Biochemical Transducers

An electrode potential is generated either at metal electrolyte interface or on either side of semi- permeable membranes that separate two solutions concentration. Both methods are used to sense gases dissolved in blood and other liquids. To measure this, two electrodes are required. One electrode (indicator or active 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 volts. Hence the hydrogen electrode was used as the reference in biochemical measurements. 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 an electrode potential. A lead wire is taken from the platinum electrode. But the problem is that the hydrogen electrode is not stable enough to act as reference electrode. Another difficulty is passing hydrogen gas through the electrode during use. So, it is applicable to special situations only. There are two types of electrodes which have sufficiently stable interface to act as reference electrodes. They are silver-silver chloride electrode and the calomel electrode. The basic structure is shown in Figure 6.1.

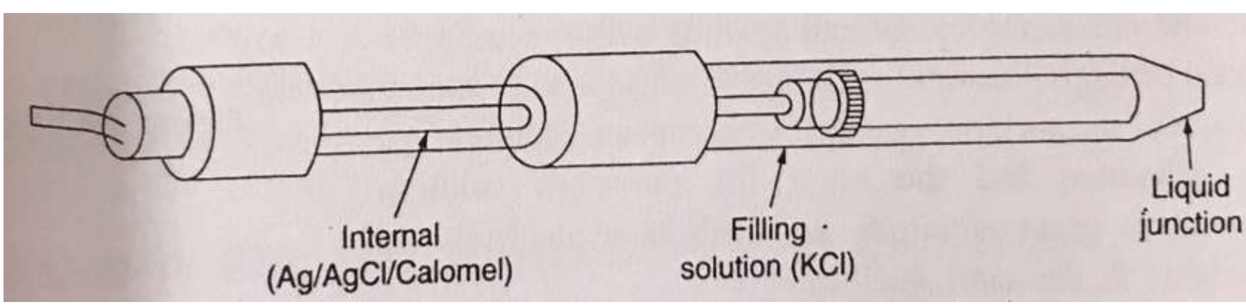

Figure 6.1 Basic structure of reference electrode.

The silver-silver chloride electrode interface is connected to the potassium chloride (KCI) 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 KCI solution is saturated with the precipitated silver chloride. The reference electrode potential is function of KCI concentration. For a 0.01 mole solution, it is 0.343 volts, and for a I mole solution, it is 0.236 volts.

Another popular reference electrode is calomel electrode or mercurous chloride electrode. The interaction between mercury and mercurous chloride generates the electrode potential. Both types are very stable for long period. Calomel electrode produces 0.388 volts for 0.01 mole KCI solution and 0.247 volts for 3.5 mole KCI solutions.

The pH electrode

Chemical balance in the body can be found by measuring pH of the blood. Similarly, pH value of other body fluids also gives the status of chemical balance in the body. pH is the logarithm of the reciprocal of the Hydrogen (H") ion concentration in the fluid, i.e., $pH = -\log_{10} H^+ = \log_{10} (1/H^+)$. pH is the measure of the acid-base balance in a fluid. A neutral solution has a pH value of 7. If the pH value is less than 7, then the solution is acidic, and if it is greater than 7, then the solution is basic. pH value of arterial blood is in the range from 7.38 to 7.42, whereas pH value of venous blood is about 7.35 due to high CO, content. A glass electrode generates an electric potential when two solutions with different pH are placed on two sides of its membrane. This potential can be used to measure pH of a solution. The silicate structure of the glass conducts a positive charge from the electrode to the ionic solution inside the electrode. The sensitivity of the pH electrode is 60 mV/pH. The range of physiological pH is 0.07 pH units. Hence the pH meter for the biological purpose has to be capable of accurately measuring a change of 0.1 mV. The basic idea is to place a solution of known pH inside the membrane and the unknown pH value solution is to place outside the membrane. Hydrochloric acid is generally used as a reference with known pH value. A reference electrode made up of either Ag/AgCl or a calomel electrode is being placed inside this solution. The glass electrode is normally used as a pH electrode. Figure 6.2 shows the glass electrode consists

1. a sensing part of electrode, a bulb made from a specific glass
2. internal electrode, usually silver chloride electrode or calomel electrode
3. internal solution, usually a pH=7 buffered solution of 0.1 mol/L KCl for pH electrodes or 0.1 mol/L MCl for pM electrodes
4. when using the silver chloride electrode, a small amount of AgCl can precipitate inside the glass electrode
5. reference electrode, usually the same type as 2
6. reference internal solution, usually 0.1 mol/L KCl
7. junction with studied solution, usually made from ceramics or capillary with asbestos or quartz fiber.
8. body of electrode, made from non-conductive glass or plastics.

In this case, two arrangements are required, one for reference and the other for unknown solution. Nowadays glass electrode and reference electrode are available in the same enclosure.

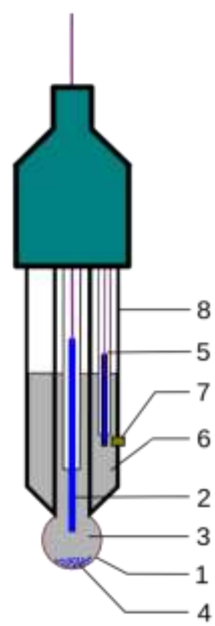

Figure 6.2 Glass electrodes.

pO_2 electrode (Clark electrode)

The term pO2 is defined as the partial pressure of oxygen respectively. The determination of pO2 is one the most important physiological chemical measurement. The effective functioning of both respiratory and cardiovascular system can be by pO2 measurement. The partial pressure of a gas is proportional to the quantity of that gas present in the blood. The oxygen electrode is a piece of platinum wire embedded in an insulating glass holder with the end of the wire exposed to the electrolyte into which the oxygen from the solution under measurement is allowed to diffuse through the membrane as shown in Figure 6.3. A membrane through which O_2, can diffuse from the measuring solution into electrolyte solution is placed. A 0.7 volt is applied between platinum electrode and Ag-AgCI electrode. Due to oxygen reduction at the platinum wire, a current is flowing through the ammeter proportional to the partial pressure of the oxygen.

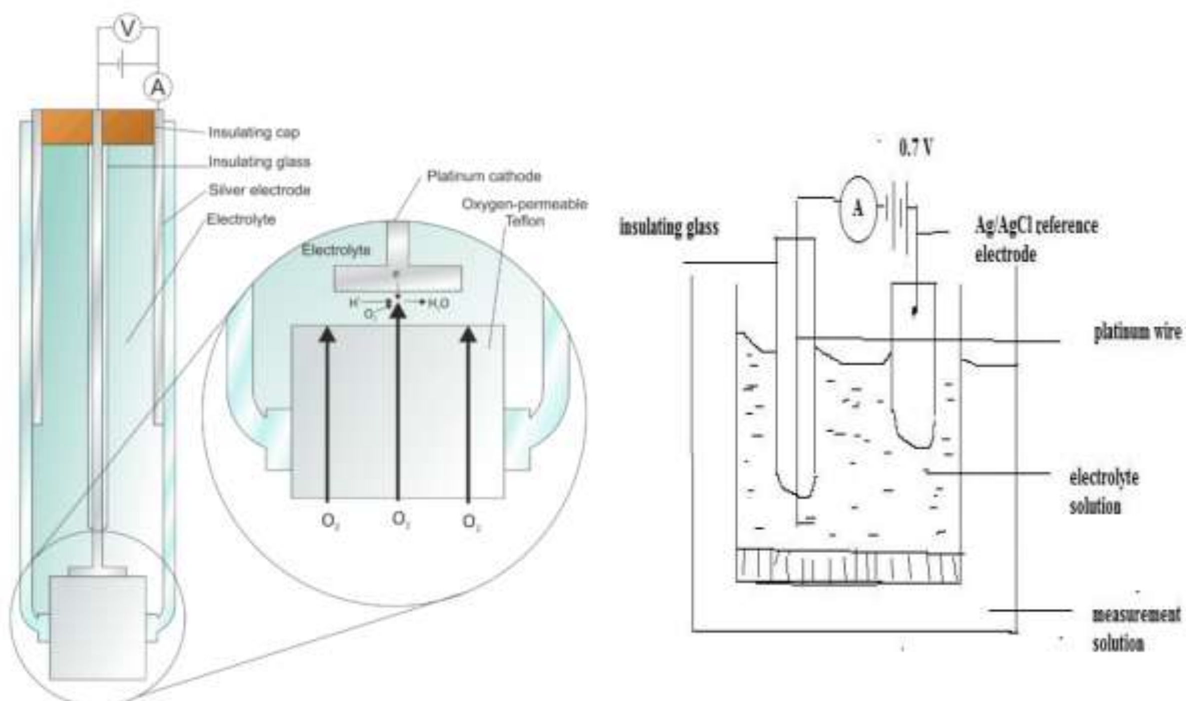

Figure 6.3 Membrane allows O_2 to diffuse.

There are two types of pO2 measurement. They are

I) Vitro measurement.

II) Vivo measurement

In case of dark electrode the platinum cathode and the reference electrode is present in a single unit. This electrode is used for vitro and vivo measurements.

In Vitro Measurements

In this method the blood sample is taken and the measurement for oxygen saturation is made in the laboratory. The electrode is placed in the sample blood solution and the pO_2 value is determined.

In Vivo Measurements

In this method the oxygen saturation is determined while the blood is flowing in the circulatory system. A micro version of the pO2 electrode is placed at the tip of the catheter so that it can be inserted into various parts of the heart or circulatory system.

Nowadays oxygen electrode is available in an integrated version consisting of both electrodes in a single enclosure.

pCO_2 electrode

Partial pressure of carbon dioxide (pCO_2) can be measured by measuring pH of a solution since there is a linear relationship between pCO_2 and pH. A standard glass pH electrode covered by a membrane permeable to CO_2 is used to measure dissolved CO_2. The solution under test is placed to the other side of membrane. Now, the measurement of pH can be calibrated in terms of pCO_2. Rubber which is permeable to CO_2 can be used as a membrane. The main disadvantage is that the CO_2 molecules require more time to diffuse through membrane. The time taken to diffuse through membrane can be considerably reduced by replacing the surface membrane with teflon membrane. The electrode using teflon as membrane allows CO_2 permeability to be rapid and takes less time.

Transducers for Biomedical Applications

1. Transducer

It is a device which converts one form of energy into another form of energy. A biomedical transducer is used to convert energy available in the physical variables existing in the human body into another form of energy. A biomedical transducer may sense temperature, flow. Pressure and other variables of a human body and convert it-into other variables usually electrical. Transducers are broadly classified into two types: active transducers and passive transducers. Active transducers do not require any external power to function, whereas passive transducers require external power to function. Thermocouple, mercury filled thermometer, piezo voltaic transducer, and photo voltaic transducer are the examples of the active transducers, and RTD and strain gauges are examples of the passive transducers. If the energy consumed by the transducer is large, then it may affect the measurement and measured value may be erroneous. Large consumption of energy by the transducer is called loading effect.

2. Sensor

A sensor always converts a physical parameter into an electrical output. A sensor may be called a transducer, but a transducer need not be a sensor. On the other

Strain Gauges

Strain gauges are transducers used to measure stress or pressure in terms of strain using the principle of change of resistivity due to mechanical stress. Consider a fine wire of about 25 micrometers. If this fine wire is strained but within its elastic limit, then there is a change in length, diameter and resistivity and hence the resistance. This property may be used to measure extremely small displacements in the order of nanometers. The relation between the resistance R. resistivity ρ, Length l and cross-sectional area A is given by

$$R = \frac{\rho l}{A}$$

In (R) = In (ρ) + In (l) - In (A)

Partial differentiation on both sides, yields

$$\frac{\partial R}{R} = \frac{\partial \rho}{\rho} + \frac{\partial l}{l} - \frac{\partial A}{A} \; but \; A = \pi D^2$$

Therefore $\frac{\partial R}{R} = \frac{\partial \rho}{\rho} + \frac{\partial l}{l} - 2\frac{\partial D}{D}$

The relation between the ∂D and ∂l using Poison's ratio µ is

$$\frac{\partial D}{D} = \square \frac{\partial l}{l}$$

Hence, we get $\frac{\partial R}{R} = (1 + 2\mu)\frac{\partial l}{l} + \frac{\partial \rho}{\rho}$

The first term is due to dimensional effect and the second term is due to piezo-resistive effect. The gauge factor G of a strain gauge is defined as percentage change in resistance of the gauge and due to percentage change in length of wire (strain). That is,

$$G = \frac{\left[\frac{\partial R}{R}\right]}{\left[\frac{\partial l}{l}\right]} = (1 + 2\mu) + \frac{\left[\frac{\partial \rho}{\rho}\right]}{\left[\frac{\partial l}{l}\right]}$$

It is the combination of dimensional effect and piezo-resistive effect. Metals with typical u value of 0.3 gave an approximate gauge factor of 1.6. On the other hand for semiconductors, μ is approximately 50 to 70 times than that of metals.

Therefore, a gauge factor of about 120 is possible if the semiconductor material is used. In semiconductors, piezo-resistive effect is also dominant. So, a temperature compensating circuit is required for semiconductor materials. Strain gauges can be classified into two types either as un-bonded strain gauges and bonded strain gauges. Figure 6.4 shows an un-bonded strain gauge unit. It consists of four sets of strain sensitive wires connected as a Wheatstone bridge. Wires are mounted under stress between the frame and movable armature to avoid expected external compressive load. This type can be used to measure blood pressure.

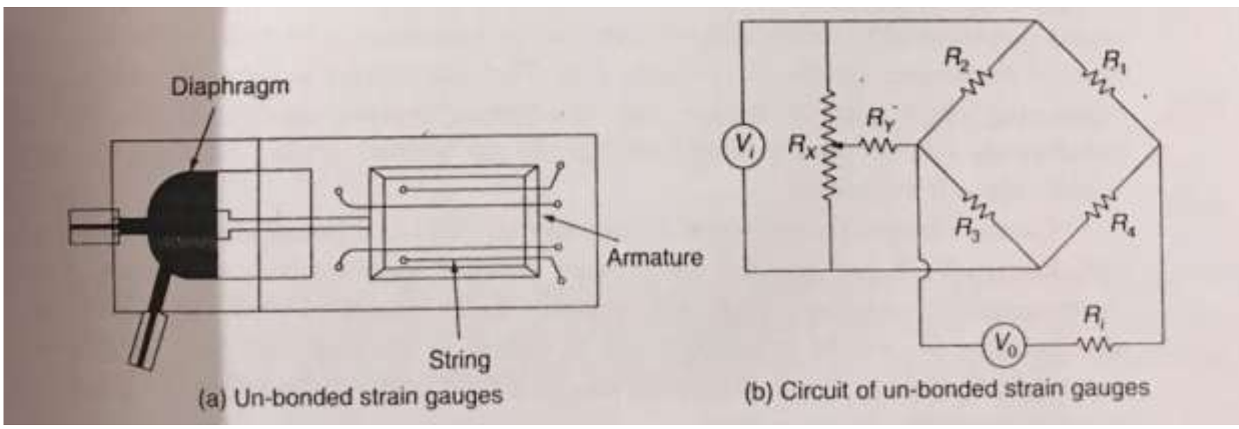

Figure 6.4 un-bonded strain gauges.

A bonded strain gauge element consists of either a metallic wire or semiconductor bar cemented to a strained base. Instead of a metallic wire, an etched foil or a vacuum deposition film may be used as shown in Figure 2.19. Bonded strain gauges are sensitive to temperature and have a dummy gauge may be used to compensate temperature effects. There is difference between the strain gauge and dummy gauge. Strain gauge is subjected to strain but the dummy gauge is not subject to strain.. The dummy gauge is connected to the bridge in such a way that the change in resistance due to temperature is nullified .four gauge type can be used for measurement of bite force in dental research. Semiconductor strain gauge used to measure blood pressure. Elastic resistance strain gauges are used in cardiovascular and respiratory dimensional and volume measurements.

Inductive Transducers

In inductive transducers, the measured quantity is converted into electrical output due to change in the self inductance L of the coil. Inductance L of a coil is function of number of turnes geometric form factor G and effective permeability μ of the medium. While sensing a displacement, any one of these parameters will be varied. The relation between the parameters and L is $L = n^2 G\mu$. The main advantage of inductive transducer is that it is not being affected by dielectric parameters of the environment. However, it is affected by magnetic fields around it. Self inductance of the coil L may be varied for a change in geometric form factory change in permeability u of the core proportional to displacement. Similarly, L can also varied proportional to displacement in the mutual inductance type and transformer type. The types of transducers are shown in Figure 6.5. They can be used to measure cardiac dimension monitoring respiration in infants and ascertaining arterial diameters. Mutual inductance transformers can be used to detect changes in the internal organs like kidney, major blood vessels and left ventricles.

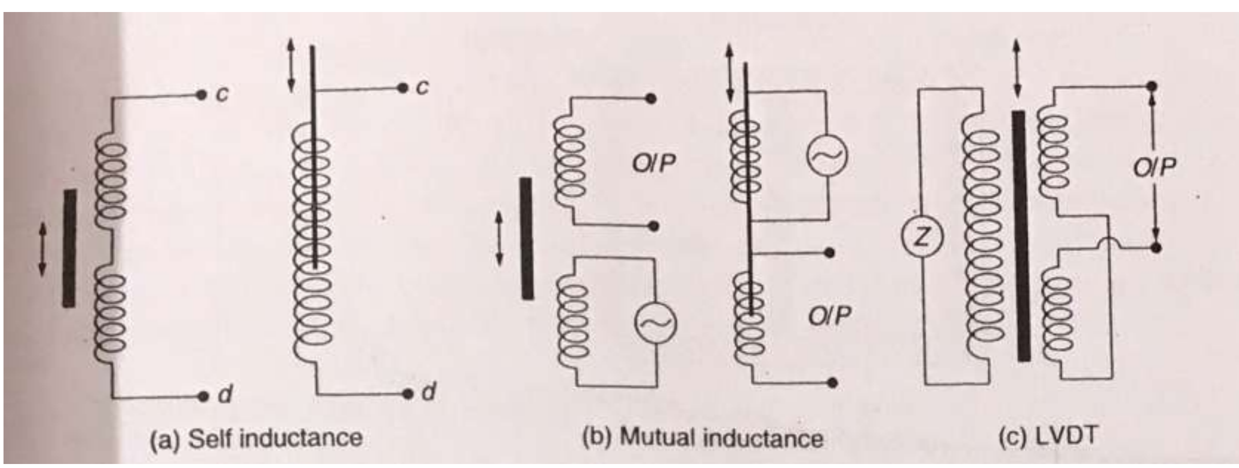

Figure 6.5 inductive transducers.