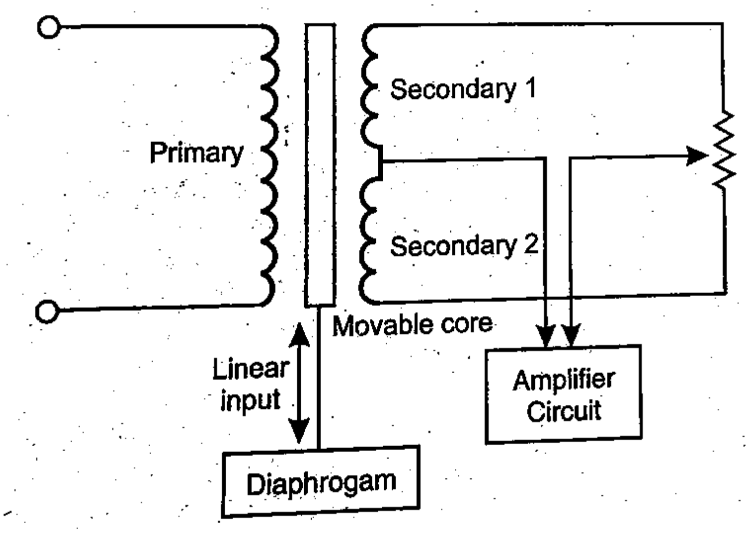
The gage factor for metals is about 2, whereas the gage factor for silicon (a crystalline semiconductor material) is about 120.

Linear Variable Differential Transformer

In principle, the inductance of a coil can be changed either by varying its physical dimensions or by changing the effective permeability of its magnetic core. The latter can be achieved by moving a core having a permeability higher than air through the coil.

However, in the inductive transducer the core is a permanent magnet which when moved induces a voltage in the coil. In this passive transducer the core is made of a soft magnetic material which changes the inductance of the coil when it is moved inside. The inductance can then be measured using an ac signal.

The linear variable differential transformer (LVDT), shown in Figure,It consists of a transformer with one primary and two secondary windings.



The secondary windings are connected so that their induced voltages oppose each other. If the core is in the center position, as shown in the figure, the voltages in the two secondary windings are equal in magnitude and the resulting output voltage is zero.

If the core is moved upward as indicated by the arrow, the voltage in secondary 1 increases while that in secondary 2 decreases.

The magnitude of the output voltage changes with the amount of displacement of the core from its central or neutral position. Its phase with respect to the voltage at the primary winding depends on the direction of the displacement.

Because nonlinearities in the magnitudes of the voltages induced in the two output coils tend to compensate each other, the output voltage of the differential transducer is proportional to core movement even with large displacements.